

# Switzerland's Greenhouse Gas Inventory 1990–2021

## National Inventory Document

Submission of April 2023  
under the United Nations Framework Convention on Climate Change



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Bern, April 2023

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## Glossary

°C	degree Celsius
AD	Activity data
AFOLU	Agriculture, Forestry and Other Land Use
AREA1	Swiss Land Use Statistics, first survey 1979/85
AREA2	Swiss Land Use Statistics, second survey 1992/97
AREA3	Swiss Land Use Statistics, third survey 2004/09
AREA4	Swiss Land Use Statistics, fourth survey 2013/18
AREA5	Swiss Land Use Statistics, fifth survey 2020/25
ART	Agroscope Reckenholz-Tänikon Research Station (formerly FAL) since 2014 Agroscope
Avenergy	Avenergy Suisse (Swiss Petroleum Association) formerly Erdöl-Vereinigung (EV)
BAFU	Bundesamt für Umwelt (German for FOEN)
BCEF, BEF	Biomass conversion and expansion factor, biomass expansion factor
CAEP	Committee on Aviation Environmental Protection
Carbura	Swiss organisation for the compulsory stockpiling of oil products
Cemsuisse	Association of the Swiss Cement Industry
CC	Combination category
CFC	Chlorofluorocarbon (organic compound: refrigerant, propellant)
CH <sub>4</sub>	Methane, GWP: 28 (UNFCCC 2019; Myhre 2013)
CHP	Combined heat and power
chp.	Chapter
CNG	Compressed natural gas
CLRTAP	UNECE Convention on Long-Range Transboundary Air Pollution
CO	Carbon monoxide
CO <sub>2</sub> , CO <sub>2</sub> eq	Carbon dioxide, carbon dioxide equivalent (GWP = 1 by definition)
COVID-19	Coronavirus disease 2019 is a contagious disease caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2)
CORINAIR	CORe INventory of AIR emissions (under the European Topic Centre on Air Emissions and under the European Environment Agency)
CRF	Common Reporting Format
CRT	Common Reporting Tables ( <a href="https://unfccc.int/documents/311076">https://unfccc.int/documents/311076</a> )
CSC	Carbon stock change
CSCF	Carbon stock change factor
DBH	Diameter (of trees) at breast height
DDPS	Federal Department of Defence, Civil Protection and Sport
DETEC	Dept. of the Environment, Transport, Energy and Communications
dt	decitonne (100 kg)

EF	Emission factor
EMEP	European Monitoring and Evaluation Programme (under the Convention on Long-range Transboundary Air Pollution)
EMIS	Swiss Emission Information System (German: Emissions Informations System Schweiz)
Empa	Swiss Federal Laboratories for Materials Science and Technology
EnAW	Energy Agency of the Swiss Private Sector
ERT	Expert review team (under the UNFCCC)
ETS	Emission Trading System
EU	European Union
EV	Erdöl-Vereinigung (Swiss Petroleum Association), since 1. July 2019 Avenergy Suisse
FAL	Swiss Federal Research Station for Agroecology and Agriculture (since 2006: ART; since 2014 Agroscope)
FAO	Food and Agriculture Organization of the United Nations
FC	Fuel consumption
FCA	Federal Customs Administration, since 03.01.2022: Federal Office for Customs and Border Security (FOCBS)
FDFA	Federal Department of Foreign Affairs
FEDRO	Swiss Federal Roads Office
FOAG	Federal Office for Agriculture
FOCA	Federal Office of Civil Aviation
FOCBS	Federal Office for Customs and Border Security, formerly FCA
FOD	First order decay (model)
FOEN	Federal Office for the Environment (former name SAEFL until 2005)
FSO	Federal Statistical Office (formerly SFSO)
GHG	Greenhouse gas
GL	Guidelines
g	gram
GVS	Swiss Foundry Association
GWP	Global Warming Potential
ha	hectare
HFC	Hydrofluorocarbons (e.g. HFC-32 difluoromethane)
HAFL	School for Agricultural, Forest and Food Sciences
HWP	Harvested wood products
ICAO	International Civil Aviation Organization
IDP	Inventory Development Plan
IEA	International Energy Agency
IFR	Instrument Flight Rules
IPCC	Intergovernmental Panel on Climate Change

IPPU	Industrial processes and product use
IVZ	Information system for traffic admission (Informationssystem Verkehrszulassung IVZ) run by FEDRO, formerly MOFIS
KCA	Key category analysis
kha	kilo hectare
kt	kilo tonne (1'000 tonnes)
L1, L2	Key category according to level assessment with approach 1, approach 2
LPG	Liquefied Petroleum Gas (Propane/Butane)
LTO	Landing/Take-Off cycle (Aviation)
LULUCF	Land Use, Land-Use Change and Forestry
MOFIS	Swiss federal vehicle registration database run by FEDRO (since 2022: IVZ)
MSW	Municipal solid waste
MSWIP	Municipal solid waste incineration plant
NABO	Swiss Soil Monitoring Network
NCV	Net calorific value
NCAC	(livestock) not covered by agricultural census
NF <sub>3</sub>	Nitrogen trifluoride, GWP: 16'100 (UNFCCC 2019; Myhre 2013)
NFI1, NFI2, NFI3, NFI4, NFI5	First (1983–1985), Second (1993–1995), Third (2004–2006), Fourth (2009–2017) and Fifth (ongoing) National Forest Inventory
NID	National Inventory Document (formerly known as NIR)
NIR	National Inventory Report (NIR = NID + CRT)
NIS	National Inventory System
NFR	Nomenclature for Reporting (under the UNECE)
NMVOC	Non-methane volatile organic compounds
N <sub>2</sub> O	Nitrous oxide, GWP: 265 (UNFCCC 2019; Myhre 2013)
NO <sub>x</sub>	Nitrogen oxides
ODS	Ozone-depleting substances (CFCs, halons etc.)
PFC	Perfluorinated carbon compounds (e.g. Tetrafluoromethane)
SAF	Sustainable aviation fuels
SAEFL	Swiss Agency for the Environment, Forests and Landscape (since 2006: Federal Office for the Environment FOEN)
SBV	Schweizerischer Bauernverband; Swiss Farmers Union
SCR	Selective catalytic reduction
SD	Standard deviation
SDC	Swiss Agency for Development and Cooperation (of the FDFA)
SF <sub>6</sub>	Sulphur hexafluoride, GWP:23'500 (UNFCCC 2019; Myhre 2013)
SGWA	Swiss Gas and Water Industry Association
SECO	State Secretariat for Economic Affairs

SDC	Swiss Agency for Development and Cooperation (German: DEZA)
SFOE	Swiss Federal Office of Energy
SFSO	Swiss Federal Statistical Office, now: Federal Statistical Office (FSO)
SGWA	Swiss Gas and Water Industry Association (see SVGW/SSIGE)
SO <sub>2</sub>	Sulphur dioxide
SO <sub>x</sub>	Sulphur oxides (sum of SO <sub>2</sub> and SO <sub>3</sub> , expressed as SO <sub>2</sub> equivalents)
SOC	Soil organic carbon
SOLV	Swiss Organisation for the Solvent Recovery of Industrial Enterprises in the Packaging Sector
SSIP	Sewage sludge incineration plant
SVGW/SSIGE	Schweizerischer Verein des Gas- und Wasserfaches / Société Suisse de l'Industrie du Gaz et des Eaux (Swiss Gas and Water Industry Association)
SWIP	Special waste incineration plant
Swissmem	Swiss Mechanical and Electrical Engineering Industries (Schweizer Maschinen-, Elektro- und Metallindustrie)
T1, T2	Key category according to trend assessment with approach 1, approach 2
PSD	Prosperity and Sustainability Division (of the FDFA)
QA/QC	Quality assurance/Quality control
QMS	Quality management system
UBA	Umweltbundesamt (Federal Environment Agency in Germany)
UNECE	United Nations Economic Commission for Europe
UNFCCC	United Nations Framework Convention on Climate Change
VFR	Visual Flight Rules
VOC	Volatile organic compounds
VSG	Verband der Schweizerischen Gasindustrie / Association Suisse de l'Industrie Gazière (ASIG) (Swiss Gas Industry Association)
VSZ	Verband Schweizerische Ziegelindustrie (Swiss association of brick and tile industry)
VSLF	Swiss association for coating and paint applications
VSTB	Swiss Association of Grass Drying Plants
VTG	Swiss Armed Forces – Defense
WSL	Swiss Federal Institute for Forest, Snow and Landscape Research
WWT	Wastewater treatment
ZPK	Verband der Schweizerischen Zellstoff-, Papier- und Kartonindustrie

## Executive summary

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Internal review	Michael Bock (FOEN)

### ES.1 Background information on greenhouse gas inventories and climate change

Long-term measurements indicate a marked shift towards a warmer climate for Switzerland. Between 1864 and 2020, the average temperature in Switzerland has increased by more than +2.0°C, about twice as much as observed on global average (FOEN 2022j). In the course of the 21<sup>st</sup> century, Swiss climate is projected to further depart from present and past conditions. Mean temperature will very likely increase in all regions and seasons (CH2018 2018). Summer mean precipitation will likely decrease by the end of the century all over Switzerland by up to 40 %, while winter precipitation will likely increase, particularly in Southern Switzerland. This will have consequences for all regions and sectors (FOEN et al. 2020n). Based on a decision of the Federal Council, Switzerland has established its National Centre for Climate Services, which coordinates the development and dissemination of climate services (<https://www.nccs.admin.ch/nccs/en/home.html>).

The Federal Office for the Environment (FOEN) is the designated national authority for climate policy and environmental monitoring. The FOEN bears overall responsibility for Switzerland's national greenhouse gas inventory and the national registry and is in charge of compiling the emission data. In addition to the FOEN, the Swiss Federal Office of Energy (SFOE), Agroscope, the Swiss centre of excellence for agricultural research, and the Federal Office of Civil Aviation (FOCA) participate directly in the compilation of the inventory. Several other administrative offices and research institutions are involved in the preparation of the inventory. In preparing the national greenhouse gas inventory, Switzerland takes recommendations and encouragements of the review process under the UNFCCC into account. The changes in response to the review process are documented in chp. 10.1.1.

### ES.2 Summary of trends related to national emissions and removals

In 2021, Switzerland emitted 45'249 kt CO<sub>2</sub> eq (kilo tonnes of CO<sub>2</sub> equivalent), corresponding to 5.2 t CO<sub>2</sub> eq per capita. This includes indirect CO<sub>2</sub> emissions (113 kt CO<sub>2</sub> eq), but emissions from international aviation and marine bunkers (2'352 kt CO<sub>2</sub> eq), and emissions and removals from Land use, land-use change, and forestry (LULUCF, -1'875 kt CO<sub>2</sub> eq) are excluded. Mean uncertainty of the emission level in 2021 is 2.9 % (excl. LULUCF) and 4.9 % (incl. LULUCF), the uncertainty of the emission trend between 1990 and 2021 is 3.3% (excl. LULUCF) and 4.9 % (incl. LULUCF) (based on approach 2, see chp. 1.6 for details).

Figure E-1 shows Switzerland's annual GHG emissions by individual gases from 1990 to 2021. Total emissions excluding LULUCF were lowest in 2020, partly due to the COVID-19 pandemic. In 2021, total emissions were 18.2 % below 1990.

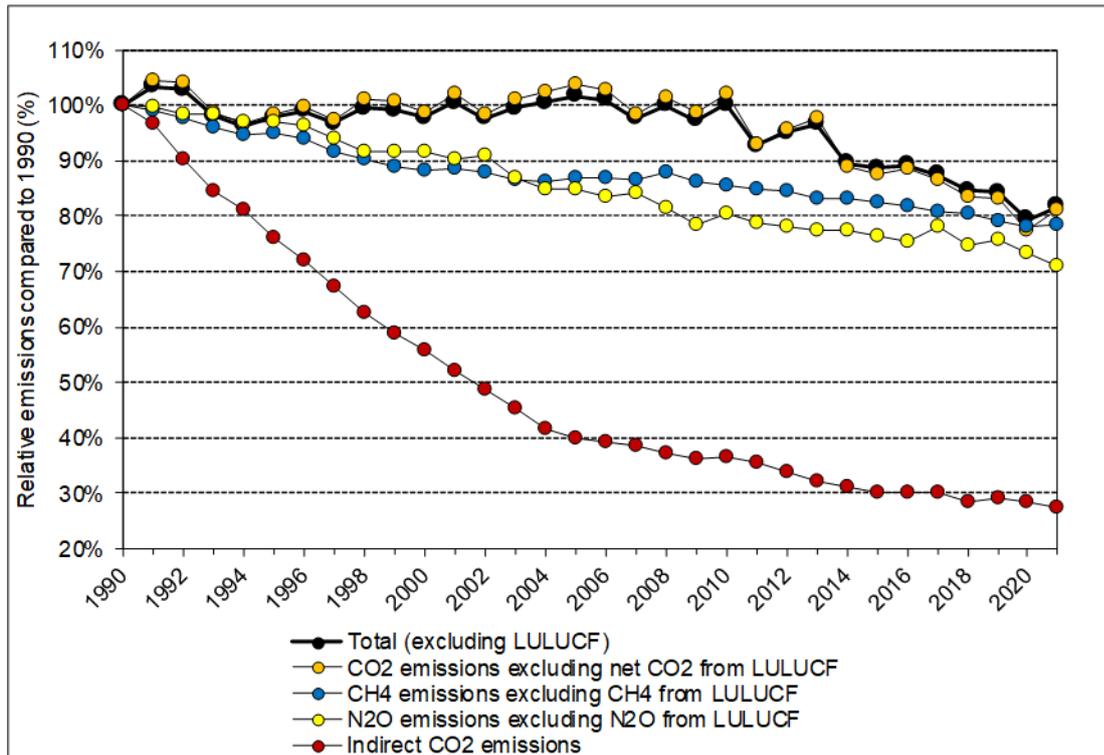


Figure E-1 Relative trends of Switzerland's main greenhouse gas emissions (excluding LULUCF). The base year 1990 represents 100 %. F-gases are not illustrated here.

### ES.3 Overview of source and sink category emission estimates and trends

Figure E-2 shows the GHG emissions and removals by the main source and sink categories. Sector 1 Energy clearly dominates national emissions, accounting for more than three quarters of the total GHG emissions (excluding LULUCF). Sectors 2 Industrial processes and product use (IPPU) and 3 Agriculture contribute a considerable share of GHG emissions as well, while sectors 5 Waste and 6 Other are of minor importance. The total includes indirect CO<sub>2</sub> emissions; however, those too are of minor importance. Sector 4 LULUCF is a net GHG sink over the inventory period except for the year 2000.

Overall, Switzerland's GHG emissions decreased in 2021 compared to 1990. This effect is mainly driven by decreases in the Energy and Agriculture sectors, which outweigh the increase in the Industrial processes and product use sector. The decrease in the energy sector is dominated by a substantial decrease in 1A4 Other sectors and 1A2 Manufacturing industries and construction (see Figure 2-6 and Table 2-4).

As shown in Figure E-2 GHG emissions in the period 1990–2021 are subject to fluctuations with a decreasing trend starting after 2005. The fluctuations derive from the year-to-year variability of the energy sector emissions caused by changing winter temperatures and hence, changing heating fuel use. Since around 2006, a growing decoupling of fuel combustion emissions and winter temperature is observed, reflecting the impact of emission reduction measures in the building sector.

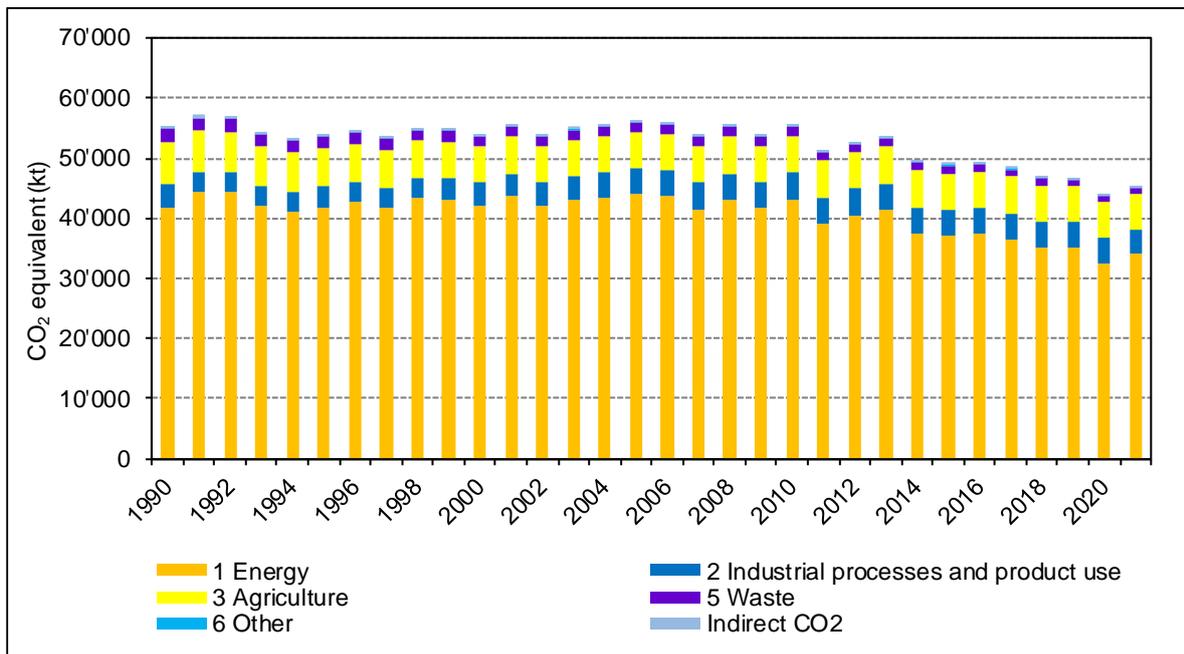


Figure E-2 Greenhouse gas emissions in CO<sub>2</sub> equivalent (kt) by sectors (excluding LULUCF).

### ES.4 Other information

Emissions from precursor gases show a very pronounced decline (see Table 2-6 and Figure 2-10). A strict air pollution control policy led to strong decreases in emissions of precursor gases over the period 1990–2021. An overview concerning precursors is given in chp. 2.2.3 and details are provided in Switzerland's Informative Inventory Report (FOEN 2023b).

## ES.5 Key category analysis (KCA)

Key category analyses were conducted according to approaches 1 and 2 (see details in chp. 1.4.2 and IPCC (2006)). For both approaches, level assessments were conducted for the years 2021 and 1990 and a trend assessment for 1990–2021, including LULUCF categories and indirect CO<sub>2</sub> emissions. A total of 47 key categories out of 192 considered categories have been identified, detailed as follow:

- Approach 1: For 2021, 31 categories among a total of 192 are identified as level key categories. About half of these categories are part of sector 1 Energy, accounting for the largest share of total national emissions.
- Approach 2: For 2021, 28 categories among a total of 192 are identified as level key categories. Under approach 2, the most important categories originate from sectors 3 Agriculture and 4 LULUCF.

Key category analyses are also performed excluding LULUCF categories. They are not represented in the NID but are available on request.

## ES.6 Improvements introduced

Major improvements are mentioned here only. A quantitative description of major recalculations is provided in chapter 10.1.2. Further, minor recalculations are described in the sector chapters.

### General

- The Swiss greenhouse gas inventory 1990–2021 (reporting tables (CRF) and National Inventory Document (NID)) uses GWP values from the Fifth Assessment Report of the IPCC (Myhre 2013), according to paragraph 37 of the Modalities, procedures and guidelines for the transparency framework of the Paris Agreement (UNFCCC 2019).

### Agriculture

- Various methodologies and parameters were updated due to the implementation of the 2019 Refinement to the 2006 IPCC Guidelines (IPCC 2019). New norm temperature values were used to model CH<sub>4</sub> emissions from manure management (see chp. 10.1.2.3).

### Waste

- 5D: New country-specific methods for estimating CH<sub>4</sub> and N<sub>2</sub>O emissions from 5D Wastewater treatment and discharge (see chp. 7.5.2 and chp. 7.5.5) for both, centralised and decentralised emission estimates have been implemented resulting in considerably higher emissions compared to earlier submissions. For a summary see chp. 10.1.2.5 and Figure 10-16.

# 1. National circumstances, institutional arrangements and cross-cutting information

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On 10 December 1993, Switzerland ratified the United Nations Framework Convention on Climate Change (UNFCCC) (UNFCCC 1992). Since 1996, the submission of its national greenhouse gas inventory has been based on IPCC Guidelines. In 2004, Switzerland started submitting annually its National Inventory Report (NIR) under the UNFCCC.

After ratifying the Kyoto Protocol under the UNFCCC (UNFCCC 1998) in July 2003, Switzerland submitted its Initial Report under Article 7, paragraph 4 of the Kyoto Protocol in 2006 (FOEN 2006h), including the description of the Swiss National Inventory System (NIS) according to Article 5.1 of the Kyoto Protocol. On 6 December 2007, the NIS quality management system (QMS) was certified to comply with ISO 9001. The QMS has been audited annually and recertified according to the ISO 9001 requirements ever since.

## 1.2. National circumstances and institutional arrangements

### 1.2.1. National entity

Based on the Organisation Ordinance for the Federal Department of the Environment, Transport, Energy and Communications (DETEC), the Federal Office for the Environment (FOEN) is the designated national authority for climate policy and environmental monitoring. According to the decree of the Federal Council of 8 November 2006, the FOEN is in charge of the National Inventory System (NIS) (Figure 1-1). The Swiss National Inventory System

was formally set up in 2006 in compliance with the requirements of the UNFCCC and the Kyoto Protocol (FOEN 2006h). The FOEN established a process led by the Climate division, which covers maintaining the National Inventory System and fulfilling all reporting obligations under the UNFCCC.

### National entity with overall responsibility for the inventory

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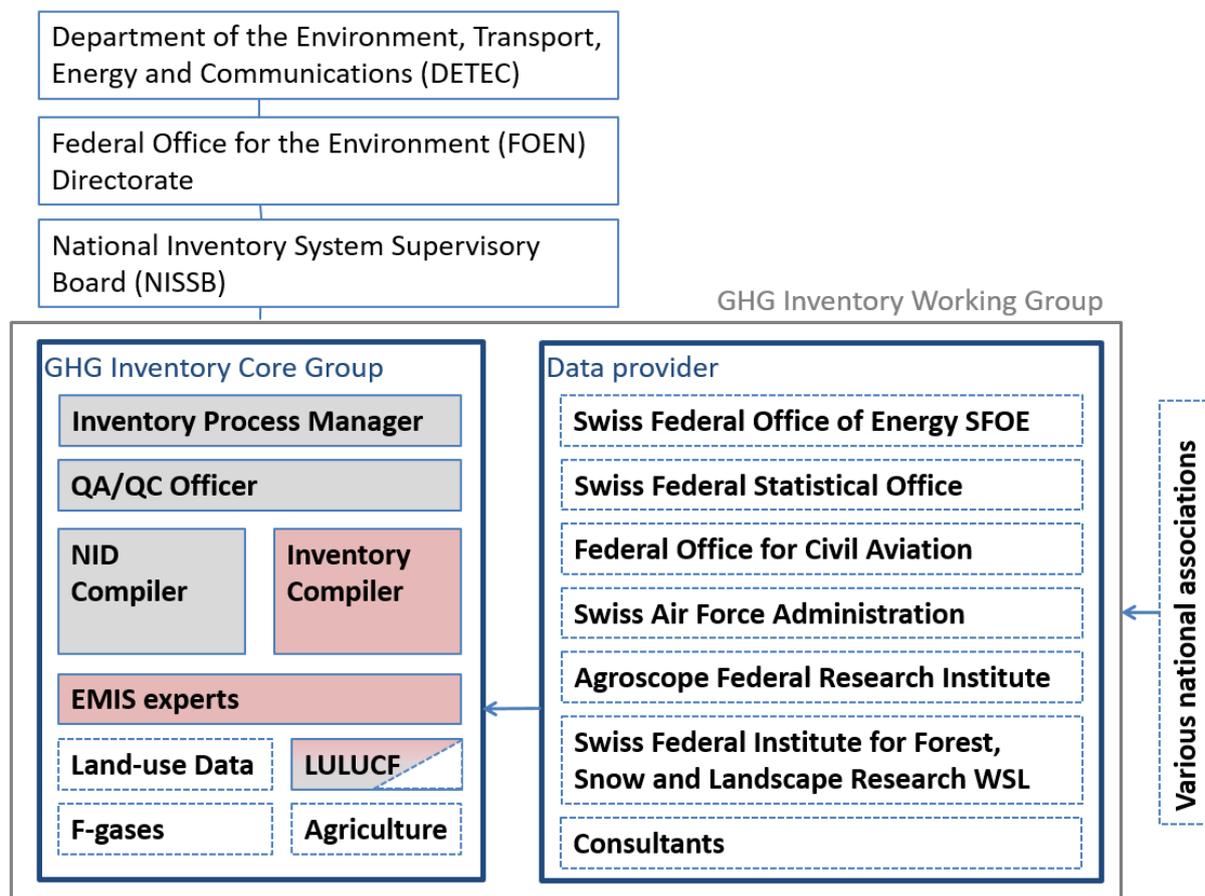


Figure 1-1 The National Inventory System. Colours refer to divisions at FOEN. Grey: Climate division, red: Air Pollution Control and Chemicals division, Forest division. Boxes with dashed lines refer to external mandates.

### 1.2.2. Inventory preparation process

The process of inventory planning, preparation and management in Switzerland is well-established. Responsibilities and decision-making power are assigned to specific people or groups of people (Figure 1-1). The management responsibility for the NIS lies with the National Inventory System Supervisory Board (NISSB). The board consists of a member of the FOEN directorate and FOEN division heads of the relevant divisions (Climate, Forest, Air Pollution Control and Chemicals, International Affairs).

At the operational level, the process of planning, preparation and management of the greenhouse gas inventory is led by the process manager. The QA/QC officer oversees design, development, and operation of the quality management system and is the primary contact point during the UN review process. The greenhouse gas (GHG) inventory core group is the committee that combines all technical expertise required for greenhouse gas inventory planning, preparation and management. It consists of the process manager, the QA/QC officer, the inventory compiler, sectoral experts, as well as the NID compiler. Additional experts join the core group as required. The GHG inventory core group ensures conformity of the inventory with the relevant UNFCCC reporting guidelines (UNFCCC 2019, 2022a), timely inventory preparation, and consideration and approval of methodological changes, choice of data and recalculations. The GHG inventory working group encompasses all technical personnel involved in the inventory preparation process or representing institutions that play a significant role as suppliers of data.

The overall responsibility for the greenhouse gas inventory lies with the Climate division of the FOEN. The Air Pollution Control and Chemicals division of the FOEN maintains and updates the emissions database (greenhouse gases and air pollutants), named EMIS, in close collaboration with the Climate division. The national energy statistics from the Federal Office of Energy (SFOE) provides the basis for the Energy sector. The Federal Office for Civil Aviation (FOCA) delivers the domestic and international aviation emissions. A consultancy (Carbotech) is mandated to survey and model fluorinated gases use and emissions and to provide an annual update thereof. Agriculture emissions are compiled by the Federal Research Institute Agroscope. For LULUCF, detailed land use survey data are provided by the Federal Statistical Office (FSO). Two consultancies (SigmaPlan, Meteotest) are mandated to process the land use survey data to derive land-use and land-use change data and associated emissions and removals. The Swiss Federal Institute for Forest, Snow and Landscape Research (WSL) is in charge of the national forest inventory and forestry-related modelling. The WSL provides the input for the FOEN Forest division, which compiles emissions and removals data for Forest land. The LULUCF sector is coordinated by a member of the Climate division of the FOEN. A collaboration between two consultancies (Meteotest, Infrac) is mandated to support data handling in the Swiss Emission Information System (EMIS), the reporting tables (CRF) and updating the National Inventory Document (NID).

### **1.2.3. Archiving of information**

Archiving of inventory material is performed during preparation and after submission by the EMIS and sectoral experts, by the contributing authors and by the QA/QC officer.

The EMIS database as well as background information on activity data and emission factors are archived by the national inventory compiler for each submission. In the sectors where data collection is made by EMIS experts (e.g. Energy, IPPU, Waste), additional background information is compiled as appropriate (e.g. interim worksheets; references; rationale for choice of methods, data sources, activity data, emission factors). Whenever such documents are cited, they are labelled as “EMIS 2023/NFR-Code” in this report.

Nearly all of the data necessary to compile the Swiss GHG inventory are publicly available. There are exceptions for emission data that refer to a single enterprise, for the most disaggregated level of F-gases, and for land use statistics raw data as long as they have not yet been published the Federal Statistical Office (FSO). However, confidential data will be

made available by the FOEN in line with the procedures agreed under the UNFCCC for the technical review of GHG inventories (UNFCCC 2019).

FOEN operates a website ([www.climatereporting.ch](http://www.climatereporting.ch)) where the Swiss GHG inventories (NID, reporting tables, UNFCCC review reports), the Swiss National Communications and other reports submitted to the UNFCCC may be downloaded. On this website, most papers, reports, domestic reviews, and other difficult-to-access materials ('grey literature') quoted in the Swiss GHG inventory are provided online. The climate reporting homepage thus provides the option for public review.

#### **1.2.4. Processes for official consideration and approval of inventory**

The NIS supervisory board (NISSB) normally meets twice a year. At its spring meeting, the inventory is presented for official consideration. Based on that, the NISSB submits the inventory to the FOEN directorate for official approval. Submission is coordinated by the process manager and carried out by the national inventory compiler and the QA/QC officer.

### **1.3. General description of methodologies and data sources used**

According to the revised reporting guidelines under the UNFCCC and the Paris Agreement (UNFCCC 2019), emissions are calculated based on standard methods and procedures provided in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2006) its 2019 Refinement (IPCC 2019), the 2013 KP Supplement (IPCC 2014), and the 2013 Wetlands supplement (IPCC 2014a). All key categories are estimated using approach 2 or higher or country-specific methods. The methodological tier used is described in detail in the sectoral chapters of the NID and compiled in CRF Summary3s1 and CRF Summary3s2.

Various data suppliers contribute to the greenhouse gas inventory. While most data stem from official statistics either from the FOEN or from other federal offices, some data is drawn from national associations or consultancies that maintain well-established models or data-bases. Details on activity data and emission factors are provided in the sectoral chapters of the NID.

### **1.4. Description of key categories**

The aim of the key category analysis (KCA) is to identify relevant categories that have a strong influence on Switzerland's GHG inventory in terms of absolute emission and removal levels, trends and uncertainties (IPCC 2006, chp. 4). The KCA can be performed based on two approaches: in approach 1 of the KCA, categories are set out in decreasing order of contribution to the inventory emissions or trend. In approach 2, this ranking is weighted by the uncertainty assigned to each category. Approach 1 therefore highlights categories which mostly contribute to emissions or to emission changes, while approach 2 identifies categories mostly contributing to the inventory uncertainty. Data collection as well as quality assurance and control are prioritised for key categories during the inventory resource allocation (see also the planned improvements in chp. 10.4).

### 1.4.1. Methodology

The key category analysis is performed according to the 2006 IPCC Guidelines (IPCC 2006, chp. 4) and Decision 18/CMA.1 (UNFCCC 2019, paragraph 25) for 1990 and the latest reported year 2021 including all GHG (CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, HFCs, PFCs, SF<sub>6</sub>, NF<sub>3</sub> and indirect CO<sub>2</sub>). A total of 192 categories (including categories from the LULUCF sector) are used to disaggregate Switzerland's total GHG emissions for the purpose of this key category analysis (Table A – 1). The disaggregation level of the categories is selected based on country-specific relevance, i.e. the most important sources in Switzerland are disaggregated on a more detailed level.

Both approach 1 (with a threshold set at 95 %) and approach 2 (with a threshold set at 90 %) level and trend assessments are applied, including emissions from sector 4 LULUCF. For approach 2 of the KCA, uncertainties for emissions of each category are taken from the results of the Monte Carlo simulations (approach 2 uncertainty analysis, see details in chp. 1.6.2.2). Indirect CO<sub>2</sub> emissions are included in the key category analysis, indirect N<sub>2</sub>O emissions are not.

### 1.4.2. Results of the key category analysis (including LULUCF categories)

Compared to the previous submission, the following methodological changes were conducted which influence the KCA calculation:

- Source category 1B2 Oil and Natural Gas Energy Production, which was a key category for the level and the trend according to approach 1 for submission 2022, is now divided into the source categories 1B2a Oil, 1B2b Natural gas and 1B2c Venting and flaring. Category 1B2b Natural gas is a key category for the level and the trend according to approach 1 and for the level according to approach 2.
- Source category 2D Non-Energy Products from Fuels and Solvent Use, which was not a key category for submission 2022, is now subdivided into the source categories 2D1 Lubricant use, 2D2 Paraffin wax use and 2D3 Other. None of these new source categories is a key category.
- Source category 2G Other Product Manufacture and Use for N<sub>2</sub>O, which was not a key category for submission 2022, is now subdivided into the source categories 2G3 N<sub>2</sub>O from product uses and 2G4 Other product manufacture and use, other. Source category 2G3 is a key category for the trend according to approach 2.

For the year 2021, there are 47 identified key categories among the 192 categories taken into account (see overview in Table 1-6). The large majority of the key categories are sources of CO<sub>2</sub> (see also Table 2-3 and discussion in chp. 2.2), a few of CH<sub>4</sub> and N<sub>2</sub>O, only one of HFCs and also one of PFCs. There are no key categories for neither SF<sub>6</sub> nor NF<sub>3</sub>.

The detailed results of the key category analyses, approaches 1 and 2, level and trend assessments, are reported in Table 1-1 to Table 1-5. For level assessments, columns are labelled A to G according to Table 4-2 in the IPCC Guidelines (IPCC 2006, chp. 4) and for trend assessments, columns are labelled A to H according to Table 4-3 in the same guidelines. The following abbreviations are used:

- E<sub>x,0</sub>: base year emission/removal estimate.

- $E_{x,t}$ : reporting year emission/removal estimate.
- $L_{x,0}$ ,  $L_{x,t}$ : level assessment for the base year and the reporting year, respectively.
- $T_{x,t}$ : trend assessment for the trend between base year and reporting year.

### Approach 1

For the year 2021, among a total of 192 categories, 31 are identified as level key categories under approach 1 (see Table 1-1).

Fifteen of these key categories belong to sector 1 Energy, accounting for the largest share of CO<sub>2</sub> equivalent emissions in 2021 (see Table 2-1 for emission share per sector). Sector 2 Industrial processes and product use (3 key categories) and sector 3 Agriculture (5 key categories) are also significant contributors to the emissions for the year 2021 (Table 2-1), while sector 5 Waste (3 key categories) and sector 6 Other (no key category) have only marginal contributions. Sector 4 LULUCF (5 key categories) has a net negative contribution to the total emissions for the year 2021.

Within the ten most relevant key categories (level contribution), only 3A Enteric fermentation, 4A1 Forest land remaining forest land and 2A1 Cement production are not part of sector 1 Energy. Note that category 4A1 has a net negative emission contribution.

For the base year 1990, 34 categories are identified as level key categories under approach 1 (see Table 1-2). The following categories are key according to level in the base year 1990, but not anymore in the latest reported year:

- 1A3a Domestic aviation, kerosene fossil, CO<sub>2</sub>
- 1A5 Other (military), liquid fuels, CO<sub>2</sub>
- 2D Non-energy products from fuels and solvent use, indirect CO<sub>2</sub> from NMVOCs
- 3B1-4 Manure management, all livestock, direct, N<sub>2</sub>O
- 4G HWP Harvested wood products, CO<sub>2</sub>

On the other hand, the following categories are key according to level in the latest reported year, but not in the base year 1990:

- 2F1 Refrigeration and air conditioning, HFCs
- 4C2 Land converted to grassland, CO<sub>2</sub>

Regarding the trend assessment between the base year 1990 and the latest reported year, 34 categories are identified as trend key categories under approach 1 (see Table 1-3). Among these, 13 have an increasing trend and 21 a decreasing trend. See chp. 2.2 Emission trends by gas and chp. 2.2.2 Emission trends by sources and sinks for a further discussion.

Table 1-1 Switzerland's key categories according to approach 1 level assessment for the year 2021, including LULUCF categories and indirect CO<sub>2</sub> emissions, sorted by decreasing contribution. Categories in grey are not key and are given for information only.

KCA APPROACH 1 LEVEL ASSESSMENT FOR 2021						
A	B	C	D	E	F	G
Code	IPCC category	Gas	Ex, t (kt CO <sub>2</sub> eq.)	Ex, t  (kt CO <sub>2</sub> eq.)	Lx, t (%)	Cumulative Total (%)
1A3b	Road transportation; Diesel oil	CO <sub>2</sub>	7'035	7'035	14.2	14.2
1A3b	Road transportation; Gasoline	CO <sub>2</sub>	6'346	6'346	12.8	27.1
1A4b	Residential; Liquid fuels	CO <sub>2</sub>	4'879	4'879	9.9	36.9
3A	Enteric fermentation	CH <sub>4</sub>	3'631	3'631	7.3	44.3
1A4b	Residential; Gaseous fuels	CO <sub>2</sub>	2'968	2'968	6.0	50.3
1A1	Energy industries; Other fuels	CO <sub>2</sub>	2'409	2'409	4.9	55.1
4A1	Forest land remaining forest land	CO <sub>2</sub>	-2'332	2'332	4.7	59.8
1A4a	Commercial; Liquid fuels	CO <sub>2</sub>	2'328	2'328	4.7	64.5
1A2	Manufacturing industries and construction; Gaseous fuels	CO <sub>2</sub>	2'215	2'215	4.5	69.0
2A1	Cement production	CO <sub>2</sub>	1'732	1'732	3.5	72.5
1A2	Manufacturing industries and construction; Liquid fuels	CO <sub>2</sub>	1'552	1'552	3.1	75.7
1A4a	Commercial; Gaseous fuels	CO <sub>2</sub>	1'348	1'348	2.7	78.4
2F1	Refrigeration and air conditioning	HFCs	1'195	1'195	2.4	80.8
3Da	Direct emissions from managed soils	N <sub>2</sub> O	856	856	1.7	82.5
4A2	Land converted to forest land	CO <sub>2</sub>	-628	628	1.3	83.8
3B1-4	Manure management, all livestock, direct	CH <sub>4</sub>	618	618	1.2	85.1
5D	Wastewater treatment and discharge	N <sub>2</sub> O	533	533	1.1	86.1
1A1	Energy industries; Gaseous fuels	CO <sub>2</sub>	515	515	1.0	87.2
1A4c	Agriculture and forestry; Liquid fuels	CO <sub>2</sub>	453	453	0.9	88.1
1A2	Manufacturing industries and construction; Other fuels	CO <sub>2</sub>	445	445	0.9	89.0
3Db	Indirect emissions from managed soils	N <sub>2</sub> O	408	408	0.8	89.8
2B10	Chemical industry, other	N <sub>2</sub> O	389	389	0.8	90.6
1A2	Manufacturing industries and construction; Solid fuels	CO <sub>2</sub>	342	342	0.7	91.3
5A	Solid waste disposal	CH <sub>4</sub>	289	289	0.6	91.9
1A1	Energy industries; Liquid fuels	CO <sub>2</sub>	276	276	0.6	92.4
4C2	Land converted to grassland	CO <sub>2</sub>	264	264	0.5	93.0
3B5	Manure management, indirect	N <sub>2</sub> O	232	232	0.5	93.4
5D	Wastewater treatment and discharge	CH <sub>4</sub>	217	217	0.4	93.9
4E2	Land converted to settlements	CO <sub>2</sub>	213	213	0.4	94.3
1B2b	Natural gas; All fuels	CH <sub>4</sub>	209	209	0.4	94.7
4B1	Cropland remaining cropland	CO <sub>2</sub>	191	191	0.4	95.1
4C1	Grassland remaining grassland	CO <sub>2</sub>	168	168	0.3	95.4
4F2	Land converted to other land	CO <sub>2</sub>	130	130	0.3	95.7
1A4c	Agriculture and forestry; Gaseous fuels	CO <sub>2</sub>	129	129	0.3	96.0
2G	Other product manufacture and use	SF <sub>6</sub>	125	125	0.3	96.2
2B8	Petrochemical and carbon black production	CO <sub>2</sub>	116	116	0.2	96.5
1A5	Other (military); Liquid fuels	CO <sub>2</sub>	114	114	0.2	96.7
1A3d	Water-borne navigation; Liquid fuels	CO <sub>2</sub>	110	110	0.2	96.9
3B1-4	Manure management, all livestock, direct	N <sub>2</sub> O	107	107	0.2	97.1

Table 1-2 Switzerland's key categories according to approach 1 level assessment for the year 1990, including LULUCF categories and indirect CO<sub>2</sub> emissions, sorted by decreasing contribution. Categories in grey are not key and are given for information only.

KCA APPROACH 1 LEVEL ASSESSMENT FOR 1990						
A	B	C	D	E	F	G
Code	IPCC category	Gas	Ex, 0 (kt CO <sub>2</sub> eq.)	Ex, 0  (kt CO <sub>2</sub> eq.)	Lx, 0 (%)	Cumulative Total (%)
1A3b	Road transportation; Gasoline	CO <sub>2</sub>	11'343	11'343	19.2	19.2
1A4b	Residential; Liquid fuels	CO <sub>2</sub>	10'099	10'099	17.1	36.2
1A2	Manufacturing industries and construction; Liquid fuels	CO <sub>2</sub>	3'974	3'974	6.7	42.9
3A	Enteric fermentation	CH <sub>4</sub>	3'930	3'930	6.6	49.5
1A4a	Commercial; Liquid fuels	CO <sub>2</sub>	3'918	3'918	6.6	56.2
1A3b	Road transportation; Diesel oil	CO <sub>2</sub>	2'632	2'632	4.4	60.6
2A1	Cement production	CO <sub>2</sub>	2'581	2'581	4.4	65.0
1A1	Energy industries; Other fuels	CO <sub>2</sub>	1'492	1'492	2.5	67.5
1A4b	Residential; Gaseous fuels	CO <sub>2</sub>	1'451	1'451	2.4	69.9
1A2	Manufacturing industries and construction; Solid fuels	CO <sub>2</sub>	1'275	1'275	2.2	72.1
4G	HWP Harvested Wood Products	CO <sub>2</sub>	-1'127	1'127	1.9	74.0
4A1	Forest land remaining forest land	CO <sub>2</sub>	-1'113	1'113	1.9	75.9
1A2	Manufacturing industries and construction; Gaseous fuels	CO <sub>2</sub>	1'091	1'091	1.8	77.7
5D	Wastewater treatment and discharge	N <sub>2</sub> O	1'074	1'074	1.8	79.5
3Da	Direct emissions from managed soils	N <sub>2</sub> O	1'073	1'073	1.8	81.3
1A4a	Commercial; Gaseous fuels	CO <sub>2</sub>	920	920	1.6	82.9
5A	Solid waste disposal	CH <sub>4</sub>	862	862	1.5	84.3
3B1-4	Manure management, all livestock, direct	CH <sub>4</sub>	776	776	1.3	85.7
1A4c	Agriculture and forestry; Liquid fuels	CO <sub>2</sub>	742	742	1.3	86.9
1A1	Energy industries; Liquid fuels	CO <sub>2</sub>	686	686	1.2	88.1
3Db	Indirect emissions from managed soils	N <sub>2</sub> O	596	596	1.0	89.1
4A2	Land converted to forest land	CO <sub>2</sub>	-540	540	0.9	90.0
4B1	Cropland remaining cropland	CO <sub>2</sub>	398	398	0.7	90.7
2B10	Chemical industry, other	N <sub>2</sub> O	384	384	0.6	91.3
1B2b	Natural gas; All fuels	CH <sub>4</sub>	372	372	0.6	91.9
4E2	Land converted to settlements	CO <sub>2</sub>	258	258	0.4	92.4
1A3a	Domestic aviation; Kerosene fossil	CO <sub>2</sub>	253	253	0.4	92.8
1A1	Energy industries; Gaseous fuels	CO <sub>2</sub>	243	243	0.4	93.2
1A5	Other (military); Liquid fuels	CO <sub>2</sub>	218	218	0.4	93.6
5D	Wastewater treatment and discharge	CH <sub>4</sub>	209	209	0.4	93.9
3B5	Manure management, indirect	N <sub>2</sub> O	209	209	0.4	94.3
2D	Non-energy products from fuels and solvent use	Indirect CO <sub>2</sub> from NMVOC	194	194	0.3	94.6
1A2	Manufacturing industries and construction; Other fuels	CO <sub>2</sub>	192	192	0.3	94.9
3B1-4	Manure management, all livestock, direct	N <sub>2</sub> O	168	168	0.3	95.2
2A4	Other process uses of carbonates	CO <sub>2</sub>	160	160	0.3	95.5
1A3b	Road transportation; Gasoline	N <sub>2</sub> O	143	143	0.2	95.7
2G	Other product manufacture and use	SF <sub>6</sub>	141	141	0.2	96.0
2C3	Aluminium production	CO <sub>2</sub>	139	139	0.2	96.2
1A3b	Road transportation; Gasoline	CH <sub>4</sub>	129	129	0.2	96.4
2G	Other product manufacture and use	Indirect CO <sub>2</sub> from NMVOC	125	125	0.2	96.6
1A3d	Water-borne navigation; Liquid fuels	CO <sub>2</sub>	114	114	0.2	96.8
2C3	Aluminium production	PFCs	105	105	0.2	97.0
1A4b	Residential; Biomass	CH <sub>4</sub>	104	104	0.2	97.2

Table 1-3 Switzerland's key categories according to approach 1 trend assessment for 1990–2021, including LULUCF categories and indirect CO<sub>2</sub> emissions, sorted by decreasing contribution. Categories in orange have increased emissions in 2021 compared to 1990. Categories in grey are not key and are given for information only.

KCA APPROACH 1 TREND ASSESSMENT 1990 - 2021								
A	B	C	D	E	F	G	H	
Code	IPCC category	Gas	Ex, 0 (kt CO <sub>2</sub> eq.)	Ex, t (kt CO <sub>2</sub> eq.)	Category trend (%)	Trend Assessment	Contribution to trend (%)	Cumulative Total (%)
1A3b	Road transportation; Diesel oil	CO2	2'632	7'035	167	0.083	17.5	17.5
1A4b	Residential; Liquid fuels	CO2	10'099	4'879	-52	0.056	11.7	29.2
1A3b	Road transportation; Gasoline	CO2	11'343	6'346	-44	0.048	10.1	39.3
1A4b	Residential; Gaseous fuels	CO2	1'451	2'968	105	0.030	6.4	45.7
1A2	Manufacturing industries and construction; Liquid fuels	CO2	3'974	1'552	-61	0.028	5.9	51.6
1A2	Manufacturing industries and construction; Gaseous fuels	CO2	1'091	2'215	103	0.022	4.7	56.4
4G	HWP Harvested Wood Products	CO2	-1'127	-39	-97	0.022	4.6	61.0
1A1	Energy industries; Other fuels	CO2	1'492	2'409	62	0.020	4.3	65.3
2F1	Refrigeration and air conditioning	HFCs	0	1'195	5'305'025	0.020	4.3	69.5
4A1	Forest land remaining forest land	CO2	-1'113	-2'332	-109	0.017	3.6	73.1
1A4a	Commercial; Liquid fuels	CO2	3'918	2'328	-41	0.014	3.0	76.1
1A2	Manufacturing industries and construction; Solid fuels	CO2	1'275	342	-73	0.012	2.5	78.6
1A4a	Commercial; Gaseous fuels	CO2	920	1'348	47	0.010	2.1	80.7
3A	Enteric fermentation	CH4	3'930	3'631	-8	0.008	1.6	82.3
5A	Solid waste disposal	CH4	862	289	-66	0.007	1.5	83.8
2A1	Cement production	CO2	2'581	1'732	-33	0.006	1.3	85.1
5D	Wastewater treatment and discharge	N2O	1'074	533	-50	0.006	1.2	86.3
1A1	Energy industries; Gaseous fuels	CO2	243	515	111	0.005	1.1	87.4
1A2	Manufacturing industries and construction; Other fuels	CO2	192	445	132	0.005	1.0	88.4
1A1	Energy industries; Liquid fuels	CO2	686	276	-60	0.005	1.0	89.4
4C2	Land converted to grassland	CO2	95	264	178	0.003	0.7	90.1
4C1	Grassland remaining grassland	CO2	17	168	894	0.003	0.5	90.6
1A4c	Agriculture and forestry; Liquid fuels	CO2	742	453	-39	0.002	0.5	91.2
1A3a	Domestic aviation; Kerosene fossil	CO2	253	59	-77	0.002	0.5	91.7
4B1	Cropland remaining cropland	CO2	398	191	-52	0.002	0.5	92.2
2D	Non-energy products from fuels and solvent use	Indirect CO2 from NMVOC	194	35	-82	0.002	0.4	92.6
2C3	Aluminium production	CO2	139	0	-100	0.002	0.4	93.0
1A3b	Road transportation; Gasoline	N2O	143	15	-89	0.002	0.4	93.4
1B2b	Natural gas; All fuels	CH4	372	209	-44	0.002	0.3	93.7
1A3b	Road transportation; Gasoline	CH4	129	14	-89	0.002	0.3	94.0
1A3b	Road transportation; Diesel oil	N2O	5	91	1'572	0.001	0.3	94.3
2C3	Aluminium production	PFCs	105	0	-100	0.001	0.3	94.6
2B10	Chemical industry, other	N2O	384	389	1	0.001	0.3	94.9
3Db	Indirect emissions from managed soils	N2O	596	408	-32	0.001	0.3	95.2
1A4c	Agriculture and forestry; Gaseous fuels	CO2	70	129	84	0.001	0.3	95.4
3B5	Manure management, indirect	N2O	209	232	11	0.001	0.2	95.6
1A5	Other (military); Liquid fuels	CO2	218	114	-48	0.001	0.2	95.9
2A4	Other process uses of carbonates	CO2	160	68	-58	0.001	0.2	96.1
2G	Other product manufacture and use	Indirect CO2 from NMVOC	125	40	-68	0.001	0.2	96.3
4F2	Land converted to other land	CO2	88	130	48	0.001	0.2	96.5
1A4b	Residential; Biomass	CH4	104	26	-75	0.001	0.2	96.7
5D	Wastewater treatment and discharge	CH4	209	217	4	0.001	0.2	96.9
2B2	Nitric acid production	N2O	58	0	-100	0.001	0.2	97.1

## Approach 2

Given that the threshold is set at 90 %, the number of key categories is smaller under approach 2 compared to approach 1 for both level and trend assessments.

Concerning the level assessment, 28 out of 192 categories are identified as key categories for the latest reported year (see Table 1-4). Regarding the trend assessment between the base year 1990 and the latest reported year 2021, 27 categories are identified as trend key categories under approach 2 (see Table 1-5).

Contrary to approach 1 of the KCA, highlighting significant emission contributions from the Energy sector, approach 2 is dominated by contributions from categories having a large uncertainty, mostly from sector 3 Agriculture and sector 4 LULUCF, and to a lesser extent from sector 5 Waste and sector 2 IPPU.

Table 1-4 Switzerland's key categories according to approach 2 level assessment for the year 2021, including LULUCF categories and indirect CO<sub>2</sub> emissions, sorted by uncertainty-weighted emission contribution (column F). Categories in grey are not key and are given for information only. Compare also with results of the sensitivity study for the year 2021, see bottom panel of Figure 1-3.

KCA APPROACH 2, UNCERTAINTY APPROACH 2, LEVEL ASSESSMENT FOR 2021						
A	B	C	D	E	F	G
Code	IPCC category	Gas	Ex, t (kt CO <sub>2</sub> eq.)	Ex, t  (kt CO <sub>2</sub> eq.)	Lx, t (%)	Cumulative Total (%)
4C1	Grassland remaining grassland	CO <sub>2</sub>	168	168	14.8	14.8
4A1	Forest land remaining forest land	CO <sub>2</sub>	-2'332	2'332	13.0	27.8
3A	Enteric fermentation	CH <sub>4</sub>	3'631	3'631	8.8	36.6
3Da	Direct emissions from managed soils	N <sub>2</sub> O	856	856	7.8	44.3
1A1	Energy industries; Other fuels	CO <sub>2</sub>	2'409	2'409	5.1	49.4
3B1-4	Manure management, all livestock, direct	CH <sub>4</sub>	618	618	4.1	53.5
4A2	Land converted to forest land	CO <sub>2</sub>	-628	628	3.5	57.0
3Db	Indirect emissions from managed soils	N <sub>2</sub> O	408	408	3.3	60.3
5D	Wastewater treatment and discharge	N <sub>2</sub> O	533	533	3.1	63.4
4B1	Cropland remaining cropland	CO <sub>2</sub>	191	191	2.9	66.3
2B10	Chemical industry, other	N <sub>2</sub> O	389	389	2.8	69.1
2F1	Refrigeration and air conditioning	HFCs	1'195	1'195	2.7	71.9
3B5	Manure management, indirect	N <sub>2</sub> O	232	232	2.5	74.4
5D	Wastewater treatment and discharge	CH <sub>4</sub>	217	217	2.4	76.8
1A4b	Residential; Gaseous fuels	CO <sub>2</sub>	2'968	2'968	1.8	78.5
1A2	Manufacturing industries and construction; Gaseous fuels	CO <sub>2</sub>	2'215	2'215	1.3	79.9
4E2	Land converted to settlements	CO <sub>2</sub>	213	213	1.3	81.2
4C2	Land converted to grassland	CO <sub>2</sub>	264	264	1.1	82.3
5A	Solid waste disposal	CH <sub>4</sub>	289	289	1.0	83.3
2A1	Cement production	CO <sub>2</sub>	1'732	1'732	0.9	84.3
3B1-4	Manure management, all livestock, direct	N <sub>2</sub> O	107	107	0.9	85.2
4D1	Wetland remaining wetland	CO <sub>2</sub>	66	66	0.9	86.1
1A4a	Commercial; Gaseous fuels	CO <sub>2</sub>	1'348	1'348	0.8	86.9
4F2	Land converted to other land	CO <sub>2</sub>	130	130	0.8	87.7
1B2b	Natural gas; All fuels	CH <sub>4</sub>	209	209	0.8	88.4
1A3b	Road transportation; Diesel oil	CO <sub>2</sub>	7'035	7'035	0.7	89.2
5C	Incineration and open burning of waste	N <sub>2</sub> O	48	48	0.7	89.9
4III	Direct N <sub>2</sub> O from disturbance	N <sub>2</sub> O	38	38	0.7	90.6
2G	Other product manufacture and use	SF <sub>6</sub>	125	125	0.6	91.2
1A2	Manufacturing industries and construction; Other fuels	CO <sub>2</sub>	445	445	0.6	91.8
4B2	Land converted to cropland	CO <sub>2</sub>	31	31	0.6	92.3

Table 1-5 Switzerland's key categories according to approach 2 trend assessment for 1990–2021, including LULUCF categories and indirect CO<sub>2</sub> emissions, sorted by decreasing uncertainty-weighted contribution to the trend assessment (column G). Categories in orange have an increased emission in 2021 compared to 1990. Categories in grey are not key and are given for information only.

KCA APPROACH 2, UNCERTAINTY APPROACH 2, TREND ASSESSMENT 1990 - 2021								
A	B	C	D	E	F	G	H	
Code	IPCC category	Gas	Ex, 0 (kt CO <sub>2</sub> eq.)	Ex, t (kt CO <sub>2</sub> eq.)	Category trend (%)	Trend Assessment	Contribution to trend (%)	Cumulative Total (%)
4C1	Grassland remaining grassland	CO <sub>2</sub>	17	168	894	0.003	24.6	24.6
4G	HWP Harvested Wood Products	CO <sub>2</sub>	-1'127	-39	97	0.022	15.8	40.3
4A1	Forest land remaining forest land	CO <sub>2</sub>	-1'113	-2'332	-109	0.017	10.2	50.5
2F1	Refrigeration and air conditioning	HFCs	0	1'195	5'305'025	0.020	5.0	55.5
1A1	Energy industries; Other fuels	CO <sub>2</sub>	1'492	2'409	62	0.020	4.6	60.1
4B1	Cropland remaining cropland	CO <sub>2</sub>	398	191	-52	0.002	3.7	63.7
5D	Wastewater treatment and discharge	N <sub>2</sub> O	1'074	533	-50	0.006	3.6	67.3
5A	Solid waste disposal	CH <sub>4</sub>	862	289	-66	0.007	2.7	70.0
3A	Enteric fermentation	CH <sub>4</sub>	3'930	3'631	-8	0.008	2.0	71.9
1A4b	Residential; Gaseous fuels	CO <sub>2</sub>	1'451	2'968	105	0.030	1.9	73.9
4C2	Land converted to grassland	CO <sub>2</sub>	95	264	178	0.003	1.5	75.3
1A2	Manufacturing industries and construction; Gaseous fuels	CO <sub>2</sub>	1'091	2'215	103	0.022	1.4	76.8
3B5	Manure management, indirect	N <sub>2</sub> O	209	232	11	0.001	1.2	78.0
1A3b	Road transportation; Gasoline	N <sub>2</sub> O	143	15	-89	0.002	1.1	79.1
3Db	Indirect emissions from managed soils	N <sub>2</sub> O	596	408	-32	0.001	1.1	80.2
1A2	Manufacturing industries and construction; Solid fuels	CO <sub>2</sub>	1'275	342	-73	0.012	1.1	81.2
2G	Other product manufacture and use	Indirect CO <sub>2</sub> from NMVOC	125	40	-68	0.001	1.0	82.2
2B10	Chemical industry, other	N <sub>2</sub> O	384	389	1	0.001	1.0	83.3
5D	Wastewater treatment and discharge	CH <sub>4</sub>	209	217	4	0.001	1.0	84.2
2D	Non-energy products from fuels and solvent use	Indirect CO <sub>2</sub> from NMVOC	194	35	-82	0.002	0.9	85.1
1A3b	Road transportation; Diesel oil	CO <sub>2</sub>	2'632	7'035	167	0.083	0.9	86.1
2G3	N <sub>2</sub> O from product uses	N <sub>2</sub> O	92	28	-70	0.001	0.8	86.9
1A3b	Road transportation; Gasoline	CH <sub>4</sub>	129	14	-89	0.002	0.7	87.6
1A2	Manufacturing industries and construction; Other fuels	CO <sub>2</sub>	192	445	132	0.005	0.7	88.3
1A4a	Commercial; Gaseous fuels	CO <sub>2</sub>	920	1'348	47	0.010	0.7	88.9
4F2	Land converted to other land	CO <sub>2</sub>	88	130	48	0.001	0.6	89.6
1B2b	Natural gas; All fuels	CH <sub>4</sub>	372	209	-44	0.002	0.6	90.2
2F2	Foam blowing agents	HFCs	0	23	nan	0.000	0.6	90.8
1A4b	Residential; Liquid fuels	CO <sub>2</sub>	10'099	4'879	-52	0.056	0.5	91.2
3B1-4	Manure management, all livestock, direct	N <sub>2</sub> O	168	107	-36	0.000	0.4	91.7
1A3b	Road transportation; Gasoline	CO <sub>2</sub>	11'343	6'346	-44	0.048	0.4	92.1

### 1.4.3. Summary of combined KCA including LULUCF categories

A summary of the key category analysis including LULUCF categories and indirect CO<sub>2</sub> emissions is shown in Table 1-6, considering the level assessment for 2021 and the trend assessment for 1990–2021, for both approach 1 and approach 2. A category is counted multiple times as key category if it is a key category for multiple gases.

Table 1-6 Summary of Switzerland key category analysis, including LULUCF categories and indirect CO<sub>2</sub> emissions. L: Level assessment (2021); T: Trend assessment (1990–2021); 1: KCA approach 1; 2: KCA approach 2. SF<sub>6</sub> and NF<sub>3</sub> are not emitted from any key category. Results of the level assessment for the base year are not reported in this table.

SUMMARIES TO IDENTIFY KEY CATEGORIES							
A	B	C & D					
Code	IPCC category	CO2	CH4	N2O	HFCs	PFCs	Indirect CO2
1A1	Energy industries; Gaseous fuels	L1, T1					
1A1	Energy industries; Liquid fuels	L1, T1					
1A1	Energy industries; Other fuels	L1, T1, L2, T2					
1A2	Manufacturing industries and construction; Gaseous fuels	L1, T1, L2, T2					
1A2	Manufacturing industries and construction; Liquid fuels	L1, T1					
1A2	Manufacturing industries and construction; Other fuels	L1, T1, T2					
1A2	Manufacturing industries and construction; Solid fuels	L1, T1, T2					
1A3a	Domestic aviation; Kerosene fossil	T1					
1A3b	Road transportation; Diesel oil	L1, T1, L2, T2		T1			
1A3b	Road transportation; Gasoline	L1, T1	T1, T2	T1, T2			
1A4a	Commercial; Gaseous fuels	L1, T1, L2, T2					
1A4a	Commercial; Liquid fuels	L1, T1					
1A4b	Residential; Gaseous fuels	L1, T1, L2, T2					
1A4b	Residential; Liquid fuels	L1, T1					
1A4c	Agriculture and forestry; Liquid fuels	L1, T1					
1B2b	Natural gas; All fuels		L1, T1, L2, T2				
2A1	Cement production	L1, T1, L2					
2B10	Chemical industry, other			L1, T1, L2, T2			
2C3	Aluminium production	T1				T1	
2D	Non-energy products from fuels and solvent use; Indirect CO2 from NMVOC						T1, T2
2F1	Refrigeration and air conditioning				L1, T1, L2, T2		
2G	Other product manufacture and use; Indirect CO2 from NMVOC						T2
2G3	N2O from product uses			T2			
3A	Enteric fermentation		L1, T1, L2, T2				
3B1-4	Manure management, all livestock, direct		L1, L2	L2			
3B5	Manure management, indirect			L1, L2, T2			
3Da	Direct emissions from managed soils			L1, L2			
3Db	Indirect emissions from managed soils			L1, T1, L2, T2			
4A1	Forest land remaining forest land	L1, T1, L2, T2					
4A2	Land converted to forest land	L1, L2					
4B1	Cropland remaining cropland	L1, T1, L2, T2					
4C1	Grassland remaining grassland	T1, L2, T2					
4C2	Land converted to grassland	L1, T1, L2, T2					
4D1	Wetland remaining wetland	L2					
4E2	Land converted to settlements	L1, L2					
4F2	Land converted to other land	L2, T2					
4G	HWP Harvested Wood Products	T1, T2					
4I11	Direct N2O from disturbance			L2			
5A	Solid waste disposal		L1, T1, L2, T2				
5C	Incineration and open burning of waste			L2			
5D	Wastewater treatment and discharge		L1, L2, T2	L1, T1, L2, T2			

## 1.5. General description of QA/QC plan and implementation

The national inventory system has an established and certified quality management system (QMS) that complies with the requirements of ISO 9001:2015 and the UNFCCC reporting guidelines (UNFCCC 2019, 2022a) to ensure and continuously improve transparency, consistency, comparability, completeness, accuracy, and confidence in national GHG emission and removal estimates. The quality manual (FOEN 2023a) contains all relevant information regarding the QMS. It is updated annually and made available to everyone contributing to the GHG inventory.

### General QC procedures

The general QC activities as described in Table 6.1 of the IPCC reporting guidelines (IPCC 2006) are implemented in the annual cycle of inventory compilation (Table 1-7). Routine annual quality control procedures comprise checks related to new data and database operations, spot-checks for transcription errors, correct use of conversion factors and units, and correct calculations. There are checklists for the most important sectoral data suppliers and EMIS database experts.

The NID is subject to an internal review prior to submission. The review of every section is carried out by personnel not involved in the preparation of the reviewed section, but who is familiar with the reporting under the UNFCCC.

Table 1-7 Annual cycle of inventory planning, preparation and management

	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Data compilation												
QC EMIS Experts												
QC Sectoral Experts												
UN Review												
Inventory Development Plan												
CRF Tables												
QC CRF Tables												
KCA / Uncertainties												
NID												
Internal review NID and CRF Tables												
Official consideration and approval												
Submission												x
Archiving												
Meeting of Core Group	x				x			x		x		
Meeting of Working Group												x
Meeting of NIS Supervisory Board						x					x	

### Category-specific QC procedures

Quite often, sectoral and/or EMIS experts commission research to look into a particular topic in more detail. Results from these mid- to long-term projects are presented to the inventory core group, particularly with regard to whether the new data provide a better estimate given the country-specific circumstances and whether a consistent time-series can be derived from the new data. The core group then decides if and how to best implement the results and documents the agreed procedure in the inventory development plan. The general procedures regarding category-specific QC are also described in the quality manual (FOEN 2023a), while specific activities are documented in the corresponding sectoral chapters.

### Quality assurance procedures

As required by ISO 9001 there are periodic internal audits covering all processes. In addition, an external organisation is mandated to do the annual audit of the ISO 9001 quality management system. Apart from these audits, there are expert peer reviews for specific sectors commissioned on a case-by-case basis. The results and suggestions for improvements from these reviews are discussed in the core group and specific tasks for future implementation are taken up into the inventory development plan.

Likewise, recommendations and encouragements from the UNFCCC expert review teams (ERT) are also added to the inventory development plan, discussed in the core group and implemented in future submissions. Specific actions resulting from suggestions from the ERT are listed in chp. 10 Recalculations.

### Verification activities

In the energy sector, the standard verification activity carried out on an annual basis is the reference approach, as documented in chp. 3.2.1 of the NID and CRF Table1.A(b).

In addition, the FOEN supports a long-term monitoring programme carried out by the Swiss Federal Laboratories for Materials Science and Technology (Empa). In the frame of this programme, continuous measurements of atmospheric concentrations of various halogenated gases are made at the high-Alpine research station Jungfraujoch (3580 m a.s.l.), from which Swiss emissions of some fluorinated greenhouse gases can be estimated. These data are compared with the emissions reported in the greenhouse gas inventory. The results are briefly summarized in Annex A6.1.

Furthermore, an ongoing project is developing an independent estimate of CH<sub>4</sub> and N<sub>2</sub>O emissions in Switzerland based on atmospheric measurements and inverse modelling of atmospheric transport. The results show a very good agreement between modelled emissions and emission estimates according to the greenhouse gas inventory for CH<sub>4</sub> and reasonable agreement within the uncertainties for N<sub>2</sub>O. A summary of the current state of these verification activities is provided in Annex A6.2.

## 1.6. General uncertainty assessment

We hereafter present the input uncertainty estimates for the greenhouse gas inventory under the UNFCCC and the obtained results as required by UNFCCC (2019, paragraph 29).

### 1.6.1. Data used

Input uncertainty values are mostly given for activity data and emissions factors. For categories concerning indirect CO<sub>2</sub> emissions and F-gases, uncertainty values are available for emissions only.

Input uncertainty values are selected and/or computed based on available data and according to the following order of preference:

- As a first choice, specific uncertainty information from studies or from data suppliers is used, if available. This is the case for most key categories.
- As a second choice, authors of the NID chapters, FOEN experts involved and several data suppliers derived estimates of uncertainties based on the 2006 IPCC Guidelines (IPCC 2006) default values and on information concerning the process of data collection for activity data and emission factors (import or sales statistics, surveys or modelling). Several experts from data suppliers were contacted for further information on some of the uncertainties. Industry associations/sources also provided published or unpublished uncertainty estimates for their data.
- As a last choice, for categories with no quantitative uncertainty data available, the NID provides qualitative estimates of uncertainties. The elaboration of a quantitative uncertainty assessment for these categories would present a large effort with only limited effect on the overall uncertainty and therefore it has been decided to realize a semi-quantitative assessment. This includes the definition of a list of the combined uncertainties for all gases and three uncertainty levels: low, medium and high (see Table 1-8). These values are motivated by the comparison of uncertainty analyses of several countries carried out by de Keizer et al. (2007), as presented at the 2<sup>nd</sup> International Workshop on Uncertainty in Greenhouse Gas Inventories (Vienna 27–28 September 2007), and by expert judgement from sectoral experts and authors.

The following sources of uncertainties are not taken into account:

- Uncertainties in the GWP values.
- Uncertainty due to unknown bias.
- Uncertainty due to neglected temporal variability when assuming constant parameters over time (e.g. emission factors).

Several uncertainty values have been changed for submission 2023 (see detailed input values in Annex A2.1):

- The uncertainty for the emission factor of category 1A Gaseous fuels CO<sub>2</sub> was updated.
- The uncertainties assigned to emissions of HFCs, PFCs, SF<sub>6</sub> and NF<sub>3</sub> in sector 2 IPPU were updated (yearly update).
- The uncertainties assigned to activity data and emission factors in sector 3 Agriculture for CH<sub>4</sub> and N<sub>2</sub>O emissions were updated (yearly update). In addition, uncertainties of agricultural N<sub>2</sub>O emissions decreased significantly due to lower default uncertainties of N<sub>2</sub>O emission factors in the 2019 IPCC Refinement (IPCC 2019) (see also chp. 5.3.3 and 5.5.3). This caused a significant uncertainty decrease for the inventory emissions of N<sub>2</sub>O, as well as for the overall inventory uncertainty estimate.
- The uncertainties for the emission factors for categories 4B1, 4B2, 4C1, 4C2, 4D2 and 4F2 were updated (yearly update).
- The uncertainties for the emissions for categories 5D for CH<sub>4</sub> and N<sub>2</sub>O were updated because of a methodology update (see chp. 7.5.3).
- The uncertainties for the emissions for all indirect CO<sub>2</sub> emissions were updated (yearly update).

The detailed data sources can be found in the relevant chapters on “Uncertainties and time-series consistency” in each of the sectoral chapters (chp. 3 to 9) below.

Table 1-8 Semi-quantitative (combined) uncertainties (U) for the emission of categories with no quantitative uncertainty data available. Note that there is no source of HFCs, PFCs, SF<sub>6</sub> or NF<sub>3</sub> for which a semi-quantitative uncertainty value is required.

Gas	Uncertainty category	Combined uncertainty
CO <sub>2</sub>	low	2%
	medium	10%
	high	40%
CH <sub>4</sub>	low	15%
	medium	30%
	high	60%
N <sub>2</sub> O	low	40%
	medium	80%
	high	150%

## 1.6.2. Methodology

The uncertainty aggregation for the greenhouse gases is carried out for the latest submission according to approach 1 (uncertainty propagation) and approach 2 (Monte Carlo simulations).

Input uncertainty values for activity data and emission factors at the same aggregation level as required for the key category analysis are used for the computation. A total of 192 categories were considered, including LULUCF and indirect CO<sub>2</sub> emissions. Indirect N<sub>2</sub>O emissions are not included in the uncertainty analysis.

Uncertainties are assessed in accordance with the IPCC Guidelines 2006 (IPCC 2006). The Monte Carlo simulations follow the recommendations by JCGM (2008, Supplement 1).

The following assumptions were applied to both approaches:

- Full correlation or no correlation can be set between the base year and the reporting year for the same input variable.
- The following statistical distributions may be used: normal, triangular, gamma. If a variable cannot physically have negative values and has an uncertainty >100 %, a gamma distribution is preferred in order to not generate negative values during Monte Carlo simulations. This is particularly relevant for emission factors.
- Asymmetric distribution: in approach 1, this is taken into account by computing the uncertainty propagation separately for each side of the mean. In approach 2, each distribution can be simulated, and asymmetric distributions are not an issue.

The following factors are not accounted for:

- Partial correlation between the base year and the reporting year for the same input variable.
- Correlations between categories (for different input variables).

For both approaches, all uncertainty results represent a 95 % confidence interval. For a symmetrical distribution, this interval is centred on the mean, from 2.5 % up to 97.5 % of the distribution. For non-symmetrical distributions obtained by Monte Carlo simulations, the reported uncertainties represent the narrowest 95 % interval, in agreement with JCGM (2008, S1). This has consequences in particular for combined uncertainties strongly influenced by input gamma distributions, with the narrowest interval having the tendency to be shifted towards the lower end of the distribution (for example, from 1 % up to 96 % of the distribution). Uncertainties are given for the lower range (from the lower edge to the mean) and the upper range (from the mean to the upper edge), expressed as a percentage of the mean.

#### **1.6.2.1. Aggregation of uncertainties using approach 1: uncertainty propagation**

The uncertainty propagation is computed using the open-source software Python (version 3.6.1, <https://www.python.org/>), in which the equations given in the guidelines (IPCC 2006) are programmed. Results of approach 1 for the reporting year and for the trend are summarised in Table 1-9.

#### **1.6.2.2. Aggregation of uncertainties using approach 2: Monte Carlo simulations**

The Monte Carlo simulations were performed for the base year 1990, the reporting year 2021 and the trend at the aggregation level required for the KCA. All input variables can be found in Annex A2.1. Results for each gas are summarized in Table 1-11.

The main strategy in Monte Carlo analysis is to simulate a probability distribution for each input variable (distribution type, mean and standard deviation) and propagate these probability distributions to the final value of the model, in order to obtain a realistic uncertainty envelope for the final quantity. In practice, this is achieved by generating a large set of random numbers for each input quantity according to its distribution probability and by computing the intermediate (if any) and final values according to the equations of the model. The strength of this method is to propagate uncertainties accurately even if the equations of the model are non-linear and even if the final uncertainty envelope is non-symmetric. Another advantage is that a distribution is produced to represent the final quantity, while this information is not available from approach 1.

In our settings, each input quantity is, for each year, an activity data value associated with an emission factor or if applicable, a direct emission. The final quantity is the emission at the inventory level and the mathematical model is the sum of emissions from each process.

## Modelling framework

The Monte Carlo simulations are programmed using the open-source software Python (version 3.6.1, <https://www.python.org/>). Python is run through the Anaconda installation (<https://www.anaconda.com/>, version 4.4.0 (64 bit)) on a Windows PC.

To generate random numbers corresponding to the selected distributions, mean and variances, the Python function `random` is used. In practice, for each input emission factor and activity data value (or direct emission, if applicable), random numbers are generated according to the input parameters. The final uncertainty envelope is obtained by computing the emissions as the product of simulated activity data and emission factors and by then adding up all simulated emissions. Intermediate sums can also be obtained, for example the sum for a given sector.

For each input quantity, 1'000'000 random values were generated resulting in equal numbers of values for the base year, the reporting year and the trend.

The average offset between the simulated mean for each process and the input mean is less than 0.15 %. This reflects the uncertainty introduced by the Monte Carlo method itself. This computational uncertainty remains small compared to the uncertainty introduced by activity data and emission factors.

## Correlation

If two variables representing the base year (BY) and the reporting year (RY) for the same process are fully correlated, a random number is generated for the base year only, written  $BY_{\text{random}}$ . The random value for the reporting year  $RY_{\text{random}}$  is then computed as:

$$RY_{\text{random}} = BY_{\text{random}} * RY_{\text{input, mean}}/BY_{\text{input, mean}}$$

where  $RY_{\text{input, mean}}$  and  $BY_{\text{input, mean}}$  are the input mean values for the variables in the reporting year and the base year, respectively.

This method implicitly assumes that the uncertainty for the base year and the reporting year, expressed in percentage of the mean value, stays the same.

No correlation between activity data (or emission factors) resulting from different processes for the same year is programmed.

## Sensitivity analysis

The sensitivity analysis investigates how sensitive the total emission is to each input emission. This analysis was conducted for the base year and the reporting year.

The sensitivity of a total value (total base year emission, total reporting year emission) to the variability of input quantities is computed as the correlation coefficient between total and input values, using in Python the function `corrcoef` from the `numpy` package. Each sensitivity value is computed on 1'000'000 pairs of points.

The sensitivity therefore has a value between -1 and +1, where a negative value indicates a negative correlation, and a positive value a positive correlation. For emissions, since the total values are a sum of input values, we expect only positive correlations.

Intuitively, the variability in the total value will be very sensitive to a process with also a high variability, compared to other processes with a smaller variability. In other words, the inventory total is expected to be mostly sensitive to processes with a high uncertainty (expressed in absolute values or in the same unit as the emissions).

### Source code availability

The Python source code is available on the Github public repository with the repository name <inventory\_uncertainty\_UNFCCC\_CLRTAP>.

### 1.6.3. Results of approaches 1 and 2 uncertainty evaluation

In Table 1-9 the results of the uncertainty evaluations for the previous and latest submissions are summarised, using approaches 1 and 2 for the base year, the respective reporting year and the trend, excluding and including the LULUCF sector.

Table 1-9 Relative uncertainties for Switzerland's national total greenhouse gas emissions and removals excluding and including the LULUCF sector for the latest and previous submissions. The uncertainties are given considering a 95% confidence interval and expressed as the distance from edge to mean, in percentage of the mean. Uncertainties are obtained by approach 1 (uncertainty propagation) and 2 (Monte Carlo simulations) for emission levels in 1990, 2021 and for the trend (1990–2021) and are detailed by lower range, upper range and mean uncertainty for submission 2023 as displayed in the upper panel. The uncertainty analysis is based on emissions and removals including indirect CO<sub>2</sub> emissions. For comparison purposes, the corresponding values from the previous submission are reported as well in the lower panel labelled submission 2022.

Submission 2023									
Inventory	Level uncertainty 1990			Level uncertainty 2021			Trend uncertainty 1990-2021		
	(-)%	(+)%	mean %	(-)%	(+)%	mean %	(-)%	(+)%	mean %
Approach 2 Uncertainty analysis									
excl. LULUCF	3.1	3.2	3.1	2.8	2.9	2.9	3.4	3.3	3.3
incl. LULUCF	4.3	4.5	4.4	4.8	4.9	4.9	4.8	4.9	4.9
Approach 1 Uncertainty analysis									
excl. LULUCF	2.7	2.9	2.8	2.6	3.3	3.0	2.8	3.6	3.2
incl. LULUCF	4.2	4.3	4.2	4.8	5.2	5.0	4.7	5.2	5.0
Submission 2022									
Inventory	Level uncertainty 1990			Level uncertainty 2020			Trend uncertainty 1990-2020		
	(-)%	(+)%	mean %	(-)%	(+)%	mean %	(-)%	(+)%	mean %
Approach 2 Uncertainty analysis									
excl. LULUCF	4.6	5.7	5.2	4.3	4.8	4.6	5.7	5.4	5.6
incl. LULUCF	6.0	6.8	6.4	6.1	6.4	6.2	6.7	6.8	6.7
Approach 1 Uncertainty analysis									
excl. LULUCF	3.2	7.4	5.3	3.3	5.9	4.6	3.5	3.6	3.6
incl. LULUCF	4.6	8.3	6.4	5.3	7.3	6.3	5.3	5.3	5.3

In general, mean uncertainties resulting from approaches 1 and 2 are in concordance. For the lower range uncertainty, approach 1 may result in a smaller estimate in cases where the inventory probability distribution is asymmetric. We therefore recommend to take into consideration the uncertainty estimate provided by approach 2 (Monte Carlo simulations). Uncertainties including the LULUCF sector are in each case larger than excluding the LULUCF sector, as processes in the LULUCF sector have comparatively large uncertainties.

The overall level uncertainties are smaller for the latest submission compared to the previous one, which is due to smaller uncertainty estimates for several categories, and in particular for Sector 3 Agriculture. The overall trend uncertainty decreased for the present inventory compared to the previous one. This is probably due to the general uncertainty decrease for the emissions.

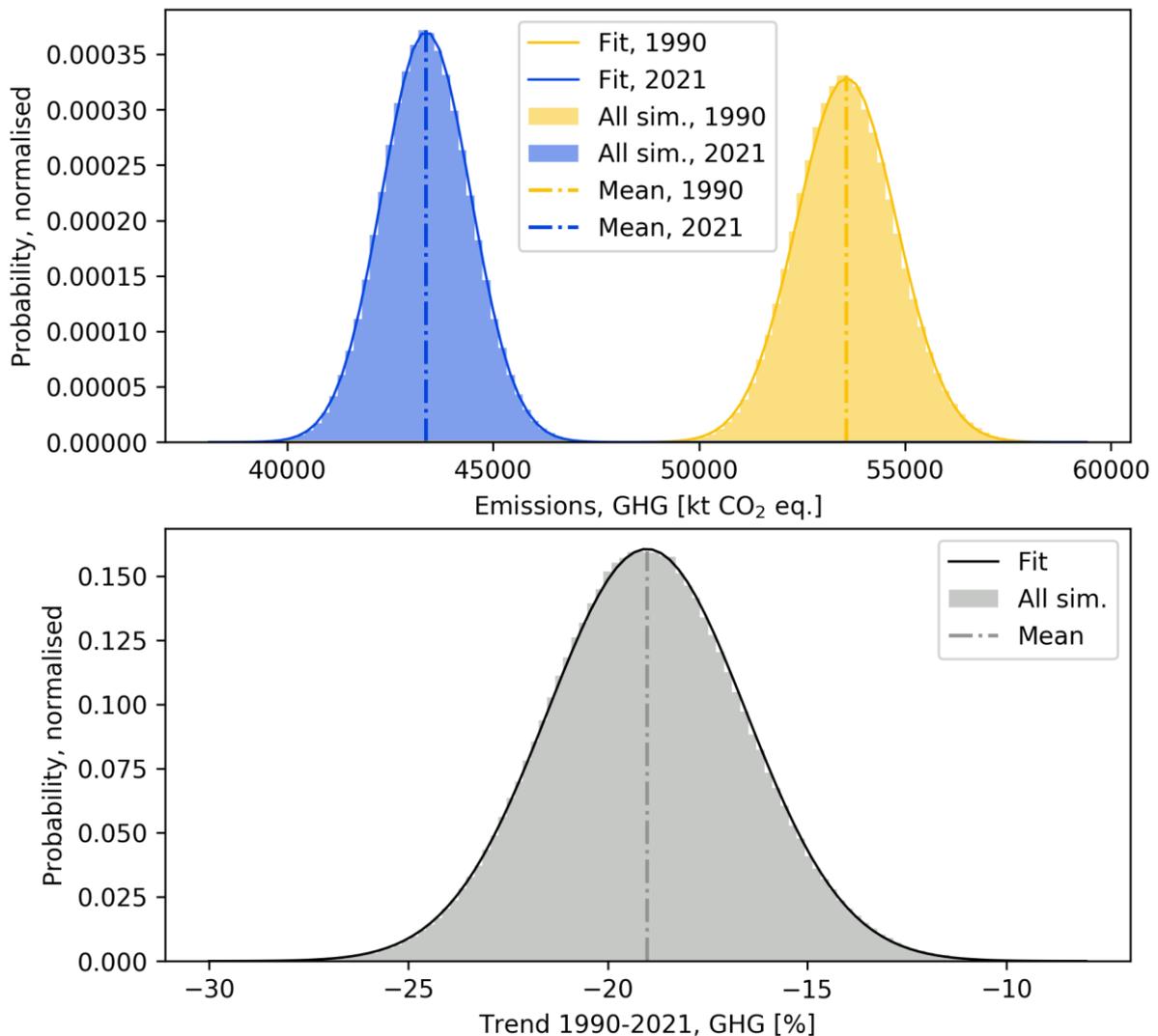


Figure 1-2 Results of Monte Carlo simulations: Distributions obtained for the inventory mean emission for all greenhouse gases, for the base year 1990 (top panel, yellow), the reporting year 2021 (top panel, blue) and the trend 1990–2021 (bottom panel, grey). All sim.: all simulations (1'000'000 values for each distribution). Fit: fit of the distribution using a normal distribution. By definition, the integral of the fit (or area) has an exact numeric value of one. Mean: mean inventory emission obtained from the simulations.

Table 1-10 Overview of sector contributions to inventory uncertainties for the reporting year emissions and removals and for the trend, including indirect CO<sub>2</sub> emissions. Uncertainties are computed using approach 2 (Monte Carlo simulations).

Sector	Emissions or removals in base year (1990)	Emissions or removals in reporting year (2021)	Contribution to total uncertainty by sector in reporting year	Contribution to total trend uncertainty by sector
	kt CO <sub>2</sub> eq.	kt CO <sub>2</sub> eq.	%	%
1: Energy	41'972	34'175	5	3
2: Industrial processes and product use	4'277	4'017	3	2
3: Agriculture	6'801	5'898	27	34
4: Land use, land use change and forestry	-1'764	-1'875	62	48
5: Waste	2'281	1'143	3	12
6: Other	14	16	0.0	0.0
<b>Total</b>	<b>53'581</b>	<b>43'374</b>	<b>100</b>	<b>100</b>

Table 1-11 For each gas, net emission levels for 1990 and 2021, trend (1990–2021), and associated uncertainties obtained from Monte Carlo simulations and from uncertainty propagation, including indirect CO<sub>2</sub> emissions and LULUCF categories. Note that the trend and its associated uncertainty are expressed in the same unit, in percent. As an example, for a trend of -10 % with uncertainties of 2 %, the trend is comprised between -12 % and -8 %.

Gas	Base year (1990)			Reporting year (2021)			Trend (1990-2021)		
	Emissions, kt CO <sub>2</sub> eq.	U(-) %	U(+) %	Emissions, kt CO <sub>2</sub> eq.	U(-) %	U(+) %	Trend, %	U(-) %	U(+) %
Monte Carlo simulations (approach 2)									
CO <sub>2</sub>	42'313	4	4	33'850	5	5	-20	4	4
CH <sub>4</sub>	6'544	15	15	5'118	16	16	-22	17	17
N <sub>2</sub> O	4'066	33	35	2'894	28	30	-29	30	33
HFCs	0.023	19	19	1'241	18	18	5'510'648	1'441'392	1'507'380
PFCs	104.8	9	9	28.37	13	13	-73	4	4
SF <sub>6</sub>	141.2	41	40	129.0	40	39	-9	2	2
NF <sub>3</sub>	0.000			0.370	86	107			
Indirect CO <sub>2</sub>	411.1	30	32	112.9	28	32	-73	11	13
Uncertainty propagation (approach 1)									
CO <sub>2</sub>	42'313	4	4	33'850	5	5	-20	5	5
CH <sub>4</sub>	6'544	14	15	5'118	16	17	-22	17	19
N <sub>2</sub> O	4'066	27	29	2'894	24	37	-29	24	37
HFCs	0.023	19	19	1'241	19	19	5'510'648	1'449'599	1'466'316
PFCs	104.8	0.0	0.0	28.37	14	14	-73	5	5
SF <sub>6</sub>	141.2	41	41	129.0	40	40	-9	2	2
NF <sub>3</sub>	0.000			0.370	76	131			
Indirect CO <sub>2</sub>	411.1	28	19	112.9	26	37	-73	10	14

Changes in total level and trend uncertainties are on one hand due to changes in uncertainties assigned to emission factors and activity data in the different categories. On the other hand, changes in activity data and emission factor values cause changes in the contribution to the total level and trend uncertainty of each category.

Contribution to level uncertainty and the uncertainty introduced to the trend in total national emissions of each category are shown in Annex A2.2 for approach 1 (uncertainty propagation) and in Annex A2.3 for approach 2 (Monte Carlo simulations).

The Monte Carlo simulations provide data to conduct a sensitivity analysis between emissions from each category and the inventory (total) emission. This analysis quantifies the influence of a change in the emission of a given category on the inventory total. The results of the sensitivity analysis for the base year and the reporting year are shown in Figure 1-3. The processes ranked in descending order of importance according to the sensitivity analysis follow almost the same order as the processes ranked according to approach 2 of the key category analysis. In both cases, results are dominated by categories from sectors 3 Agriculture and 4 LULUCF. Both methods highlight categories with large uncertainties, expressed in absolute values. The sensitivity analysis therefore confirms the results obtained by approach 2 of the KCA.

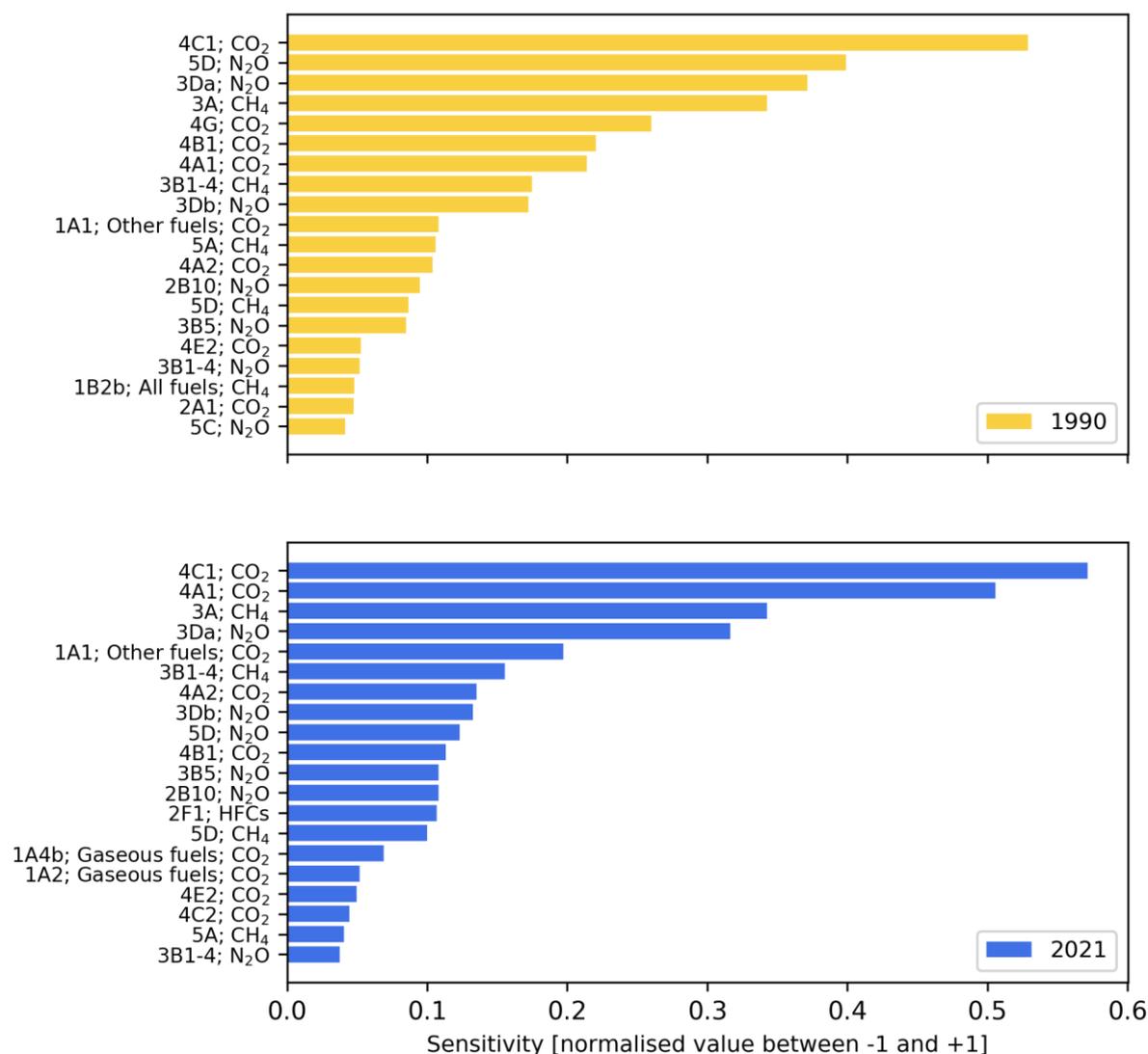


Figure 1-3 Results of the sensitivity analysis between emissions and removals from each category and inventory emissions and removals for all greenhouse gases, for the base year 1990 and the reporting year 2021. Only the twenty categories ranked first are listed. See chp. 1.6.2.2 for details and compare also with Table 1-4 (results for the key category analysis approach 2, i.e. using uncertainties).

Based on the analysis of the predominant contributions to the uncertainty of the national GHG inventory, the FOEN commissions and/or supports various projects. Planned improvements are given in the sectoral chapters and an overview list is reported in chp. 10.4.

## 1.7. General assessment of completeness

### 1.7.1. Information on completeness

The inventory is compiled using notation keys in the reporting tables as appropriate, according to the modalities, procedures and guidelines for the transparency framework under the Paris Agreement (UNFCCC 2019). Explanations for using the notation keys “NE” and “IE” are provided in CRF table 9.

The CRF reporter does not transfer the use of notation keys in tables 1.A(b) Reference approach and 1.A(d) Feedstock, reductants and other non-energy use of fuels into CRF table 9. Therefore, information on the use of notation key “IE” in tables 1.A(b) and 1.A(d) is provided here for completeness:

- 1.A(b) Reference approach, liquid fuels: Imports of refinery feedstocks are included in crude oil.
- 1.A(b) Reference approach, liquid fuels: Imports of other kerosene are included in jet kerosene.
- 1.A(b) Reference approach, liquid fuels: Carbon stored of liquefied petroleum gas, naphtha and petroleum coke are included in other oil.
- 1.A(b) Reference approach, solid fuels: Import and stock change of anthracite and coke oven/gas coke are included in other bituminous coal.
- 1.A(d) Feedstock, reductants and other non-energy use of fuels, liquid fuels: fuel quantity, C excluded from reference approach and CO<sub>2</sub> emissions for liquefied petroleum gas, naphtha and petroleum coke are included in other oil.

### 1.7.2. Description of insignificant categories

- A study commissioned by FOEN measuring greenhouse gas emissions from waste incineration plants came to the conclusion that "CH<sub>4</sub> emission concentrations were very low and below the background concentration of 1.8 ppm" (Mohn 2013). These measurements showed that CH<sub>4</sub> concentration in the exhaust air was below the CH<sub>4</sub> concentration in ambient air, which would indicate CH<sub>4</sub> removal rather than emissions. Therefore, CH<sub>4</sub> emissions from municipal waste incineration are reported as not estimated because they are considered insignificant (see chp. 3.2.5.2.1).
- Use of soda ash is reported for glass production (2A3) and ceramics (2A4a). A study investigating carbonate use in industry (INFRAS 2015) could not identify any other uses of soda ash. However, the amounts of soda ash used and reported in 2A3 and 2A4a are slightly smaller than net imports of soda ash. Assuming that the amount of soda ash unaccounted for in 2A3 and 2A4a caused additional CO<sub>2</sub> emissions in category 2A4b Other uses of soda ash, this would result in roughly 5 kt CO<sub>2</sub> in recent years (see chp. 4.2.2.4).

### **1.7.3. Total aggregate emissions considered insignificant**

CH<sub>4</sub> emissions from waste incineration are not occurring. Based on the exhaust measurements, the process would rather destroy ambient CH<sub>4</sub> than release any. Therefore, this does not contribute to total aggregate emissions considered insignificant.

Potential other uses of soda ash not already accounted for in Switzerland might produce 5 kt CO<sub>2</sub>.

National total emissions excluding LULUCF in 2021 were 45'249 kt CO<sub>2</sub> equivalent. Therefore, the significance threshold for aggregated emissions equals 45.2 kt CO<sub>2</sub> equivalent.

## **1.8. Metrics**

The inventory is prepared using the 100-year time-horizon global warming potential (GWP) values from the IPCC Fifth Assessment Report (Myhre 2013) as required by the modalities, procedures and guidelines for the transparency framework under the Paris Agreement (UNFCCC 2019), implemented in the CRF reporter released by the secretariat at the end of January 2023.

## **1.9. Summary of any flexibility applied**

Not applicable.

## 2. Trends in greenhouse gas emissions and removals

Responsibilities for Trends in greenhouse gas emissions and removals	
Authors	Regine Röthlisberger (FOEN), Nele Rogiers (FOEN; LULUCF), Andreas Schellenberger (FOEN; LULUCF)
Annual updates (NID text, tables, figures)	Beat Rihm (Meteotest; LULUCF), Nele Rogiers (FOEN), Felix Weber (INFRAS)
Quality control NID (annual updates)	Beat Rihm (Meteotest), Andreas Schellenberger (FOEN; LULUCF)
Internal review	Michael Bock (FOEN), Daniel Bretscher (Agroscope), Markus Didion (WSL), Martin Lindenmann (Sigmaphan), Andreas Schellenberger (FOEN)

This chapter provides an overview of Switzerland's GHG emissions and removals in 2021 as well as trends for the period 1990–2021.

### 2.1. Aggregated greenhouse gas emissions and removals

Table 2-1 shows the aggregated emissions of all greenhouse gases (GHG) 2021 for each sector (including indirect CO<sub>2</sub>) and the relative shares of the sectors. Furthermore, emission data on international aviation and marine bunkers are provided. As the table indicates, CO<sub>2</sub> is the main contributor to total GHG emissions followed by CH<sub>4</sub>, N<sub>2</sub>O and F-gases. Sector 1 Energy is the main source concerning climate-related emissions followed by sectors 3 Agriculture, 2 IPPU, 5 Waste and 6 Other. In contrast, sector 4 LULUCF is a net sink regarding GHG net emissions and removals in 2021.

Table 2-1 Switzerland's GHG emissions in CO<sub>2</sub> equivalent (kt) by gas and sector in 2021. The last column shows the share of the total for each sector including indirect CO<sub>2</sub> emissions (excluding LULUCF). Emission and removal estimates for LULUCF for individual years are not relevant for accounting. Emissions and removals in the land use sector will be accounted for relative to a reference level in the biennial transparency report (see also Switzerland's NDC (FOEN 2021n)).

Sectors	CO <sub>2</sub>	CH <sub>4</sub>	N <sub>2</sub> O	HFCs	PFCs	SF <sub>6</sub>	NF <sub>3</sub>	Total	Share
	CO <sub>2</sub> equivalent (kt)								
1 Energy	33'617	304	227					34'148	75%
2 Industrial processes and product use	2'102	6.8	425	1'241	28	129	0.37	3'933	8.7%
3 Agriculture	46	4'249	1'603					5'898	13%
5 Waste	8.7	544	590					1'142	2.5%
6 Other	13	0.78	0.52					14	0.032%
Indirect CO <sub>2</sub>	113							113	0.25%
<b>Total (excluding LULUCF, including indirect CO<sub>2</sub>)</b>	<b>35'900</b>	<b>5'104</b>	<b>2'845</b>	<b>1'241</b>	<b>28</b>	<b>129</b>	<b>0.37</b>	<b>45'249</b>	<b>100%</b>
4. Land use, land-use change and forestry	-1'937	14	48					-1'875	-4.1%
<b>Total (including LULUCF, including indirect CO<sub>2</sub>)</b>	<b>33'963</b>	<b>5'118</b>	<b>2'894</b>	<b>1'241</b>	<b>28</b>	<b>129</b>	<b>0.37</b>	<b>43'374</b>	<b>96%</b>
<i>International aviation bunkers</i>	2'318	0.22	17					2'336	
<i>International marine bunkers</i>	17	0.0039	0.14					17	

A breakdown of Switzerland's total emissions by gas (excluding LULUCF) is given in Figure 2-1. Figure 2-2 charts the relative contributions of the individual sectors (excluding LULUCF) to the emissions of each GHG. Trends in GHG emissions per gas and per sector are given in chp. 2.2. The national total of 45'249 kt of CO<sub>2</sub> equivalent (excluding LULUCF; see Table 2-1) corresponds to 5.2 tonnes of CO<sub>2</sub> equivalent per capita (CO<sub>2</sub>: 4.1 tonnes per capita)

emitted to the atmosphere in 2021. Emissions per capita are calculated based on population statistics from the Federal Statistical Office (FSO).

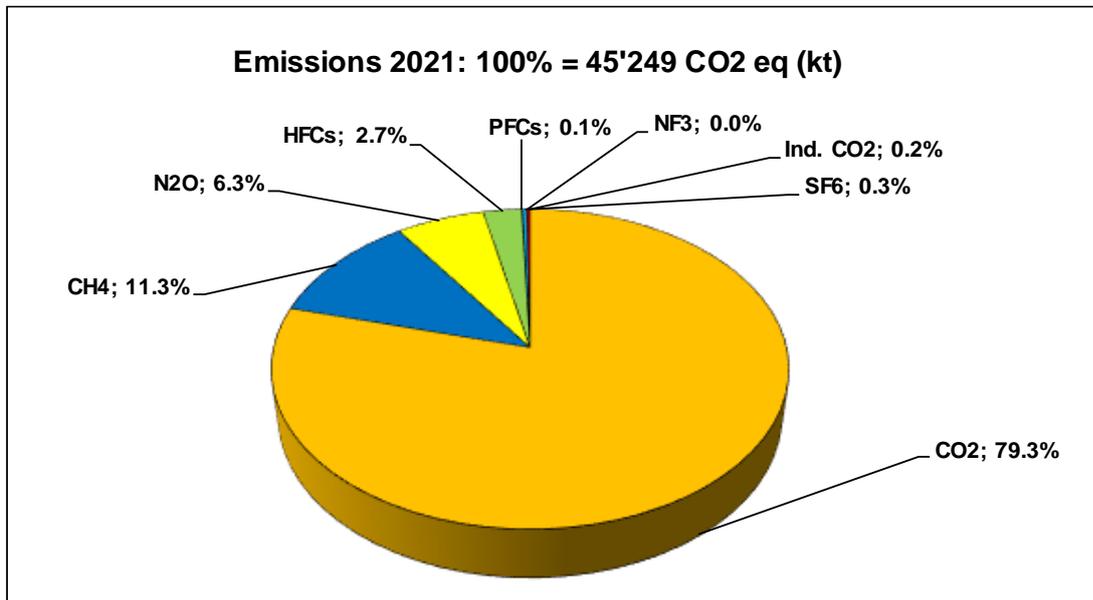


Figure 2-1 Contribution of individual gases to total greenhouse gas emissions in 2021 (excluding LULUCF).

A clear dominance of CO<sub>2</sub> emissions in 2021 is related to source category 1A Fuel combustion within sector 1 Energy. CH<sub>4</sub> and N<sub>2</sub>O emissions mainly originate from sector 3 Agriculture, while F-gas emissions by definition only originate from sector 2 Industrial processes and product use.

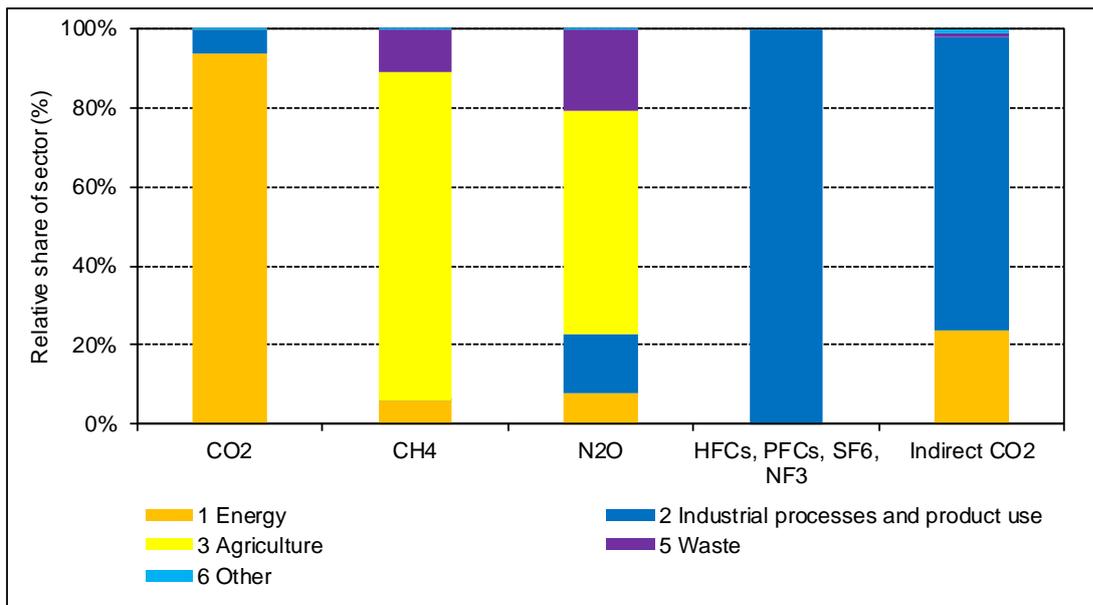


Figure 2-2 Relative contributions of the individual sectors (excluding LULUCF) to GHG emissions in 2021.

## 2.2. Emission and removal trends by gas and by sector

### 2.2.1. Emission and removal trends by gas

Emission trends by gas for the period 1990–2021 are summarized in Table 2-2.

Table 2-2 Greenhouse gas emissions in CO<sub>2</sub> equivalent (kt) by gas. The last column of the lower panel indicates the percentage change in emissions in the latest year compared to the base year 1990. HFC emissions increased by more than 5 million percent when compared to 1990 levels. No NF<sub>3</sub> was emitted in 1990. Emission and removal estimates for LULUCF for individual years are not relevant for accounting. Emissions and removals in the land use sector will be accounted for relative to a reference level in the biennial transparency report (see also Switzerland's NDC (FOEN 2021n)).

Greenhouse Gas Emissions	1990	1995	2000	2005	2010						
	CO <sub>2</sub> equivalent (kt)										
CO <sub>2</sub> emissions including net CO <sub>2</sub> from LULUCF	42'313	39'545	48'819	42'828	42'177						
CO <sub>2</sub> emissions excluding net CO <sub>2</sub> from LULUCF	44'161	43'408	43'614	45'778	45'043						
CH <sub>4</sub> emissions including CH <sub>4</sub> from LULUCF	6'544	6'198	5'755	5'669	5'595						
CH <sub>4</sub> emissions excluding CH <sub>4</sub> from LULUCF	6'513	6'177	5'739	5'654	5'581						
N <sub>2</sub> O emissions including N <sub>2</sub> O from LULUCF	4'066	3'941	3'715	3'448	3'282						
N <sub>2</sub> O emissions excluding N <sub>2</sub> O from LULUCF	4'014	3'894	3'671	3'404	3'236						
HFCs	0.023	227	604	997	1'244						
PFCs	105	16	54	46	36						
SF <sub>6</sub>	141	96	157	210	155						
NF <sub>3</sub>	NO	NO	NO	NO	12						
Indirect CO <sub>2</sub>	411	313	230	164	150						
<b>Total (including LULUCF)</b>	<b>53'581</b>	<b>50'336</b>	<b>59'334</b>	<b>53'363</b>	<b>52'650</b>						
<b>Total (excluding LULUCF)</b>	<b>55'345</b>	<b>54'131</b>	<b>54'069</b>	<b>56'254</b>	<b>55'457</b>						

Greenhouse Gas Emissions	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2021 vs. 1990
	CO <sub>2</sub> equivalent (kt)										%
CO <sub>2</sub> emissions including net CO <sub>2</sub> from LULUCF	39'672	41'379	39'006	36'710	37'132	36'423	35'718	34'899	32'747	33'850	-20.0%
CO <sub>2</sub> emissions excluding net CO <sub>2</sub> from LULUCF	42'249	43'182	39'229	38'726	39'179	38'172	36'867	36'727	34'235	35'787	-19.0%
CH <sub>4</sub> emissions including CH <sub>4</sub> from LULUCF	5'512	5'432	5'420	5'389	5'353	5'287	5'253	5'163	5'106	5'118	-21.8%
CH <sub>4</sub> emissions excluding CH <sub>4</sub> from LULUCF	5'498	5'418	5'406	5'375	5'336	5'272	5'239	5'149	5'093	5'104	-21.6%
N <sub>2</sub> O emissions including N <sub>2</sub> O from LULUCF	3'179	3'158	3'158	3'118	3'076	3'190	3'046	3'092	2'996	2'894	-28.8%
N <sub>2</sub> O emissions excluding N <sub>2</sub> O from LULUCF	3'133	3'111	3'111	3'071	3'027	3'141	2'998	3'044	2'948	2'845	-29.1%
HFCs	1'375	1'354	1'389	1'426	1'397	1'390	1'419	1'343	1'323	1'241	see caption
PFCs	37	26	21	24	18	29	33	29	34	28	-72.9%
SF <sub>6</sub>	225	270	270	281	254	239	184	178	156	129	-8.6%
NF <sub>3</sub>	0.5	0.13	0.57	0.68	0.72	0.75	0.47	0.51	0.39	0.37	see caption
Indirect CO <sub>2</sub>	139	133	128	123	124	123	117	120	117	113	-72.5%
<b>Total (including LULUCF)</b>	<b>50'139</b>	<b>51'751</b>	<b>49'393</b>	<b>47'072</b>	<b>47'356</b>	<b>46'683</b>	<b>45'771</b>	<b>44'824</b>	<b>42'480</b>	<b>43'374</b>	<b>-19.1%</b>
<b>Total (excluding LULUCF)</b>	<b>52'656</b>	<b>53'494</b>	<b>49'554</b>	<b>49'027</b>	<b>49'336</b>	<b>48'368</b>	<b>46'858</b>	<b>46'591</b>	<b>43'907</b>	<b>45'249</b>	<b>-18.2%</b>

As shown in Table 2-2, Table 2-3, and Figure 2-3, total emissions excluding LULUCF in 2021 are clearly below base year emissions. There is no discernible trend of overall emissions in the period 1990–2005. Only from 2005 onwards, a decreasing trend starts to develop. Also when including LULUCF categories, a decreasing trend is visible compared to the base year 1990, although the net CO<sub>2</sub> eq removals generated by LULUCF categories were generally smaller after 1997 (see Figure 2-8, Figure 2-9 and Figure 6-3). The overall emission reduction between 1990 and 2021 amounts to 18.2 % when LULUCF categories are excluded and 19.1 % when including LULUCF. The emission maximum occurred in 1991. Compared to 2020, emissions have significantly increased in 2021 (by 3.1 %) after the strong decrease between 2019–2020.

The decrease of emissions between 2019 and 2020 can partially be interpreted as a consequence of the lockdown and subsequent measures associated with the COVID-19 pandemic that affected Switzerland from March 2020 onwards. In particular, the measures to contain the pandemic mainly led to reduced traffic volumes, which reduced CO<sub>2</sub> emissions from source category 1A3b Road transportation. In 2021, the effects of the measures against

the pandemic are still visible in the emission levels of 1A3b Road transportation. However, due to comparably cold winter months in 2021 and a strong increase in heating degree days (see Figure 2-7), emissions from source category 1A4 increased, which is the main reason why overall emission levels in 2021 are higher than in 2020.

The trends of the different greenhouse gases can be described as follows:

- There is a strong correlation between **CO<sub>2</sub>** emissions and winter climatic conditions (number of heating degree days; see box 1 on page 49 for further information) in the period 1990–2021. However, the relative developments of heating degree days and **CO<sub>2</sub>** emissions are clearly drifting apart in the years since 2002, which indicates that additional effects like reduction measures contribute to emission reductions (see Figure 2-7).
- Between 1990 and 2021, **CH<sub>4</sub>** emissions (excluding LULUCF) decreased. An important driver for this reduction is sector 5 Waste. Mainly, **CH<sub>4</sub>** emissions from 5A Solid waste disposal decreased from 2000 onwards, due to a change in waste legislation banning the disposal of municipal solid waste in landfills. Furthermore, the development of livestock in sector 3 Agriculture is relevant for the overall reduction of **CH<sub>4</sub>** emissions, in particular cattle, where a reduction in the years 1990–2004 and 2012–2021 led to a reduction of emissions from enteric fermentation in the agricultural sector (see Table 5-8).
- A strong decrease in **N<sub>2</sub>O** emissions could be achieved between 1990–2021 due to progress in nitrogen removal in centralised wastewater treatment plants (sector 5 Waste). Furthermore, as a consequence of the declining livestock population and reduced input of synthetic fertilisers, **N<sub>2</sub>O** emissions that mainly stem from manure management and agricultural soils decreased between 1990 und 2021 as well.
- **HFC** emissions are significantly higher in 2021 compared to the base year due to their application as substitutes for CFCs, while **PFC** emissions declined (mainly due to the decrease and stop of aluminium production). Decreasing tendencies are found for HFC emissions since 2018 due to restrictions of HFC use in mobile air-conditioning and stationary refrigeration. **SF<sub>6</sub>** emissions show relatively large fluctuations between 1990 and 2021. This effect bases on annual fluctuations of the market volumes in the production of electrical equipment as well as on changes in other applications. The temporary increase of **SF<sub>6</sub>** emissions between 2010 and 2013 is mainly due the disposal of sound proof windows. Although soundproof windows containing **SF<sub>6</sub>** are not produced or installed in Switzerland anymore, the disposal of old windows still leads to emissions. On the other hand, the **SF<sub>6</sub>** emissions from electrical equipment (2G1) are decreasing due to the agreement of Swissmem and FOEN on the reduction of **SF<sub>6</sub>** emissions since 2008. Furthermore, the import of **SF<sub>6</sub>** for magnesium foundries (2C4) is prohibited in Switzerland since 2017, leading to an additional decrease of **SF<sub>6</sub>** emissions over the past couple of years. **NF<sub>3</sub>** has been used only short-term in the photovoltaic industry (around 2010).

Table 2-3 Contribution of individual gases to total emissions (excluding LULUCF) in CO<sub>2</sub> equivalent (kt) and (%).

Greenhouse Gas Emissions (excluding LULUCF)	1990		1995		2000		2005		2010	
	kt CO <sub>2</sub> eq	%								
CO <sub>2</sub>	44'161	79.8%	43'408	80.2%	43'614	80.7%	45'778	81.4%	43'182	80.7%
CH <sub>4</sub>	6'513	11.8%	6'177	11.4%	5'739	10.6%	5'654	10.1%	5'418	10.1%
N <sub>2</sub> O	4'014	7.3%	3'894	7.2%	3'671	6.8%	3'404	6.1%	3'111	5.8%
HFCs	0.023	0.0%	227	0.4%	604	1.1%	997	1.8%	1'354	2.5%
PFCs	105	0.2%	16	0.0%	54	0.1%	46	0.1%	26	0.0%
SF <sub>6</sub>	141	0.3%	96	0.2%	157	0.3%	210	0.4%	270	0.5%
NF <sub>3</sub>	NO	-	NO	-	NO	-	NO	-	0.13	0.0%
Indirect CO <sub>2</sub>	411	0.7%	313	0.6%	230	0.4%	164	0.3%	150	0.3%
<b>Total (excluding LULUCF)</b>	<b>55'345</b>	<b>100%</b>	<b>54'131</b>	<b>100%</b>	<b>54'069</b>	<b>100%</b>	<b>56'254</b>	<b>100%</b>	<b>53'512</b>	<b>100%</b>

Greenhouse Gas Emissions (excluding LULUCF)	2017		2018		2019		2020		2021	
	kt CO <sub>2</sub> eq	%								
CO <sub>2</sub>	38'172	78.9%	36'867	78.7%	36'727	78.8%	34'235	78.0%	35'787	79.1%
CH <sub>4</sub>	5'272	10.9%	5'239	11.2%	5'149	11.1%	5'093	11.6%	5'104	11.3%
N <sub>2</sub> O	3'141	6.5%	2'998	6.4%	3'044	6.5%	2'948	6.7%	2'845	6.3%
HFCs	1'390	2.9%	1'419	3.0%	1'343	2.9%	1'323	3.0%	1'241	2.7%
PFCs	29	0.1%	33	0.1%	29	0.1%	34	0.1%	28	0.1%
SF <sub>6</sub>	239	0.5%	184	0.4%	178	0.4%	156	0.4%	129	0.3%
NF <sub>3</sub>	0.75	0.0%	0.47	0.0%	0.51	0.0%	0.39	0.0%	0.37	0.0%
Indirect CO <sub>2</sub>	123	0.3%	117	0.2%	120	0.3%	117	0.3%	113	0.2%
<b>Total (excluding LULUCF)</b>	<b>48'368</b>	<b>100%</b>	<b>46'858</b>	<b>100%</b>	<b>46'591</b>	<b>100%</b>	<b>43'907</b>	<b>100%</b>	<b>45'249</b>	<b>100%</b>

Figure 2-3 shows Switzerland's relative GHG emission trends by gas. The base year 1990 is set to 100 %.

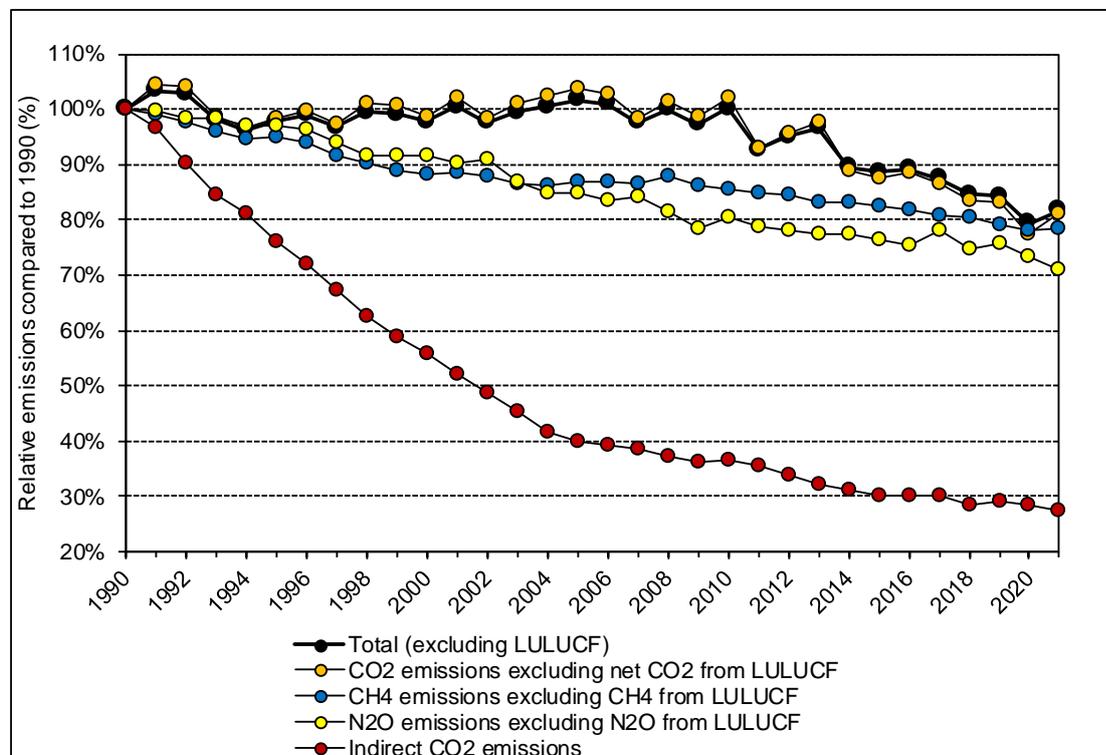


Figure 2-3 Relative trends of Switzerland's main greenhouse gas emissions (excluding LULUCF). The base year 1990 represents 100 %. F-gases are not illustrated here (see Figure 4-3).

## 2.2.2. Emission and removal trends by sector

Table 2-4 shows the emission trends for all major source and sink categories. As the largest share of emissions originates from sector 1 Energy, the table includes further information concerning the contributions of energy-related source categories.

### 2.2.2.1. Overview

In order to understand trends within the sector 1 Energy, the individual source categories are considered separately (see chp. 2.2.2.2 and Figure 2-6 below).

In line with economic development, overall emissions in sector 2 Industrial processes and product use (IPPU) show a decreasing trend in the early 1990s and a gradual increase between 1997 and 2011, except for the economically difficult year 2009. After 2011, emissions from the sector remained on a similar level until 2019. Since 2019, emissions show a decreasing tendency, mainly due to a reduction of N<sub>2</sub>O emissions in category 2B Chemical industry and a reduction of HFC emissions in category 2F Product uses as substitutes for ozone-depleting substances (ODS). The Chemical Risk Reduction Ordinance (Swiss Confederation 2005) was put in place in 2005 and regulates the use of F-gases since then. The dominant source category of sector 2 is 2A Mineral industry although the emissions decreased by approximately one third since 1990. If sources are analysed in more detail, 2A1 Cement production is the most relevant emitter in this category. Emissions of 2F Product uses as substitutes for ozone-depleting substances (ODS), the second most important source in sector 2, increased by some orders of magnitude since 1990 due to the replacement of CFCs with HFCs. The third-most important source category from the IPPU sector is 2B Chemical industry, in particular due to N<sub>2</sub>O emissions from category 2B10 Niacin production. Source category 2G Other product manufacture and use, another important source category, contains in particular SF<sub>6</sub> and PFC emissions from electrical equipment and other product use, as well as N<sub>2</sub>O emissions from the application in households and hospitals. Other source categories in sector 2 are of minor importance with regard to the overall greenhouse gas emissions.

GHG emissions in sector 3 Agriculture are driven by populations of cattle and swine and by fertiliser use. Both factors have been declining (see Table 5-8 and Table 5-24, respectively), thus leading to a decrease in CH<sub>4</sub> and N<sub>2</sub>O emissions until 2004. Subsequently, CH<sub>4</sub> emissions increased slightly until 2008 and decreased again afterwards. N<sub>2</sub>O emissions remained more or less on a constant level since 2004 with a decreasing trend in the last years. This general development can be explained by the development of the cattle population and the input of mineral fertilisers.

Total emissions from the source category 5 Waste continuously decrease between 1990 and 2021. The main driver of the decreasing trend is the emission reduction in solid waste disposal (sector 5A), which was reinforced through a change of legislation in 2000 that banned disposal of combustible waste in landfills. Therefore, an increasing amount of municipal solid waste is being incinerated, with emissions reported under source 1A1 Energy industries rather than sector 5 Waste. A similar reduction could be achieved in sector 5D Wastewater treatment mainly due to improvements concerning nitrogen removal in centralised wastewater treatment plants. Altogether, “waste-related” emissions (including emissions from all waste management activities reported in 1 Energy, 3 Agriculture, and 5 Waste) are increasing since 1994 and show a stagnation since 2006 (see Figure 7-3 in chp. 7.1).

The total emissions from sector 6 Other (fire damages) show fluctuations within a range of about 20 % throughout the reporting period. Emissions from sector 6 Other account for well below 1 ‰ of total emissions.

Table 2-4 Greenhouse gas emissions in CO<sub>2</sub> equivalent (kt) by individual source (positive numbers) and sink (negative numbers) categories. Emission and removal estimates for LULUCF for individual years are not relevant for accounting. Emissions and removals in the land use sector will be accounted for relative to a reference level in the biennial transparency report (see also Switzerland's NDC (FOEN 2021n)).

Source and Sink Categories	1990	1995	2000	2005	2010
	CO <sub>2</sub> equivalent (kt)				
1 Energy	41'899	41'935	42'240	44'011	43'229
1A1 Energy industries	2'514	2'639	3'169	3'813	3'843
1A2 Manufacturing industries and construction	6'568	6'293	6'005	6'039	5'860
1A3 Transport	14'688	14'287	15'954	15'847	16'322
1A4 Other sectors	17'507	18'077	16'565	17'832	16'761
1A5 Other	219	163	151	139	137
1B Fugitive emissions from fuels	402	476	396	342	306
2 Industrial processes and product use	3'943	3'341	3'675	4'299	4'395
3 Agriculture	6'801	6'583	6'137	6'076	6'183
5 Waste	2'278	1'945	1'772	1'687	1'484
6 Other	13	14	15	16	16
Indirect CO <sub>2</sub>	411	313	230	164	150
Total (excluding LULUCF)	55'345	46'995	55'659	49'064	48'254
4. Land use, land-use change and forestry	-1'764	-3'795	5'265	-2'891	-2'807
Total (including LULUCF)	53'581	43'200	60'923	46'173	45'447

Source and Sink Categories	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2021 vs. 1990
	CO <sub>2</sub> equivalent (kt)										%
1 Energy	40'557	41'480	37'429	37'098	37'497	36'510	35'216	35'093	32'660	34'148	-18.5%
1A1 Energy industries	3'637	3'729	3'600	3'287	3'371	3'290	3'352	3'362	3'271	3'221	28.1%
1A2 Manufacturing industries and construction	5'430	5'496	5'095	4'976	4'983	4'948	4'789	4'702	4'499	4'594	-30.1%
1A3 Transport	16'260	16'172	16'065	15'329	15'167	14'905	14'910	14'869	13'563	13'752	-6.4%
1A4 Other sectors	14'816	15'692	12'282	13'131	13'594	12'998	11'798	11'804	10'974	12'237	-30.1%
1A5 Other	132	133	139	135	139	127	126	115	119	115	-47.8%
1B Fugitive emissions from fuels	281	258	248	240	242	242	239	241	233	229	-43.1%
2 Industrial processes and product use	4'376	4'381	4'388	4'340	4'303	4'405	4'285	4'270	4'087	3'933	-0.3%
3 Agriculture	6'158	6'079	6'214	6'113	6'098	6'060	6'000	5'895	5'859	5'898	-13.3%
5 Waste	1'410	1'405	1'381	1'338	1'300	1'256	1'224	1'199	1'171	1'142	-49.9%
6 Other	16	17	13	15	14	15	16	13	13	14	14.7%
Indirect CO <sub>2</sub>	139	133	128	123	124	123	117	120	117	113	-72.5%
Total (excluding LULUCF)	52'656	53'494	49'554	49'027	49'336	48'368	46'858	46'591	43'907	45'249	-18.2%
4. Land use, land-use change and forestry	-2'516	-1'743	-161	-1'954	-1'980	-1'686	-1'087	-1'766	-1'427	-1'875	6.3%
Total (including LULUCF)	50'139	51'751	49'393	47'072	47'356	46'683	45'771	44'824	42'480	43'374	-19.1%

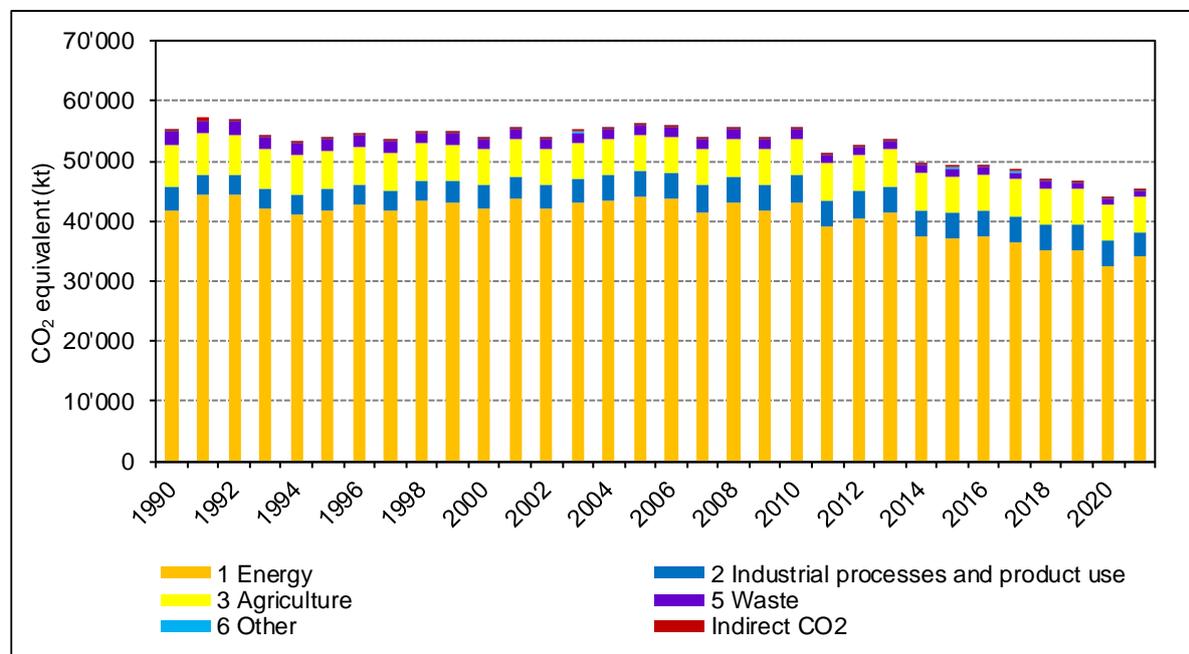
The percentage shares of source categories are shown for selected years in Table 2-5 whereas Figure 2-4 to Figure 2-6 are graphical representations of the data in Table 2-4. For the time series of the source categories of sector 1 Energy see chp. 3.

Table 2-5 Greenhouse gas emissions (excluding LULUCF) in CO<sub>2</sub> equivalent (kt) and the relative contribution (%) of individual source categories.

Source and Sink Categories	1990		1995		2000		2005		2010	
	kt CO <sub>2</sub> eq	%	kt CO <sub>2</sub> eq	%	kt CO <sub>2</sub> eq	%	kt CO <sub>2</sub> eq	%	kt CO <sub>2</sub> eq	%
1 Energy	41'899	75.7%	41'935	77.5%	42'240	78.1%	44'011	78.2%	43'229	78.0%
1A1 Energy industries	2'514	4.5%	2'639	4.9%	3'169	5.9%	3'813	6.8%	3'843	6.9%
1A2 Manufacturing industries and construction	6'568	11.9%	6'293	11.6%	6'005	11.1%	6'039	10.7%	5'860	10.6%
1A3 Transport	14'688	26.5%	14'287	26.4%	15'954	29.5%	15'847	28.2%	16'322	29.4%
1A4 Other sectors	17'507	31.6%	18'077	33.4%	16'565	30.6%	17'832	31.7%	16'761	30.2%
1A5 Other	219	0.4%	163	0.3%	151	0.3%	139	0.2%	137	0.2%
1B Fugitive emissions from fuels	402	0.7%	476	0.9%	396	0.7%	342	0.6%	306	0.6%
2 Industrial processes and product use	3'943	7.1%	3'341	6.2%	3'675	6.8%	4'299	7.6%	4'395	7.9%
3 Agriculture	6'801	12.3%	6'583	12.2%	6'137	11.3%	6'076	10.8%	6'183	11.1%
5 Waste	2'278	4.1%	1'945	3.6%	1'772	3.3%	1'687	3.0%	1'484	2.7%
6 Other	13	0.0%	14	0.0%	15	0.0%	16	0.0%	16	0.0%
Indirect CO <sub>2</sub>	411	0.7%	313	0.6%	230	0.4%	164	0.3%	150	0.3%
Total (excluding LULUCF)	55'345	100.0%	54'131	99.4%	54'069	99.6%	56'254	99.7%	55'457	99.7%

Source and Sink Categories	2017		2018		2019		2020		2021	
	kt CO <sub>2</sub> eq	%								
1 Energy	36'510	75.5%	35'216	75.2%	35'093	75.3%	32'660	74.4%	34'148	75.5%
1A1 Energy industries	3'290	6.8%	3'352	7.2%	3'362	7.2%	3'271	7.4%	3'221	7.1%
1A2 Manufacturing industries and construction	4'948	10.2%	4'789	10.2%	4'702	10.1%	4'499	10.2%	4'594	10.2%
1A3 Transport	14'905	30.8%	14'910	31.8%	14'869	31.9%	13'563	30.9%	13'752	30.4%
1A4 Other sectors	12'998	26.9%	11'798	25.2%	11'804	25.3%	10'974	25.0%	12'237	27.0%
1A5 Other	127	0.3%	126	0.3%	115	0.2%	119	0.3%	115	0.3%
1B Fugitive emissions from fuels	242	0.5%	239	0.5%	241	0.5%	233	0.5%	229	0.5%
2 Industrial processes and product use	4'405	9.1%	4'285	9.1%	4'270	9.2%	4'087	9.3%	3'933	8.7%
3 Agriculture	6'060	12.5%	6'000	12.8%	5'895	12.7%	5'859	13.3%	5'898	13.0%
5 Waste	1'256	2.6%	1'224	2.6%	1'199	2.6%	1'171	2.7%	1'142	2.5%
6 Other	15	0.0%	16	0.0%	13	0.0%	13	0.0%	14	0.0%
Indirect CO <sub>2</sub>	123	0.3%	117	0.2%	120	0.3%	117	0.3%	113	0.2%
Total (excluding LULUCF)	48'368	100.0%	46'858	100.0%	46'591	100.0%	43'907	100.0%	45'249	100.0%

Figure 2-4 Greenhouse gas emissions in CO<sub>2</sub> equivalent (kt) by sectors (excluding LULUCF).

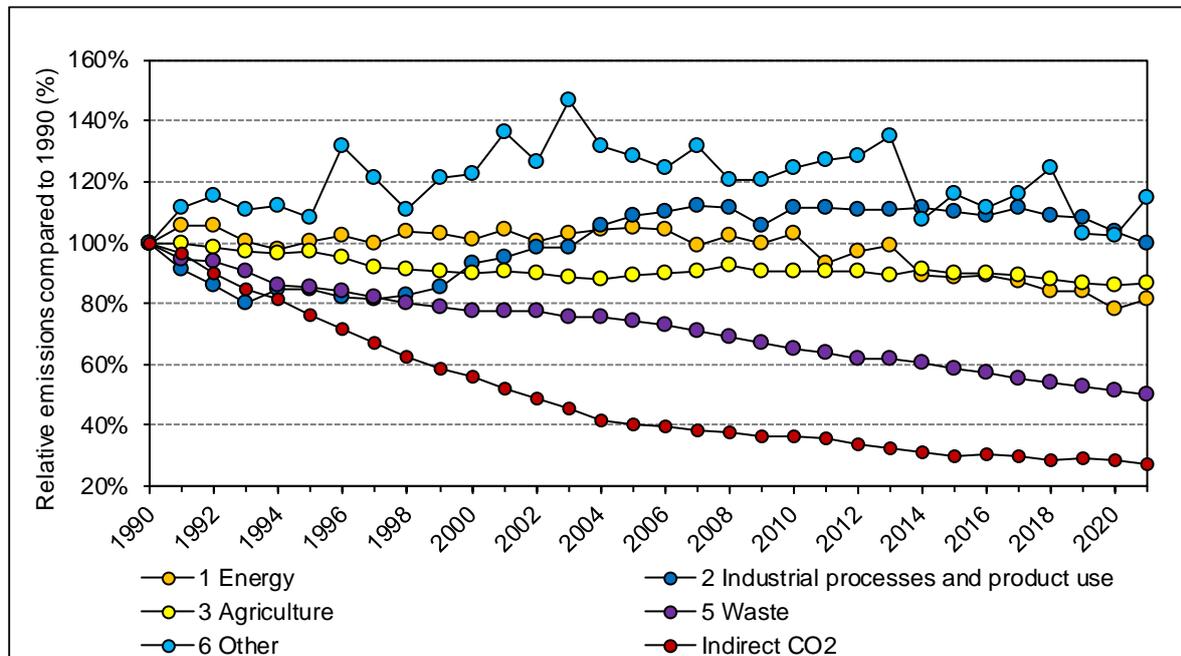


Figure 2-5 Relative emission trends (CO<sub>2</sub> eq) by main source categories (base year 1990 = 100 %).

### 2.2.2.2. Emission trends in sector 1 Energy

The main source categories within sector 1 Energy – representing the major sources of Switzerland’s GHG emissions – are shown in Figure 2-6 and Table 2-5.

The following emission trends emerge within the sector 1 Energy:

- Despite differing trends of individual source categories, the overall emissions from the sector 1 Energy remain at a relatively constant level (orange/bold line in Figure 2-6) in the period 1990–2006. Afterwards, the trend is determined by a combination of effective reduction measures and a decreasing trend of heating degree days (see Figure 2-7; see further details below under 1A1 Energy industries and 1A4 Other sectors).
- It is noteworthy that due to Switzerland’s electricity production structure (mainly hydroelectric and nuclear power in 2021; see SFOE (2022), Table 24), category 1A1 Energy industries plays only a minor role. It does not represent thermal power stations as in many other countries, but primarily waste incineration plants. The increase in waste incineration is the reason why overall emissions from source category 1A1 Energy industry are higher in 2021 than in 1990. The time series shows an increase until 2006 and a decrease thereafter. Fluctuations are caused by varying combustion activities for district heating. The emission reduction in 2015 was due to the closure of one of two refineries (see Figure 2-6 and values in Table 2-5).
- Emissions from 1A2 Manufacturing industries show a decreasing trend since 1990, mainly due to continuous changes in the use of fuel types for stationary combustion (see table 3-43).
- The increasing trend of emissions in source category 1A3 Transport between 1990 and 2008 is based on increasing traffic volumes (in all different types of transport). The effect of increasing energy efficiency of vehicles was unable to counterbalance the substantial growth in transport. The decrease of transport emissions since 2008 as well as the drop from 2014 to 2015 is largely caused by decreasing fuel tourism (EV 2015a) (see chp. 3.2.9.2.2). The strong decrease between 2019 and 2020/2021 can be attributed to the COVID-19 pandemic, when a lockdown and further measures reduced traffic volumes, in particular of passenger cars.

- The trend for source category 1A4 Other sectors reflects the impact of climatic variations on energy demand for heating in stationary source-categories (1A4ai/bi/ci). The strong correlation with the number of “heating degree days” (see box 1 on page 49) – used as an index of cold weather conditions over the year – is apparent from Figure 2-7, which shows CO<sub>2</sub> emissions from source category 1A4 Other sectors (only stationary sources) and the number of heating degree days. Since 2002, heating degree days and CO<sub>2</sub> emissions are clearly drifting apart, which indicates that additional effects like reduction measures contribute to emission reductions (see Figure 2-7). In the period 1990–2021, the number of buildings and apartments increased as well as the average floor space per person and workplace. Both phenomena result in an increase in the total area heated by around forty-five percent (FOEN 2022). Over the same period, however, higher standards were specified for insulation and for combustion equipment efficiency for both new and renovated buildings, compensating for the emissions from the additional area heated.
- CO<sub>2</sub> emissions from 1A5 Other mainly stem from military aircraft and therefore show almost the same decreasing trend as the use of jet kerosene within this source-category (see Table 3-94).
- The development of CO<sub>2</sub> equivalent emissions in 1B are dominated by the trend of the CH<sub>4</sub> emissions from leakage in the natural gas distribution network. From 1990 to 1994, emissions increased due to network expansion. Thereafter, emissions decreased substantially due to gradual replacement of old pipelines.

**Box 1: Heating degree days**

Heating degree days: a standardized measure for linking heating demand and weather conditions. Number of degrees per day calculated as the difference between 20°C (room temperature) and the daily average outdoor temperature for such days where the daily average temperature is below 12°C (e.g. daily outdoor average equals 7°C, then for that day  $20 - 7 = 13$ ). The number of degrees per day are summed up for a year  $t$  to yield the heating degree days of year  $t$ .

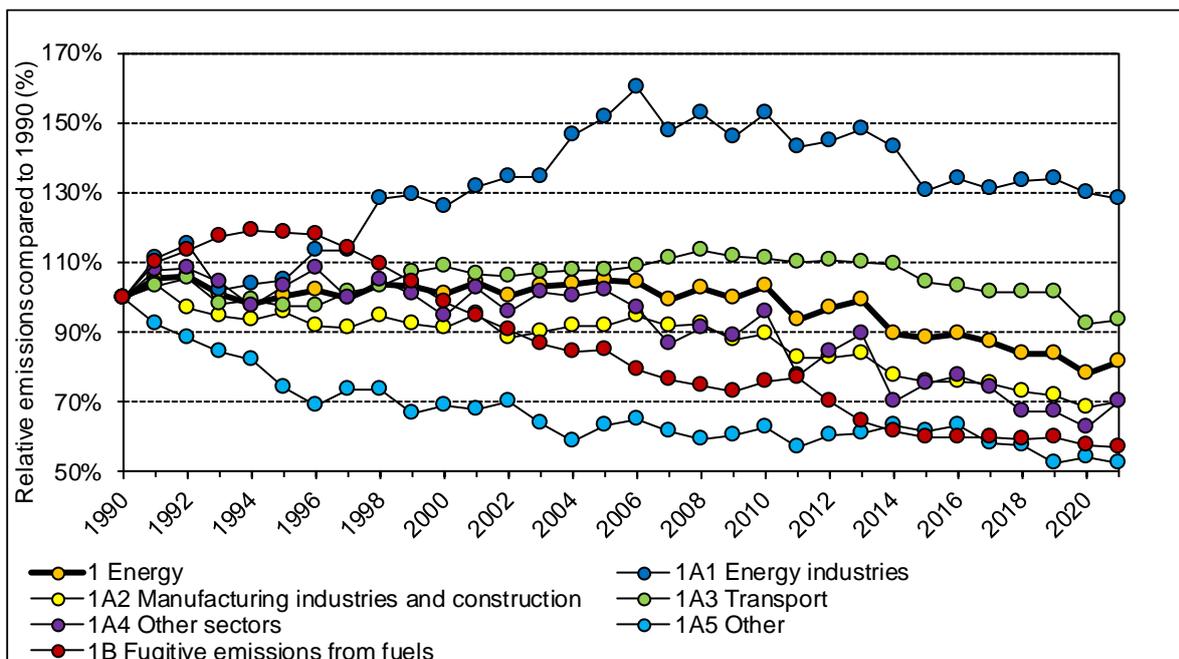


Figure 2-6 Emission trends (CO<sub>2</sub> eq) for the source categories in sector 1 Energy. The trend for the entire sector 1 Energy is represented by the bold line with orange bullets.

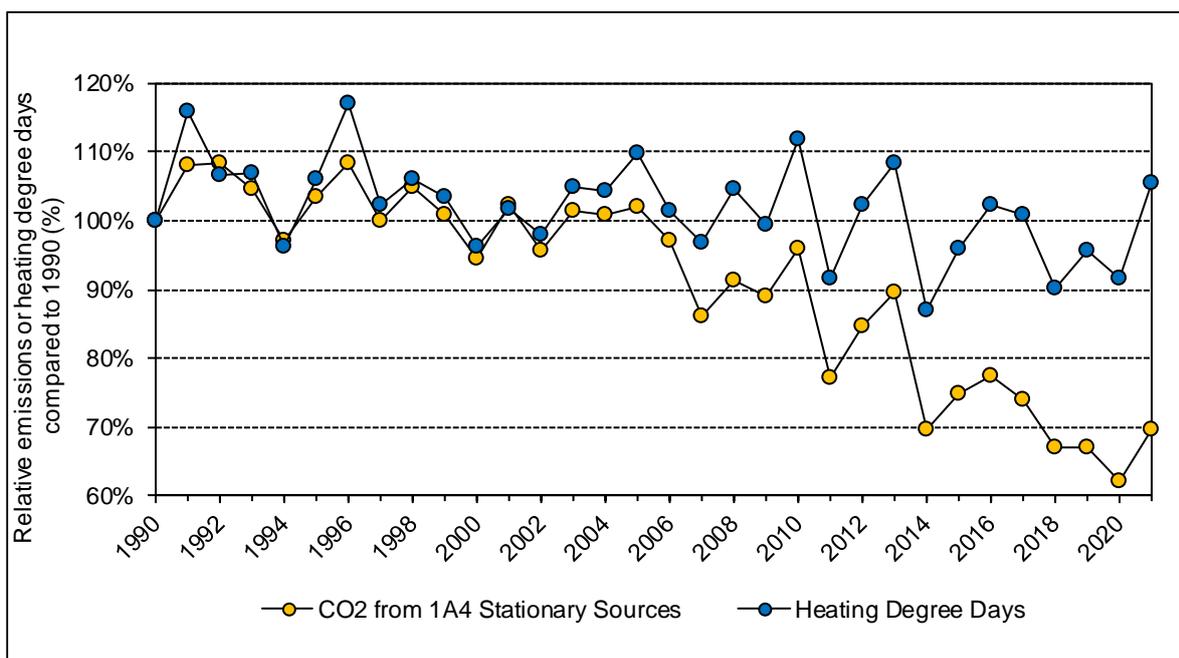


Figure 2-7 Relative trend for CO<sub>2</sub> emissions from 1A4 Fuel Combustion – Other Sectors (stationary sources only) compared with the number of heating degree days.

### 2.2.2.3. Emission and removal trends in sector 4 LULUCF

Figure 2-8 illustrates the net CO<sub>2</sub> eq emissions and removals in sector 4 LULUCF. Associated data are given in Table 2-4.

The GHG fluxes are reported for six land-use categories: 4A Forest land, 4B Cropland, 4C Grassland, 4D Wetlands, 4E Settlements and 4F Other land. The carbon stock of 4G Harvested wood products made from Swiss wood is also recorded. CO<sub>2</sub> is the most

important greenhouse gas by far in the LULUCF sector. CH<sub>4</sub> and N<sub>2</sub>O from fires, soil organic matter decomposition, reservoirs and drained organic soil make a minor contribution to the emissions (see Figure 6-2). With the exception of 2000, Switzerland's land use resulted in more CO<sub>2</sub> eq being absorbed from the atmosphere by the soil and vegetation than were emitted (Figure 2-8, see also Figure 2-9, Figure 6-1 and Figure 6-3). Quantitatively, most CO<sub>2</sub> eq removals were achieved in the decade between 1990 and 1999.

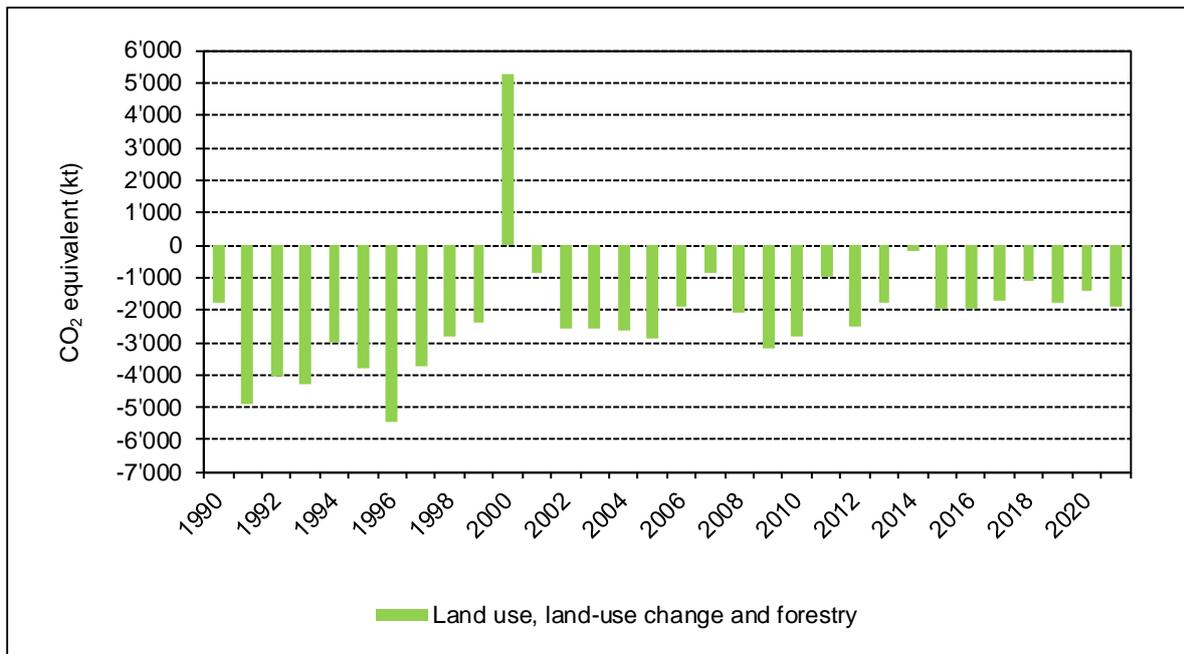


Figure 2-8 Net GHG (CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O) emissions and removals of sector 4 Land use, land-use change and forestry (LULUCF), in kt CO<sub>2</sub> eq. Positive values refer to net emissions, negative values refer to net removals.

4A: Forest land dominates the GHG balance of Switzerland's land use. For most years, management of Forest land resulted in a distinct increase in the total carbon stocks in living biomass, dead wood, litter and forest soils (i.e. a net removal of CO<sub>2</sub> from the atmosphere; Figure 2-9). Salvage logging following severe storms (Vivian in February 1990, Lothar in December 1999) and the rise in harvested volumes in some years (e.g. 2006, 2007) are clearly recognisable. In 2008 harvesting rates dropped (Table 6-15) due to the international and domestic economic framework conditions and remained relatively constant thereafter with interannual fluctuation of ca. 2 to 8 %. These fluctuations are reflected in the year-to-year variability of the removals from Forest land.

4G: In terms of climate policy, sustainable forest management can be achieved by using the wood grown in a cascade, firstly for long-lived harvested wood products and subsequently for energy purposes. In almost all years since 1990, more wood has been incorporated into new products (such as construction timber or wood panels) than has been released from old ones. However, the size of the annual net CO<sub>2</sub> removals from harvested wood products decreased clearly since 2011. In 2013, 2017 and 2019 HWP fluxes resulted in net CO<sub>2</sub> emissions (see Figure 2-9 and Figure 6-20 for details).

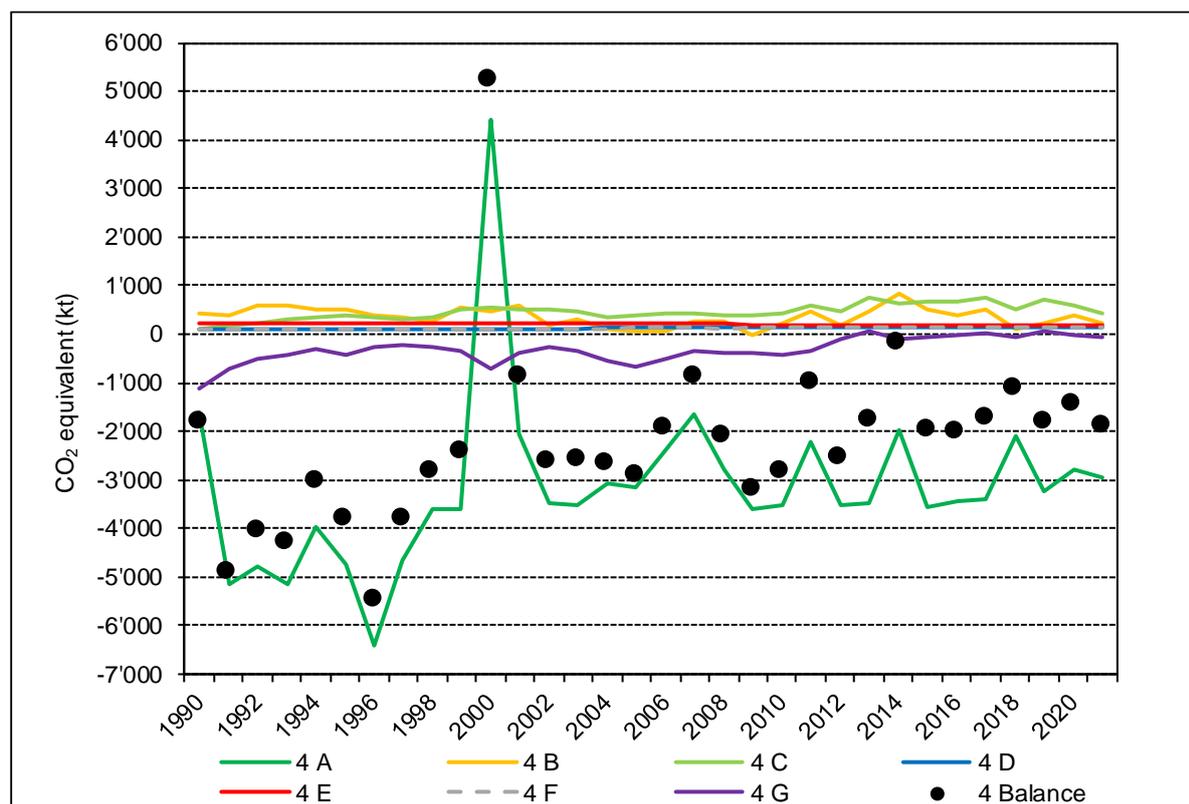


Figure 2-9 Net GHG (CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O) emissions and removals in the LULUCF sector (in kt CO<sub>2</sub> eq) broken down by categories 4A-4G. Balance indicates the annual net total. Positive values refer to net emissions, negative values refer to net removals.

4B, 4C: The agricultural use of Cropland and Grassland affects the carbon stocks of the soil. For example, ploughing promotes the decomposition of soil organic matter, whereas spreading farmyard manure or leaving harvest residues on the fields increases soil carbon stocks. As well as the farming method, the main factors influencing the annual fluctuations are the crops grown and the climatic conditions. The case of drained former peatlands is a special one. When subjected to intense agricultural use, these organic soils release large amounts of CO<sub>2</sub> and N<sub>2</sub>O. In both categories 4B Cropland and 4C Grassland, the 1990–2021 patterns of net CO<sub>2</sub> eq emissions and removals caused by carbon dynamics in living biomass and in mineral soil are pushed towards an overall net CO<sub>2</sub> eq source by persistently high emissions from organic soil. As a consequence, categories 4B and 4C show weakly to moderately fluctuating net CO<sub>2</sub> eq emissions at an intermediate level over most of the inventory period (Figure 2-9).

4D: Unproductive wetlands only account for a small part of the land area. As most remaining peatland are impaired by the consequences of previous use (particularly drainage), many organic soils are now net GHG sources. CO<sub>2</sub> eq emissions in category 4D are comparatively low and increased by 25 % over the inventory period (Figure 2-9).

4E: The development of new settlements and infrastructure resulted in comparatively low and slowly fluctuating CO<sub>2</sub> eq emissions since 1990 (-22 % change from 1990 to 2021) (Figure 2-9). Emissions in category 4E are mainly produced by loss of plant biomass and soil organic carbon during construction work.

4F: CO<sub>2</sub> eq emissions in 4F2 Land converted to other land increased by 47 % between 1990 and 2021 (Figure 2-9). Mudflows, erosion, landslides, and dynamic changes in stream beds

were identified as the main processes causing these land-use changes. The contribution to the GHG balance of the LULUCF sector remains small.

### 2.2.3. Emission trends for precursor gases

The methodologies concerning calculation of emissions of the precursor gases NO<sub>x</sub>, CO, NMVOC and SO<sub>2</sub> (IPCC 2006, Volume 1, Chapter 7) are provided in detail in Switzerland's Informative Inventory Report (FOEN 2023b). Emission trends for precursor gases show a very pronounced decline (see Table 2-6 and Figure 2-10). A strict air pollution control policy and the implementation of a large number of emission reduction measures led to decreasing emissions of precursor gases over the period 1990–2021.

Overall, the most effective reduction measures were the abatement of exhaust emissions from road vehicles and stationary installations and the incentive taxes on VOC (since 2000) and on fossil combustible fuels (since 2008). The latter measure was (jointly) responsible for the significant shift in the fuel mix of standard fossil fuels in industry from solid and liquid fuels to natural gas and the almost complete disappearance of residual fuel oil. As a result, NO<sub>x</sub>, NMVOC and CO emissions clearly declined between 1980 and 2021.

Furthermore, due to legal restriction of sulphur content in liquid fuels and decrease in coal consumption, a decreasing trend can also be observed for SO<sub>x</sub> emissions (SO<sub>x</sub> = SO<sub>2</sub> + SO<sub>3</sub>, expressed as SO<sub>2</sub> equivalents). The lowering of the maximum sulphur content in liquid fuels is shown in Table A – 15, whereas the time series of Switzerland's decreasing coal consumption is given in Table 3-12. Both trends resulted in a considerable reduction of the SO<sub>x</sub> emissions. Annual fluctuations of SO<sub>x</sub> emissions occur mainly due to annual variations of heating degree days, which affects the consumption of gas oil.

Table 2-6 Emissions of precursor gases (kt) (excluding NO<sub>x</sub>, CO and NMVOC from LULUCF).

Precursor gases and SO <sub>2</sub>	1990	1995	2000	2005	2010						
	kt										
NO <sub>x</sub>	144	115	102	93	83						
CO	817	531	418	321	252						
NMVOC	302	210	157	116	100						
SO <sub>2</sub>	37	26	16	14	10						
Precursor gases and SO <sub>2</sub>	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2021 vs. 1990
	kt										
NO <sub>x</sub>	79	79	76	71	69	66	63	59	52	51	-65%
CO	221	213	192	184	184	178	169	168	152	151	-81%
NMVOC	93	90	86	82	79	78	77	76	74	75	-75%
SO <sub>2</sub>	8.5	7.9	7.1	5.5	5.1	4.8	4.6	4.3	3.7	3.7	-90%

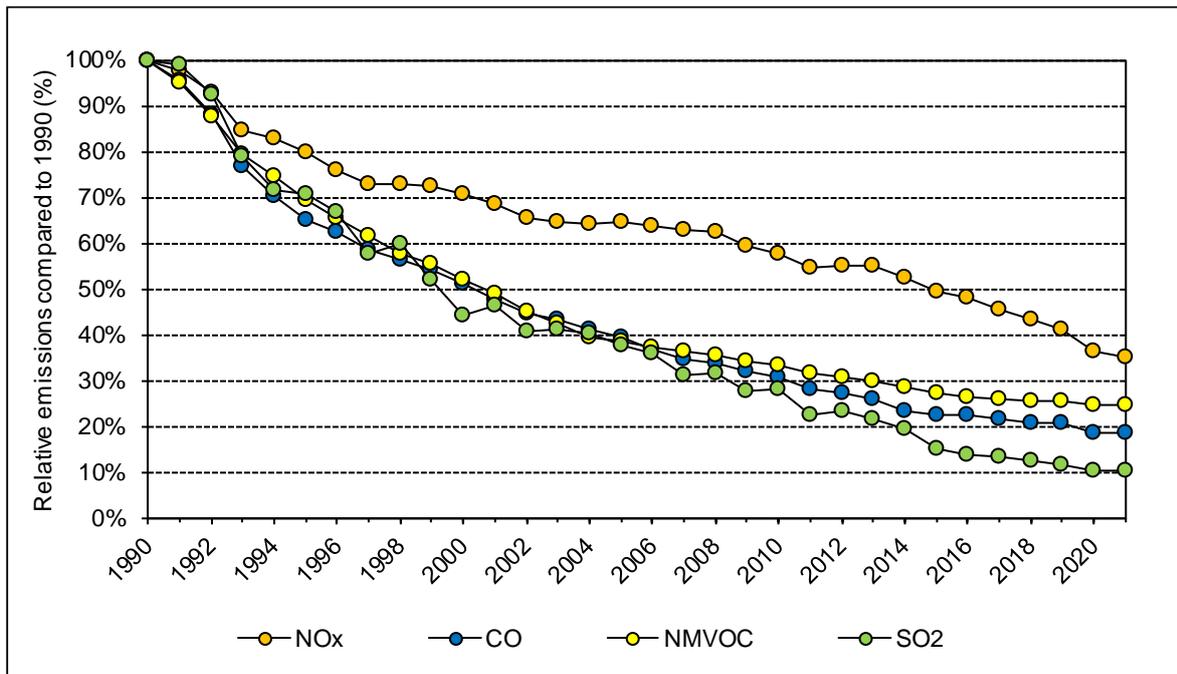


Figure 2-10: Relative trends for precursor gas emissions (excluding NO<sub>x</sub>, CO and NMVOC from LULUCF; base year 1990 = 100 %).

Sector 1 Energy is by far the largest source of precursor gas emissions (see Table 2-7), with the only exception being NMVOC, where sector 4 LULUCF is the dominant source followed by sector 2 Industrial processes and product use (see Figure 2-11).

Table 2-7: Precursor gas emissions (kt) by source category in 2021. Totals include LULUCF emissions.

Sectors	NO <sub>x</sub>		CO		NMVOC		SO <sub>2</sub>	
	kt	%	kt	%	kt	%	kt	%
1 Energy	46	91.7%	143	94.4%	17	11.5%	3.2	86.4%
2 IPPU	0.25	0.5%	5.7	3.7%	37	25.6%	0.47	12.5%
3 Agriculture	3.8	7.5%	NA	NA	19	13.3%	NA	NA
4 LULUCF	0.017	0.0%	0.57	0.4%	70	48.3%	0.00143	0.038%
5 Waste	0.12	0.2%	1.4	0.9%	1.8	1.2%	0.029	0.8%
6 Other sources	0.017	0.0%	0.79	0.5%	0.13	0.1%	0.012	0.3%
<b>Total</b>	<b>51</b>	<b>100.0%</b>	<b>152</b>	<b>100.0%</b>	<b>144</b>	<b>100.0%</b>	<b>3.7</b>	<b>100.0%</b>

Figure 2-11 shows the relative contributions of the various sectors for each individual precursor gas excluding LULUCF (data deduced from Table 2-7).

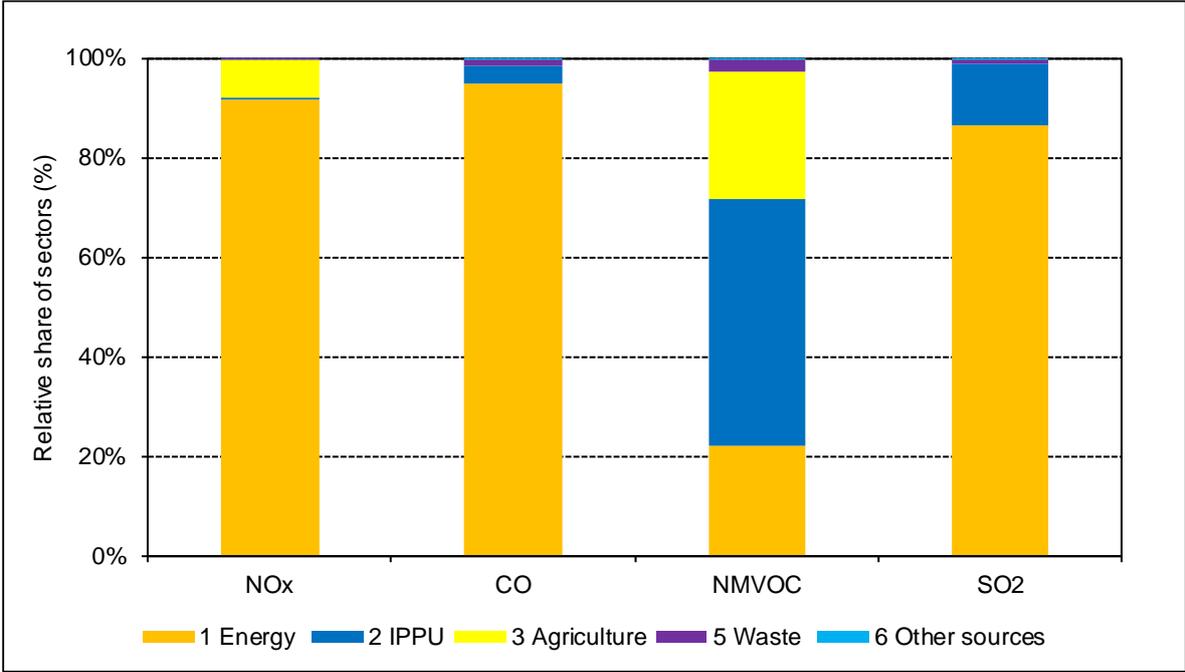


Figure 2-11: Relative contributions of individual sectors to precursor gas emissions in 2021 (excluding LULUCF, note data given in Table 2-7 especially for NMVOC).

## 3. Energy

Responsibilities for sector Energy	
Overall responsibility	Anouk-Aimée Bass (FOEN)
Experts for source-categories	Anouk-Aimée Bass (FOEN; Overview, Stationary sources in 1A1, 1A4, Bunker fuels, Country-specific issues, Mobile sources in 1A2-1A5), Daiana Leuenberger (FOEN; Waste related processes), Benedikt Notter (INFRAS; Non-road and Road transportation), Sabine Schenker (FOEN; Sectoral/Reference Approach, Feedstocks and non-energy use of fuels, Wood combustion, 1A2 (stationary)), Adrian Schilt (FOEN; Country-specific issues Fuel consumption, Industry Model), Theo Rindlisbacher (FOCA; Civil Aviation)
EMIS database operation	Anouk-Aimée Bass (FOEN), Sabine Schenker (FOEN)
Annual updates (NID text, tables, figures)	Dominik Eggli (Meteotest), Anna Ehrler (INFRAS), Lukas Meyer (Meteotest), Beat Rihm (Meteotest), Regine Röthlisberger (FOEN), Adrian Schilt (FOEN), Felix Weber (INFRAS)
Quality control NID (annual updates)	Dominik Eggli (Meteotest), Regine Röthlisberger (FOEN), Adrian Schilt (FOEN), Felix Weber (INFRAS)
Internal review	Anouk-Aimée Bass (FOEN), Daiana Leuenberger (FOEN; Waste related processes), Benedikt Notter (INFRAS; Non-road and Road transportation), Theo Rindlisbacher (FOCA; Civil Aviation), Regine Röthlisberger (FOEN), Sabine Schenker (FOEN), Adrian Schilt (FOEN)

### 3.1. Overview

This chapter provides information on the estimation of the greenhouse gas emissions from the sector 1 Energy. The following source categories are reported:

- 1A Fuel combustion
- 1B Fugitive emissions from fuels

In Switzerland, the sector 1 Energy is the most relevant source of greenhouse gases. The emissions of the period 1990–2021 are illustrated in Figure 3-1 and Table 3-1.

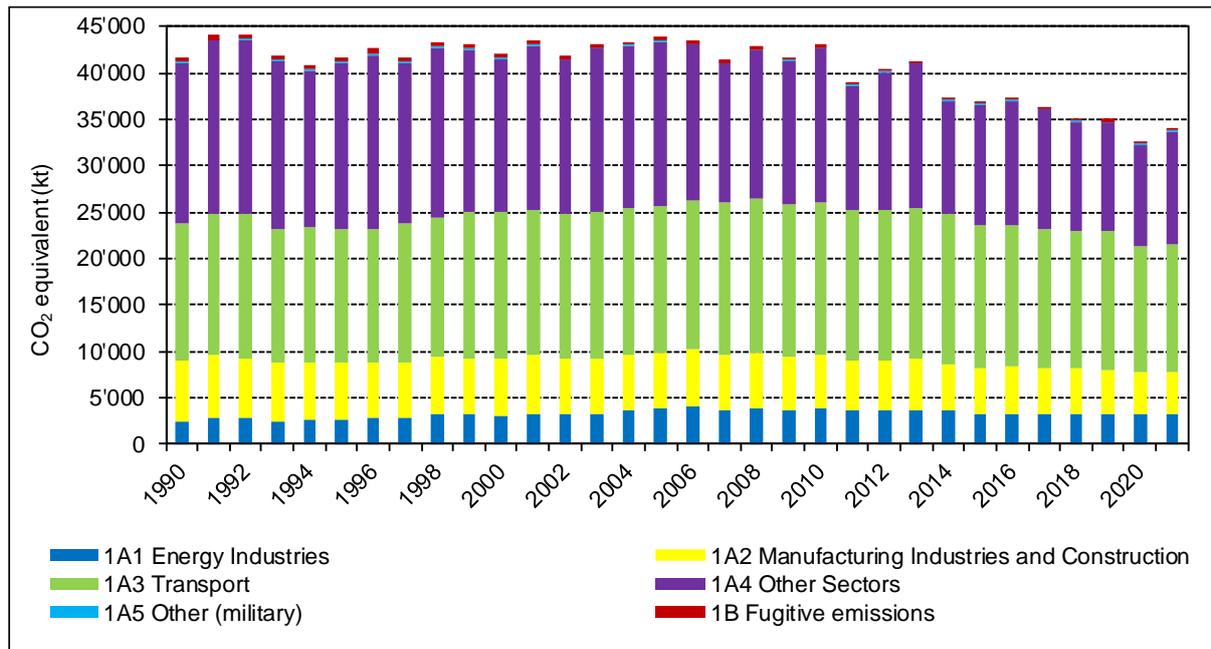


Figure 3-1 Switzerland's GHG emissions of sector 1 Energy in CO<sub>2</sub> equivalent (kt).

Considering total emissions of sector 1 Energy, fluctuations with no trend are observed in the period 1990–2005. From 2006 onwards, a decreasing trend can be identified, again superposed by fluctuations. The years 2020 and 2021 show the lowest values of the entire period 1990–2021. The following source categories contribute to the total emissions (see also Figure 2-6 and explanations in chp. 2.2.2.2):

- 1A3 Transport and 1A4 Other sectors are the main sources of the sector 1 Energy with 1A3 Transport being the most important category over the last years. Emissions in 1A3 Transport increased after 1990, reaching a maximum in 2008 and decreasing again to the 1990 level thereafter. Emissions from 1A4 Other sectors are strongly influenced by meteorological conditions in winter. A systematic decrease of emissions from 1A4 is observed since 2005.
- 1A1 Energy industries and 1A2 Manufacturing industries and construction contribute to total emissions as well, but are less important. Emissions in 1A1 Energy industries increased until 2006 with no clear trend since then except for a stepwise reduction in 2015, when one of two refineries closed. Emissions from 1A2 Manufacturing industries are gradually decreasing since 1990.
- 1A5 Other (military) and 1B Fugitive emissions from fuels play only a minor role. Both categories show a decrease since 1990.

The trends of the individual gases are given in Table 3-1 and Figure 3-2:

- By far the most important gas emitted from sector 1 Energy is CO<sub>2</sub>. Fluctuations reflect inter alia the climatic variability in Switzerland (see Figure 2-7 and related comments). A decreasing trend is observed since approximately 2005, predominantly due to the decrease in 1A4 Other sectors, but also due to decreasing fuel tourism and the closure of one refinery in 2015. The strong reduction of CO<sub>2</sub> emissions in 2020 compared to previous years is a result of the measures to contain the COVID-19 pandemic leading to reduced CO<sub>2</sub> emissions from source category 1A3b Road transportation and mild winter temperatures leading to reduced emissions from source category 1A4 Other sectors.

- The decreasing trend of CH<sub>4</sub> emissions in the energy sector since 1990 is the result of improved gas transmission and distribution networks, resulting in substantially lower fugitive emissions, and reduced emissions from gasoline passenger cars due to catalytic converters. Furthermore, improved combustion technologies in 1A4 Other sectors – stationary sources also contribute to the decreasing trend.
- The changes in N<sub>2</sub>O emissions can mainly be explained by changes in the emission of road transportation due to changes in emission factors for diesel oil and gasoline combustion. The first generation of catalytic converters generated N<sub>2</sub>O as an unintended by-product in the exhaust gases, leading to an increase in N<sub>2</sub>O emissions until 1997. With new converter materials being used, the emission factors are decreasing since 1999 with strongest reduction in the course of the introduction of the Euro 3 standard during 2003 and 2004 (see Figure 3-2). The massive effective reduction of the maximum sulphur content of the fuels from 2003 to 2004 led to a higher efficiency of the catalytic converters, which additionally strengthened the effect (see Table A – 15). Since 2007, the N<sub>2</sub>O emissions are slightly increasing in line with increasing mileages (see Table 3-76). For further details, see chp. 3.2.9.2.2. The low level of N<sub>2</sub>O emissions in 2020 is a result of the measures to contain the Covid-19 pandemic.

Table 3-1 GHG emissions of source category 1 Energy by gas in CO<sub>2</sub> equivalent (kt)

Gas	1990	1995	2000	2005	2010
	CO <sub>2</sub> equivalent (kt)				
CO <sub>2</sub>	40'908	40'911	41'336	43'338	42'605
CH <sub>4</sub>	707	698	570	470	415
N <sub>2</sub> O	284	326	334	204	209
Sum	41'899	41'935	42'240	44'011	43'229

Gas	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2020	1990	
	CO <sub>2</sub> equivalent (kt)										vs. 2021	vs. 2021	
												%	
CO <sub>2</sub>	39'981	40'914	36'905	36'573	36'960	35'977	34'688	34'565	32'148	33'617	4.6%	-18%	
CH <sub>4</sub>	367	352	321	321	324	316	310	305	296	304	2.8%	-57%	
N <sub>2</sub> O	208	215	202	204	213	216	218	223	216	227	5.0%	-20%	
Sum	40'557	41'480	37'429	37'098	37'497	36'510	35'216	35'093	32'660	34'148	4.6%	-18%	

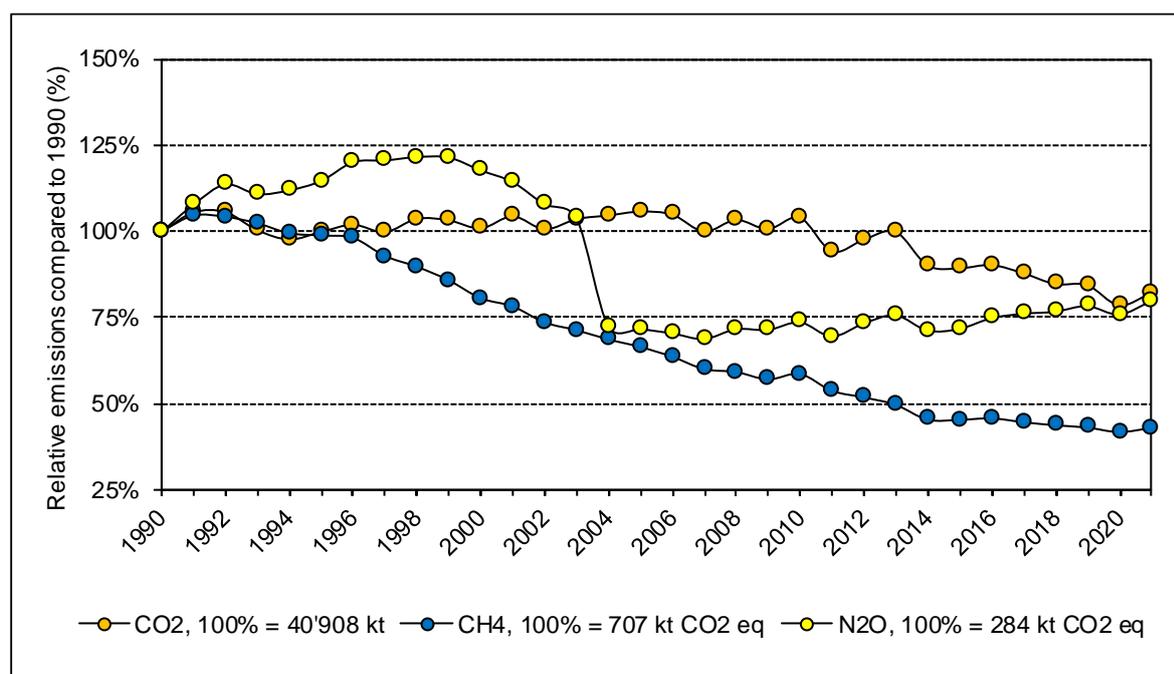


Figure 3-2 Relative trends of the greenhouse gas emissions of sector 1 Energy. The base year 1990 represents 100 %.

The following table summarises the emissions of sector 1 Energy in 2021. The table also includes two additional lines with emissions from international bunkers (aviation and marine) as well as CO<sub>2</sub> emissions from biomass burning, which both are not accounted for under the UNFCCC but are included in the reporting tables.

Table 3-2 Summary of sector 1 Energy, emissions in 2021 in kt CO<sub>2</sub> equivalent (Total: rounded values). For full biomass CO<sub>2</sub> emissions see Table 3-21.

Sector Energy	CO <sub>2</sub>	CH <sub>4</sub>	N <sub>2</sub> O	Total
	CO <sub>2</sub> equivalent (kt)			
1 Energy	33'617	304	227	34'148
1A Fuel combustion	33'598	95	227	33'919
1A1 Energy industries	3'200	0.58	21	3'221
1A2 Manufacturing industries and construction	4'554	5.5	35	4'594
1A3 Transport	13'617	22	114	13'752
1A4 Other sectors	12'114	66	57	12'237
1A5b Other (mobile)	114	0.039	0.90	115
1B Fugitive emissions from fuels	20	210	0.00019	229
International bunkers	2'335	0.22	17	2'352
CO <sub>2</sub> emissions from biomass	8'458	-	-	8'458

In 2021, a total of 47 key source categories are identified in the Swiss greenhouse gas inventory (Table 1-6). Amongst these, 19 belong to sector 1 Energy. The key categories for approaches 1 and 2 (according to level and trend) from sector 1 Energy are shown in Figure 3-3. While 19 categories are identified as key according to approach 1, only 10 categories are also identified as key according to approach 2. Indeed, Sector 1 Energy is the major sector in terms of emissions, while sector 3 Agriculture and 4 LULUCF dominate the uncertainty contribution (see also Figure 5-3 to compare with sector 3 Agriculture).

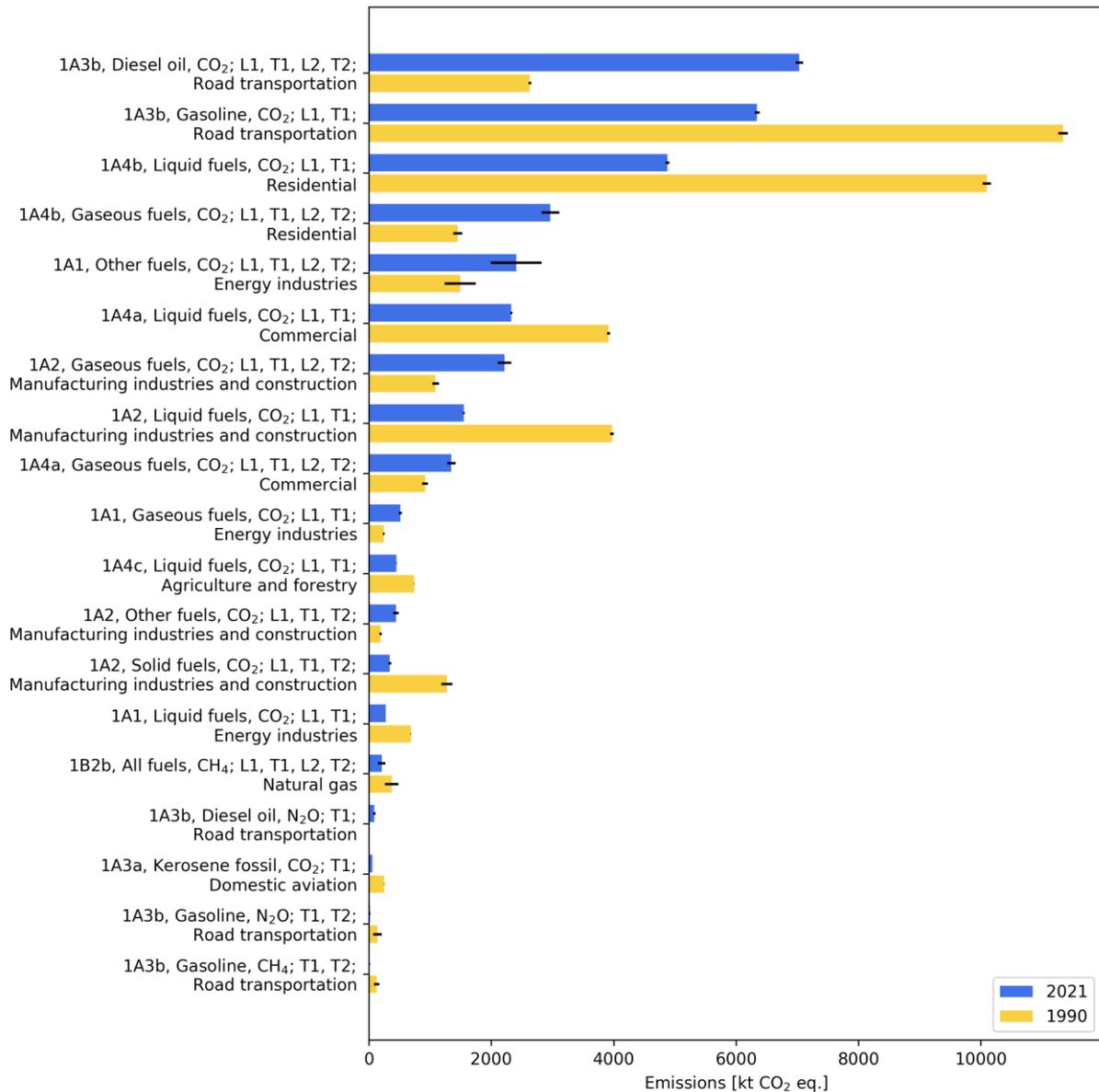


Figure 3-3 Key categories in the Swiss GHG inventory from sector 1 Energy determined by the key category analyses, approaches 1 and 2. Categories are set out in order of decreasing emissions in 2021. L1: key category according to approach 1 level in 2021; L2: same for approach 2; T1: key category according to approach 1 trend 1990–2021; T2: same for approach 2. Black uncertainty bars represent the narrowest 95 % confidence interval obtained by Monte Carlo simulations (see chp. 1.6 for details).

## 3.2. Source category 1A – Fuel combustion activities

### 3.2.1. Comparison of the Sectoral Approach with the Reference Approach

Two methods are applied for modelling CO<sub>2</sub> emissions from the sector 1 Energy, the Sectoral Approach and the Reference Approach. For the inventory under the Framework Convention on Climate Change the Sectoral Approach is used. The Reference Approach is only used for verification purposes (quality control activity).

Figure 3-4 shows the input data used and the disaggregation of fuel types for each of the two approaches.

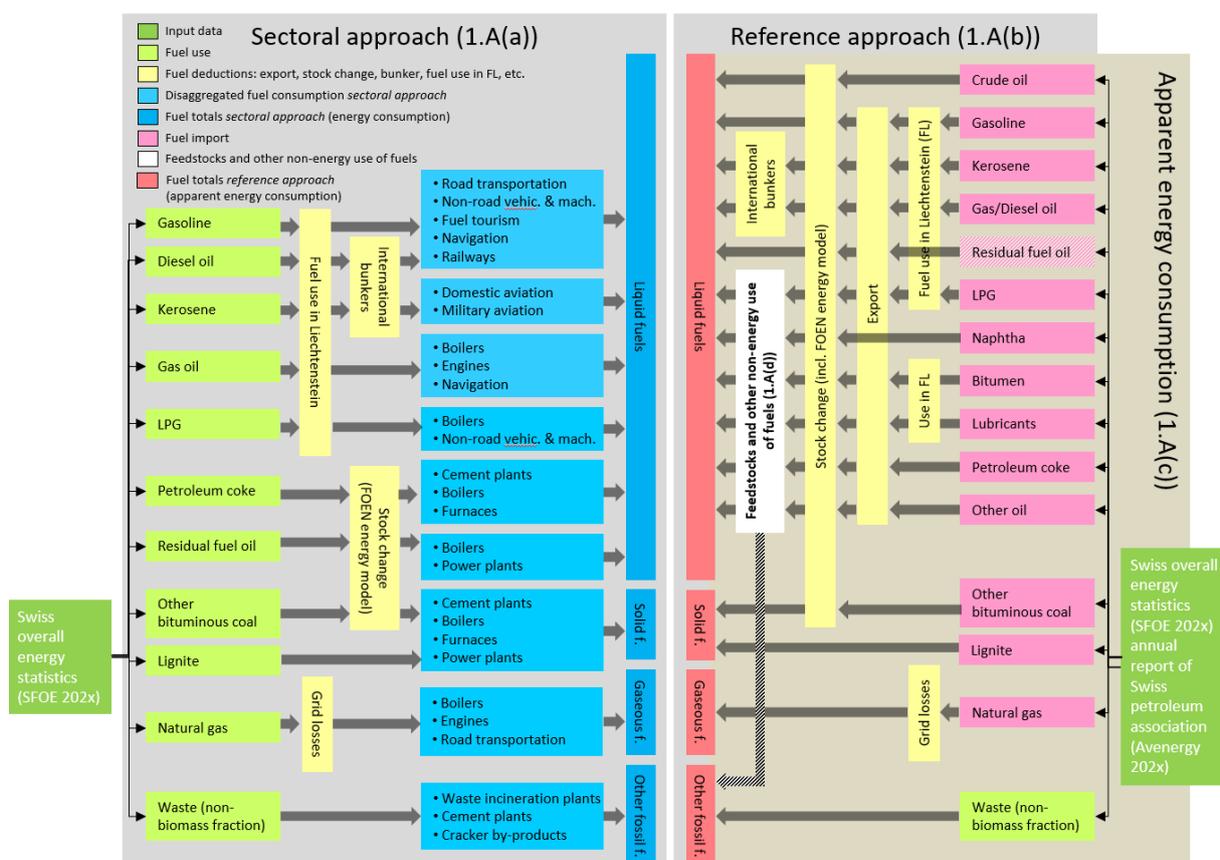


Figure 3-4 Calculation of Reference and Sectoral Approach. The input data for both approaches stem from the Swiss overall energy statistics (SFOE 2022). For the Reference Approach, additional information from Avenergy Suisse (formerly Swiss Petroleum Association) (Avenergy 2022) is used. While the Reference Approach considers the net import/export balance, the Sectoral Approach considers the fuel consumption. The dark grey arrows represent fuel deductions where occurring. The dashed arrow from the Feedstock use to Other fossil fuels stands for the CO<sub>2</sub> emissions from cracker by-products (originating from feedstock use of liquefied petroleum gas and naphtha) which are accounted for under Other fossil fuels. The graphic box of the import of Residual fuel oil is dashed since there is no more import of residual fuel oil. Coke oven coke and anthracite are included under other bituminous coal.

The Sectoral Approach is based on sectoral energy consumption data from the Swiss overall energy statistics (SFOE 2022) and additional source-specific information. In the Sectoral Approach, fossil fuel consumption statistics are combined with bottom-up data and modelling of fuel consumption. A detailed description of the Sectoral Approach is provided in chp. 3.2.4.

The Reference Approach on the other hand corresponds to a top-down approach based on net quantities of fuel imported into Switzerland as listed in the energy supply statistics of the Swiss overall energy statistics (SFOE 2022). Apparent consumption (in tonnes) is derived from imports and exports of primary fuels (crude oil, natural gas, coal), secondary fuels (gasoline, diesel oil etc.) and stock changes. For crude oil, a constant value for carbon content and net calorific value is applied for the entire time period, although these properties may vary depending on origin. For solid, gaseous, secondary liquid and other fuels, the same carbon content values and net calorific values are applied as in the Sectoral Approach (see Table 3-10 and Table 3-11, Table 3-13 and Table 3-14 in chp. 3.2.4.2 and 3.2.4.4). After the deduction of feedstocks and non-energy use of fuels (see chp. 3.2.3), the net carbon emissions and effective CO<sub>2</sub> emissions are calculated for the Reference Approach as shown in the reporting tables 1.A(b)–1.A(d). The oxidation factor is set to one (see chp. 3.2.4.4.1). The Reference Approach covers the CO<sub>2</sub> emissions of all net imported primary fuels and emissions of imported secondary fuels. In 2014, 44 % of all liquid fossil fuels sold in Switzerland (without kerosene) were produced in Swiss refineries. In 2015 after closing of one refinery, the share dropped down to 30 % (EV 2016) and has since declined further (Avenegy 2022). In addition, the reporting tables 1.A(b) provide information of the Reference Approach of total biomass use as well as consumption of so-called other non-fossil fuels (biogenic waste) in Switzerland.

All necessary data for calculating the Reference Approach are implemented in the EMIS database and all the data on import, export, bunkers, stock changes, apparent consumption, carbon emission factors, carbon stored and actual emissions are calculated in the EMIS database under the following conditions:

- For the Reference Approach, gas oil and diesel oil are reported together, since the reporting table template structure requires this aggregation. Accordingly, a weighted average NCV is calculated based on values given in Table 3-10. In contrast, marine bunkers consist of diesel oil only and are reported using the country-specific NCV as of Table 3-10.
- Liechtenstein's liquid fossil fuel consumption is subtracted from the input figures in SFOE (2022), as the Swiss overall energy statistics includes Liechtenstein's liquid fuel consumption as well (customs union with Switzerland) (see also chp. 3.2.4). The same holds for the non-energy use of bitumen and lubricants.

The differences in energy consumption and CO<sub>2</sub> emissions between Reference and Sectoral Approach are calculated within the EMIS database. For the entire period, they are below 1 % for energy consumption and in the range of about 1 % for CO<sub>2</sub> emissions, as shown in Table 3-3 and in Figure 3-5. Various effects influence the difference between Reference and Sectoral Approach. On the one hand, energy and carbon contents of crude oil may vary over time. However, no data are available to quantify this effect. On the other hand, the efficiency of refineries and the market share of secondary fuel imports potentially influence the difference between the Reference and Sectoral Approach. Apparent differences between the Reference Approach and the IEA energy statistics (IEA 2012) are discussed in Annex A3.2.

Table 3-3 Differences in energy consumption and CO<sub>2</sub> emissions between the Reference and the Sectoral Approach. The difference is calculated according to  $[(RA-SA)/SA] * 100 \%$  with RA = Reference Approach, SA = Sectoral Approach.

	1990	1995	2000	2005	2010						
	%										
Energy consumption	0.6	0.8	0.5	0.5	0.5						
CO <sub>2</sub> emissions	0.8	0.9	0.8	0.9	1.0						

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
	%									
Energy consumption	0.5	0.4	0.4	0.2	0.6	0.3	0.1	0.7	0.1	-0.1
CO <sub>2</sub> emissions	0.8	0.9	1.0	0.6	1.1	0.8	0.8	1.2	0.7	0.4

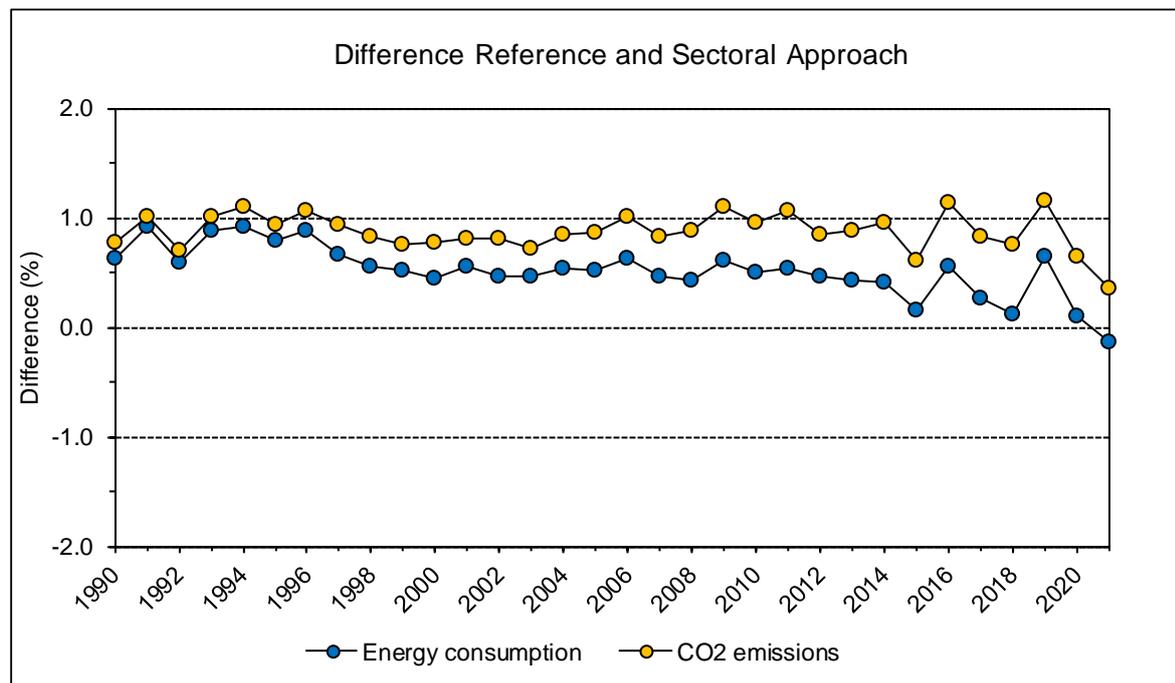


Figure 3-5 Time series for the differences between Reference and Sectoral Approach. Numbers are taken from Table 3-3. See caption there for further information.

### 3.2.1.1. Category-specific recalculations for the Reference Approach

The following recalculations were implemented in submission 2023. Recalculations are also described in the relevant chapters of the sectoral approach or the chapter on feedstock and non-energy use of fuels if they have an impact.

- 1AB: Recalculations of import and thus of apparent consumption and actual CO<sub>2</sub> emissions of natural gas due to revised natural gas consumption in the Swiss energy statistics (SFOE 2022) for the years 2013–2021.
- 1AB: Revised data of bunker and thus of apparent consumption and actual CO<sub>2</sub> emissions of jet kerosene in 2020 due to recalculations of activity data in 1A3a Civil domestic aviation and 1D1 International aviation (bunker).
- 1AB: Revised stock changes of residual fuel oil for the years 2008–2010 and 2020 and thus apparent consumption and CO<sub>2</sub> emissions since more residual fuel oil was consumed in industry in the years 2020 and 2021 than reported in the Swiss energy statistics (SFOE 2022).

- 1AB: Revised import and stock changes of lubricants in 2020 and thus apparent consumption and CO<sub>2</sub> emissions due to recalculations in the petroleum balance (Avenegy 2022), yielding recalculated values of these quantities for other oil in 2020 as well.
- 1AB: Revised stock changes and thus of apparent consumption and actual CO<sub>2</sub> emissions of residual fuel oil and petroleum coke for 2008–2012, 2014–2020 and 2007–2008, 2018–2019, respectively, due to correction of a sign error.

## 3.2.2. International bunker fuels (1D)

### 3.2.2.1. Source category description for 1D

With Switzerland being a landlocked country, international aviation dominates emissions from bunker fuels by far. International navigation is limited to activities on the river Rhine (Basel – Rotterdam) and navigation on Lake Geneva (bordering France) and Lake Constance (bordering Germany and Austria).

Table 3-4 Source category description of International bunkers.

1D	Source category	Specification
1D1	International aviation (aviation bunkers)	Bunker fuels include fuel used for international aviation only.
1D2	International navigation (marine bunkers)	Marine bunkers of the Rhine river and navigation on the Lake Geneva and the Lake Constance.

### 3.2.2.2. Methodological issues for 1D

#### 3.2.2.2.1. International aviation / aviation bunkers (1D1)

Following the decision tree of the 2006 IPCC Guidelines (IPCC 2006, Volume 2 Energy, chp. 3 Mobile Combustion, Figure 3.6.1), the emissions from aviation bunkers are calculated with a Tier 3A method because of availability of data on the origin and destination of flights and also on air traffic movements delivered by the Federal Office of Civil Aviation (FOCA).

The Tier 3A method follows standard modelling procedures at the level of single aircraft movements based on detailed movement statistics. For international aviation (aviation bunkers), the flights departing from Switzerland to a destination abroad are selected. The emission factors are country-specific based on measurement and analyses of fuel samples. The activity data of the international aviation bunker are summarised in Table 3-6 (see also Table 3-73). Given that detailed information about activity data is available, the resulting fuel consumption is considered complete. In spite of this, there remain small differences between the fuel consumption modelled bottom-up and the total fuel sold (SFOE 2022, FOCA 2022). In 1990, the modelled consumption adds up to 1.01 million tonnes, whereas 1.05 million tonnes of fuel was sold. Such difference of 4 % is considered acceptable, because discrepancies up to 10 % can easily result from fuelling strategies of airlines (FOCA 2006a). Investigation showed, that airlines are calculating whether it is economically beneficial to refuel at a place with lower fuel price. In order to match the bottom-up calculation with the fuel quantity sold, any occurring difference is attributed to international bunker emissions. The factor between calculated international fuel consumption and adjusted international fuel consumption is used to scale the bunker emissions linearly. For instance in 2020, the bunker fuel consumption and the emissions had to be expanded by the factor 1.10, the correction

factor was 0.902 (FOCA 2022). For the years 2020 and 2021, the overestimation of emissions from international aviation was very high compared to previous years because the modelling of aircraft fuel consumption is based on practically fully loaded aircraft (high load). Due to exceptional measures to contain the COVID-19 pandemic during the years 2020 and 2021, many flights were very lightly loaded which in terms of aircraft led to slightly lower fuel consumption per route. More direct flight paths (low traffic volume) may be another reason. These effects relate almost exclusively to international flights. For the more recent years, the modelled and actual total fuel sales are listed in Table 3-5.

Table 3-5 Comparison between modelled and actual fuel sales in bunker fuel consumption (FC) for aviation.

Modelled and actual fuel sales	Unit	2007	2008	2009	2010	2011
Modelled fuel sales domestic	FC in t	43'968	37'627	39'626	39'252	42'047
Modelled fuel sales international	FC in t	1'287'062	1'391'656	1'345'919	1'395'428	1'511'279
Actual fuel sales SFOE minus modelled fuel sales domestic	FC in t	1'289'152	1'382'835	1'324'224	1'390'824	1'488'805
Correction factor for emission international		0.967	0.967	0.954	0.969	0.957
Overestimation emission international (modelled)	%	3.3%	3.3%	4.6%	3.1%	4.3%

Modelled and actual fuel sales	Unit	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Modelled fuel sales domestic	FC in t	43'414	42'064	44'462	43'680	44'716	37'985	36'561	36'357	24'449	18'763
Modelled fuel sales international	FC in t	1'527'522	1'528'863	1'561'678	1'590'013	1'711'227	1'741'752	1'818'355	1'836'385	727'941	818'030
Actual fuel sales SFOE minus modelled fuel sales domestic	FC in t	1'523'116	1'539'963	1'549'228	1'602'319	1'679'034	1'723'717	1'823'917	1'846'453	677'093	756'549
Correction factor for emission international		0.969	0.980	0.964	0.980	0.955	0.968	0.983	0.986	0.897	0.902
Overestimation emission international (modelled)	%	3.1%	2.0%	3.6%	2.0%	4.5%	3.2%	1.7%	1.4%	10.3%	9.8%

Table 3-6 International bunker fuels (1D1): aviation bunkers. Consumption of kerosene in TJ (Liechtenstein's kerosene consumption is subtracted, see chp. 3.2.4).

1D1 International aviation	1990	1995	2000	2005	2010
	Fuel consumption in TJ				
1D1 International aviation	41'884	49'918	63'726	47'775	58'334
1990 = 100%	100%	119%	152%	114%	139%

1D1 International aviation	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
	Fuel consumption in TJ									
1D1 International aviation	63'903	64'709	65'006	67'333	70'603	72'824	77'214	78'196	28'194	31'847
1990 = 100%	153%	154%	155%	161%	169%	174%	184%	187%	67%	76%

### 3.2.2.2. International navigation / navigation bunkers (1D2)

According to the decision tree concerning navigation bunkers (IPCC 2006, Volume 2 Energy, chp. 3 Mobile Combustion, Figure 3.5.1), emissions from international navigation are calculated with a Tier 2 approach for CO<sub>2</sub> (with country-specific carbon contents) and with a Tier 1 approach for CH<sub>4</sub> and N<sub>2</sub>O using IPCC default emission factors. On the river Rhine and on Lake Geneva and Lake Constance, some of the boats cross the border and go abroad (Germany, France). Fuels bought in Switzerland will therefore become bunker fuel. Accordingly, the amount of bunker diesel oil is reported as a memo item "International bunker / navigation".

- Only diesel oil is relevant for navigation on the river Rhine. Since there is an exemption from fuel taxation, activity data on marine river bunkers on the Rhine are well documented by the customs administration for the years 1997–2021 (SFOE 2022f).
- For navigation on two border lakes (Lake Constance, Lake Geneva), bunker fuel consumption was reported in INFRAS (2011a) after having performed surveys among the shipping companies involved. Activity data of these bunkers is summarised in Table 3-7. Data from 1995–2012 have been provided by the three navigation companies concerned as documented in INFRAS (2011a), data from 2013 onwards are constant on the 2012

level. For the years 1990 to 1994, proxies such as passenger data on a national basis had to be consulted. As marine lake bunkers provided only a minor share of the total international navigation in the early 1990s (about 7 %) this approach is justified. The emission factor for CO<sub>2</sub> is country-specific and in accordance with Table 3-13.

Table 3-7 International bunker fuels (1D2): Navigation. Consumption of diesel oil in TJ.

1D2 International navigation	1990	1995	2000	2005	2010
Fuel consumption in TJ					
1D2 International navigation	821	739	531	493	471
1990 = 100%	100%	90%	65%	60%	57%

1D2 International navigation	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Fuel consumption in TJ										
1D2 International navigation	385	342	299	342	299	256	200	197	189	228
1990 = 100%	47%	42%	36%	42%	36%	31%	24%	24%	23%	28%

### 3.2.2.3. Uncertainties and time-series consistency for 1D

International bunker fuels: see general remarks in chp. 3.2.4.7.

Consistency: Time series of 1D are all considered consistent.

### 3.2.2.4. Category-specific QA/QC and verification for 1D

The general QA/QC procedures are described in chp. 1.5. Furthermore QA/QC procedures conducted for all 1A source categories are listed in chp. 3.2.4.8.

### 3.2.2.5. Category-specific recalculations for 1D

The following recalculation was implemented in submission 2023. Major recalculations, which contribute significantly to the total differences in GHG emissions of sector 1 Energy between the latest and the previous submissions are presented also in chp. 10.1.2.1.

- 1D1: Recalculation of activity data in 1D1 International aviation for the year 2020.
- 1D2: Recalculation in the reported amount of diesel oil consumption for international shipping on the river Rhine for the years 1997, 2001–2003, 2005, 2008, 2010, 2012.

### 3.2.2.6. Category-specific planned improvements for 1D

No category-specific improvements are planned.

## 3.2.3. Feedstocks and non-energy use of fuels

The Swiss overall energy statistics (SFOE 2022) reports feedstocks and non-energy fuel use on an aggregated level only. Some disaggregation is provided by the petroleum balance of the annual report of Avenergy Suisse (formerly Swiss petroleum association, EV) (Avenergy 2022). To complement this source, bottom-up data from annual monitoring reports of the Swiss emissions trading scheme (ETS) and from surveys of individual companies are used to provide a detailed breakdown into specific petroleum products and coal types. For

submission 2015, a more differentiated breakdown of feedstocks and non-energy use of fuels was developed, which is described in an internal documentation (FOEN 2015g).

Feedstocks and non-energy use of fuels is reported in reporting tables 1.A(d) and differentiated in the following fuel types:

- Liquefied petroleum gas and naphtha are exclusively used in one single Swiss plant as feedstocks in the thermal cracking process for the production of ammonia and ethylene (see source categories 2B1 and 2B8b under chp. 4.3.2.1 and 4.3.2.4, respectively). Accordingly, activity data for liquefied petroleum gas and naphtha are confidential and included in fuel type Other oil in reporting table 1.A(d).
- Bitumen is the most important petroleum product which is used as a feedstock in Switzerland. It is mainly used for road paving with asphalt and to a lower extent in asphalt roofing (see source category 2D3 under 4.5.2.2).
- Lubricants are used in a variety of processes, including the blending with gasoline for 2-stroke engines. Two different ways of lubricant use are considered: lubricants used in 2-stroke engines are assumed to be 100 % oxidised, whereas the use of all other lubricants are partly emissive. According to the 2006 IPCC Guidelines (IPCC 2006), 20 % of those lubricants are oxidized during use (ODU). All CO<sub>2</sub> emissions from use of lubricants are reported under source category 2D1, see chp. 4.5.2.1.
- Petroleum coke is used as a feedstock by two consumers only, i.e. for the production of silicium carbide and graphite as well as of anodes in primary aluminium production (up to 2006) in source categories 2B5 and 2C3, respectively (see chp. 4.3.2.3 and 4.4.2.2). Apart from bottom-up information from these two consumers, top-down information is provided by Avenergy Suisse (Avenergy 2022). Activity data are confidential and included in fuel type Other oil in reporting table 1.A(d).
- Paraffin waxes for non-energy use are reported under Other oil, since there is no separate category for paraffin waxes in reporting table 1.A(d). The information used stems from the statistics of Avenergy Suisse (Avenergy 2022). Use of paraffin waxes is considered partly emissive (see source category 2D2 under chp. 4.5.2.1). According to the 2006 IPCC Guidelines (IPCC 2006), 20 % of paraffin waxes are oxidized during use (ODU).
- Other oil comprises all other unspecified petroleum products for non-energy use. The net consumption of non-energy use of fuels reported in the Swiss overall energy statistics includes also sulphur produced by the refineries. This amount of sulphur is subtracted, resulting in lower fuel quantities for non-energy use of other oil for the entire time series compared to the Swiss overall energy statistics.
- Anthracite is also used as feedstock in the Swiss production plant for silicium carbide and graphite in source category 2B5 (chp. 4.3.2.3). Accordingly, activity data for anthracite are confidential and thus denoted as "C" in reporting tables 1.A(d). Based on personal communication with the relevant experts for the Swiss overall energy statistics, the feedstock use of anthracite is included in the stock changes of other bituminous coal.

Table 3-8 This table is only available in the confidential version of this chapter. It provides a complete time series of the fuel quantity, carbon excluded and the reported CO<sub>2</sub> emissions from feedstocks and non-energy use of fuels.

### 3.2.3.1. Category-specific recalculations

There were no category-specific recalculations in 1AD.

### 3.2.4. Country-specific issues of 1A Fuel combustion

#### 3.2.4.1. System boundaries: Differences between UNFCCC and CLRTAP reporting

Switzerland uses the same data base for the Swiss greenhouse gas inventory as for the Swiss air pollution inventory and reports its greenhouse gas emissions according to the requirements of the UNFCCC as well as air pollutants according to the requirements of the CLRTAP. The nomenclature for both types of reporting is (almost) the same (NFR), but there are differences concerning the system boundaries. Under the UNFCCC, the national total for assessing compliance is based on fuel sold within the national territory, whereas under the CLRTAP, the national total for assessing compliance is based on fuel used within the territory.

One difference occurs for 1A3b Road transportation as can be seen from Table 3-9, columns CLRTAP / NFR Template “national total” and UNFCCC/CRF-Tables “national total” compared to CLRTAP / NFR Template “national total for compliance”. The CLRTAP / NFR tables “national total for compliance” does not contain the amount of fuel sold in Switzerland but consumed abroad, which is called “fuel tourism and statistical difference”, and which is accounted for in Switzerland’s GHG inventory, but not in the reporting under the CLRTAP (see chp. 3.2.9.2.2). The difference between the two approaches amounts to several percent, with considerable variation from year to year due to fluctuating fuel price differences between Switzerland and its neighbouring countries.

Also, emissions from civil aviation are reported differently under the UNFCCC and the CLRTAP: Only emissions from domestic flights are accounted for under the UNFCCC, while emissions from international flights are reported as aviation bunker in 1D1. For the reporting of air pollutants under the CLRTAP, landing and take-off (LTO) cycle emissions of domestic and international flights are accounted for, while cruise emissions of international and domestic flights are reported as memo items (Table 3-9).

Table 3-9 Accounting rules for emissions from 1A3a Domestic aviation and 1A3b Road transportation under the CLRTAP and the UNFCCC.

Differences between reporting under CLRTAP and UNFCCC concerning the accounting to the national total			CLRTAP / NFR tables			UNFCCC / CRF tables	
			National total	National total for compliance	accounted to		National total
		Separated information / Memo items					
Road transportation (1A3b)	Fuels sold (1A3b)	Fuel used (1A3bi-v)	Yes	Yes	Yes	Yes	No
		Fuel tourism and statistical differences	Yes	No	No	Yes	No
Aviation (1A3a)	Civil and domestic aviation	Landing and Take-Off (LTO)	Yes	Yes	No	Yes	No
		Cruise	No	No	Yes	Yes	No
	International aviation	Landing and Take-Off (LTO)	Yes	Yes	No	No	Yes
		Cruise	No	No	Yes	No	Yes

#### 3.2.4.2. Net calorific values (NCVs)

Table 3-10 summarizes the net calorific values (NCVs) which are used in order to convert from energy amounts in tonnes into energy quantities in gigajoules (GJ). More detailed explanations including information about the origin of the NCVs of the different fuels are given below.

Table 3-10 Net calorific values (NCVs) of various fuels. Where values for two years are indicated, the NCV is interpolated between these two years and constant NCVs are used before the first and after the second year (corresponding to the two indicated values). For the NCV of wood, a range covering all facility categories and years is provided. For the NCVs of natural gas and biogas see Table 3-11.

Fuel	Data sources	NCV [GJ/t]
Gasoline	EMPA (1999), SFOE/FOEN (2014)	42.5 (1998), 42.6 (2013)
Jet kerosene	EMPA (1999), SFOE/FOEN (2014)	43.0 (1998), 43.2 (2013)
Diesel oil	EMPA (1999), SFOE/FOEN (2014)	42.8 (1998), 43.0 (2013)
Gas oil	EMPA (1999), SFOE/FOEN (2014)	42.6 (1998), 42.9 (2013)
Residual fuel oil	EMPA (1999)	41.2
Liquefied petroleum gas	SFOE (2022)	46.0
Petroleum coke	SFOE (2022), Cemsuisse (2010a)	35.0 (1998), 31.8 (2010)
Other bituminous coal	SFOE (2022), Cemsuisse (2010a)	28.052 (1998), 25.5 (2010)
Lignite	SFOE (2022), Cemsuisse (2010a)	20.097 (1998), 23.6 (2010)
Natural gas	SGWA	<i>see caption</i>
<b>Biofuel</b>	<b>Data sources</b>	
Biodiesel	SFOE (2022)	38.0
Bioethanol	SFOE (2022)	26.5
Biogas	<i>assumed equal to natural gas</i>	<i>see caption</i>
Wood	SFOE (2022b)	8.6-14.6

### Gasoline, jet kerosene, diesel oil and gas oil

For gasoline, jet kerosene, diesel oil and gas oil, the NCV for 1998 and 2013 are based on national measurement campaigns and are the same as used by the Swiss Federal Office of Energy (SFOE 2022). A first campaign was conducted by the Swiss Federal Laboratories for Materials Science and Technology (Empa) in 1998 (EMPA 1999). Since earlier data are not available, the values for 1990–1998 are assumed to be constant at the 1998 levels. A second campaign, commissioned by the Swiss Federal Office of Energy (SFOE) and the Swiss Federal Office for the Environment (FOEN), was conducted in 2013 (SFOE/FOEN 2014). This study was based on representative samples covering summer and winter fuel qualities from the main import streams. The sampling started in July 2013 and lasted six months. Samples were taken fortnightly from nine different sites (large-scale storage facilities and the two refineries operating at that time in Switzerland) and analysed for carbon contents and NCVs amongst other. These updated values are used from 2013 onwards, while the NCVs for 1999–2012 are linearly interpolated between the measured values of 1998 and 2013.

### Residual fuel oil

Residual fuel oil plays only a minor role in the Swiss energy supply. Therefore, this fuel was not analysed in the most recent measurement campaign in 2013 (SFOE/FOEN 2014). Thus, the respective NCV refers to the measurement campaign in 1998 (EMPA 1999). The NCV for residual fuel oil, which is the same as used by the Swiss Federal Office of Energy (SFOE 2022), is assumed to be constant over the entire reporting period. The same approach is applied for the CO<sub>2</sub> emission factor (see Table 3-13).

### Liquefied petroleum gas

The NCV of liquefied petroleum gas is the same as used by the Swiss Federal Office of Energy (SFOE 2022) and is – as in the Swiss overall energy statistics – constant over the

entire reporting period. It is assumed that liquefied petroleum gas is a mixture of propane and butane in equal proportions.

### **Petroleum coke, other bituminous coal, lignite**

For the entire reporting period, the NCVs of petroleum coke, other bituminous coal and lignite are the same as used by the Swiss Federal Office of Energy (SFOE 2022). For these fuels, the Swiss overall energy statistics contains NCVs for the years 1998 and 2010. Values in between are interpolated, before the first and after the last year of available data values are held constant. The NCVs for 2010 are based on measured samples taken from Switzerland's cement plants as they are the largest consumers of these fuels in Switzerland. Samples from the individual plants were taken from January to September 2010 and analysed for NCVs by an independent analytical laboratory (Cemsuisse 2010a). For each fuel, the measurements from the individual plants were weighted according to the relative consumption of each plant.

### **Natural gas, biogas**

The NCV of natural gas (and also the CO<sub>2</sub> emission factor of natural gas, see Table 3-14 ) is calculated based on measurements of gas properties and corresponding import shares of individual gas import stations. Measurements of gas properties are available from the Swiss Gas and Water Industry Association (SGWA) on an annual basis since 2009 and for selected years before. The latest report is SGWA (2022). Import shares are available for 1991, 1995, 2000, 2005, 2007 and from 2009 onwards on an annual basis. Estimated import shares for the years 1991, 1995 and 2000 are taken from Quantis (2014). Values for the years in between are interpolated. The calculation procedure is documented in FOEN (2022i). The NCV of biogas is assumed to be equal to the NCV of natural gas since the raw biogas is treated to become the same quality level including its energetic properties as natural gas.

Table 3-11 Net calorific values (NCVs) of natural gas and biogas for years with available data. Values for the years in between are linearly interpolated. Data source: Annual reports of the Swiss Gas and Water Industry Association (SGWA), the latest report is SGWA (2022). Spreadsheet to determine national averages: FOEN (2022i).

Year	NCV of natural gas and biogas [GJ/t]
1990	46.5
1991	46.5
1995	47.5
2000	47.2
2005	46.6
2007	46.3
2009	46.4
2010	46.3
2011	46.1
2012	45.8
2013	45.7
2014	45.7
2015	46.6
2016	47.1
2017	47.4
2018	47.6
2019	47.5
2020	47.6
2021	48.2

## Wood

The NCV of wood depends on the type of wood fuel (e.g. log wood, wood chips, pellets) and is based on the Swiss wood energy statistics (SFOE 2022b). Table 3-10 illustrates the range of the NCVs of all wood fuel types.

## Bioethanol and biodiesel

The NCVs of bioethanol and biodiesel are the same as used by the Swiss Federal Office of Energy (SFOE 2022) and are – as in the Swiss overall energy statistics – constant over the entire reporting period.

### 3.2.4.3. Swiss energy model and final energy consumption

#### 3.2.4.3.1. Swiss overall energy statistics

The fundamental data on final energy consumption is provided by the Swiss overall energy statistics (SFOE 2022). However, since Switzerland and Liechtenstein form a customs and monetary union governed by a customs treaty, data regarding liquid fuels in the Swiss overall energy statistics also cover liquid fuel consumption in Liechtenstein. In order to calculate the correct Swiss fuel consumption, Liechtenstein's liquid fossil fuel consumption, given by Liechtenstein's energy statistics (OS 2022), is subtracted from the numbers provided by the Swiss overall energy statistics. In all years of the reporting period, the sum of liquid fossil fuels used in Liechtenstein was less than half a percent of the Swiss consumption.

The energy-related activity data in the energy model and thus in the GHG inventory correspond to the energy balance provided in the Swiss overall energy statistics (SFOE 2022). The energy statistics are updated annually and contain all relevant information about primary and final energy consumption. This includes annual aggregated consumption data for various fuels and main consumers such as households, transport, energy industries, industry, and services (see energy balance in Annex 4).

The main data sources of the Swiss overall energy statistics are:

- The Swiss organization for the compulsory stockpiling of oil products (Carbura) and Avenegy Suisse (formerly Swiss petroleum association, EV) for data on import, export, sales, stocks of oil products and for processing of crude oil in refineries.
- Annual import data for natural gas from the Swiss Gas Industry Association (VSG).
- Annual import data for petroleum products and coal from the Federal Office for Customs and Border Security (FOCBS).
- Data provided by industry associations (GVS, SGWA, Cemsuisse, VSG, VSTB, etc.).
- Swiss electricity statistics (SFOE 2022g).
- Swiss renewable energy statistics (SFOE 2022a).
- Swiss wood energy statistics (SFOE 2022b).
- Swiss statistics on combined heat and power generation (SFOE 2022c).

As can be seen in Figure 3-6, fossil fuels amount to slightly less than half of primary energy consumption (i.e. of the total energy demand including losses during transformation and distribution; the losses during transformation and distribution are larger for nuclear fuel and hydro power than for fossil fuels). The main end-users of fossil fuels are the transport and the housing sector, as electricity generation is predominantly based on hydro and nuclear power stations. The most recent energy balance is given in Annex A3.1.

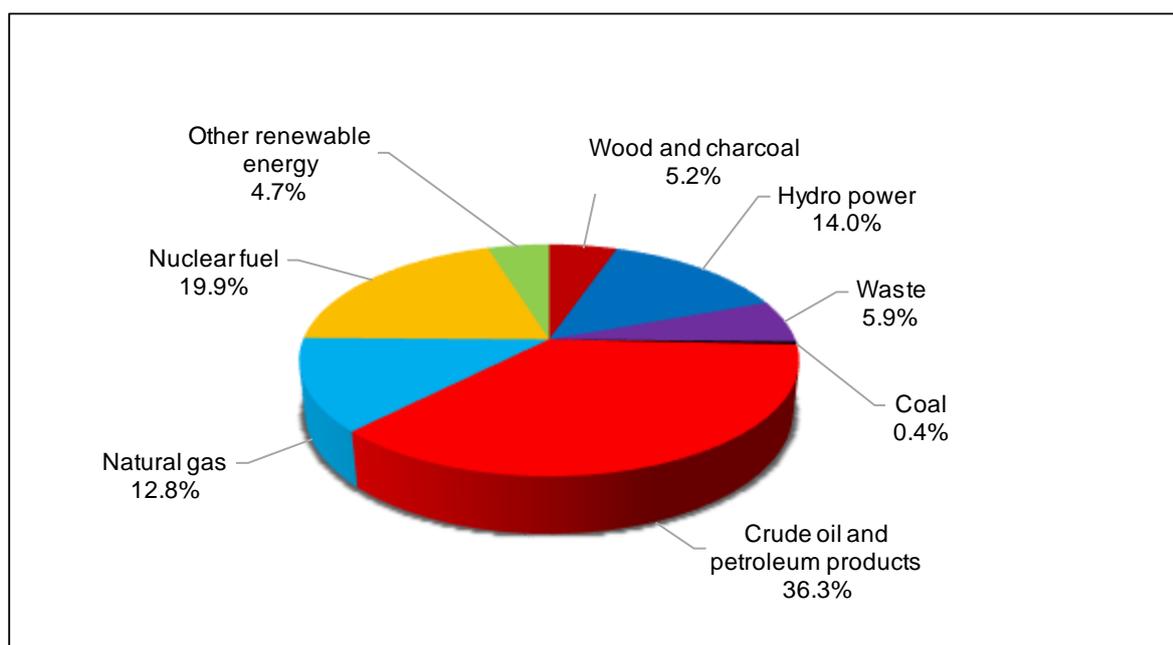


Figure 3-6 Switzerland's primary energy consumption in 2021 by fuels (see corresponding data in SFOE 2022).

Table 3-12 shows primary energy consumption excluding nuclear fuel and hydro power. On the one hand, the combined effect of decreasing consumption of gasoline and increasing consumption of kerosene and diesel oil led to an increasing trend until about 2010 and a stabilization thereafter in the transport sector. On the other hand, consumption of liquid fuels in the residential and services sectors (mainly gas oil) as well as in the industry sector (mainly gas oil and residual fuel oil) substantially decreased. Natural gas consumption increased since 1990, compensating to some extent the decreasing use of gas oil and residual fuel oil in the various sectors. Due to the restrictions related to the COVID-19 pandemic the years 2020 and 2021 are exceptional, with lower fuel consumption, especially in the transport sector.

Table 3-12 Switzerland's energy consumption by fuel type. Only those fuels are shown that are implemented in the EMIS database (no hydro and nuclear power). The numbers are based on the fuels sold principle; thus, they include gasoline, diesel oil and biofuels consumption from fuel tourism, as well as all kerosene sold for domestic and international aviation. Natural gas and gasoline losses due to fugitive emissions (reported in sector 1B) are not included.

Year	Gasoline	Kerosene domestic aviation	Kerosene international aviation (bunker)	Diesel oil	Diesel oil international navigation (bunker)	Gas oil	Residual fuel oil	Refinery gas & Liquefied petroleum gas	Petroleum coke	Solid fuels	Natural gas excl. natural gas losses	Other fuels	Bio fuels	Total as reported in CRF reporting tables	Total incl. bunker
	TJ	TJ	TJ	TJ	TJ	TJ	TJ	TJ	TJ	TJ	TJ	TJ	TJ	TJ	TJ
1990	155'904	6'183	41'884	46'736	821	218'510	23'342	8'890	1'400	14'901	67'861	19'074	46'820	609'620	652'326
1991	162'255	5'690	40'872	47'417	737	238'602	23'590	12'437	980	12'162	76'114	18'514	48'809	646'569	688'178
1992	168'219	5'600	43'499	45'926	780	236'809	24'170	11'492	315	8'758	79'984	18'931	47'766	647'969	692'249
1993	155'960	5'434	45'342	44'197	781	225'920	17'165	12'388	1'120	7'442	83'911	19'048	48'102	620'685	666'808
1994	155'934	5'269	46'840	46'924	824	207'141	17'860	13'455	1'470	7'632	82'737	19'069	46'054	603'543	651'208
1995	151'210	5'029	49'918	47'865	739	217'523	17'278	12'756	1'260	7'962	91'275	19'588	48'130	619'876	670'534
1996	155'136	4'778	51'975	44'946	651	226'289	15'097	13'939	1'015	5'456	98'876	20'443	51'674	637'650	690'276
1997	161'121	4'791	53'983	46'728	657	212'223	12'581	14'236	280	4'590	95'453	21'498	48'552	622'054	676'694
1998	162'390	4'669	56'599	48'681	528	222'407	15'882	15'259	455	3'960	98'301	23'586	50'159	645'748	702'875
1999	167'874	4'419	60'824	51'626	558	212'349	11'058	15'805	521	4'105	101'863	24'189	50'920	644'731	706'114
2000	168'051	4'334	63'726	55'146	531	196'137	7'923	13'649	551	6'120	101'282	26'294	50'597	630'086	694'342
2001	163'466	4'055	60'153	56'262	447	213'089	9'942	14'069	410	6'233	105'478	26'796	53'832	653'634	714'234
2002	160'283	3'870	55'536	58'389	333	196'655	6'446	15'584	679	5'665	103'548	27'624	53'398	632'040	687'909
2003	159'521	3'598	49'840	61'808	443	208'040	7'061	13'642	202	5'663	109'522	27'361	56'010	652'428	702'711
2004	156'718	3'458	46'983	66'447	446	203'370	7'561	16'429	1'819	5'420	113'047	28'518	56'954	659'741	707'170
2005	151'978	3'326	47'775	72'572	493	205'729	5'805	16'432	2'906	5'940	116'100	28'849	59'124	668'761	717'028
2006	147'357	3'338	50'233	78'606	457	195'926	6'419	18'578	3'324	6'467	112'887	30'846	62'248	665'996	716'686
2007	145'938	3'473	53'692	84'420	465	171'313	5'179	15'587	2'730	7'196	109'874	29'617	61'310	636'636	690'793
2008	142'729	3'128	58'023	92'670	473	178'833	4'581	16'288	3'616	6'562	117'083	30'385	65'486	661'359	719'856
2009	138'900	3'239	55'426	94'143	425	173'219	3'530	16'301	3'254	6'193	112'313	29'296	65'656	646'044	701'896
2010	133'972	3'286	58'334	97'776	471	182'295	2'967	15'463	3'498	6'208	125'494	30'627	70'511	672'097	730'901
2011	128'791	3'235	62'461	100'449	428	143'760	2'292	14'856	2'957	5'792	111'269	30'269	66'197	609'867	672'757
2012	124'243	3'402	63'903	106'611	385	154'448	2'780	12'247	3'148	5'269	122'051	30'555	72'128	636'883	701'171
2013	118'583	3'359	64'709	111'482	342	162'532	1'959	15'053	2'735	5'567	128'592	30'249	75'829	655'938	720'989
2014	113'830	3'535	65'006	114'385	299	122'694	1'581	14'473	3'148	5'704	111'346	30'608	70'266	591'569	658'874
2015	105'548	3'454	67'333	112'808	342	129'349	862	9'822	1'145	5'205	118'996	31'398	73'670	592'258	659'933
2016	102'256	3'559	70'603	114'079	299	132'325	378	9'136	890	4'795	125'030	32'835	79'949	605'232	678'134
2017	99'116	3'110	72'824	113'750	256	123'726	350	8'770	763	4'609	125'289	32'515	83'292	595'291	668'371
2018	97'548	3'036	77'214	115'283	200	111'225	87	8'890	781	4'285	118'611	33'805	83'168	576'520	653'933
2019	96'750	2'874	78'196	115'347	197	108'625	111	8'108	777	3'812	121'818	34'044	85'700	577'784	656'156
2020	85'682	2'421	28'194	109'312	189	97'246	76	7'627	700	3'664	118'461	33'733	84'512	543'432	571'815
2021	87'542	2'112	31'847	110'489	228	107'991	139	7'543	604	3'697	128'997	32'826	90'683	572'623	604'698

### 3.2.4.3.2. Energy model – Conceptual overview

For the elaboration of the greenhouse gas and air pollutants inventories, information about energy consumption is needed at a much more detailed level than provided by the Swiss overall energy statistics (SFOE 2022). Activity data in sector 1 Energy are therefore calculated and disaggregated by the Swiss energy model, which is an integral part of the emission database EMIS. The model is developed and updated annually by the Swiss Federal Office for the Environment (FOEN). It relies on the Swiss overall energy statistics and is complemented with further data sources, e.g. Liechtenstein's liquid fuel sales (OS 2022), the Swiss renewable energy statistics (SFOE 2022a), the Swiss wood energy statistics (SFOE 2022b), the energy consumption statistics in the industry and services sectors (SFOE 2022d), as well as additional information from the industry.

The Swiss overall energy statistics are not only the main data input into the energy model, but also serve as calibration and quality control instrument. The total energy consumption given by the Swiss overall energy statistics has to be equal to the sum of the disaggregated

activity data of all source categories within the energy sector (including memo items/bunker). Differences are explicitly taken into account as “statistical differences” (see chp. 3.2.4.1).

As shown in Figure 3-7, the energy model consists of several sub-models, such as the industry model, the civil aviation model, the road transportation model, the non-road transportation model, and the energy model for wood combustion. A brief overview of each of these models is given below. However, depending on the scope of these sub-models, they are either described in the chapter dedicated to the corresponding source category or in an overarching chapter preceding the detailed description of the individual source categories. In chp. 3.2.4.3.3, the resulting sectoral disaggregation is shown separately for each fuel type.

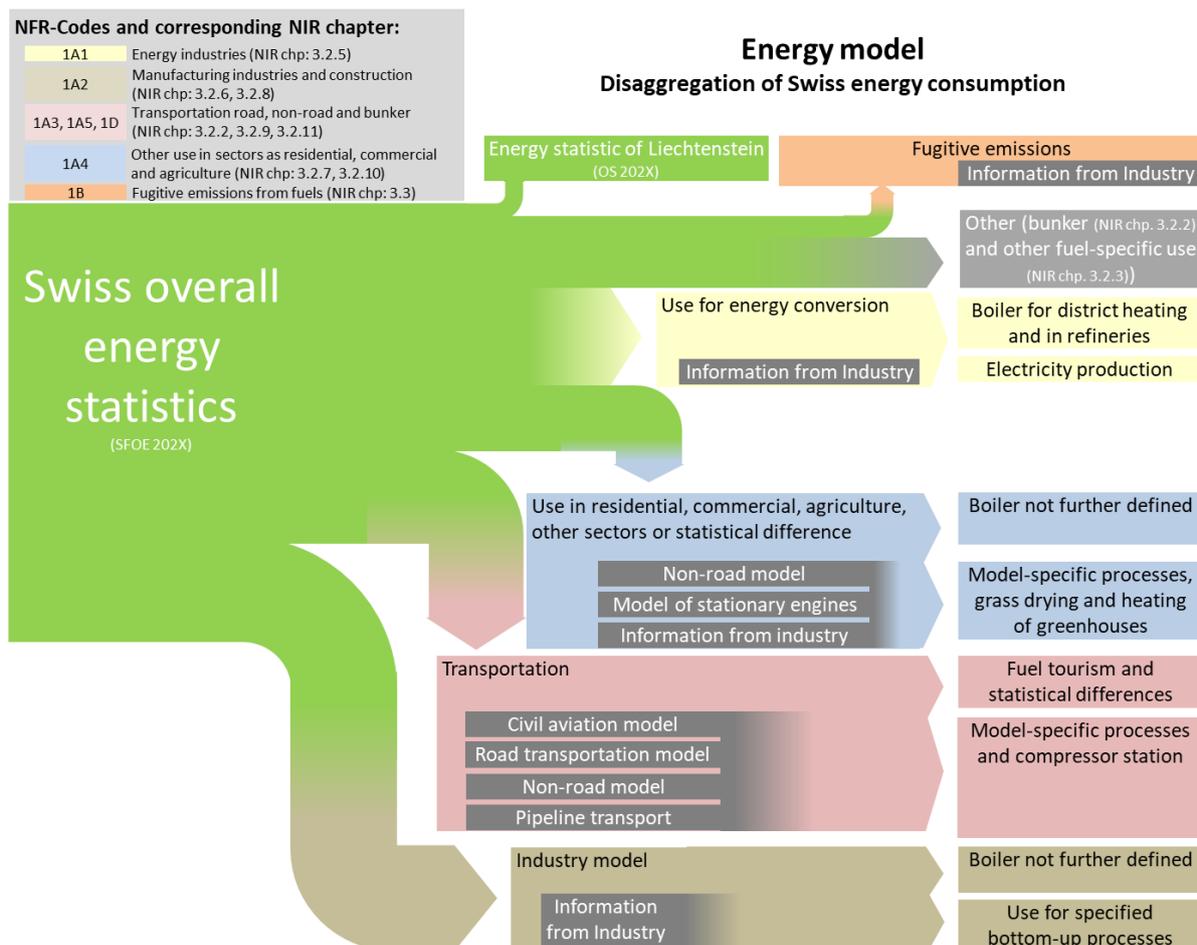


Figure 3-7 Overview of Switzerland's energy model. In the abbreviations SFOE 202X and OS 202X the “X” refers to the latest edition of the respective statistics.

### Industry model (Details are given in chp. 3.2.6.2.1)

The industry model disaggregates the total fuel consumption in the industry sector (SFOE 2022) by source category and fuel type. It is based on the following two pillars. First, the energy consumption statistics in the industry and services sectors (SFOE 2022d) provide a comprehensive annual survey of fuel consumptions for all years since 1999 or 2002 (depending on the fuel type). These statistics are consistently extended back to 1990 based on a bottom-up industry model (Prognos 2013). Second, further disaggregation is achieved by using plant-level industry data for specific processes, as far as available.

### **Civil aviation model** (Details are given in chp. 3.2.2.2.1 and 3.2.9.2.1)

The civil aviation model is developed and updated by the Federal Office for Civil Aviation (FOCA). It aggregates single aircraft movements according to detailed movement statistics of the Swiss airports. Differentiation of domestic and international aviation is based on the information on departure and destination of each flight in the movement database.

### **Road transportation model** (Details are given in chp. 3.2.9.2.2)

The road transportation model is a territorial model, accounting for traffic on Swiss territory only. The model is based on detailed vehicle stock data from the vehicle registration database of the Federal Roads Office (FEDRO), mileage per vehicle category differentiated into different driving patterns, and specific consumption and emission factors. The difference between fuel sales and the territorial model (road and non-road transportation models combined) is considered as fuel tourism and statistical differences, emissions of which are included in the most appropriate categories (see 3.2.9.2.2).

### **Non-road transportation model** (Details are given in chp. 3.2.4.5.1)

The non-road transportation model covers all remaining mobile sources, i.e. industrial vehicles, construction machinery, agricultural and forestry machinery, gardening machinery as well as railways, navigation and military vehicles, except for military aviation, which is considered separately (see chp. 3.2.11.2.1). The model combines vehicle or machinery numbers, their operation hours, engine power, and load factors to derive specific fuel consumption, emission factors and resulting emissions. Data stem from surveys among producers, various user associations, and the national database of non-road vehicles run by FEDRO.

### **Model for wood energy combustion** (Details are given in chp. 3.2.4.5.2)

Based on the Swiss wood energy statistics (SFOE 2022b), total wood consumption is disaggregated into source categories (public electricity and heat production, industry, commercial/institutional, residential, agriculture/forestry/fisheries) and into 24 different combustion installations (ranging from open fireplaces to large-scale automatic boiler or heat and power plants). Where available, industry data on wood combustion is taken into account to allocate parts of the wood consumption as given by the Swiss wood energy statistics to a specific source category.

#### **3.2.4.3.3. *Disaggregation of the energy consumption by source category and fuel types***

The energy model as outlined above disaggregates total energy consumption as provided by the Swiss overall energy statistics (SFOE 2022) into the relevant source categories 1A1–1A5. Figure 3-9 to Figure 3-18 visualize for each fuel type separately the disaggregation process of the energy model (as shown schematically in Figure 3-7), the interaction between the different sub-models as well as additional data sources.

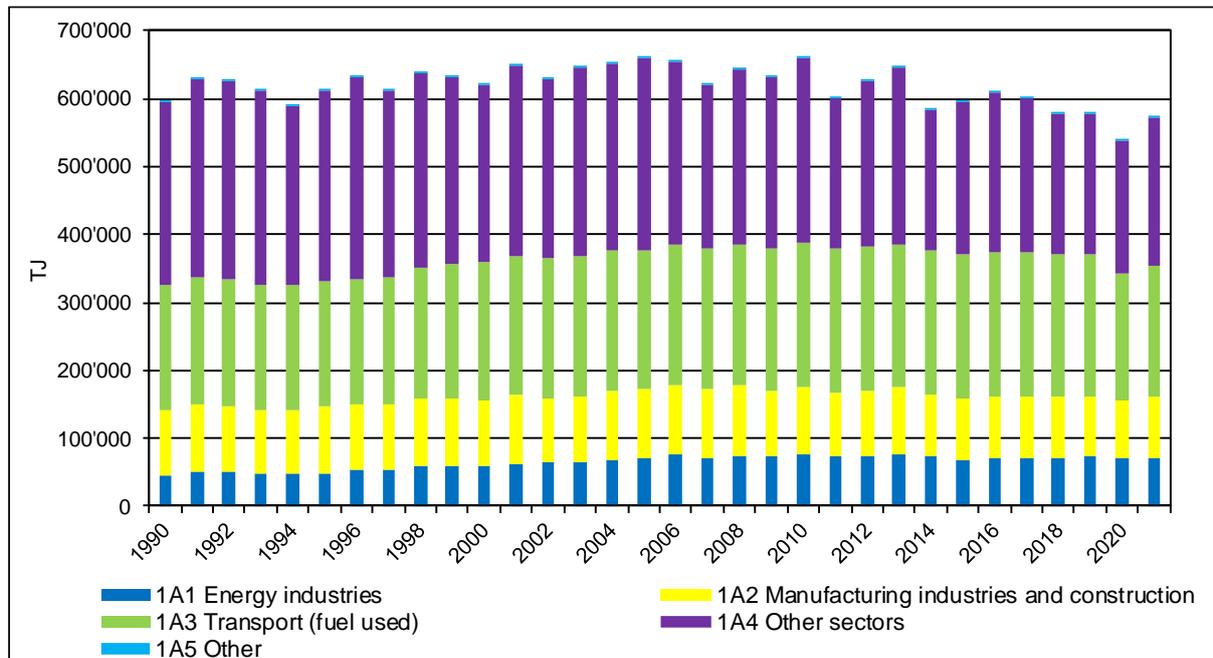


Figure 3-8 Switzerland's energy consumption in the source categories 1A1–1A5 according to the Swiss energy model. Since 1990 population has increased by about one third, industrial production by about three quarters and the motor vehicle fleet by about two thirds (SFOE 2022, table 43a).

Starting from the total energy consumption from the Swiss overall energy statistics for each fuel type, the energy is assigned to the relevant source categories based on the various sub-models of the energy model (mentioned in chp. 3.2.4.3.2 above). In addition, the following assignments are considered as well:

- Within the source categories 1A4a and 1A4b, the amount of gas oil and natural gas used for co-generation in turbines and engines is derived from a model of stationary engines developed by Eicher + Pauli (Kaufmann 2015) for the statistics on combined heat and power generation (SFOE 2014c). The residual energy is then assigned to boilers which are not further specified.
- For source category 1A4ci Other sectors – Agriculture/forestry/fishing, specific bottom-up industry information is available for grass drying and heating of greenhouses. The fuel consumption for grass drying is provided by the Swiss association of grass drying plants (VSTB). Further, based on annual energy consumption data from the Energy Agency of the Swiss Private Sector (EnAW) regarding agricultural greenhouses exempt from the CO<sub>2</sub> levy, total energy consumption of all greenhouses within Switzerland is extrapolated. The fuel consumption for grass drying and greenhouses is subtracted from the total fuel consumption of residential, commercial, agriculture and statistical differences (see Figure 3-7).
- In order to report all energy consumption, the statistical differences as reported in the Swiss overall energy statistics are allocated to source category 1A4ai Other sectors – Commercial/institutional (stationary combustion) and 1A3bviii Fuel tourism and statistical differences. In the greenhouse gas inventory, emissions from 1A3bviii Fuel tourism and statistical differences are reported in the source categories 1A3bi, 1A3bii, and 1A3biii (see chp. 3.2.9.2.2 for a more detailed description).



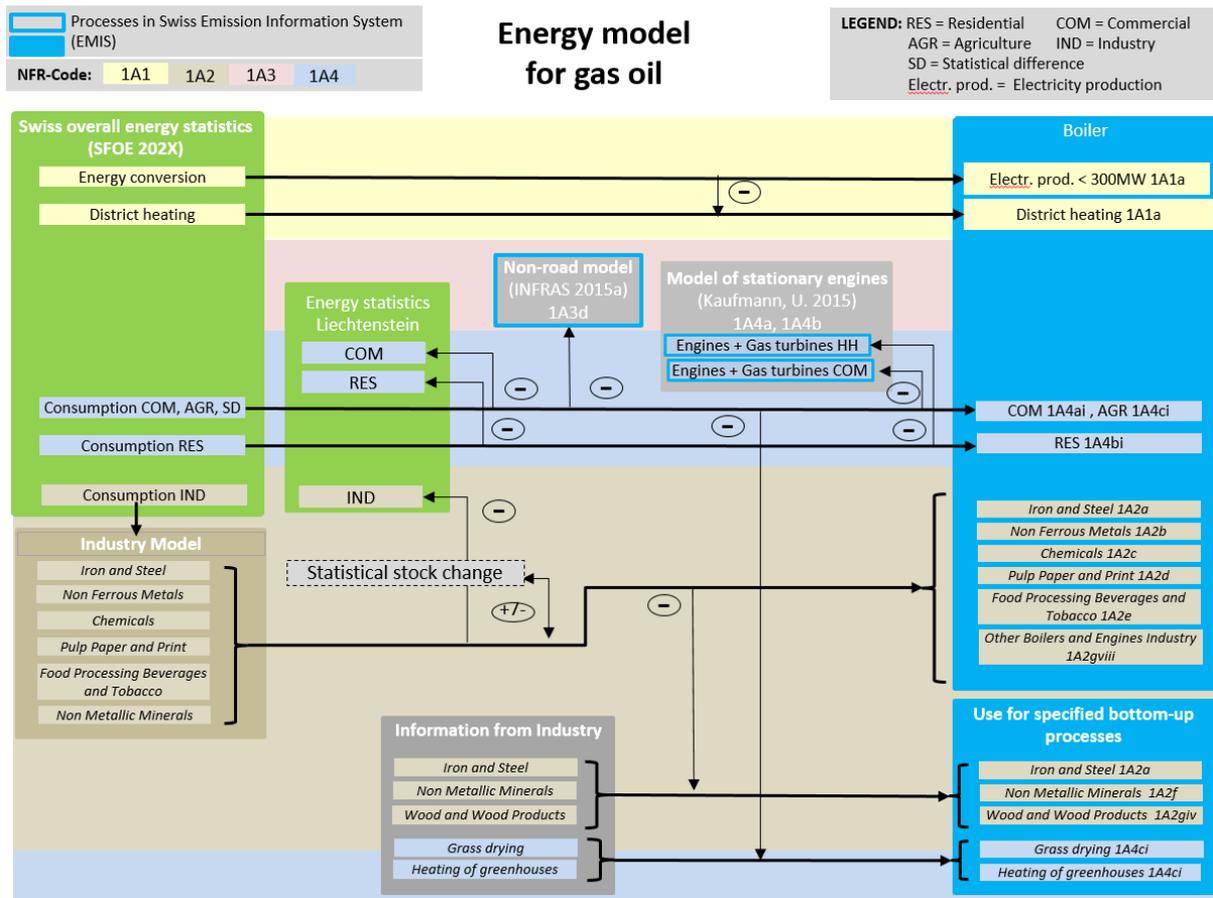


Figure 3-11 Schematic disaggregation of fuel consumption for gas oil. The Swiss overall energy statistics provides gas oil use for energy conversion and the amount thereof being used for district heating. Based on this information, gas oil use is split into the source categories 1A1ai Electricity generation and 1A1aiii Heat plants. According to the non-road model, a small amount of gas oil is consumed in source category 1A3d navigation (steam-powered vessels).

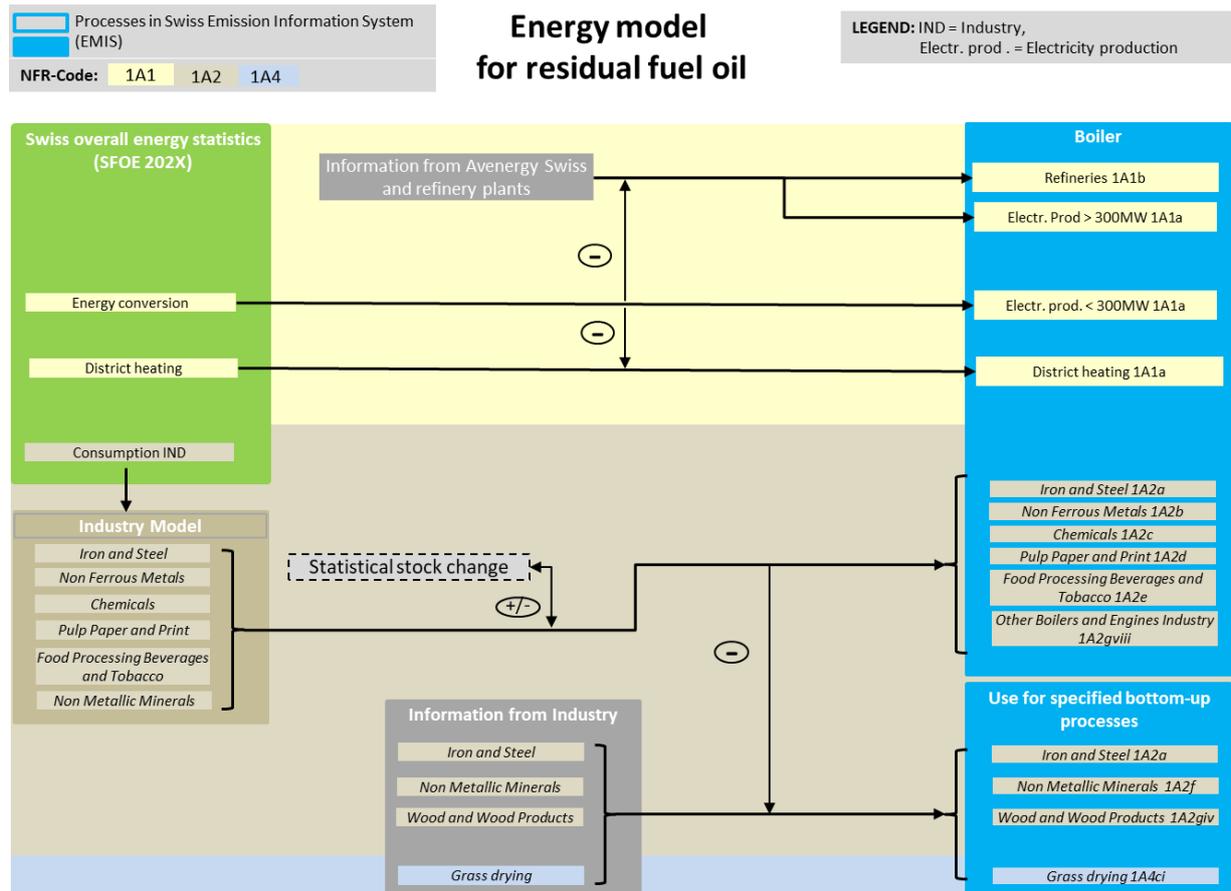


Figure 3-12 Schematic disaggregation of fuel consumption for residual fuel oil. The Swiss overall energy statistics reports residual fuel oil use in energy conversion and the amount thereof consumed in electricity production (one single fossil fuel power station, operational from 1985 to 1994), district heating, and in petroleum refineries. Based on this information, residual fuel oil use in Energy industries is split into the source categories 1A1ai Electricity generation, 1A1aiii Heat plants and 1A1b Petroleum refining.

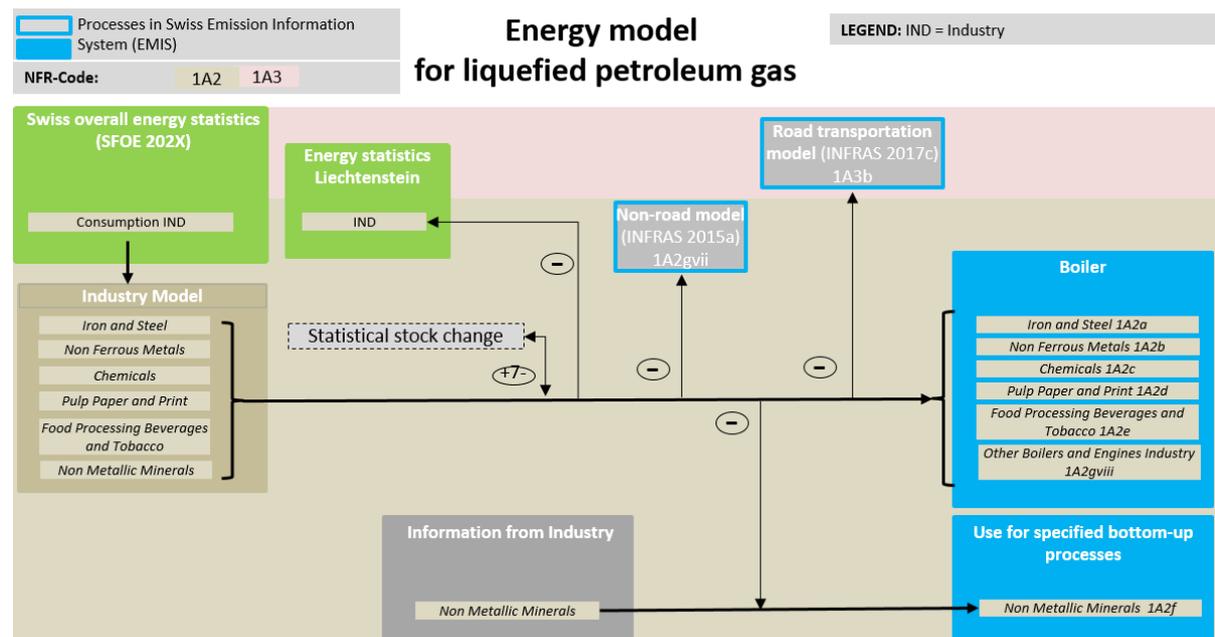


Figure 3-13 Schematic disaggregation of fuel consumption for liquefied petroleum gas.

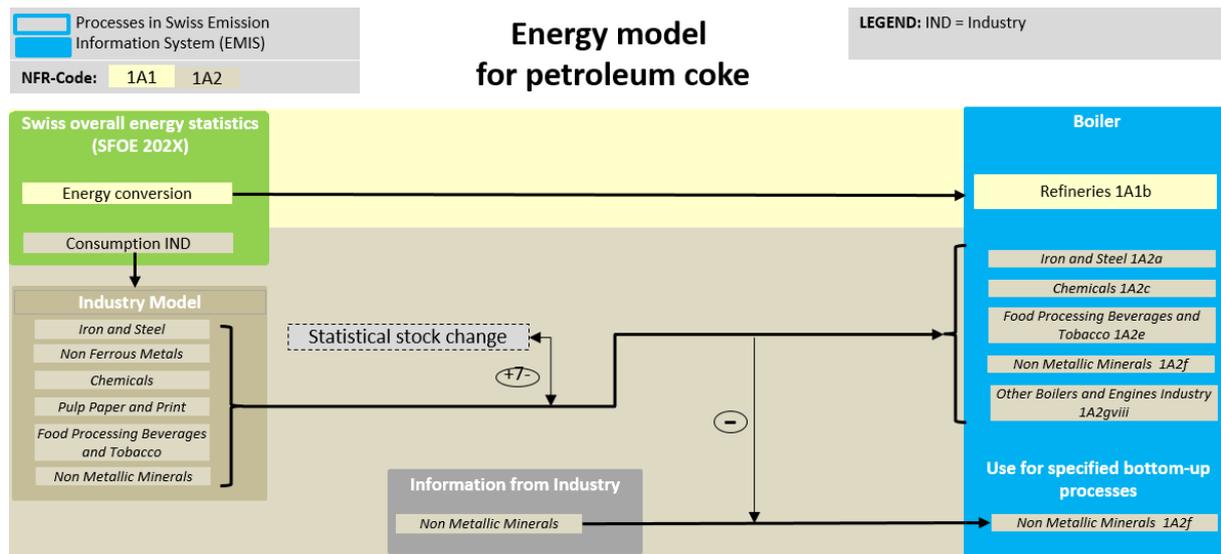


Figure 3-14 Schematic disaggregation of fuel consumption for petroleum coke.

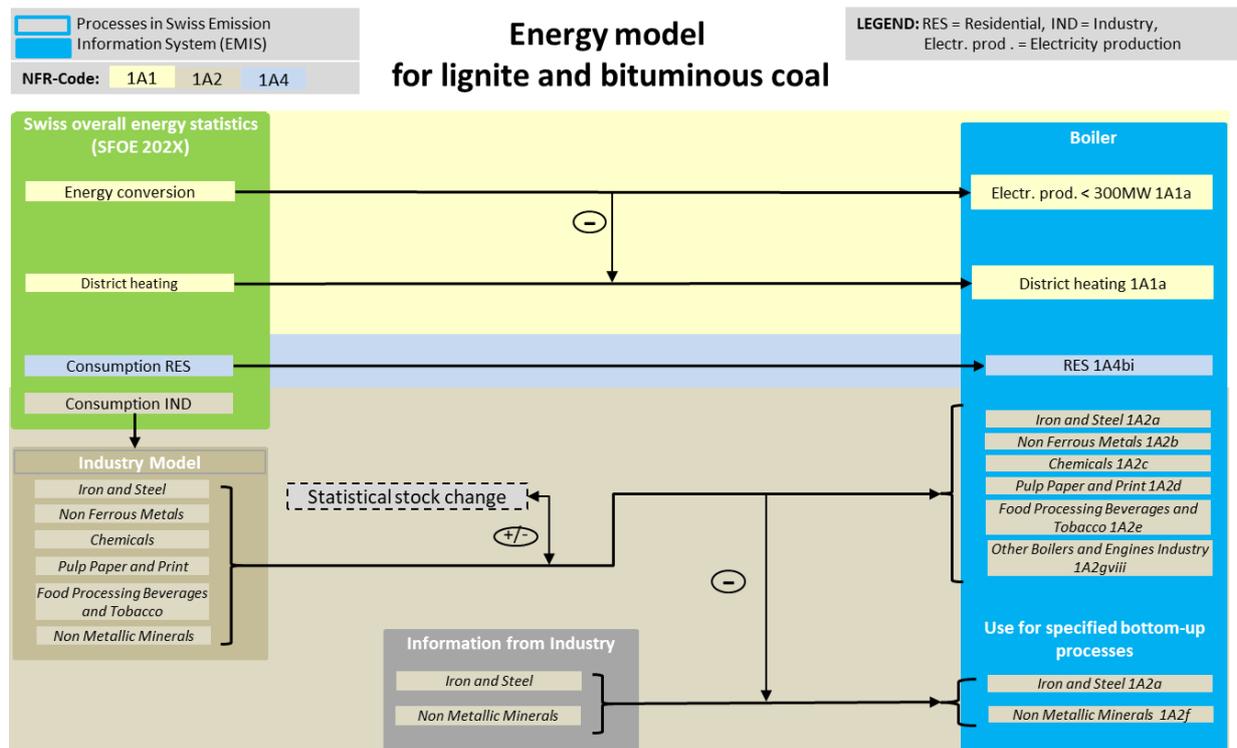


Figure 3-15 Schematic disaggregation of fuel consumption for lignite and bituminous coal. The Swiss overall energy statistics provides bituminous coal use for energy conversion and the amount thereof being used for district heating. Based on this information, use of bituminous coal in Energy industries is split into the source categories 1A1ai Electricity generation and 1A1aiii Heat plants up to 1995. Coal consumption for public electricity and heat production ceased thereafter.

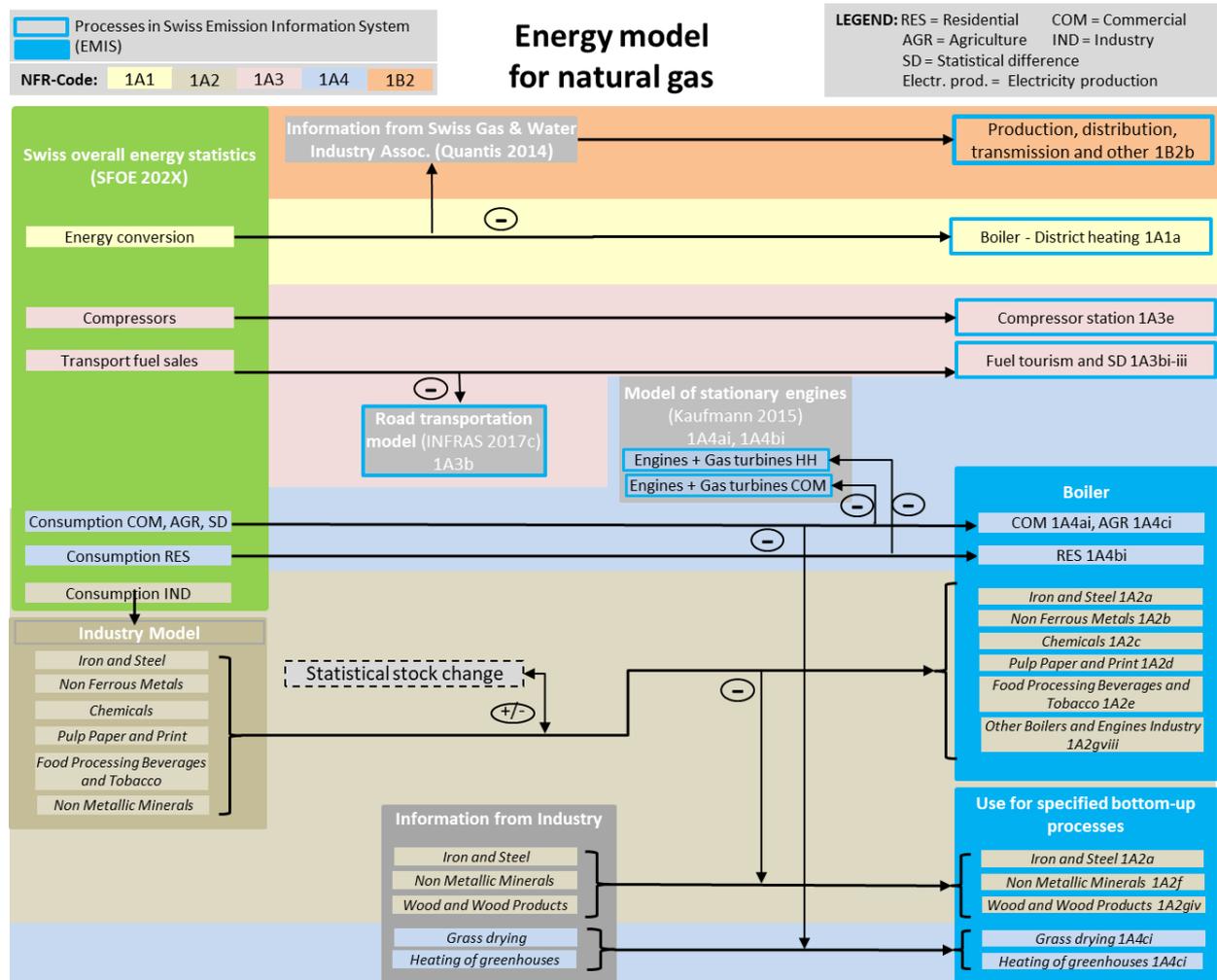


Figure 3-16 Schematic disaggregation of fuel consumption for natural gas. The Swiss overall energy statistics provides gas use in the transformation sector (energy conversion and distribution losses). Distribution losses as estimated by the Swiss Gas and Water Industry Association (SGWA) are subtracted and reported under source category 1B2 Fugitive emissions from fuels. The remaining fuel consumption for natural gas is reported under source category 1A1a Public electricity and heat production. In the greenhouse gas inventory, emissions from 1A3bviii Fuel tourism and statistical differences are reported in the source categories 1A3bi, 1A3bii, and 1A3biii (see chp. 3.2.9.2.2 for a more detailed description).

A corresponding Figure 3-16b is available in the confidential version of this chapter, providing more details.

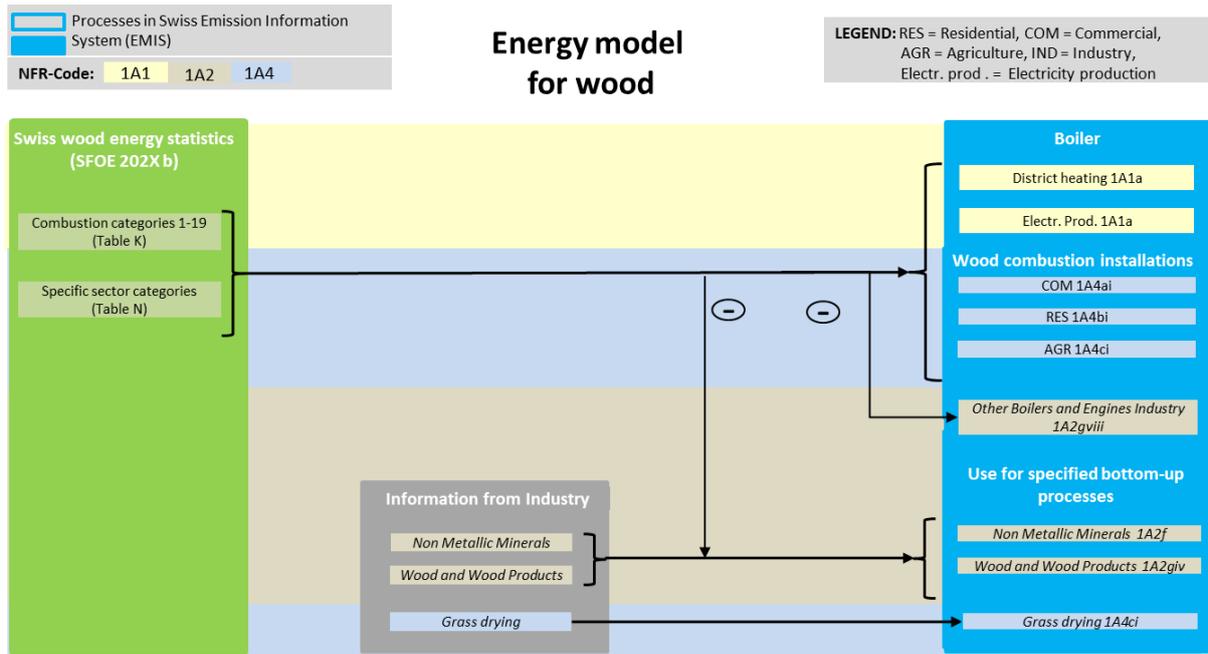


Figure 3-17 Schematic disaggregation of fuel consumption for wood (see chp. 3.2.4.5.2.)

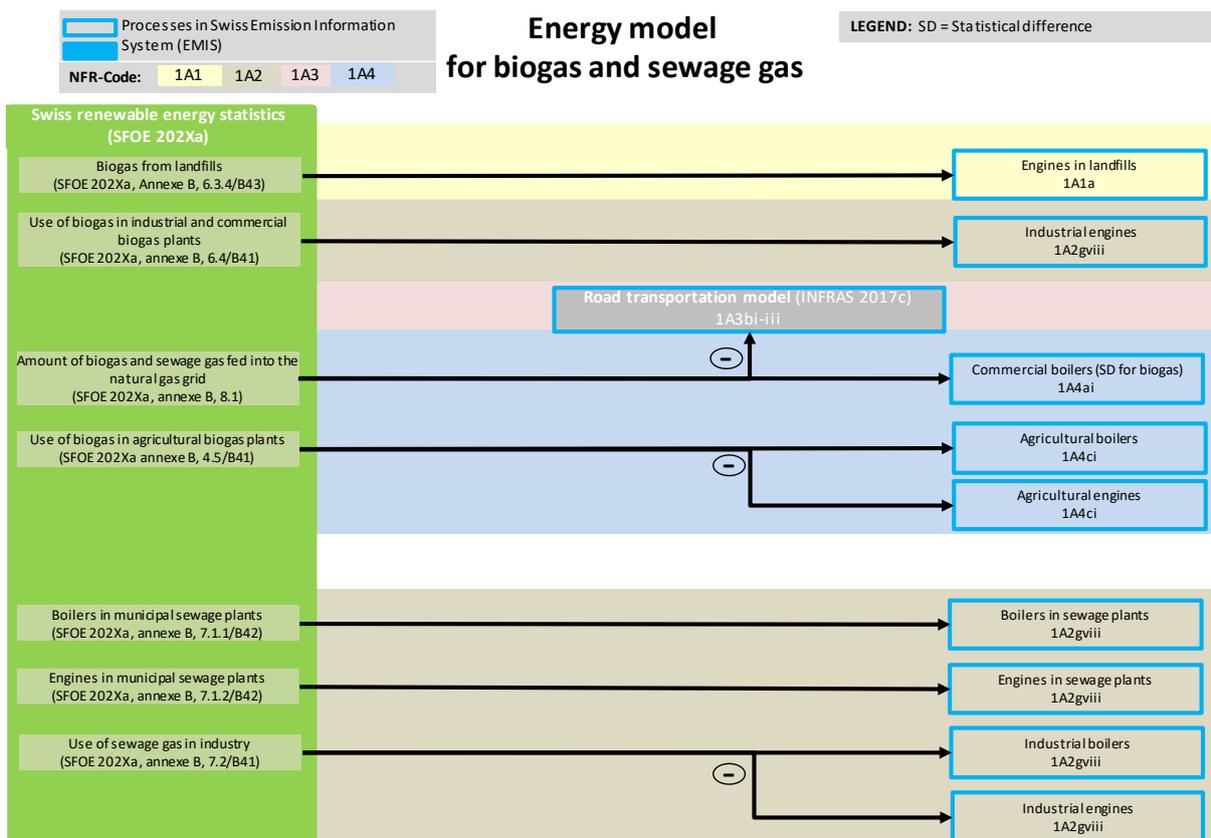


Figure 3-18 Schematic disaggregation of fuel consumption for biogas and sewage gas.

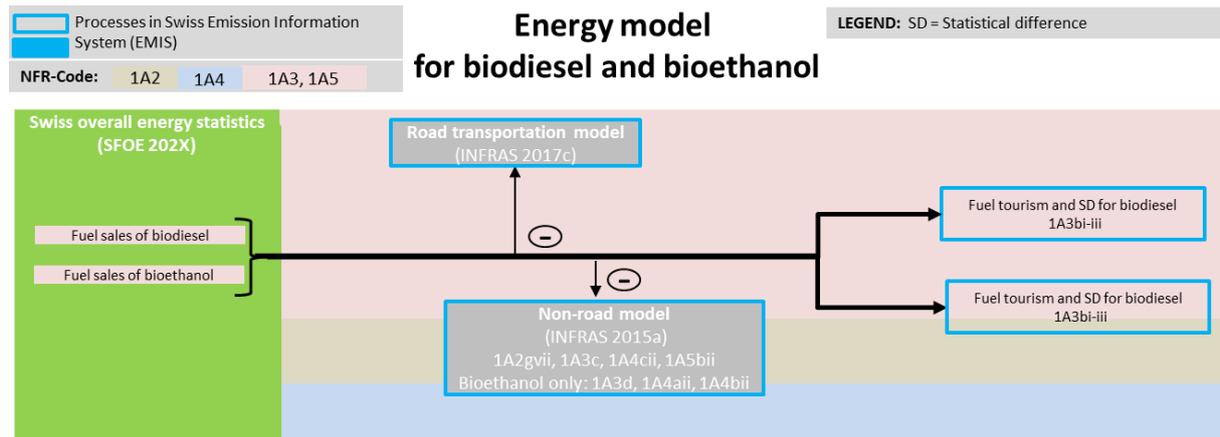


Figure 3-19 Schematic disaggregation of fuel consumption for biodiesel and bioethanol.

### Statistical stock change

In a few years the quantity of a fuel sold in a year according to total energy statistics may be smaller (or larger) than the quantity effectively used in the same year as reported from bottom-up data. The reason for such deviations is due to further stocks which are not taken into consideration at the level of the Swiss energy statistics and are managed at the individual plant level. Some plants manage their own intermediate fuel stocks, which they may carry over to use in later years. To mitigate the difference between less fuel sold (according to the total energy statistics) than fuel used (according to bottom-up information) in one year, so-called “stock shifts” are assumed in the energy model. Stockpiling can only be performed in the years in which more fuel was sold according to total energy statistics than was used based on bottom-up information. Stock which was accumulated in such years can be used in later years to level out the deviations between the total energy statistics and bottom-up data. Currently, stocks are formed in different years for residual fuel oil, petroleum coke and other bituminous coal:

- For residual fuel oil stock was built up in the years 2008–2010, 2014, 2015 and used in the years 2011, 2012, 2016–2021.
- For petroleum coke stock was built up in the years 2007, 2018 and used in the years 2008, 2019.
- For other bituminous coal stock was built up in the years 1991, 1996, 2003, 2005–2007 and used in the years 1993, 1994, 1998–2001, 2011, 2012.

#### 3.2.4.4. Emission factors of 1A Fuel combustion

##### 3.2.4.4.1. Oxidation factor for 1A Fuel combustion

For the emission calculation, an oxidation factor of 100 % is assumed for all fossil fuel combustion processes, since the technical standards for combustion installations in Switzerland are high and the small fraction of originally non-oxidised carbon retained in ash, particulates or soot is likely to be oxidized later. This is consistent with the 2006 IPCC Guidelines (IPCC 2006) and the EU and Swiss guidelines for the Emissions Trading Scheme (ETS), where also a default oxidation factor of 100 % was applied.

Because an oxidation factor of 100 % is assumed, indirect CO<sub>2</sub> emissions from CH<sub>4</sub>, CO and NMVOC are implicitly reported as direct CO<sub>2</sub> emissions in source category 1A Energy.

Therefore, from this source category no indirect CO<sub>2</sub> emissions are included in CRF Table6 as documented in chp. 9.

### 3.2.4.4.2. CO<sub>2</sub> emission factors for 1A Fuel combustion

#### General CO<sub>2</sub> emission factors

The CO<sub>2</sub> emission factors applied for the time series 1990–2021 are given in Table 3-13. Detailed information regarding the underlying data and assumptions are provided in chp. 3.2.4.2 Net calorific values (NCV), since in most cases, NCVs and carbon content were determined jointly.

Table 3-13 CO<sub>2</sub> emission factors 1990–1998 and years from 2013 onwards. For years between 1998 and 2013, the factors are linearly interpolated. Data source SGWA stands for annually updated reports of the Swiss Gas and Water Industry Association (SGWA).

CO <sub>2</sub> emission factors			1990-1998	2013-2021
Fossil fuel	CS/D	Data sources	t CO <sub>2</sub> / TJ	t CO <sub>2</sub> / TJ
Gasoline	CS	EMPA (1999), SFOE/FOEN (2014)	73.8	73.8
Jet kerosene	CS	EMPA (1999), SFOE/FOEN (2014)	72.8	72.8
Diesel oil	CS	EMPA (1999), SFOE/FOEN (2014)	73.3	73.3
Gas oil	CS	EMPA (1999), SFOE/FOEN (2014)	73.7	73.7
Residual fuel oil	CS	EMPA (1999)	77.0	77.0
Liquefied petroleum gas	CS	FOEN (2019k)	65.5	65.5
Petroleum coke	CS	Cemsuisse (2010a)	91.4	91.4
Other bituminous coal	CS	Cemsuisse (2010a)	92.7	92.7
Lignite	CS	Cemsuisse (2010a)	96.1	96.1
Natural gas	CS	SGWA	<i>see table below</i>	
Biofuel	CS/D	Data sources		
Biodiesel	CS	assumed equal to diesel oil	73.3	73.3
Bioethanol	CS	assumed equal to gasoline	73.8	73.8
Biogas	CS	assumed equal to natural gas	<i>see table below</i>	
Wood	CS	Cemsuisse (2010a)	99.9	99.9

#### CO<sub>2</sub> emission factors for natural gas and biogas

Table 3-14 Time series of CO<sub>2</sub> emission factors of natural gas and biogas. SGWA refers to annual updates of properties of natural gas that are provided by the Swiss Gas and Water Industry Association (SGWA).

CO <sub>2</sub> emission factors			1990	1995	2000	2005	2010					
Fuel	CS/D	Data sources	t CO <sub>2</sub> / TJ									
Natural gas/Biogas	CS	SGWA	56.1	55.7	56.2	56.4	56.5					
CO <sub>2</sub> emission factors			2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Fuel	CS/D	Data sources	t CO <sub>2</sub> / TJ									
Natural gas/Biogas	CS	SGWA	56.5	56.4	56.5	56.4	56.4	56.3	56.2	56.4	56.2	55.9

#### CO<sub>2</sub> emission factors for wood

The CO<sub>2</sub> emission factor for wood combustion activities is taken from Cemsuisse (2010a).

### 3.2.4.4.3. CH<sub>4</sub> emission factors for 1A Fuel combustion

#### General CH<sub>4</sub> emission factors

An overview of the general CH<sub>4</sub> emission factors is given in Table 3-15. These emission factors are used for most stationary combustion processes (exceptions are discussed in the detailed sectoral chapters where they occur). For stationary combustion, mainly IPCC default emission factors are used for the entire time period (IPCC 2006). For wood combustion, country-specific factors are used. Details are given below in Table 3-16. CH<sub>4</sub> emission factors related to transport activities (aviation, road and non-road transportation) are category-specific and given in the corresponding chapters.

Table 3-15 CH<sub>4</sub> emission factors for stationary combustion for the whole time period.

CH <sub>4</sub> emission factors			1990-2021
Fuel	CS/D	Data sources	g CH <sub>4</sub> / GJ
Gas oil	D	IPCC (2006)	3
Residual fuel oil	D	IPCC (2006)	3
Liquefied petroleum gas	D	IPCC (2006)	1
Petroleum coke	D	IPCC (2006)	3
Other bituminous coal	D	IPCC (2006)	10
Lignite	D	IPCC (2006)	10
Natural gas	D	IPCC (2006)	1
Biofuel	CS/D	Data Sources	
Biogas	D	IPCC (2006)	1
Wood	CS	Zotter and Nussbaumer (2022)	0.19 - 230

#### CH<sub>4</sub> emission factors for wood

There are many different combustion installations in use which have very different CH<sub>4</sub> emission factors. A detailed overview of all applied wood related CH<sub>4</sub> emission factors for the entire time series is given in Table 3-16.

The CH<sub>4</sub> emission factors are based on a country-specific emission factor model for wood energy that was completely revised for the submission 2021 (Zotter and Nussbaumer 2022). The model is based on a large number of air pollution control measurements, laboratory and field measurements, literature data (e.g. beReal, emission factors in the Nordic countries) and the EMEP/EEA air pollutant emission inventory guidebook (EMEP/EEA 2019) and covers the entire time series. The CH<sub>4</sub> emission factors are modelled based on VOC emissions of each combustion installation type and a mean CH<sub>4</sub> to VOC ratio of 0.3.

The emission factor for the different combustion installations varies depending on the year, rated thermal input and technology used. The emission factor of a single category represents the emission characteristics of a large number of combustion installations with a range of technology types, maintenance and operating conditions at a given time. According to their lifespan, existing combustion installations are gradually replaced by installations of new technology with better combustion, resulting in gradually decreasing emission factors.

Table 3-16 CH<sub>4</sub> emission factors for wood combustion installations.

1A Wood combustion	1990	1995	2000	2005	2010					
	g CH <sub>4</sub> /GJ									
Open fireplaces	160	154	149	143	133					
Closed fireplaces, log wood stoves	160	152	143	135	127					
Pellet stoves	NO	NO	16	13	10					
Log wood hearths	230	222	213	205	187					
Log wood boilers	70	62	53	45	37					
Log wood dual chamber boilers	230	222	213	205	187					
Automatic chip boilers < 50 kW	60	52	43	35	27					
Automatic pellet boilers < 50 kW	NO	NO	14	12	10					
Automatic chip boilers 50-300 kW w/o wood proc. companies	30	27	24	22	17					
Automatic pellet boilers 50-300 kW	NO	NO	7.8	6.7	5.0					
Automatic chip boilers 50-300 kW within wood proc. companies	30	27	24	22	17					
Automatic chip boilers 300-500 kW w/o wood proc. companies	30	27	24	22	17					
Automatic pellet boilers 300-500 kW	NO	NO	NO	6.7	5.0					
Automatic chip boilers 300-500 kW within wood proc. companies	30	27	24	22	17					
Automatic chip boilers > 500 kW w/o wood proc. companies	10	8.9	7.8	6.7	5.0					
Automatic pellet boilers > 500 kW	NO	NO	NO	3.0	2.3					
Automatic chip boilers > 500 kW within wood proc. companies	12	11	10	9.5	7.0					
Combined chip heat and power plants	NO	0.89	0.78	0.67	0.47					
Plants for renewable waste from wood products	4.0	3.7	3.4	3.2	2.3					

1A Wood combustion	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
	g CH <sub>4</sub> /GJ									
Open fireplaces	127	123	120	120	120	120	120	120	120	117
Closed fireplaces, log wood stoves	123	122	120	118	117	115	113	112	110	107
Pellet stoves	8.0	7.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	5.8
Log wood hearths	173	167	160	158	157	155	153	152	150	146
Log wood boilers	33	32	30	30	30	30	30	30	30	29
Log wood dual chamber boilers	173	167	160	158	157	155	153	152	150	148
Automatic chip boilers < 50 kW	23	22	20	20	20	20	20	20	20	19
Automatic pellet boilers < 50 kW	10	10	10	9	8.7	8.0	7.3	6.7	6.0	5.7
Automatic chip boilers 50-300 kW w/o wood proc. companies	13	12	10	10	10	10	10	10	10	10
Automatic pellet boilers 50-300 kW	4.0	3.5	3.0	3.0	3.0	3.0	3.0	3.0	3.0	2.9
Automatic chip boilers 50-300 kW within wood proc. companies	13	12	10	10	10	10	10	10	10	10
Automatic chip boilers 300-500 kW w/o wood proc. companies	13	12	10	10	10	10	10	10	10	10
Automatic pellet boilers 300-500 kW	4.0	3.5	3.0	3.0	3.0	3.0	3.0	3.0	3.0	2.9
Automatic chip boilers 300-500 kW within wood proc. companies	13	12	10	10	10	10	10	10	10	10
Automatic chip boilers > 500 kW w/o wood proc. companies	4.0	3.5	3.0	3.0	3.0	3.0	3.0	3.0	3.0	2.9
Automatic pellet boilers > 500 kW	1.7	1.3	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Automatic chip boilers > 500 kW within wood proc. companies	5.0	4.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	2.9
Combined chip heat and power plants	0.33	0.27	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.19
Plants for renewable waste from wood products	1.7	1.3	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

#### 3.2.4.4.4. N<sub>2</sub>O emission factors for 1A Fuel combustion

Table 3-17 shows the general N<sub>2</sub>O emission factors in source category 1A which are based on default values from the 2006 IPCC Guidelines (IPCC 2006) and kept constant over the whole period. N<sub>2</sub>O emission factors related to transport activities (military aviation, road and non-road transportation) are category-specific and given in the corresponding chapters.

Table 3-17 N<sub>2</sub>O emission factors. Default emission factors are used for all fuels for the whole time period.

N <sub>2</sub> O emission factors			1990-2021
Fuel	CS/D	Data sources	g N <sub>2</sub> O / GJ
Jet Kerosene	D	IPCC (2006)	2
Gas oil	D	IPCC (2006)	0.6
Residual fuel oil	D	IPCC (2006)	0.6
Liquefied petroleum gas	D	IPCC (2006)	0.1
Petroleum coke	D	IPCC (2006)	0.6
Other bituminous coal	D	IPCC (2006)	1.5
Lignite	D	IPCC (2006)	1.5
Natural gas	D	IPCC (2006)	0.1
<b>Biofuel</b>	<b>CS/D</b>	<b>Data sources</b>	
Biogas	D	IPCC (2006)	0.1
Wood	D	IPCC (2006)	4

### 3.2.4.5. Models overlapping more than one source category

#### 3.2.4.5.1. Non-road transportation model (excl. aviation)

##### Choice of method

- The GHG emissions are calculated by a Tier 3 method based on the decision tree in Fig. 3.3.1 in chp. 3. Mobile Combustion in IPCC (2006), complemented with
- Tier 2 for railways CO<sub>2</sub>, Fig. 3.4.1 in IPCC (2006)
- Tier 3 for railways CH<sub>4</sub>, N<sub>2</sub>O and precursors, Fig. 3.4.2 in IPCC (2006)
- Tier 2 for navigation, Fig. 3.5.1 (Box 1) in IPCC (2006)

##### Methodology

The emissions of the non-road sector underwent an extended revision in 2014/2015, resulting in an update of GHG emissions including precursors. Results are documented in FOEN (2015j). The non-road categories considered are listed in Table 3-18. All of them include several technologies, fuels (diesel oil, 2- or 4-stroke gasoline, liquefied petroleum gas, gas oil), and emission standards according to the classification shown in Figure 3-20.

Table 3-18 Non-road categories as specified in FOEN (2015j) and the corresponding code in the reporting tables (CRF).

Non-road categories (by Corinair)	Nomenclature CRF
Construction machinery	1.A.2.g.vii Off-road vehicles and other machinery
Industrial machinery	1.A.2.g.vii Off-road vehicles and other machinery
Railway machinery	1.A.3.c Railways
Navigation machinery	1.A.3.d Domestic Navigation
Garden-care/professional appliances	1.A.4.a.ii Commercial/institutional, Off-road vehicles and other machinery
Garden-care/hobby appliances	1.A.4.b.ii Residential, Off-road vehicles and other machinery
Agricultural machinery	1.A.4.c.ii Agriculture/forestry/fishing, Off-road vehicles and other machinery
Forestry machinery	1.A.4.c.ii Agriculture/forestry/fishing, Off-road vehicles and other machinery
Military machinery (excl. aviation)	1.A.5.b Other, mobile, Military

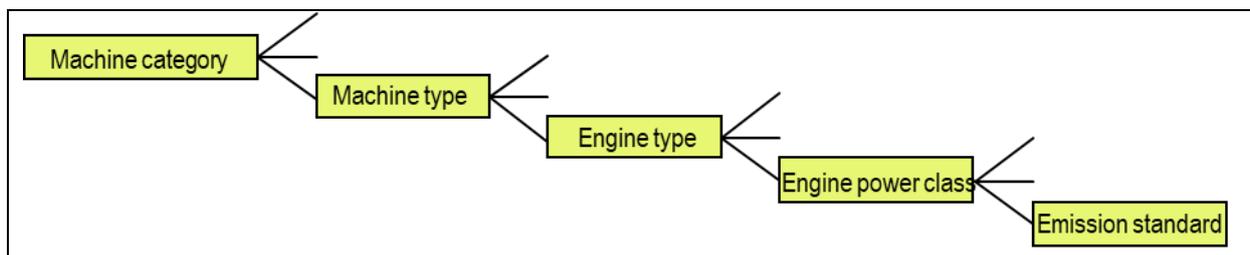


Figure 3-20 Each non-road vehicle is classified by its machine category, machine type, engine type and engine-power class and emission standard (FOEN 2015j, INFRAS 2015a).

The emission modelling is based on activity data and emission factors by means of the following equation, which holds on the most disaggregated level of engine power class (Figure 3-20):

$$Em = N \cdot H \cdot P \cdot \lambda \cdot \varepsilon \cdot CF_1 \cdot CF_2 \cdot CF_3$$

with

$Em$	=	emission per engine type (in g/a)
$N$	=	number of vehicles (--)
$H$	=	number of operation hours per year (h/a)
$P$	=	engine power output (kW)
$\lambda$	=	effective load factor (--)
$\varepsilon$	=	emission factor (g/kWh)
$CF_1$	=	correction factor for the effective load (--)
$CF_2$	=	correction factor for dynamical engine use (--)
$CF_3$	=	degradation factor due to aging (--)

With this equation, the emissions of the following gases and also the fuel consumption are calculated:

- GHG: CH<sub>4</sub>, N<sub>2</sub>O
- precursor gases: NO<sub>x</sub>, CO
- air pollutant: VOC
- fuel consumption: in this case,  $\varepsilon$  represents the consumption instead of emission factor (in g/kWh)

For other gases, the following method is applied:

- CO<sub>2</sub> is calculated as product of fuel consumption and CO<sub>2</sub> emission factors (according to Table 3-13)
- SO<sub>2</sub> is calculated as product of fuel consumption and SO<sub>2</sub> emission factors (according to Table A – 15)
- NMVOC is calculated as the difference between VOC and CH<sub>4</sub>
- CO<sub>2</sub> emissions from the use of lubricants as an additive in gasoline for 2-stroke engines are modelled separately and the corresponding CO<sub>2</sub> emissions from the lubricants are reported under 2D1 Lubricant use (chp. 4.5.2.1). Non-CO<sub>2</sub> emissions from the combustion of lubricants in 2-stroke engines however are reported in the energy sector (1A2gvii, 1A3b, 1A3d, 1A4aii, 1A4bii, 1A4cii, 1A5bii).

The total emission and consumption per non-road category is calculated by taking the sum over all engine-power classes, engine types, machine types and emission standards.

Emissions are only calculated in steps of 5 years from 1980 to 2050. Emissions for years in-between are interpolated linearly. A more detailed description of the analytical details is given in the Annex of FOEN (2015j).

### **Emission factors**

Emission factors are taken from FOEN (2015j). They have been derived from various sources based on measurements, modelling and literature:

- CO<sub>2</sub> and SO<sub>2</sub> emission factors are country-specific, see Table 3-13 and Table A – 15.
- For other gases, the main data sources are USEPA (2010), IFEU (2010), EMEP/EEA (2016), EMEP/EEA (2019) and Integer (2013).

For a detailed description of emission factors and their origin, see tables in the annex of FOEN (2015j) and online in the database belonging to INFRAS (2015a).

### **Activity data**

Activity data were collected by surveys among producers and several user associations in Switzerland (FOEN 2015j), and by evaluating information from the national information system for traffic admission (IVZ, formerly MOFIS) run by the Federal Roads Office (FEDRO 2014). In addition, several publications serve as further data sources:

- SBV (2013) for agricultural machinery
- SFSO (2013a) for agricultural machinery
- Jardin Suisse (2012) for garden care /hobby and professional appliances
- KWF (2012) for forestry machinery
- The national statistics on imports/exports of non-road vehicles was assessed by FCA (2015c)
- Off-Highway Research (2005, 2008, 2012) provided information on the number of non-road vehicles.
- Federal Department of Defence, Civil Protection and Sport: List of military machinery with vehicle stock, engine-power classes and operating hours (DDPS 2014a).

From these data sources, all necessary information like size distributions, fleet turnover, annual operating hours (age-dependent), load factors, year of market entry, and age distributions, was derived. Details are documented in FOEN (2015j). All activity data (vehicle stock, operating hours, consumption factors) can be downloaded by query from the online non-road database INFRAS (2015a), which corresponds to the data described in FOEN (2015j). They can be queried by vehicle type, fuel type, power class and emission standard either at aggregated or disaggregated levels.

### 3.2.4.5.2. *Model for wood energy combustion*

#### Choice of method

The emissions from wood combustion in 1A Fuel combustion are calculated by a Tier 2 method based on the decision tree for stationary fuel combustion (IPCC 2006, Volume 2 Energy, chp. 2 Stationary Combustion, Figure 2.1 on page 2.15).

#### Methodology

The Swiss wood energy statistics (SFOE 2022b) distinguish 24 wood combustion installation types (excl. municipal solid waste plants) that are fired with logwood, pellets, chips or so-called renewable waste from wood products and provide both the annual wood consumption for the individual categories of combustion installation types (table K, categories 1–19, see Table 3-19), and the allocations of the installation types to the sectoral consumer categories (table N, household, agriculture/forestry, industry, services, electricity and district heating). This allows for assigning the annual wood consumption at the level of combustion installation categories directly to the source categories 1A1a Public electricity and heat production, 1A2gviii Other, 1A4ai Commercial/institutional, 1A4bi Residential and 1A4ci Agriculture/forestry/fishing (EMIS 2023/1A Holzfeuerungen). Installation types of the wood energy statistics with the same emission behaviour are grouped into one category in Table 3-19. For information purposes, the category numbers according to the statistics are listed in parentheses.

Table 3-19 Categories of wood combustion installations based on the Swiss wood energy statistics (SFOE 2022b). The category numbers according to the statistics are listed in parentheses.

<b>1A Wood combustion, categories</b>
Open fireplaces (1)
Closed fireplaces, log wood stoves (2, 3, 4a, 5)
Pellet stoves (4b)
Log wood hearths (6, 7)
Log wood boilers (8, 9)
Log wood dual chamber boilers (10)
Automatic chip boilers < 50 kW (11a)
Automatic pellet boilers < 50 kW (11b)
Automatic chip boilers 50-300 kW w/o wood processing companies (12a)
Automatic pellet boilers 50-300 kW (12b)
Automatic chip boilers 50-300 kW within wood processing companies (13)
Automatic chip boilers 300-500 kW w/o wood processing companies (14a)
Automatic pellet boilers 300-500 kW (14b)
Automatic chip boilers 300-500 kW within wood processing companies (15)
Automatic chip boilers > 500 kW w/o wood processing companies (16a)
Automatic pellet boilers > 500 kW (16b)
Automatic chip boilers > 500 kW within wood processing companies (17)
Combined chip heat and power plants (18)
Plants for renewable waste from wood products (19)

#### Emission factors

Emission factors are described in chp. 3.2.4.4.2 for CO<sub>2</sub>, 3.2.4.4.3 for CH<sub>4</sub>, and 3.2.4.4.4 for N<sub>2</sub>O.

## Activity data

Total activity data are based on the Swiss wood energy statistics (SFOE 2022b). As additional data source, specific bottom-up information from the industry is used in order to allocate wood combustion emissions directly to a particular source category. Thus, activity data of wood combustion within 1A2f, 1A2giv and 1A4ci are allocated on the basis of industry information (see Figure 3-17 and EMIS 2023/1A Holzfeuerungen):

- Wood energy consumption in the source categories 1A2f Brick and tile production (2000–2012), 1A2f Cement production and 1A2giv Fibreboard are subtracted from the activity data of 1A2gviii Automatic chip boiler >500 kW without wood processing companies and 1A2gviii Plants for renewable waste from wood products, respectively.
- From 2013 onwards, also the wood energy consumption in 1A4ci Grass drying is available and is subtracted from the activity data in 1A4ci Automatic chip boiler >500 kW without wood processing companies.

Table 3-20 Wood energy consumption in 1A Fuel combustion.

1A Wood combustion	1990	1995	2000	2005	2010
	TJ				
Total	28'215	29'693	27'419	31'386	40'073
Open fireplaces	226	270	195	181	124
Closed fireplaces, log wood stoves	7'273	7'166	6'487	7'036	8'519
Pellet stoves	NO	NO	7.0	48	151
Log wood hearths	8'520	7'017	4'737	4'020	2'348
Log wood boilers	5'307	5'564	5'105	5'357	4'909
Log wood dual chamber boilers	1'964	1'777	977	480	273
Automatic chip boilers < 50 kW	239	433	550	753	1'008
Automatic pellet boilers < 50 kW	NO	NO	56	804	2'106
Automatic chip boilers 50-300 kW w/o wood proc. companies	461	854	1'158	1'859	2'723
Automatic pellet boilers 50-300 kW	NO	NO	3.0	113	596
Automatic chip boilers 50-300 kW within wood proc. companies	895	1'186	1'216	1'364	1'531
Automatic chip boilers 300-500 kW w/o wood proc. companies	237	521	713	998	1'496
Automatic pellet boilers 300-500 kW	NO	NO	NO	19	195
Automatic chip boilers 300-500 kW within wood proc. companies	412	570	586	630	670
Automatic chip boilers > 500 kW w/o wood proc. companies	314	1'084	1'705	2'355	4'423
Automatic pellet boilers > 500 kW	NO	NO	NO	9.0	186
Automatic chip boilers > 500 kW within wood proc. companies	1'388	2'188	2'393	2'795	2'988
Combined chip heat and power plants	NO	3.0	186	127	2'756
Plants for renewable waste from wood products	979	1'060	1'345	2'439	3'070

1A Wood combustion	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
	TJ									
Total	40'007	44'161	37'312	38'892	42'556	43'540	41'141	43'316	42'312	49'260
Open fireplaces	84	84	62	64	68	67	62	62	58	59
Closed fireplaces, log wood stoves	7'787	8'604	6'824	7'446	7'862	7'540	6'926	6'943	6'375	7'281
Pellet stoves	163	190	159	181	199	196	186	187	175	198
Log wood hearths	1'567	1'454	978	1'006	992	900	792	763	675	748
Log wood boilers	3'823	3'901	2'820	2'970	3'032	2'852	2'597	2'596	2'320	2'523
Log wood dual chamber boilers	190	182	125	119	112	88	67	57	42	38
Automatic chip boilers < 50 kW	867	946	739	786	798	742	667	644	559	582
Automatic pellet boilers < 50 kW	2'151	2'511	2'099	2'376	2'610	2'619	2'538	2'676	2'489	2'909
Automatic chip boilers 50-300 kW w/o wood proc. companies	2'762	3'164	2'628	3'012	3'328	3'351	3'227	3'347	3'199	3'752
Automatic pellet boilers 50-300 kW	733	906	845	1'077	1'295	1'436	1'478	1'604	1'610	1'971
Automatic chip boilers 50-300 kW within wood proc. companies	1'427	1'538	1'280	1'398	1'486	1'483	1'421	1'418	1'367	1'534
Automatic chip boilers 300-500 kW w/o wood proc. companies	1'548	1'744	1'430	1'635	1'806	1'811	1'728	1'797	1'726	1'992
Automatic pellet boilers 300-500 kW	246	269	239	279	337	355	352	365	350	427
Automatic chip boilers 300-500 kW within wood proc. companies	633	680	567	597	629	619	613	611	592	654
Automatic chip boilers > 500 kW w/o wood proc. companies	4'973	5'828	4'963	5'810	6'548	6'736	6'481	6'895	6'919	8'104
Automatic pellet boilers > 500 kW	258	297	281	317	364	362	346	370	354	408
Automatic chip boilers > 500 kW within wood proc. companies	2'780	2'974	2'497	2'659	2'750	2'641	2'501	2'547	2'445	2'749
Combined chip heat and power plants	5'010	5'421	5'325	3'792	3'936	4'856	4'696	5'920	6'151	6'678
Plants for renewable waste from wood products	3'005	3'468	3'450	3'367	4'404	4'887	4'463	4'513	4'906	6'653

### 3.2.4.6. Emissions from biomass (memo item)

According to the 2006 IPCC Guidelines (IPCC 2006), CO<sub>2</sub> emissions from biomass do not count for the national total emissions and therefore are a memo item only. The CO<sub>2</sub> emissions from biomass as reported in the reporting tables are incomplete as the following CO<sub>2</sub> emissions from biomass are not foreseen for reporting in the reporting tables: 2G4 Use

of tobacco, 2H2 Food and beverages, 5A Solid waste disposal, 5B Biological treatment of solid waste, 5D Wastewater treatment and discharge as well as 6 Other. In contrast, CO<sub>2</sub> emissions from biomass from source category 5C Incineration and open burning of waste are included in CRF Table5.C, but not accounted for the total CO<sub>2</sub> emissions from biomass as shown in CRF Summary1.As3, CRF Summary2, CRF Table10s1 and CRF Table10s2 (these tables include CO<sub>2</sub> emissions from biomass from sector 1 Energy only). Similarly, CO<sub>2</sub> emissions from biomass from international aviation (source category 1D1) are included in CRF Table1.D but not accounted for elsewhere.

Table 3-21 provides an overview of latest effective CO<sub>2</sub> emissions from biomass and their reporting in the reporting tables (without land use, land-use change and forestry). For further information on the CO<sub>2</sub> emissions from biomass refer to the chapters of the respective source categories.

Table 3-21 Effective CO<sub>2</sub> emissions from biomass in the latest inventory year and their representation in the reporting tables.

CO <sub>2</sub> emissions from biomass	2021	Note
	kt	
1A1 Energy industries (without MSW incineration)	508	Included in reporting tables
1A1 Energy generation from MSW Incineration	2'286	Included in reporting tables
1A2 Manufacturing industries and construction	1'787	Included in reporting tables
thereof use of waste derived fuels in cement production	83	
thereof use of biofuels (1A2gvii)	27	
1A3 Transport	446	Included in reporting tables
1A4 Other sectors (Commercial/institutional, residential)	3'431	Included in reporting tables
1A5 Other	0.81	Included in reporting tables
2H2 Food and beverages industry	14	Not included in reporting tables
2G Other product use (Consumption of tobacco)	10	Not included in reporting tables
5A Solid waste disposal	35	Not included in reporting tables
5B Biological treatment of solid waste (composting and anaerobic digestion)	176	Not included in reporting tables
5C Incineration and open burning of waste (without MSW incineration)	114	Included in CRF Table5.C, but not accounted for in the summary reporting tables
5D Wastewater treatment and discharge	4.3	Not included in reporting tables
6 Other	3.2	Not included in reporting tables
Total CO <sub>2</sub> emissions from biomass in Switzerland in 2021	8'814	Without international aviation
Total CO <sub>2</sub> emissions from biomass included in the following summary reporting tables (energy-related CO <sub>2</sub> emissions from biomass combustion included in sector 1 Energy): CRF Summary1.As3, CRF Summary2, CRF Table10s1 and CRF Table10s2	8'458	
International aviation (aviation bunkers)	1.9	Included in CRF Table1.D, but not accounted for in the summary reporting tables

### 3.2.4.7. Uncertainty and time series consistency for source category 1A

In the following, basic uncertainties of activity data and CO<sub>2</sub> emission factors by fuel type are presented for source category 1A Fuel combustion.

Table 3-22 Uncertainties of activity data, CO<sub>2</sub> emission factors and CO<sub>2</sub> emissions for 1A Fuel combustion.

Fuel type	Uncertainties		
	Activity data	CO <sub>2</sub> emission factors	CO <sub>2</sub> emissions
	%		
kerosene	0.96	0.16	0.97
gasoline	0.69	0.13	0.70
diesel oil	0.88	0.068	0.88
liquid fuels	0.69	0.081	0.69
solid fuels	5	5.1	7.1
gaseous fuels	5	0.34	5.0
other fuels	5	9.2	10
biomass	10	--	--

### Liquid fuels

**Uncertainty of the CO<sub>2</sub> emission factors:** In 2013, a large measurement campaign was carried out to determine the CO<sub>2</sub> emission factors of the dominant liquid fuels (SFOE/FOEN 2014). From the standard deviation presented in this study, the 95 % uncertainties are derived and shown in Table 3-23 as lower and upper values as well as relative uncertainties.

For mobile combustion, the 2006 IPCC Guidelines provide default uncertainties for the CO<sub>2</sub> emission factors of 2 % for kerosene, 4 % for gasoline and 1 % for diesel oil (IPCC 2006, vol. 2, TABLE 3.2.1). The Swiss measurements indicate much lower uncertainties. For stationary combustion, the 2006 IPCC Guidelines give no default values but show instead a summary of an uncertainty assessment of CO<sub>2</sub> emission factors for selected countries (IPCC 2006, vol. 2, TABLE 2.13). The values lie in the range between 0.5 % and 3 % and are again higher than the values derived from the Swiss measurements.

Table 3-23 Uncertainties of aggregated results of measurements of the CO<sub>2</sub> emission factors of selected liquid fuels (SFOE/FOEN 2014).

Fuel type	CO <sub>2</sub> emission factors (measurements)			95% uncertainties emission factors (CO <sub>2</sub> )		no. samples
	mean	lower	upper	absolute	relative	
	t/TJ	t/TJ	t/TJ	t/TJ	%	
Kerosene	72.81	72.70	72.93	0.12	0.16%	24
Gasoline	73.80	73.71	73.90	0.10	0.13%	138
Diesel oil	73.30	73.25	73.35	0.05	0.07%	75
Gas oil	73.67	73.61	73.73	0.06	0.08%	138

**Uncertainties of activity data:** The values shown in Table 3-24 are based on a written message of SFOE to FOEN (SFOE 2012a). It lists two kinds of relevant sources of uncertainties: measurement uncertainties and uncertainties of the conversion from mass to energy units. For diesel oil, the transformation to other products represents a third source of uncertainty. Since the used equations are multiplications, the relative uncertainties have to be summed up.

Table 3-24 Sources of uncertainties contributing to the total uncertainty of the activity data of selected liquid fuels (SFOE 2012a).

Source of uncertainty	kerosene	gasoline	diesel oil	gasoil
	activity data uncertainty in %			
Measurement	0.39%	0.39%	0.39%	0.39%
Conversion mass to energy	0.57%	0.29%	0.29%	0.29%
Product transformation	-	-	0.20%	-
Total Uncertainty	0.96%	0.69%	0.88%	0.69%

### Gaseous fuels

**Uncertainty of the CO<sub>2</sub> emission factor:** The composition of the imported gas is analysed in detail at the import stations. From this information, the FOEN annually calculates the CO<sub>2</sub> emission factor for each import station and the weighted mean. To estimate the uncertainty of the emission factor, the weighted standard deviation is calculated and is multiplied by a factor of 1.96 to represent a 95 % uncertainty interval. This calculation has been carried out for all years with available data (selected years between 1990 and 2009 and all years thereafter). The uncertainties fluctuate from year to year. For the uncertainty analysis, the following values for the uncertainty of the CO<sub>2</sub> emission factor for gaseous fuels are used: 1.48 % for 1990 and of 0.34 % for 2021.

**Uncertainty of activity data:** There is no country-specific estimate of the uncertainty for the consumption of natural gas. It is taken from the 2006 IPCC Guidelines (IPCC 2006, vol. 2, Table 2.15), which give a range of 2 % to 5 % for industrial combustion and 3 % to 5 % for commercial, institutional and residential combustion. For Switzerland, an overall value of 5 % is used.

### Solid fuels

**Uncertainty of the CO<sub>2</sub> emission factor:** There is no country-specific uncertainty available. The 2006 IPCC Guidelines suggest a range from 0.5 % to 10 % (IPCC 2006, vol. 2, Table 2.13). For Switzerland, an uncertainty of 5 % is chosen (mean of suggested range).

**Uncertainty of activity data:** There is no country-specific estimate of the uncertainty for the consumption of coal. It is taken from the 2006 IPCC Guidelines (IPCC 2006, vol. 2, Table 2.15), which give a range of 2 % to 5 % for industrial combustion and 3 % to 5 % for commercial, institutional and residential combustion. For Switzerland, an overall value of 5 % is used (as for natural gas).

### Other fuels (waste-to-energy)

**Uncertainty of the CO<sub>2</sub> emission factor:** There are two factors influencing the uncertainty of CO<sub>2</sub> emissions from municipal solid waste incineration (1A1a), namely the carbon content of waste and the fossil carbon fraction of the carbon content.

- The carbon content is determined according to a study by Fellner et al. (2007). The relation between the calorific value of waste and the carbon content is derived therein, including upper and lower limits. The relation is verified by measurements. The relative difference between upper and lower limits (5.9 %) is interpreted as 95 % confidence interval for the carbon content.

- The fossil fraction of the carbon content was determined in a study by Mohn et al. (2011). The radiocarbon ( $^{14}\text{C}$ ) method was used to determine the ratio of fossil versus biogenic  $\text{CO}_2$  emissions from five waste-to-energy plants. Gas samples for  $^{14}\text{CO}_2$  analysis were taken at the plants during miscellaneous seasons. Six field campaigns of three weeks were carried out for three plants and three field campaigns, again of three weeks, were carried out for two plants, leading to a total sampling duration of 72 weeks. The field campaigns provided a median and (absolute) 95 % confidence interval of the fossil fraction of  $(47.7 \pm 7.5)$  % (Table 3-25). The relative uncertainty was thus 15.8 %. The results fit well to former field campaigns on three plants, which yielded a mean fossil fraction of 48.0 % (Mohn et al. 2008). For the greenhouse gas inventory and its uncertainty analysis the latest results from Mohn et al. (2011) are used.
- The emission factor for fossil  $\text{CO}_2$  results from the multiplication of the carbon content and the fossil fraction. The relative uncertainty of the  $\text{CO}_2$  emission factor is thus computed using uncertainty propagation:  $[(5.9 \%)^2 + (15.8 \%)^2]^{0.5} = 16.9 \%$ .

Table 3-25 Fossil fractions of municipal solid waste measured at five different incineration plants. The absolute uncertainty values (3<sup>rd</sup> column) are expressed in the same unit as the shares, in %.

Plant	Fossil shares	Uncertainty (95% confidence interval)		Field campaigns (duration) weeks
		absolute	relative	
	%	%	%	
Buchs	47.7			6 * 3 = 18
Winterthur	43.4			6 * 3 = 18
Linthgebiet	50.6			6 * 3 = 18
Linthgebiet	54.5			3 * 3 = 9
Zuchwil	45.9			3 * 3 = 9
Median / sum	47.7	7.5	15.8	72

**Uncertainty of activity data:** There is no country-specific estimate of the uncertainty for the combustion of waste. It is taken from the 2006 IPCC Guidelines (IPCC 2006, vol. 2, p. 2.40), which state: “Experts believe that the uncertainty resulting from the two errors (*systematic, random*) combined is probably in the range of  $\pm 5$  % for most developed countries.” In accordance with that statement, the value of 5 % is used.

## Biomass

**Uncertainty of the  $\text{CO}_2$  emission factor:** For  $\text{CO}_2$  emissions of biomass burning, no uncertainty is estimated (memo item).

**Uncertainty of activity data:** No country-specific uncertainty of the activity data is available. The 2006 IPCC Guidelines suggest 2 % to 5 % for industrial, institutional and residential combustion and 10 % to 30 % for biomass burning in small sources (IPCC 2006, vol. 2, Table 2.15). An average uncertainty of 10 % is applied for biomass burning in all source categories.

## Uncertainty of $\text{CH}_4$ and $\text{N}_2\text{O}$ emission factors

Since the  $\text{CO}_2$  emissions vastly dominate the GHG emissions of source category 1A (almost 99 % of total emissions), the uncertainty evaluation of the non- $\text{CO}_2$  emissions is carried out on a semi-quantitative level (see Table 3-26).

Only for **1A3b Road transportation**, a quantitative analysis has been performed. Following a study for the road transportation in Germany (IFEU/INFRAS 2010), where the same handbook of emission factors is used as in Switzerland, the uncertainties for the CH<sub>4</sub> and N<sub>2</sub>O emission factors have been determined (see rows 1A3b gasoline and diesel oil in Table 3-26). The uncertainties of CH<sub>4</sub> and N<sub>2</sub>O emissions of CNG (1A3b), which were not investigated in IFEU/INFRAS (2010), have been estimated qualitatively as “medium” according to Table 1-8. For the source categories **1A1, 1A2, 1A3a, 1A3c, 1A3d, 1A3e, 1A4a, 1A4b, 1A4c, 1A5** the uncertainties of CH<sub>4</sub> and N<sub>2</sub>O emissions have similarly been estimated qualitatively (see Table 3-26).

## Summary

Table 3-26 provides a summary of the uncertainties of 1A Fuel combustion as derived in the preceding sections. The combined uncertainty assigned to the CO<sub>2</sub> emissions is computed by propagating the uncertainties of the activity data and the emission factors.

Table 3-26 Uncertainties of 1A Fuel combustion categories for activity data, emission factors and combined uncertainties for 2021. The latter are calculated by uncertainty propagation (approach 1). For 1A2/Other Fuels a mean uncertainty is assumed based on semi-quantitative estimations from Table 1-8. The emission factor uncertainty is calculated “backward” ( $U(EF) = \sqrt{U(EM)^2 - U(AD)^2}$ ) from the combined and the activity data uncertainty. CH<sub>4</sub> and N<sub>2</sub>O: semi-quantitative uncertainties are used (see Table 1-8). For 1990, uncertainties are generally the same as for 2021, except for the CO<sub>2</sub> emission factor for gas (1.48 % for 1990).

1A Fuel Combustion Categories	Fuel type	Uncertainties				
		Activity data	CO <sub>2</sub> emission factor	CO <sub>2</sub> emissions	CH <sub>4</sub> emissions	N <sub>2</sub> O emissions
		%	%	%	--	--
1. Energy industries	liquid fuels	0.69	0.081	0.69	medium	medium
1. Energy industries	solid fuels	5.0	5.1	7.1	medium	medium
1. Energy industries	gaseous fuels	5.0	0.34	5.0	medium	medium
1. Energy industries	other fuels	5.0	9.2	10	medium	medium
2. Manufacturing industries and construction	liquid fuels	0.69	0.081	0.69	medium	medium
2. Manufacturing industries and construction	solid fuels	5.0	5.1	7.1	medium	medium
2. Manufacturing industries and construction	gaseous fuels	5.0	0.34	5.0	medium	medium
2. Manufacturing industries and construction	other fuels	5.0	9.2	10	medium	medium
3a. Transport; Domestic aviation	kerosene	0.96	0.16	0.97	high	high
3b. Transport; Road transportation	gasoline	0.69	0.13	0.70	37%	50%
3b. Transport; Road transportation	diesel oil	0.88	0.068	0.88	20%	22%
3b. Transport; Road transportation	gaseous fuels	5.0	0.34	5.0	medium	medium
3c. Transport; Railways	diesel oil	0.88	0.068	0.88	medium	high
3d. Transport; Domestic navigation	liquid fuels	0.69	0.081	0.69	medium	high
3e. Transport; Other transportation	gaseous fuels	5.0	0.34	5.0	medium	medium
4a. Other sectors; Commercial/institutional	liquid fuels	0.69	0.081	0.69	medium	medium
4a. Other sectors; Commercial/institutional	gaseous fuels	5.0	0.34	5.0	medium	medium
4b. Other sectors; Residential	liquid fuels	0.69	0.081	0.69	medium	medium
4b. Other sectors; Residential	solid fuels	5.0	5.1	7.1	medium	medium
4b. Other sectors; Residential	gaseous fuels	5.0	0.34	5.0	medium	medium
4c. Other sectors; Agriculture/forestry/fishing	liquid fuels	0.69	0.081	0.69	medium	medium
4c. Other sectors; Agriculture/forestry/fishing	gaseous fuels	5.0	0.34	5.0	medium	medium
5. Other	liquid fuels	0.69	0.081	0.69	medium	high
1A Stationary sources	biomass	10	--	--	medium	medium
1A Mobile sources	biomass	10	--	--	high	high

## Time series consistency 1A

Time series for 1A Fuel combustion are all considered consistent.

### 3.2.4.8. Category-specific QA/QC and verification for source category 1A

Various QA/QC activities are relevant for all source categories in 1A. Therefore, they are briefly described here and not repeated in the chapters dealing with the source categories 1A1 to 1A5.

#### Comparison of emission estimates using different approaches

At the level of total energy-related CO<sub>2</sub> emissions, a quality control consists in the comparison of emissions modelled using the sectoral approach with emissions calculated based directly on fuel consumption according to the Swiss overall energy statistics (SFOE 2022). The differences in total CO<sub>2</sub> emissions for the entire time period are negligible, indicating the completeness of the inventory.

The cross-check of the Reference and Sectoral Approach is also used for an assessment of emissions related to the consumption of fuels in the energy sector. Again, a good agreement between the two approaches is found (see chp. 3.2.1).

#### Activity data checks

The SFOE constructs a national commodity balance expressed in mass and in energy units including mass balances of fuel conversion industries.

The gross carbon supply in the Reference Approach has been adjusted for fossil fuel carbon destined for non-energy use. The numbers in the Swiss overall energy statistics (SFOE 2022) are consistent with those provided by international organisations, e.g. IEA.

#### Emission factor check and review

Emission factors for the main fossil fuels have been reassessed for submission 2015. In 2013, the Swiss Federal Office of Energy (SFOE) and the Swiss Federal Office for the Environment (FOEN) launched an in-depth investigation into the NCVs and CO<sub>2</sub> emission factors of gas oil, diesel oil, gasoline, and kerosene (SFOE/FOEN 2014, see chp. 3.2.4.2). The most recent results differ only marginally from previously used values. The CO<sub>2</sub> emission factors compare well with the IPCC default values (see Table 3-27).

Table 3-27 Comparison of default CO<sub>2</sub> emission factors from IPCC (2006) with current country-specific values of Switzerland for selected fuels.

CO <sub>2</sub> emission factors	IPCC 2006			Switzerland
	lower	upper	default	CS
	t CO <sub>2</sub> /TJ			t CO <sub>2</sub> /TJ
Gasoline	67.5	73.0	69.3	73.8
Jet kerosene	69.7	74.4	71.5	72.8
Diesel oil	72.6	74.8	74.1	73.3
Gas oil	72.6	74.8	74.1	73.7

Switzerland's country-specific CO<sub>2</sub> emission factor for gasoline is higher than the upper limit of the IPCC range (Table 3-27). However, the value is based on more than 100 fuel samples

taken from July to December 2013 (SFOE/FOEN 2014) and is in agreement with earlier measurements (EMPA 1999). Accordingly, the value is considered to correctly represent national circumstances.

For natural gas, the CO<sub>2</sub> emission factor is annually assessed. A country-specific CO<sub>2</sub> emission factor is calculated based on measurements of gas properties and corresponding import shares of individual gas import stations (see chp. 3.2.4.4). The resulting values are largely consistent with the CO<sub>2</sub> emission factor used by the countries from which gas is imported (i.e. Germany, the Netherlands, Norway, France, Italy and Denmark, with implied emission factors between 55.5 and 57.9 t CO<sub>2</sub>/TJ, based on submissions in 2022).

For submission 2021, the CH<sub>4</sub> emission factors from combustion of wood were scrutinized and revised based on Zotter and Nussbaumer (2022). The range of country-specific values is not entirely consistent with the lower IPCC default values (1A1, 1A2, Table 3-28). However, as the country-specific emission factors are based on an extensive measurement campaign, they are considered representative for Swiss circumstances.

Table 3-28 Comparison of default CH<sub>4</sub> emission factors from the 2006 IPCC Guidelines (IPCC 2006) with country-specific values for wood/wood waste.

CH <sub>4</sub> emission factors	IPCC 2006			Switzerland
	lower	upper	default	CS
	kg CH <sub>4</sub> /TJ			kg CH <sub>4</sub> /TJ
Wood/wood waste	10 (1A1, 1A2) 100 (1A4)	100 (1A1, 1A2) 900 (1A4)	30 (1A1, 1A2) 300 (1A4)	0.19 - 230

### Further QC procedures

The general QC procedures as described in chp. 1.5 (e.g. annual internal review, expert peer review, etc.) also apply to source category 1A.

#### 3.2.4.9. Planned improvements for source category 1A in general

1A stationary engines and gas turbines: Based on a new data collection and model, emissions from stationary engines and gas turbines were re-estimated for all years and will be implemented in the inventory. Within source category 1A4, several sub-categories are key categories CO<sub>2</sub>.

### 3.2.5. Source category 1A1 – Energy industries (stationary)

#### 3.2.5.1. Source category description for 1A1 (stationary)

Table 3-29 Key categories of 1A1 Energy industries. Combined KCA results, level for 2021 and trend for 1990–2021, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC category	Gas	Identification criteria
1A1	Energy Industries; Gaseous Fuels	CO <sub>2</sub>	L1, T1
1A1	Energy Industries; Liquid Fuels	CO <sub>2</sub>	L1, T1
1A1	Energy Industries; Other Fuels	CO <sub>2</sub>	L1, T1, L2, T2

Source category 1A1 Energy industries comprises emissions from fuels combusted by the fuel extraction and energy-producing industries. The most important source category is 1A1a Public electricity and heat production, followed by 1A1b Petroleum refining. Activities in source category 1A1c Manufacture of Solid Fuels and other energy industries are virtually not occurring in Switzerland (apart from a tiny charcoal production activity in historic trade).

Within source category 1A1a, heat and electricity production in waste incineration plants cause the largest emissions, as electricity production in Switzerland is dominated by hydroelectric power plants and nuclear power stations (SFOE 2022). Emissions from industries producing heat and/or electricity (CHP) for their own use are included in category 1A2 Manufacturing Industries and Construction.

Table 3-30 Specification of source category 1A1 Energy Industries.

1A1	Source category	Specification
1A1a	Public electricity and heat production	Main source are waste incineration plants with heat and power generation (Other fuels) and public district heating systems. The only fossil fuelled public electricity generation unit "Vouvry" (300 MWe; no public heat production) ceased operation in 1999.
1A1b	Petroleum refining	Combustion activities supporting the refining of petroleum products, excluding evaporative emissions.
1A1c	Manufacture of solid fuels and other energy industries	Charcoal production

### 3.2.5.2. Methodological issues for 1A1 (stationary)

#### 3.2.5.2.1. Public electricity and heat production (1A1a)

Public electricity and heat production in Switzerland encompasses different plant types where various fuels are used (Table 3-31). Energy recovery from municipal solid waste and special waste incineration is mandatory in Switzerland (Swiss Confederation 2015, Art. 27) and plants are equipped with energy recovery systems. The emissions from municipal solid waste and special waste incineration plants are therefore reported under category 1A1a. There was a single fossil fuel power station operating with residual fuel oil in Vouvry. However, the power station closed down in 1999.

Table 3-31 Plant type and fuels used in source category 1A1a.

Plant type	Fuel type
Heat plants for renewable wastes	wood waste (biomass)
Heating boilers > 300 MW (Vouvry)	residual fuel oil
Heating boilers < 300 MW	gas oil, residual fuel oil, bituminous coal
Central heating boilers for district heating	natural gas, gas oil, residual fuel oil, bituminous coal
Wood combined heat and power generation	wood, wood waste (biomass)
Engines on landfill sites	landfill gas (biogas)
Municipal solid waste incineration plants	municipal solid waste (other, waste-to-energy)
Special waste incineration plants	special wastes (other, waste-to-energy)

## Methodology (1A1a)

For CO<sub>2</sub> emissions in source category 1A1a Public electricity and heat production, a country-specific approach is used combining Tier 2 and Tier 3 methods (IPCC 2006, Volume 2 Energy, chp. 2 Stationary Combustion, Figure 2.1). For CH<sub>4</sub> emissions, a Tier 2 method was applied using IPCC default emission factors (IPCC 2006), except for biomass, where country-specific emission factors are used. For N<sub>2</sub>O IPCC default values are used (Tier 1, IPCC 2006), except for municipal solid waste and special waste incineration plants, where country-specific emission factors were used (Tier 2).

## Emission factors (1A1a)

Table 3-32 presents the emission factors used in 1A1a. Emission factors for gas oil, natural gas, biomass and biogas (highlighted green in Table 3-32) are further explained in chp. 3.2.4.4.

Table 3-32 Emission factors for 1A1a Public Electricity and Heat Production in 2021.

1A1a Public electricity and heat production	CO <sub>2</sub>	CO <sub>2</sub> biog.	CH <sub>4</sub>	N <sub>2</sub> O	NO <sub>x</sub>	NM VOC	SO <sub>2</sub>	CO
	t/TJ		kg/TJ					
Gas oil	73.7	NA	3.0	0.6	32	2	5.6	6
Residual fuel oil	NO	NA	NO	NO	NO	NO	NO	NO
Petroleum coke	NO	NA	NO	NO	NO	NO	NO	NO
Natural gas	55.9	NA	1.0	0.1	17	2	0.5	9
Other (waste-to-energy), fossil	89.2	NA	NE	1.0	32.3	2.8	4.1	6.6
Other (waste-to-energy), biogenic	NA	92.0	NE	1.1				
Biomass (wood, renewable waste)	NA	99.9	0.4	4.0	59	0.45	5.1	21
Biogas (co-generation from landfills)	NA	55.9	20	0.1	119	1	0.5	198

### *Emission factors for waste incineration and landfill gas use*

Specific emission factors within 1A1a Public electricity and heat production apply for municipal solid waste incineration, special waste incineration and for landfill gas use. The emission factors for CO<sub>2</sub>, NO<sub>x</sub>, CO, NMVOC and SO<sub>2</sub> are country-specific and based on measurements and expert estimates. Emission factors for CH<sub>4</sub> and N<sub>2</sub>O are IPCC default values (IPCC 2006), with the exception of waste and biomass as fuel, where country-specific emission factors are applied. Emission factors are documented in EMIS 2023/1A1a Kehrichtverbrennungsanlagen, EMIS 2023/1A1a Sondermüllverbrennungsanlagen and EMIS 2023/1A1a & 5A Kehrichtdeponien.

### *Source-specific CO<sub>2</sub> emission factors for municipal solid waste incineration plants*

C-content of waste is calculated based on the net calorific value, which is deduced by a standard method and published on a yearly basis since 2009 by SFOE for each municipal solid waste incineration plant and as a Swiss average (FOEN/SFOE/VBSA 2022). In deviation from the general description of oxidation factors in chp. 3.2.4.4.1, an oxidation factor of 0.99 is assumed here. The assumption is based on measurements in two municipal solid waste incineration plants in Zurich (AWEL 2009) and on a study in Austria (Zeschmar-Lahl 2004), where the municipal solid waste incineration plants have the same standards as in Switzerland. The measurements in Zurich showed transfer coefficients into air of 0.96–0.99 and the ones in Austria stated a transfer coefficient into clean air of 0.989.

The fossil fraction of waste incinerated in municipal solid waste incineration plants is based on a study conducted in the year 2014 (Rytec 2014). The study uses data from three measurement campaigns during which the waste composition has been analysed (FOEN

2014o) and measurements of the radioactive isotope carbon-14 ( $^{14}\text{C}$ ) in the flue gas for calibration have been made (Mohn et al. 2011). The  $\text{CO}_2$  emission factor in municipal solid waste incineration plants fluctuates over the reporting period because of gradual changes in the net calorific values of the waste (Table 3-33).

Table 3-33 Emission factor  $\text{CO}_2$  total, share of  $\text{CO}_2$  fossil and net calorific value (NCV) in municipal solid waste incineration plants (MSWIP).

1A1a Public electricity and heat production, Other fossil fuels	Unit	1990	1995	2000	2005	2010					
$\text{CO}_2$ total (MSWIP)	t/TJ	92.80	91.86	91.09	91.49	92.32					
Share of $\text{CO}_2$ fossil (MSWIP)	1	0.497	0.505	0.513	0.505	0.486					
NCV of waste (MSWIP)	TJ/t	0.0114	0.0119	0.0124	0.0121	0.0117					
1A1a Public electricity and heat production, Other fossil fuels	Unit	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
$\text{CO}_2$ total (MSWIP)	t/TJ	92.62	92.76	92.43	92.28	92.01	91.92	91.90	91.85	91.86	92.04
Share of $\text{CO}_2$ fossil (MSWIP)	1	0.478	0.478	0.478	0.478	0.478	0.478	0.478	0.478	0.478	0.478
NCV of waste (MSWIP)	TJ/t	0.0115	0.0114	0.0116	0.0117	0.0118	0.0119	0.0119	0.0119	0.0119	0.0118

Sodium bicarbonate and calcium carbonate are used in some municipal solid waste incineration plants for flue gas treatment. Sodium bicarbonate is used since 2013 and calcium carbonate was used between 1990 and 2005. According to IPCC 2006, the corresponding emissions are reported in source category 2A4d.

#### *Source-specific $\text{CO}_2$ emission factors for special waste incineration plants*

Based on detailed information regarding waste composition and estimated emission factors in the years 1992–2004, a weighted average emission factor for special waste incineration was calculated. Special waste is assumed to be of entirely fossil origin. Overall, a specific emission factor of 1.45 t  $\text{CO}_2$ /t waste results for special waste. This value is considerably higher than the one reported in SAEFL (2000). As there is no newer data on the special waste composition, the emission factor deduced as described above is used for the whole period from 1990 until today. See documentation in EMIS 2023/1A1a Sondermüllverbrennungsanlagen.

#### *Source-specific $\text{CH}_4$ emission factors in municipal and special waste incineration plants*

Emissions of  $\text{CH}_4$  are not occurring in waste incineration plants because of the high temperatures and the long dwell time in the combustion chamber as confirmed by Mohn (2013). In the year 2013, Empa assessed the  $\text{N}_2\text{O}$  and  $\text{CH}_4$  emission factors for municipal solid waste incineration plants (Mohn 2013). In this study, Empa evaluated measurements that were performed in 2011 in five Swiss municipal solid waste incineration plants with different Denox techniques (SCR, SNCR). For most of the measurements,  $\text{CH}_4$  concentrations were below the detection limit of 0.3 ppm. The study concluded that " $\text{CH}_4$  emission concentrations were very low and below the background concentration of 1.8 ppm". These measurements, which showed that  $\text{CH}_4$  concentration in the exhaust air was below the  $\text{CH}_4$  concentration in ambient air, would point to  $\text{CH}_4$  removal rather than emissions occurring. Therefore,  $\text{CH}_4$  emissions from municipal waste incineration are reported as not estimated because they are considered insignificant. The same fact applies for special waste incineration.

### *Source-specific N<sub>2</sub>O emission factors for municipal solid waste incineration*

In 2013, a study evaluated N<sub>2</sub>O measurements that have been performed in the years 2010–2011 in the flue gas of five Swiss municipal waste incineration plants (Mohn 2013) and derived plant-specific emission factors for Selective Catalytic Reduction (SCR) and Selective Non-Catalytic Reduction (SNCR) equipped installations.

Average Swiss emission factors have been calculated according to the state of equipment of all Swiss waste incineration plants (with two types of Denox-equipment (SCR, SNCR) and without Denox-equipment). For installations without Denox-equipment, the emission factor comes from SAEFL (2000). According to the state of equipment of all Swiss waste incineration plants in the years 1990, 1994, 1998, 2004, 2008, 2012, 2016 and 2020, weighted average N<sub>2</sub>O emission factors have been calculated, based on the amounts of waste burnt in every plant. For the years in between, the N<sub>2</sub>O emission factors were linearly interpolated. Since 2020, the emission factor is assumed to be constant (however the emission factor related to energy changes by reason of the conversion with the net calorific value of waste). It is planned to calculate new weighted averages for the N<sub>2</sub>O emission factors periodically every four years, depending on data available; see documentation in EMIS 2023/1A1a Kehricht- und Sondermüllverbrennungsanlagen. The emission factor is therefore not constant over time.

### *Source-specific N<sub>2</sub>O emission factors for special waste incineration*

The emission factor of special waste for the year 1990 is based on SAEFL (2000). It is assumed that this value (3.1 g/GJ) then increases until 2003 (6.1 g/GJ) due to the installation of Denox-equipment and thereafter declines as a result of optimized installations.

Table 3-34 N<sub>2</sub>O emission factors of municipal solid (MSWIP) and special waste incineration plants (SWIP) in 1A1a Public electricity and heat production.

1A1a Public electricity and heat production, Other fossil fuels	Unit	1990	1995	2000	2005	2010					
N <sub>2</sub> O (MSWIP)	kg/TJ	5.26	2.96	2.06	1.44	1.40					
N <sub>2</sub> O (SWIP)	kg/TJ	3.06	4.23	5.41	5.48	3.89					
1A1a Public electricity and heat production, Other fossil fuels	Unit	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
N <sub>2</sub> O (MSWIP)	kg/TJ	1.43	1.37	1.29	1.21	1.13	1.13	1.13	1.12	1.12	1.13
N <sub>2</sub> O (SWIP)	kg/TJ	3.25	2.94	2.62	2.30	1.98	1.67	1.35	1.03	0.71	0.40

### **Activity data (1A1a)**

Activity data for liquid, gaseous, solid fuels and wood are based on the Swiss overall energy statistics (SFOE 2022) and additional data sources as described in chp. 3.2.4.3. Activity data for Other fuels are based on the amount of waste incinerated in MSWIPs and SWIPs (FOEN 2022h, see Table 3-36). Activity data for combined heat and power generation in landfills are taken from the Swiss renewable energy statistics (SFOE 2022a).

Please note that waste-to-energy activities in CRF Table 1.A(a)s1 are allocated to fuel types 'Other fossil fuels' and 'Biomass'. 'Other fossil fuels' encompasses emissions from the fossil shares of MSWIP and SWIP. Whereas 'Biomass' covers emissions from wood, waste wood, landfill gas use in co-generation and biogenic share from MSWIP.

Table 3-35 Activity data in 1A1a Public Electricity and Heat Production.

1A1a Public electricity and heat production	Unit	1990	1995	2000	2005	2010					
Total fuel consumption		40'379	39'179	49'913	56'976	61'740					
Gas oil	TJ	980	554	790	1'300	490					
Residual fuel oil	TJ	3'214	1'813	340	290	40					
Petroleum coke	TJ	NO	NO	NO	NO	NO					
Other bituminous coal	TJ	530	46	NO	NO	NO					
Lignite	TJ	NO	NO	NO	NO	NO					
Natural gas	TJ	4'339	5'422	8'292	9'827	9'926					
Other (waste-to-energy), fossil	TJ	16'605	16'870	22'482	24'711	26'002					
Biomass	TJ	14'711	14'474	18'009	20'848	25'282					
Other (waste-to-energy), biogenic	TJ	14'163	13'394	16'889	19'797	22'275					
Biomass (wood, renewable waste)	TJ	301	466	547	844	2'958					
Biogas (co-generation from landfills)	TJ	247	614	573	207	49					

1A1a Public electricity and heat production	Unit	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Total fuel consumption		63'402	63'294	59'316	61'351	64'986	64'723	65'304	66'475	65'436	65'912
Gas oil	TJ	800	670	770	660	430	490	380	450	340	420
Residual fuel oil	TJ	NO									
Petroleum coke	TJ	NO									
Other bituminous coal	TJ	NO									
Lignite	TJ	NO									
Natural gas	TJ	8'213	8'409	5'032	7'050	8'926	7'907	8'111	8'444	7'501	8'551
Other (waste-to-energy), fossil	TJ	26'262	25'738	26'049	26'832	27'657	27'430	27'997	28'285	27'918	27'020
Biomass	TJ	28'127	28'476	27'464	26'809	27'973	28'896	28'816	29'296	29'678	29'920
Other (waste-to-energy), biogenic	TJ	23'051	22'489	23'112	23'716	24'765	24'886	25'100	25'267	25'331	24'838
Biomass (wood, renewable waste)	TJ	5'032	5'949	4'321	3'071	3'195	4'003	3'710	4'021	4'343	5'078
Biogas (co-generation from landfills)	TJ	44	39	31	21	13	7	6.0	8.4	4.0	4.0

Since 1990 the use of waste-derived fuels increased considerably. This is due to the fact that since 1<sup>st</sup> of January 2000, disposal of combustible wastes in landfill sites is prohibited by law, see Swiss Confederation 2015 (VVEA, Art. 25), and Swiss Confederation 1990 (the preceding Ordinance TVA, Art. 32). The increase is also partly due to municipal solid waste imported from neighbouring countries to optimize the load factor of MSWIPs. During the reporting period, the consumption of natural gas increased, and the consumption of liquid fuels decreased. This is due to a fuel shift in combined heat and power generation and the closure of the only power station located in Vouvry that has been operated with residual fuel oil in the 1990s.

#### *Municipal solid waste incineration and special waste incineration*

Figure 7-5 in Sector 5 Waste gives an overview over the waste amounts, their treatment and their reporting in the Swiss greenhouse gas inventory. Municipal solid waste includes waste generated in households and waste of similar composition from other sources.

The amount of municipal solid waste in kt reported in Table 3-36 is the total amount of waste burnt (it includes fossil and biogenic shares). The fossil and biogenic share in TJ are given as well.

Special waste is composed of special wastes with high calorific value, wastewater and sludge with organic load, inorganic solids and dusts, inorganic sludge containing heavy metals, acids and alkalis, PCB-containing wastes, non-metallic shredder residues, contaminated soil, filter materials and chemicals residues and others.

Table 3-36 Activity data for 1A1aiv Other: Municipal solid waste and special waste incinerated with heat and/or power generation. The amount of municipal solid waste in kt is the total amount of waste burnt.

1A1aiv Public electricity and heat production, Other	Unit	1990	1995	2000	2005	2010					
Total fuels	TJ	30'768	30'264	39'371	44'508	48'277					
Municipal solid waste fossil	TJ	13'995	13'664	17'790	20'197	21'062					
Municipal solid waste biogenic	TJ	14'163	13'394	16'889	19'797	22'275					
Special waste	TJ	2'610	3'206	4'692	4'514	4'941					
Total waste	kt	2'603	2'433	3'040	3'527	3'968					
Municipal solid waste (fossil and biogenic)	kt	2'470	2'270	2'801	3'297	3'717					
Special waste	kt	133	163	239	230	252					

1A1aiv Public electricity and heat production, Other	Unit	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Total fuels	TJ	49'313	48'228	49'161	50'548	52'422	52'316	53'097	53'552	53'248	51'859
Municipal solid waste fossil	TJ	21'108	20'593	21'163	21'717	22'678	22'789	22'984	23'137	23'195	22'745
Municipal solid waste biogenic	TJ	23'051	22'489	23'112	23'716	24'765	24'886	25'100	25'267	25'331	24'838
Special waste	TJ	5'155	5'145	4'886	5'115	4'979	4'641	5'013	5'148	4'722	4'276
Total waste	kt	4'104	4'035	4'066	4'150	4'264	4'248	4'297	4'322	4'312	4'245
Municipal solid waste (fossil and biogenic)	kt	3'841	3'773	3'817	3'889	4'010	4'011	4'042	4'059	4'072	4'027
Special waste	kt	263	262	249	261	254	236	255	262	241	218

### 3.2.5.2.2. Petroleum refining (1A1b)

#### Methodology (1A1b)

Up to 2015, two refineries were in operation in Switzerland. Since one of the refineries ceased operation in 2015, the data are considered confidential since 2014. Data are available to reviewers on request. Based on the generalised decision tree Fig. 2.1 for stationary combustion (IPCC 2006, vol.2, chp. 2), Switzerland applies a Tier 3 approach with country-specific emission factors for CO<sub>2</sub> emissions. The calculations are based on measurements and data from the refining industry as documented in the EMIS database (EMIS 2023/1A1b Heizkessel Raffinerien).

#### Emission factors (1A1b)

CO<sub>2</sub> emission factors of residual fuel oil, petroleum coke and refinery gas are estimated based on measurements from the refineries for the years 2005–2011 and 2013–2021 provided in the framework of the Swiss emissions trading system. From 2005 onwards, the measured emission factors are applied. The emission factors for 2012 are interpolated between 2011 and 2013. In years before 2005, the emission factors of residual fuel oil and petroleum coke are based on the weighted mean of the available data (2005–2011 and 2013–2015). The CO<sub>2</sub> emission factor of refinery gas is based on an estimate provided by one of the two refining plants for the years 1990–2004, which is assumed to be constant. Since 2013 the annual emission factor is derived from annual monitoring reports and the allocation report (2005–2011), which provide plant-specific data.

The resulting CO<sub>2</sub> emission factor of refinery gas is higher than the IPCC default value (IPCC 2006).

Table 3-37 Emission factors for 1A1b Petroleum refining in 2021.

1A1b Petroleum refining	Unit	CO <sub>2</sub>	CH <sub>4</sub>	N <sub>2</sub> O	NO <sub>x</sub>	NM VOC	SO <sub>2</sub>	CO
Residual fuel oil	kg/TJ	C	C	C	C	C	C	C
Refinery gas	kg/TJ	C	C	C	C	C	C	C
Petroleum coke	kg/TJ	NO	NO	NO	NO	NO	NO	NO
Natural gas	kg/TJ	C	C	C	C	C	C	C

### Activity data (1A1b)

Activity data on fuel combustion for 1A1b Petroleum refining is provided by the Swiss overall energy statistics (SFOE 2022) and by the industry (bottom-up data). The data from the industry is collected by Carbura and forwarded to the Swiss Federal Office of Energy for inclusion in the Swiss overall energy statistics (SFOE 2022). As one of the refineries ceased operation in 2015, the data are considered confidential since 2014. Data are available to reviewers on request.

Refinery gas is the most important fuel used in source category 1A1b. Energy consumption, in particular use of refinery gas, has increased substantially since 1990 because one of the two Swiss refineries operated at reduced capacity in 1990 and resumed full production in later years. In 2012, one of the refineries was closed over six months due to insolvency and the search for a new buyer (EV 2014). Between 2004 and 2015, one of the Swiss refineries was also using petroleum coke as a fuel and since 2015 natural gas is used additionally to residual fuel oil and refinery gas. From the year 2019 onwards only refinery gas and natural gas are used.

Net calorific values are provided by the annual monitoring reports of the refining industries for the years 2005–2011 and 2013–2021 that are required under the Swiss Federal Act and Ordinance on the Reduction of CO<sub>2</sub> Emissions (Swiss Confederation 2011, Swiss Confederation 2012). For years with missing data (1990–2004 and 2012), the weighted mean of the net calorific value is applied for residual fuel oil and petroleum coke. The net calorific value of refinery gas is based on an estimate provided by one of the two refining plants for the years 1990–2004, which is assumed to be constant. The use of a plant-specific net calorific value leads to a slight difference to the energy consumption data provided by the Swiss overall energy statistics (SFOE 2022).

Table 3-38 Activity data for 1A1b Petroleum refining.

1A1b Petroleum refining	Unit	1990	1995	2000	2005	2010					
Total fuel consumption	TJ	5'629	9'836	9'636	14'548	14'176					
Residual fuel oil	TJ	1'259	1'786	1'908	902	891					
Refinery gas	TJ	4'370	8'050	7'728	11'833	11'282					
Petroleum coke	TJ	NO	NO	NO	1'813	2'003					
Natural gas	TJ	NO	NO	NO	NO	NO					

1A1b Petroleum refining	Unit	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Total fuel consumption	TJ	11'242	13'834	14'173	7'232	6'355	6'298	6'627	5'911	5'987	5'160
Residual fuel oil	TJ	1'212	1'094	1'330	C	C	C	C	NO	NO	C
Refinery gas	TJ	8'249	11'055	10'935	C	C	C	C	C	C	C
Petroleum coke	TJ	1'781	1'685	1'908	C	NO	NO	NO	NO	NO	NO
Natural gas	TJ	NO	NO	NO	NO	NO	C	C	C	C	C

#### 3.2.5.2.3. Manufacture of solid fuels and other energy industries (1A1c)

##### Methodology (1A1c)

In source category 1A1c Manufacture of solid fuels and other energy industries, only the emissions from charcoal production are reported as no other activities occur in Switzerland.

Based on the generalised decision tree in Fig. 2.1 for stationary combustion (IPCC 2006, vol.2, chp. 2), emissions are estimated using a Tier 2 approach.

### Emission factors (1A1c)

The CO<sub>2</sub> emission factor is based on literature (USEPA 1995, chapter 10.7). CH<sub>4</sub> as well as emission factors for precursors NO<sub>x</sub>, NMVOC and CO are taken from the revised 1996 IPCC Guidelines (IPCC 1997c, EMIS 2023/1A1c).

Table 3-39 Emission factors for 1A1c Manufacture of solid fuels and other energy industries in 2021. The CO<sub>2</sub> emission factor refers to CO<sub>2</sub> of biogenic origin.

1A1c Charcoal	Unit	CO <sub>2</sub> biog.	CH <sub>4</sub>	N <sub>2</sub> O	NO <sub>x</sub>	NMVOC	SO <sub>2</sub>	CO
Charcoal production	kg/TJ	16'900	1'000	NA	10	1'700	NE	7'000

### Activity data (1A1c)

The annual amount of charcoal produced is based on detailed queries with the few remaining sites where charcoal is produced. The main producer is the Köhlerverein Romoos, small quantities are produced at individual traditional local trade shows (Karthause Ittingen, Freilichtmuseum Ballenberg), as documented in EMIS 2023/1A1c. The FAO database contained values that differ substantially from these detailed bottom-up data. FAO has been informed about the discrepancy and was provided with the data used in the greenhouse gas inventory.

The charcoal is not used in the industry anymore but mainly for barbecues. Production has increased between 1990 and 2016 due to two regular charcoal production sites starting operation in 2004, low wood prices and increased demand for local charcoal in Switzerland (Koehlerei 2014).

Table 3-40 Activity data for 1A1c Manufacture of Solid Fuels and other energy industries.

1A1c Charcoal	Unit	1990	1995	2000	2005	2010
Charcoal production	TJ	1.3	1.4	2.2	3.4	3.6

1A1c Charcoal	Unit	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Charcoal production	TJ	4.1	3.3	4.3	3.8	4.1	3.9	4.3	5.1	3.9	3.7

#### 3.2.5.3. Uncertainties and time-series consistency for 1A1 (stationary)

The uncertainty of emission estimates for source category 1A1 (stationary) is described in the general uncertainty assessment of source category 1A Fuel combustion in chp. 3.2.4.7.

Time series for 1A1 Energy industries are all considered consistent.

#### 3.2.5.4. Category-specific QA/QC and verification for 1A1 (stationary)

The general QA/QC procedures are described in chp. 1.5. Furthermore QA/QC procedures conducted for all 1A source categories are listed in chp. 3.2.4.8.

Concerning activity data and emission factors in the refinery sector, emissions and fuel combustion statistics are collected at large combustion plants for pollution legislation purposes. This plant-level data is used to cross-check national energy statistics from this sector for representativeness.

### 3.2.5.5. Category-specific recalculations for 1A1 (stationary)

The following recalculations were implemented in submission 2023. Major recalculations, which contribute significantly to the total differences in GHG emissions of sector 1 Energy between the latest and the previous submissions are presented also in chp. 10.1.2.1.

- 1A1a: According to the Swiss energy statistic there was a reallocation of natural gas use from source category 1A1a Public electricity and heat production to end users in 1A2 Manufacturing industries and construction and 1A4a Commercial/institutional in the years 2013 to 2020. This does not lead to a change in total gas consumption.
- 1A1a: Activity data (wood, wood waste) of combustion installations in source category 1A1a have been revised for 1990–2020 due to recalculations in the Swiss wood energy statistics (SFOE 2022b).

### 3.2.5.6. Category-specific planned improvements for 1A1 (stationary)

A new model for stationary engines and gas turbines within 1A Fuel combustion will be implemented. This model bases on new data collection and more detailed emission modelling.

## 3.2.6. Source category 1A2 – Manufacturing industries and construction (stationary, without 1A2gvii)

### 3.2.6.1. Source category description for 1A2 (stationary)

Table 3-41 Key categories of 1A2 Manufacturing industries and construction. Combined KCA results, level for 2021 and trend for 1990–2021, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC category	Gas	Identification criteria
1A2	Manufacturing industries and construction; Gaseous fuels	CO2	L1, T1, L2, T2
1A2	Manufacturing industries and construction; Liquid fuels	CO2	L1, T1
1A2	Manufacturing industries and construction; Other fuels	CO2	L1, T1, T2
1A2	Manufacturing industries and construction; Solid fuels	CO2	L1, T1, T2

*[Source category 1A2 contains the sum of emissions of stationary and mobile sources – the statement on key categories holds for the aggregated emissions only. The CO<sub>2</sub> emissions of 1A2 from Liquid Fuels are dominated by the stationary sources, however, 41 % (2021) of the CO<sub>2</sub> emissions stem from mobile sources 1A2gvii.]*

The source category 1A2 Manufacturing industries and construction comprises all emissions from the combustion of fuels in stationary boilers and cogeneration facilities within manufacturing industries and construction. This includes use of conventional fossil fuels as well as waste-derived fuels and biomass. Use of fossil fuels as feedstocks or other non-energy use of fuels as for example bitumen and lubricants are reported in CRF Table 1.A(d) and described in chp. 3.2.3.

Table 3-42 Specification of source category 1A2 Manufacturing industries and construction.

1A2	Source category	Specification
1A2a	Iron and steel	Iron and steel industry: boilers, cupola furnaces in iron foundries and electric arc furnaces and heating furnaces in steel production
1A2b	Non-ferrous metals	Non-ferrous metals industry: secondary aluminium production, copper alloys production
1A2c	Chemicals	Chemical industry: production of chemicals such as ammonia, niacin, nitric acid (ceased in 2018), ethylene, acetic acid and sulphuric acid as well as silicon carbide (amongst others)
1A2d	Pulp, paper and print	Pulp, paper and print industry
1A2e	Food processing, beverages and tobacco	Food processing, beverages and tobacco industry: meat production, milk products, convenience food, chocolate, sugar and baby food (amongst others).
1A2f	Non-metallic minerals	Fine ceramics, container glass, glass, glass wool, lime, rock wool, mixed goods, cement, brick and tile
1A2giv	Wood and wood products	Fibreboard production
1A2gviii	Other	Industrial fossil fuel and biomass boilers and engines that do not provide heat or electricity to the public.

### 3.2.6.2. Methodological issues for 1A2 (stationary)

#### 3.2.6.2.1. Methodology (1A2) and industry model

For CO<sub>2</sub> emissions from fuel combustion in source category 1A2 Manufacturing industries and construction, Tier 2 and 3 methods are applied (IPCC 2006, Volume 2 Energy, chp. 2 Stationary Combustion, Figure 2.1) using country-specific emission factors – except for other fossil fuels (gasolio, heating gas, and synthesis gas) in 1A2c Chemicals, where plant-specific emission factors are used from 2018 onwards.

For all fuel combustion in 1A2f Cement production, and for wood combustion in 1A2f Brick and tile production (2000–2012), 1A2giv and 1A2gviii, CH<sub>4</sub> emissions are calculated by a Tier 2 approach using country-specific emission factors. For CH<sub>4</sub> emissions from all other fuel combustion processes in source category 1A2 Manufacturing industries and construction, a Tier 1 method is applied (IPCC 2006, Volume 2 Energy, chp. 2 Stationary Combustion, Figure 2.1) using default emission factors from the 2006 IPCC Guidelines.

For N<sub>2</sub>O emissions from fuel combustion in source category 1A2 Manufacturing industries and construction, a Tier 1 method is applied (IPCC 2006, Volume 2 Energy, chp. 2 Stationary Combustion, Figure 2.1) using default emission factors from the 2006 IPCC Guidelines.

#### Overview industry model

As a sub-model of the Swiss energy model (see chp. 3.2.4.3), the industry model disaggregates, for each fuel type, the total fuel consumption in the industry sector provided by the Swiss overall energy statistics (SFOE 2022, see also description in chp. 3.2.4.3) into the source categories and processes under 1A2 Manufacturing industries and construction. As visualized in Figure 3-21, the industry model is based on two pillars. First, the energy consumption statistics in the industry and services sectors (SFOE 2022d) provide a comprehensive annual survey of fuel consumptions for all years since 1999 or 2002 (depending on the fuel type, see paragraph “Energy consumption statistics in the industry and services sectors” below). These statistics are consistently extended back to 1990 based

on a bottom-up industry model (Prognos 2013, see paragraph “Modelling of industry categories” below). Second, further disaggregation is achieved by using plant-level industry data for specific processes, as far as available (see paragraph “Bottom-up industry data” below).

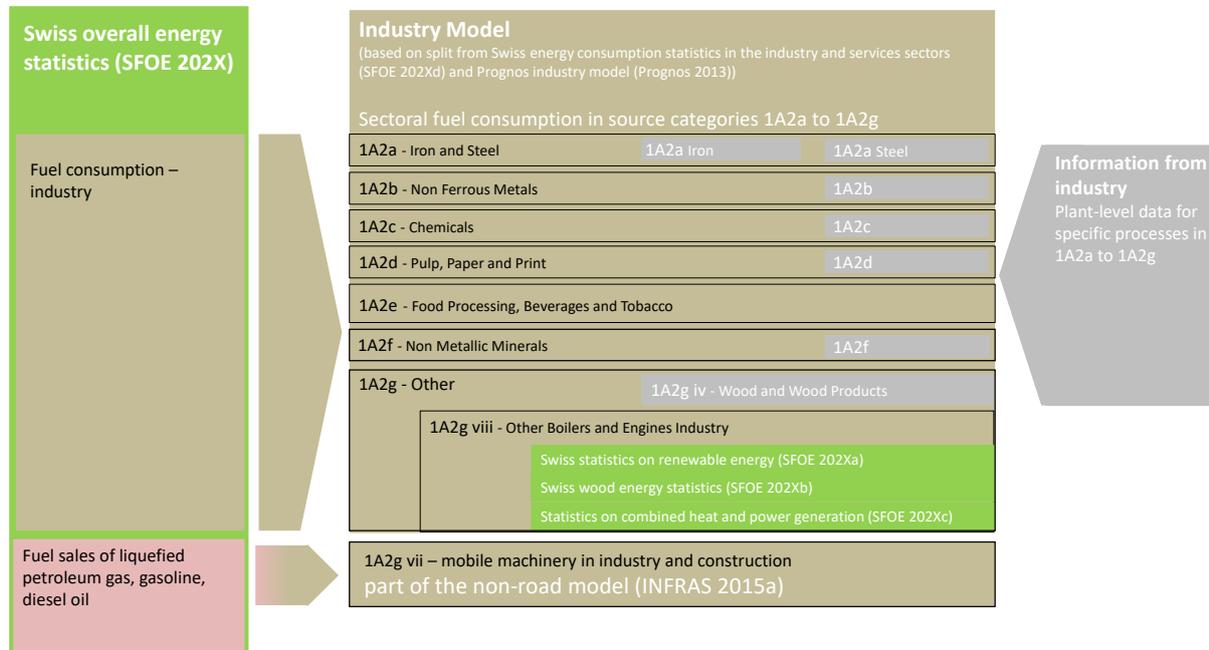


Figure 3-21 Schematic presentation of the data sources used for the industrial sectors 1A2a–1A2g. The references SFOE 202X, 202Xa, 202Xb and 202Xc refer to the 2022 edition of the corresponding energy statistics. For each fuel type, the Swiss overall energy statistics provide the total fuel consumption in the industry sector (SFOE 2022). The total fuel consumption is then distributed to the different source categories based on the energy consumption statistics in the industry and services sectors (SFOE 2022d) for all years since 1999 or 2002 (depending on the fuel type), consistently extended back to 1990 based on a bottom-up industry model (Prognos 2013). The grey boxes on the right show the further disaggregation achieved by using plant-level industry data for specific processes.

### *Energy consumption statistics in the industry and services sectors*

The energy consumption statistics in the industry and services sectors (SFOE 2022d) refer to representative annual surveys with about 13'000 workplaces in the industry and services sectors that are then grossed up or extrapolated to the entire industry branch. For certain sectors and fuel types (i.e. industrial waste, residual fuel oil, other bituminous coal and lignite) the surveys represent a census covering all fuel consumed. The surveys are available since 1999 for gas oil and natural gas. For all other fossil fuels (i.e. residual fuel oil, liquefied petroleum gas, petroleum coke, other bituminous coal and lignite) data are available since 2002.

In 2015, a change in the survey method of the energy consumption statistics in the industry and services sectors was implemented (SFOE 2015d). The business and enterprise register, which forms the basis for the samples of the surveys, was revised. While previously the business and enterprise register was based on direct surveys with work places, it is now based on annual investigations of registry data (e.g. from the old-age and survivors' insurance). In the course of this revision, a comparative assessment was conducted for the year 2013. This comparison showed that the energy consumption in the source categories of 1A2 stationary are modified by less than one percent, but also that the differences between the new and the old results for 2013 are not statistically significant (SFOE 2015d). As these

statistics are only used for allocation of total energy consumption to different source categories, the impact on the different source categories solely consists of a reallocation of the energy consumption and does not affect the total of the sector. Moreover, only consumption of gas oil and natural gas is affected. For all these reasons, the time series consisting of data based on the previous (1990–2012) and latest (since 2013) survey method are considered consistent.

#### *Modelling of industry categories*

As mentioned above, the energy consumption statistics in the industry and services sectors (SFOE 2022d) are available since 1999 or 2002. In order to get consistent time series starting in 1990, a bottom-up industry model (Prognos 2013) is used. The model is based on 164 individual industrial processes and further 64 processes related to infrastructure in industry. Fuel consumption of a specific process is calculated by multiplication of the process activity data with the process-specific fuel consumption factor.

The model provides data on the disaggregation of total fuel consumption according to different industries and services between 1990 and 2012. For the time period where the two disaggregation methods (i.e. surveys and model) overlap, systematic differences between the two time series can be detected. These two data sets have been combined in order to obtain consistent time series of the shares of each source category 1A2a–1A2g for each fuel type. For this purpose, the approach to generate consistent time series from overlapping time series is used according to the 2019 Refinement to the 2006 IPCC Guidelines (IPCC 2019, Volume 1, chp. 5.3.3.1, overlap). To illustrate the approach, an example for gas oil attributed to source category 1A2c is provided in Figure 3-22. A detailed description for all fuel types and source categories (1A2a–1A2g), including further assumptions, is provided in the underlying documentation of the EMIS database (EMIS 2023/1A2 Sektorgliederung Industrie).

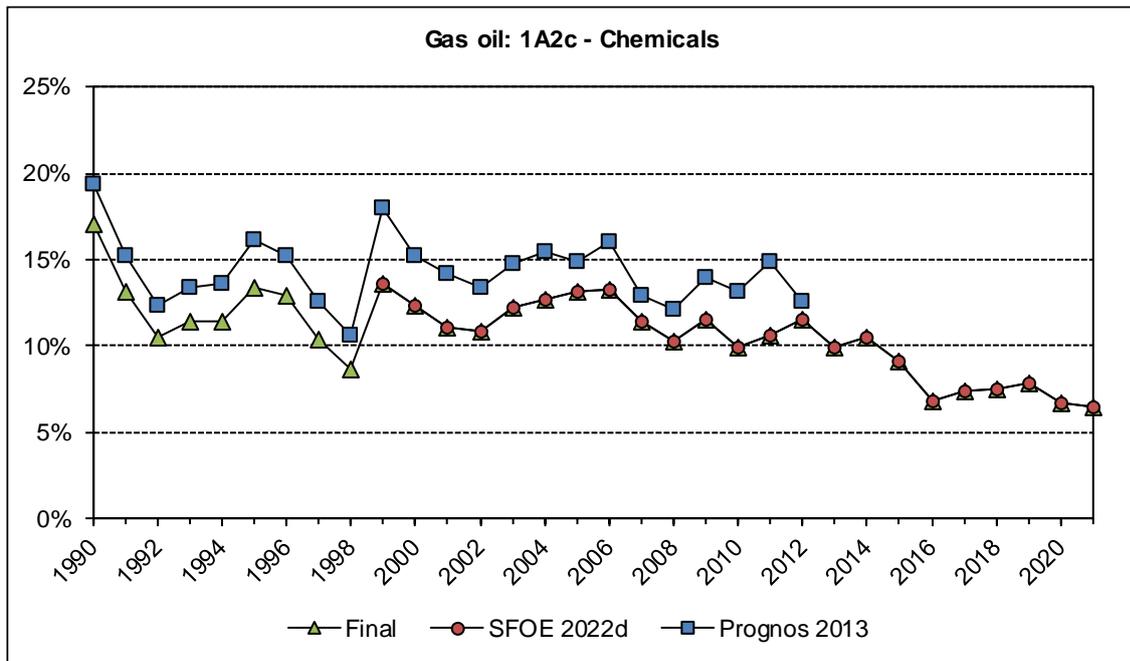


Figure 3-22 Illustrative example for combining time series with consistent overlap according to the 2019 Refinement (IPCC 2019, Volume 1, chp. 5.3.3.1, overlap). The y-axis indicates the share of source category 1A2c in total gas oil consumption in the industry sector. The green triangles correspond to the share finally used to calculate the fuel consumption in 1A2c, based on the combination of the shares from the energy consumption statistics in the industry and services sectors (SFOE 2022d, orange dots, since 1999) and the bottom-up industry model (Prognos 2013, blue squares, from 1990 to 2012). Similar calculations are performed for each source category and fuel type.

#### Bottom-up industry data

Grey coloured boxes in Figure 3-21 represent source categories (i.e. 1A2a–d, 1A2f and 1A2g) for which bottom-up data from the industry are used in order to further disaggregate the fuel consumption within a particular source category. These data consist of validated and verified monitoring data from the Swiss emissions trading scheme implemented under the Ordinance for the Reduction of CO<sub>2</sub> Emissions (Swiss Confederation 2012) and are discussed in depth in the following chapters 3.2.6.2.2 to 3.2.6.2.8.

The bottom-up information provides activity data for specific industrial production processes and forms a subset of the total fuel consumption allocated to each source category by the approach described above. Therefore, the fuel consumptions of the bottom-up industry processes are subtracted from the total fuel consumption of the respective source category and the remaining fuel consumptions are considered as fuels used in boilers of each source category. This method ensures that the sum of fuel consumption over all processes of a source category corresponds to the total fuel consumption assigned based on the energy consumption statistics in the industry and services sectors (SFOE 2022d) and the bottom-up industry model (Prognos 2013).

There is a difference in calculating the emissions of precursors from boilers and bottom-up industry processes. For boilers, fuel consumption is used as activity data whereas for bottom-up processes production data is used.

### Further specific statistical data

The share of fuel used for co-generation in turbines and engines within 1A2 is derived from a model of stationary engines developed by Eicher + Pauli (Kaufmann 2015) for the statistics on combined heat and power generation (SFOE 2022c).

Fuel consumption of wood, wood waste, biogas and sewage gas in manufacturing industries is based on the Swiss wood energy statistics (SFOE 2022b) as well as on data from the Swiss renewable energy statistics (SFOE 2022a) and the statistics on combined heat and power generation in Switzerland (SFOE 2022c), respectively. Emissions from these sources are reported under 1A2gviii Other due to insufficient information regarding sectoral disaggregation.

### Emission factors (1A2)

The following table presents the emission factors of fuel consumption in source category 1A2 Manufacturing industries and construction (see also chp. 3.2.4.4).

Table 3-43 Emission factors for 1A2 Manufacturing industries and construction in 2021. Values that are highlighted in green are described in more detail in chp. 3.2.4.4.

1A2 Emission factors for GHG (mix of bottom-up and top-down approach (modelling); without source category 1A2gvii Off-road vehicles and machinery)	CO <sub>2</sub> fossil	CO <sub>2</sub> biog.	CH <sub>4</sub>	N <sub>2</sub> O
	t/TJ	t/TJ	kg/TJ	kg/TJ
Gas oil	73.7		<3 (lower IEF than default emission factor)	0.6
Residual fuel oil	77.0		<3 (lower IEF than default emission factor)	0.6
Liquefied petroleum gas	65.5		<1 (lower IEF than default emission factor)	0.1
Petroleum coke	91.4		<3 (lower IEF than default emission factor)	0.6
Other bituminous coal	92.7		<10 (lower IEF than default emission factor)	1.5
Lignite	96.1		<10 (lower IEF than default emission factor)	1.5
Natural gas	55.9		<1 (lower IEF than default emission factor)	0.1
Other fossil fuels (including solvents, plastics, waste tyres and rubber (see 1A2c and 1A2f))	76.7		4.3	3.4
Biomass (wood, biogas and other biogenic waste)		92.4	4.5	3.5

Other fossil fuels comprise various fossil waste-derived fuels used in 1A2f Cement production as well as cracker by-products, i.e. gasolio, heating gas and synthesis gas used for steam production in a chemical plant in source category 1A2c. The emission factors of CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O are implied emission factors based on the fossil waste fuel mix. In addition, the CH<sub>4</sub> emission factor includes the total CH<sub>4</sub> emissions of the cement industry based on direct exhaust measurements at the chimneys of the cement plants (see documentation in EMIS 2023/1A2f Zementwerke\_Feuerung), based on industry data and emission declarations according to the Ordinance on Air Pollution Control (Swiss

Confederation 1985). Implied CH<sub>4</sub> emission factors of source category 1A2 for residual fuel oil, petroleum coke, other bituminous coal and lignite are lower than the default emission factors of source category 1A documented in chp. 3.2.4.4.3 (see detailed description below in chapter Cement (1A2f)).

The emission factors of the precursor gases NO<sub>x</sub>, CO, NMVOC and SO<sub>2</sub> for all fuels in source category 1A2 are provided in Switzerland's Informative Inventory Report (FOEN 2023b, chp. 3.2.3.2.1). The emission factors for NO<sub>x</sub> and CO for natural gas and gas oil used in boilers are derived from a large number of air pollution control measurements of combustion installations (Leupro 2012). This study analysed a large dataset from various cantons in Switzerland that was collected between 2000 and 2011. The emission factors for NO<sub>x</sub> and CO for residual fuel oil, petroleum coke, other bituminous coal and lignite used in boilers are country-specific and documented in the Handbook on emission factors for stationary sources (SAEFL 2000). The implied emission factors for NO<sub>x</sub> decreased significantly over the reporting period. NMVOC and SO<sub>2</sub> emission factors are country-specific and documented in SAEFL (2000).

In contrast to combustion in boilers, emission factors of precursors for fuel combustion in bottom-up industry processes are based on bottom-up industry data. Production-weighted emission factors based on various air pollution control measurements under the Ordinance on Air Pollution Control (Swiss Confederation 1985) are used to derive the corresponding process-specific emission factors.

### **Activity data (1A2)**

Table 3-44 shows the total fuel consumption reported in source category 1A2 as described above in the industry model, and displays the fuel switch within Swiss industry over the reporting period. Since 1990, the use of residual fuel oil and other bituminous coal has decreased strongly. In the same period, natural gas consumption has about doubled. Currently, natural gas consumption accounts for the largest share of fuels used within Swiss industry, followed by biomass and gas oil.

Currently, source category 1A2gviii Other comprising emissions from boilers and engines and 1A2f Non-metallic minerals are the two largest fuel consumers within source category 1A2 Manufacturing Industries and construction. 1A2e Food processing, beverages and tobacco and 1A2c Chemicals are the third and fourth largest fuel consumers, respectively.

Table 3-44 Activity data for fuel consumption in 1A2 Manufacturing industries and construction.

1A2 Manufacturing industries and constr. (stationary sources)	Unit	1990	1995	2000	2005	2010					
Total fuel consumption	TJ	89'953	90'573	89'111	92'570	91'580					
Gas oil	TJ	22'910	24'471	25'892	25'317	21'137					
Residual fuel oil	TJ	18'870	13'678	5'675	4'613	2'036					
Liquefied petroleum gas	TJ	4'354	4'458	5'627	4'309	3'912					
Petroleum coke	TJ	1'400	1'260	551	1'093	1'495					
Other bituminous coal	TJ	13'476	7'303	5'866	4'799	4'348					
Lignite	TJ	265	153	124	742	1'460					
Natural gas	TJ	19'450	28'500	31'850	34'760	38'330					
Other fossil fuels	TJ	2'469	2'718	3'812	4'138	4'625					
Biomass	TJ	6'759	8'031	9'715	12'800	14'238					

1A2 Manufacturing industries and constr. (stationary sources)	Unit	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Total fuel consumption	TJ	86'536	88'151	82'665	81'213	82'325	82'699	79'896	79'499	76'633	80'738
Gas oil	TJ	17'575	18'007	12'444	12'725	12'812	11'489	10'871	10'071	8'854	9'074
Residual fuel oil	TJ	1'568	848	231	196	155	123	34	111	76	55
Liquefied petroleum gas	TJ	3'731	3'740	3'288	3'340	2'752	3'131	3'051	2'925	2'797	2'941
Petroleum coke	TJ	1'367	1'049	1'240	795	890	763	781	777	700	604
Other bituminous coal	TJ	3'794	3'910	2'403	1'946	1'517	1'634	1'665	1'450	1'153	1'155
Lignite	TJ	1'175	1'357	3'102	3'060	3'078	2'876	2'520	2'262	2'410	2'442
Natural gas	TJ	38'280	39'630	40'220	39'370	39'880	40'920	39'240	39'480	38'100	39'620
Other fossil fuels	TJ	4'292	4'510	4'558	4'566	5'178	5'085	5'608	5'759	5'815	5'806
Biomass	TJ	14'753	15'100	15'179	15'217	16'062	16'679	16'126	16'663	16'727	19'041

The following chapters describe the fuel consumption of the different source categories 1A2a–1A2gviii, the specific industrial production processes based directly on bottom-up industry data, and additional source-specific emission factors. Further information is documented in the respective EMIS documentation (EMIS 2023/1A2a-g).

### 3.2.6.2.2. Iron and steel (1A2a)

The source category 1A2a Iron and steel consists both of fuels used in boilers and specific industrial production processes, i.e. reheating furnaces in steel plants and cupola furnaces in iron foundries.

There is no primary iron and steel production in Switzerland. Only secondary steel and iron production using recycled steel scrap occurs. Iron is produced in 14 iron foundries. About 75 % of the iron is processed in induction furnaces and 25 % in cupola furnaces using other bituminous coal as fuel. Part of the other bituminous coal acts also as carburization material as well as reducing agent. Since other bituminous coal first of all acts as fuel in cupola furnaces it was decided to report its CO<sub>2</sub> emissions in source category 1A2a. Furthermore, this allows to be consistent with the fuel use of other bituminous coal provided by the Swiss overall energy statistics (SFOE 2022). Additionally, also limestone is used as flux in cupola furnaces yielding geogenic CO<sub>2</sub> emissions. These emissions are reported in source category 2A4d Other carbonate uses. The share of induction furnaces increased since 1990 with a sharp increase in 2009 due to the closure of at least one cupola furnace. Induction furnaces use electricity for the melting process and therefore only process emissions occur, which are reported in source category 2C1 Iron and steel production. Due to the reduced iron production and the switch from cupola to induction furnaces in iron foundries, the consumption of other bituminous coal has decreased.

Today, steel is only produced in two steel production plants after closure of two plants in 1994. Both plants use electric arc furnaces (EAF) with carbon electrodes for melting the steel scrap. In these electric arc furnaces also so-called injection coal and petroleum coke for slag formation as well as natural gas are used. These fuel consumptions are reported under

source category 1A2a Electric arc furnaces of steel production based on plant-specific data from monitoring reports of the Swiss ETS for the years 2005–2011 and from 2013 onwards. In addition, emissions from the reheating furnaces are reported in source category 1A2a. Since 1995, these furnaces use natural gas only for reheating the ingot moulds prior to the rolling mills. Process emissions from steel production are included in source category 2C1 Iron and steel production. Steel production and the related natural gas consumption was significantly reduced in 1995 and the use of residual fuel oil ceased with the closure of two steel companies. Since 1995, steel production increased continuously until 2004 to reach the same production level as 1990. Since then, steel production is about constant. Only in 2009, the production was considerably lower due to the economic crisis. One steel producer switched its production to high quality steel and therefore the specific energy use per tonne of steel produced increased between 1995 and 2000. This led to higher natural gas consumption.

Today fuel consumption of source category 1A2a consists mainly of natural gas but also liquefied petroleum gas, other bituminous coal and gas oil are used.

Table 3-45 Activity data fuel consumption in 1A2a Iron and steel.

1A2a Iron and steel	Unit	1990	1995	2000	2005	2010
Total fuel consumption	TJ	3'567	2'733	3'579	3'654	4'102
Gas oil	TJ	480	262	338	401	315
Residual fuel oil	TJ	346	131	20	39	51
Liquefied petroleum gas	TJ	408	193	286	217	219
Petroleum coke	TJ	85	46	56	72	47
Other bituminous coal	TJ	606	406	439	346	346
Lignite	TJ	NO	NO	NO	NO	NO
Natural gas	TJ	1'642	1'695	2'439	2'578	3'125

1A2a Iron and steel	Unit	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Total fuel consumption	TJ	3'962	3'850	4'007	4'287	4'170	4'623	4'768	4'432	4'439	4'390
Gas oil	TJ	172	139	86	136	134	123	127	97	81	80
Residual fuel oil	TJ	NO									
Liquefied petroleum gas	TJ	438	438.1	388	393	327	368	358	342	327	342
Petroleum coke	TJ	42	53	81	69	78	77	71	57	43	NO
Other bituminous coal	TJ	341	321	325	313	303	321	319	307	285	258
Lignite	TJ	NO									
Natural gas	TJ	2'969	2'899	3'128	3'376	3'328	3'735	3'894	3'629	3'702	3'710

### 3.2.6.2.3. Non-ferrous metals (1A2b)

The source category 1A2b Non-ferrous metals consists both of fuels used in boilers and specific industrial production processes, i.e. secondary aluminium production and non-ferrous metal foundries, producing mainly copper alloys.

Until 1993, secondary aluminium production plants have been in operation using gas oil. Emissions from primary aluminium production in Switzerland are reported in source category 2C3 as induction furnaces have been used. The last primary aluminium production site closed down in April 2006.

Regarding non-ferrous metal industry in Switzerland, only casting and no production of non-ferrous metals occur. There is one large company and several small foundries, which are organized within the Swiss foundries association (Schweizerischer Giessereiverband, GVS) providing production data.

Fuel consumption of source category 1A2b represents only a small amount of the total fuel consumption in source category 1A2. Fuels consumed in 2021 are mainly natural gas as well

as gas oil and small amounts of liquefied petroleum gas. Fuel consumption within this source category decreased since 1990 due to the closing down of the secondary aluminium production and the strong reduction of the non-ferrous metal production since 2000.

Table 3-46 Activity data fuel consumption in 1A2b Non-ferrous metals.

1A2b Non-ferrous metals	Unit	1990	1995	2000	2005	2010
Total fuel consumption	TJ	2'378	1'969	1'560	977	1'218
Gas oil	TJ	587	347	236	125	112
Residual fuel oil	TJ	NO	NO	NO	NO	0.024
Liquefied petroleum gas	TJ	27	17	15	7.1	7.7
Petroleum coke	TJ	NO	NO	NO	NO	NO
Other bituminous coal	TJ	NO	NO	NO	NO	NO
Lignite	TJ	NO	NO	NO	NO	NO
Natural gas	TJ	1'764	1'605	1'309	845	1'098

1A2b Non-ferrous metals	Unit	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Total fuel consumption	TJ	1'746	1'594	1'917	1'792	1'683	1'640	1'746	1'963	1'812	2'020
Gas oil	TJ	153	128	90	78	76	78	55	61	49	66
Residual fuel oil	TJ	0.78	23	NO	44	NO	3.7	NO	NO	NO	NO
Liquefied petroleum gas	TJ	11	11	9.8	9.9	8.3	9.3	9.0	8.6	8.3	8.6
Petroleum coke	TJ	NO									
Other bituminous coal	TJ	NO									
Lignite	TJ	NO									
Natural gas	TJ	1'581	1'431	1'817	1'660	1'599	1'549	1'682	1'893	1'755	1'945

#### 3.2.6.2.4. Chemicals (1A2c)

In Switzerland, there are more than thirty chemical companies mainly producing fine chemicals and pharmaceuticals. Fossil fuels are mostly used for steam production and process heat. The process emissions from the production of chemicals such as ammonia, niacin, nitric acid, ethylene, acetic acid and sulphuric acid as well as silicon carbide are reported in source category 2B, see chp. 4.3.

There is one large company producing ammonia and ethylene by thermal cracking of liquefied petroleum gas and light virgin naphtha (see also descriptions in chp. 3.2.3 for feedstock use). As by-products from the cracking process, so-called heating gas and gasolio are produced, which are used thermally for steam production within the same plant. In 2018 the cracker process and the subsequent integrated production chain were modified yielding synthesis gas as additional cracker by-product. For reasons of confidentiality, fuel consumption and emissions of these by-products are included in Other fossil fuels of 1A2f in the reporting tables. The CO<sub>2</sub> emission factors of gasolio, heating gas and synthesis gas are plant specific based on monitoring reports of the Swiss ETS. In 2017 the fuel quality of gasolio and heating gas have been re-analysed by the production plant yielding new net calorific values and CO<sub>2</sub> emission factors. Due to changes in the cracker operation the composition of the heating gas has changed considerably. The further process modification in 2018 resulted again in changes of both net calorific value and CO<sub>2</sub> emission factor mainly for heating gas.

Since the fuel quality of gasolio and heating gas are of similar quality as residual fuel oil and gas oil, respectively, the same default IPCC emission factors (IPCC 2006) are assumed for CH<sub>4</sub> and N<sub>2</sub>O (see Table 3-15 and Table 3-17). For synthesis gas the same default IPCC emission factor as of natural gas is assumed for N<sub>2</sub>O (IPCC 2006). Whereas no CH<sub>4</sub> emissions are supposed from the combustion of synthesis gas.

Table 3-47 Emission factors for 1A2c Chemicals are documented in the confidential NID, which is available to reviewers on request.

The fuels consumed in 2021 include mainly natural gas as well as minor amounts of gas oil. Fuel consumption in this source category has decreased by more than 20 % between 1990 and 2021. Consumption of gas oil and residual fuel oil has decreased or been stopped in that period, while natural gas consumption has increased.

Table 3-48 Activity data fuel consumption in 1A2c Chemicals.

1A2c Chemicals	Unit	1990	1995	2000	2005	2010
Total fuel consumption	TJ	14'431	15'158	13'497	15'477	11'814
Gas oil	TJ	3'942	3'313	3'215	3'345	2'103
Residual fuel oil	TJ	1'434	693	252	36	66
Liquefied petroleum gas	TJ	15	13	12	10	7.5
Petroleum coke	TJ	NO	NO	NO	NO	NO
Other bituminous coal	TJ	NO	NO	NO	NO	NO
Lignite	TJ	NO	NO	NO	NO	NO
Natural gas	TJ	9'039	11'138	10'017	12'086	9'637
Other fossil fuels	TJ	IE	IE	IE	IE	IE

1A2c Chemicals	Unit	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Total fuel consumption	TJ	13'909	14'128	12'131	12'528	14'374	13'809	13'286	11'811	10'935	10'813
Gas oil	TJ	2'055	1'797	1'321	1'167	881	860	825	799	602	597
Residual fuel oil	TJ	0.16	1.2	NO							
Liquefied petroleum gas	TJ	10	10	8.9	9.0	7.5	8.4	8.2	7.9	7.5	7.9
Petroleum coke	TJ	NO									
Other bituminous coal	TJ	NO									
Lignite	TJ	NO									
Natural gas	TJ	11'845	12'320	10'800	11'352	13'485	12'941	12'454	11'004	10'325	10'208
Other fossil fuels	TJ	IE									

### 3.2.6.2.5. Pulp, paper and print (1A2d)

Around ten paper producers and several printing facilities exist in Switzerland. The only cellulose production plant was closed in 2008. Thermal energy is mainly used for provision of steam used in the drying process within paper production. Emissions from use of carbonate in flue gas treatment in cellulose production is reported in 2A4d Other process use of carbonates.

Fuel consumption in 1A2d consists both of fuels used in boilers and specific industrial production processes. In this source category only biomass (biogenic waste) from cellulose production (until 2008) is included, based on data from the only production site. The emissions were calculated using a country-specific CO<sub>2</sub> emission factor (EMIS 2023/1A2d Zellulose-Produktion) and default factors for CH<sub>4</sub> and N<sub>2</sub>O (IPCC 2006, vol. 2, chp.2, table 2.3, sulphite lyes). Biomass (e.g. wood and wood waste) used in paper production is reported in source category 1A2gviii, because no statistical data exists to allocate biomass consumption to the specific industry sectors within 1A2 as explained in chp. 3.2.4.5.2. Therefore, from 2009 onwards, emissions from biomass are reported as "IE" in CRF Table1.A(a)s2.

The overall fuel consumption within the Swiss pulp and paper industry has considerably decreased since 1990, due to the closure of the cellulose production plant in 2008 and of several paper producers in the last years. The fuels used in 2021 are mainly natural gas as well as gas oil and small amounts of liquefied petroleum gas.

Table 3-49 Activity data of fuel consumption in 1A2d Pulp, paper and print.

1A2d Pulp, paper and print	Unit	1990	1995	2000	2005	2010
Total fuel consumption	TJ	11'760	13'700	11'577	11'379	6'773
Gas oil	TJ	1'188	1'751	1'403	1'456	852
Residual fuel oil	TJ	5'250	3'061	1'417	2'092	279
Liquefied petroleum gas	TJ	86	141	148	100	61
Petroleum coke	TJ	NO	NO	NO	NO	NO
Other bituminous coal	TJ	NO	NO	NO	NO	NO
Lignite	TJ	NO	NO	NO	NO	NO
Natural gas	TJ	3'151	7'389	6'916	5'678	5'581
Biomass	TJ	2'085	1'358	1'694	2'053	NO

1A2d Pulp, paper and print	Unit	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Total fuel consumption	TJ	5'374	5'475	4'645	3'656	2'983	2'852	2'074	2'151	2'068	2'337
Gas oil	TJ	623	711	297	383	410	288	293	345	284	244
Residual fuel oil	TJ	2.8	0.018	22	19	9.0	8.8	NO	NO	NO	NO
Liquefied petroleum gas	TJ	67	67	60	60	50	57	55	53	50	53
Petroleum coke	TJ	NO									
Other bituminous coal	TJ	NO									
Lignite	TJ	NO									
Natural gas	TJ	4'681	4'697	4'266	3'194	2'513	2'499	1'726	1'754	1'734	2'041
Biomass	TJ	IE									

### 3.2.6.2.6. Food processing, beverages and tobacco (1A2e)

In Switzerland, the source category 1A2e Food, beverages and tobacco includes around 200 companies. According to the national food industry association, the major part of revenues is provided by meat production, milk products and convenience food. Further productions comprise chocolate, sugar or baby food (Fial 2013). Fossil fuels are used for steam production and drying processes. Fuel consumption in 1A2e is exclusively based on information from the energy consumption statistics in the industry and services sectors (SFOE 2022d) and Prognos (2013).

In 2021, the fuels used in this category were mainly natural gas as well as gas oil and small amounts of liquefied petroleum gas (Table 3-50). Overall, there was an increase in fuel consumption of approximately 20 % between 1990 and 2021. This is due to the increased production in this sector. The consumption of residual fuel oil ceased and gas oil consumption has decreased, while natural gas and liquefied petroleum gas consumption has increased significantly.

Biomass (e.g. wood and wood waste) used in 1A2e Food processing, beverages and tobacco is reported in source category 1A2gviii, because no statistical data exists to allocate biomass consumption to the specific industry sectors within 1A2 as explained in chp.

3.2.4.5.2. Therefore, activity data and emissions from biomass are reported as "IE" in the CRF Table1.A(a)s2.

Table 3-50 Activity data fuel consumption in 1A2e Food processing, beverages and tobacco.

1A2e Food processing, beverages and tobacco	Unit	1990	1995	2000	2005	2010					
Total fuel consumption	TJ	9'858	8'784	10'437	10'239	13'161					
Gas oil	TJ	7'410	5'511	5'515	4'070	3'778					
Residual fuel oil	TJ	1'160	466	137	NO	NO					
Liquefied petroleum gas	TJ	204	308	535	534	659					
Petroleum coke	TJ	NO	NO	NO	NO	NO					
Other bituminous coal	TJ	NO	NO	NO	NO	NO					
Lignite	TJ	NO	NO	NO	NO	NO					
Natural gas	TJ	1'085	2'500	4'250	5'635	8'723					
Biomass	TJ	IE	IE	IE	IE	IE					

1A2e Food processing, beverages and tobacco	Unit	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Total fuel consumption	TJ	11'310	13'081	12'442	11'574	10'976	11'214	10'826	11'833	11'909	12'067
Gas oil	TJ	3'237	3'681	2'395	2'522	2'503	2'110	1'925	2'119	2'009	2'301
Residual fuel oil	TJ	NO									
Liquefied petroleum gas	TJ	935	935	828	838	699	785	763	731	699	731
Petroleum coke	TJ	NO									
Other bituminous coal	TJ	NO									
Lignite	TJ	NO									
Natural gas	TJ	7'138	8'465	9'220	8'214	7'774	8'320	8'139	8'983	9'201	9'035
Biomass	TJ	IE									

### 3.2.6.2.7. Non-metallic minerals (1A2f)

The source category 1A2f Non-metallic minerals includes several large fuel consumers within mineral industry, e.g. cement, brick and tile, glass, and rock wool production. All fuel consumption of these specific industrial production processes are based on bottom-up industry data.

The fuels consumed in this source category are very diverse, depending on the fuel use within the specific industry process (see detailed documentation below). Except for brick and tile production (from 2013 onwards) bottom-up information is also available on the amount of biomass consumed. Therefore, all emissions from biomass used in these processes are reported in source category 1A2f.

Between 1990 and 2021, there has been a switch in fuel consumption from other bituminous coal and residual fuel oil to other fossil fuels, biomass, natural gas and lignite. The most important emission source within this category is cement production. Information on bottom-up data of fuel consumption and some source-specific emission factors are described in the following. Detailed data at process level cannot be provided, since they are mostly confidential. Therefore, aggregated data for 1A2f are shown in Table 3-51.

Table 3-51 Activity data fuel consumption in 1A2f Non-metallic minerals.

1A2f Non-metallic minerals	Unit	1990	1995	2000	2005	2010
Total fuel consumption	TJ	25'613	19'885	18'055	17'832	18'196
Gas oil	TJ	1'871	1'629	1'642	1'389	1'269
Residual fuel oil	TJ	5'382	5'578	3'649	2'420	1'519
Liquefied petroleum gas	TJ	523	498	468	324	102
Petroleum coke	TJ	550	300	480	638	1'130
Other bituminous coal	TJ	12'665	6'758	5'415	4'364	3'992
Lignite	TJ	265	153	124	737	1'348
Natural gas	TJ	1'769	1'566	1'496	1'861	2'048
Other fossil fuels	TJ	2'469	2'718	3'812	4'138	4'625
Biomass	TJ	119	685	970	1'962	2'162

1A2f Non-metallic minerals	Unit	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Total fuel consumption	TJ	16'956	17'119	17'677	16'484	16'518	16'536	16'716	16'643	16'257	16'622
Gas oil	TJ	1'097	1'174	1'204	1'098	1'020	1'118	1'078	1'117	997	995
Residual fuel oil	TJ	1'456	801	209	130	139	106	31	109	72	52
Liquefied petroleum gas	TJ	108	113	45	52	44	44	45	45	39	41
Petroleum coke	TJ	920	815	1'052	622	658	574	542	552	591	583
Other bituminous coal	TJ	3'403	3'478	1'973	1'498	1'089	1'210	1'206	1'085	767	879
Lignite	TJ	1'081	1'283	2'912	2'856	2'881	2'694	2'367	2'120	2'266	2'304
Natural gas	TJ	2'085	2'506	3'111	3'121	2'952	2'970	2'972	2'997	2'820	2'804
Other fossil fuels	TJ	4'292	4'510	4'558	4'566	5'178	5'085	5'608	5'759	5'815	5'806
Biomass	TJ	2'513	2'440	2'613	2'542	2'557	2'735	2'867	2'860	2'890	3'158

## Cement (1A2f)

### Methodology

In Switzerland, there are six plants producing clinker and cement. The Swiss plants are rather small and do not exceed a production capacity of 3'000 tonnes of clinker per day. All of them use modern dry process technology. Cement industry emissions occur by incinerating a wide variety of fuels: standard fossil fuels as well as mixed, biogenic and fossil, waste-derived fuels are used to generate the high temperatures needed for the calcination process. The fossil and biogenic shares are reflected in the activity data. Specific activity data have been created for the fossil and biogenic contributions, for each of the combustibles. Equal numeric values are used for emission factors of the fossil and the biogenic fraction.

### Emission factors

The CH<sub>4</sub> emission factor includes the overall CH<sub>4</sub> emissions of the cement industry based on direct exhaust measurements at the chimneys of the cement plants. Therefore, these CH<sub>4</sub> emissions are reported under the fuel type other fossil fuels in the reporting tables.

Table 3-52 Emission factors for cement industry in 2021. Emission factors for CO<sub>2</sub> and N<sub>2</sub>O are fuel specific (see Table 3-13, Table 3-17 and Table 3-53).

Cement industry (part of 1A2f)	CO <sub>2</sub>	N <sub>2</sub> O	CH <sub>4</sub>	NO <sub>x</sub>	NMVOC	SO <sub>2</sub>	CO
	t/TJ		g/t clinker				
Cement	fuel specific		7	790	67	280	2'600

The emission factors for CO<sub>2</sub> and N<sub>2</sub>O for standard fossil fuels are the same as used elsewhere (Table 3-13, Table 3-17). Regarding waste derived fuels, the NCVs and CO<sub>2</sub> emission factors for waste oil, solvents and residues from distillation, plastics, mix of special waste with saw dust (CSS), sewage sludge, wood waste, animal meal and saw dust are based on a study of Cemsuisse (Cemsuisse 2010a) providing measured values for the year 2010. A follow-up study of Cemsuisse (Cemsuisse 2018) provided measured values for the

year 2017 for the three most relevant waste derived fuels – i.e. waste oil, solvents and residues from distillation and plastics – as well as for mix of special waste with saw dust (CSS). Emission factors between 2010 (the year of the previous assessment) and 2017 are interpolated, while constant values are used before the first and after the last year with available data.

The values for waste tyres and rubber are taken from Hackl and Mauschwitz (2003). The biogenic fraction of waste tyres and rubber is based on an Austrian study and published by the German Ministry of Environment (UBA 2006). The emission factor of N<sub>2</sub>O is the same for all waste derived fuels and is taken from the IPCC Guidelines (IPCC 2006, vol. 2, chp. 2 table 2.3 industrial wastes).

Table 3-53 NCVs, fossil fractions as well as CO<sub>2</sub> (fossil and biogenic) and N<sub>2</sub>O emission factors of waste derived fuels (Other fossil fuels and Biomass) used in the cement industry. Where data for more than one year is available, values in between are interpolated and constant values are used before the first and after the last year with available data.

Cement industry (part of 1A2f) Waste derived fuel	Data sources	For the years		NCV	Fossil fraction	EF CO <sub>2</sub> fossil, biog.	EF N <sub>2</sub> O
				GJ/t	%	t CO <sub>2</sub> /TJ	kg N <sub>2</sub> O/TJ
Waste oil	Cemsuisse (2010a)	until	2010	32.5	100	74.4	4
	Cemsuisse (2018)	from	2017	31.0	92.7	73.2	4
Waste coke from coke filters	Cemsuisse (2001)	all		23.7	100	97	4
	Hackl and Mauschwitz (2003)						
Mixed industrial waste	Cemsuisse, FOEN	all		18.3	100	74	4
Other fossil waste fuels	Cemsuisse, FOEN	all		20.9	100	97	4
Solvents and residues from distillation	Cemsuisse (2010a)	until	2010	23.6	99.1	74.0	4
	Cemsuisse (2018)	from	2017	23.5	89.7	70.7	4
Waste tyres and rubber	Hackl and Mauschwitz (2003) UBA (2006)	all		26.4	73	84	4
Plastics	Cemsuisse (2010a)	until	2010	25.2	72.3	84.7	4
	Cemsuisse (2018)	from	2017	23.6	76.6	84.5	4
Mix of special waste with saw dust (CSS)	Cemsuisse (2010a)	until	2010	9.2	21.5	102.4	4
	Cemsuisse (2018)	from	2017	9.1	27.0	112.2	4
Sewage sludge (dried)	Cemsuisse (2010a)	all		9.4	0	94.5	4
Wood waste	Cemsuisse (2010a)	all		16.3	0	99.9	4
Animal meal	Cemsuisse (2010a)	all		16.8	0	86.7	4
Agricultural waste / other biomass	Cemsuisse, FOEN	all		12.7	0	110.0	4

### Activity data

Data on fuel consumption is provided by the industry, for recent years based on monitoring reports of the Swiss ETS as documented in the EMIS database (EMIS 2023/1A2f Zementwerke Feuerung).

In 2021, the Swiss cement industry used about two-thirds of waste derived fuels and one-third of standard fossil fuels. Today, fossil fuels used in cement industry are mainly lignite, plastics, waste oil and solvents and residues from distillation whereas petroleum coke and other bituminous coal are less important. Biogenic wastes contain mainly wood waste, sewage sludge and (bio)plastics. The main fossil fuel used in 1990 was other bituminous coal, but residual fuel oil, and waste oil were also of importance.

Fuel consumption in cement plants has decreased between 1990 and 2021. This is partly due to a decrease in production since 1990 and an increase in energy efficiency. In the same period, the fuel mix has changed significantly from mainly standard fossil fuels to the above-mentioned mix of fuels.

In the reporting tables, the biogenic waste derived fuels are reported under fuel type Biomass, whereas fossil waste derived fuels are reported under fuel type Other fossil fuels.

Table 3-54 Activity data: Overview on fuel use in cement industry (part of 1A2f). The waste derived fuel is split into Other fossil fuels and Biomass.

<b>Cement industry (part of 1A2f)</b>	<b>Unit</b>	<b>1990</b>	<b>1995</b>	<b>2000</b>	<b>2005</b>	<b>2010</b>					
Total fuel consumption	TJ	17'194	12'774	11'017	11'623	12'388					
Cement fossil without waste	TJ	15'319	9'993	7'332	6'208	6'278					
Gas oil	TJ	NO	NO	NO	72	5.4					
Residual fuel oil	TJ	1'907	2'825	1'530	637	112					
Petroleum coke	TJ	550	300	480	638	1'130					
Other bituminous coal	TJ	12'235	6'547	5'176	4'120	3'662					
Lignite	TJ	265	153	124	737	1'348					
Natural gas	TJ	362	168	22	3.9	21					
Cement, waste derived fuel	TJ	1'874	2'781	3'685	5'415	6'109					
Other fossil fuels	TJ	1'755	2'096	2'755	3'544	4'021					
Industrial waste	TJ	NO	NO	NO	NO	NO					
Mix of special waste with saw dust (C	TJ	5.0	29	34	29	26					
Other fossil waste fuels	TJ	NO	NO	NO	NO	45					
Plastics	TJ	NO	40	413	608	905					
Solvents and residues from distillation	TJ	281	180	422	967	1'178					
Waste coke from coke filters	TJ	59	59	59	58	NO					
Waste oil	TJ	1'170	1'485	1'520	1'411	1'253					
Waste tyres	TJ	241	303	307	471	614					
Biomass	TJ	119	685	930	1'871	2'088					
Agricultural waste	TJ	NO	NO	NO	NO	7.3					
Animal meal	TJ	NO	NO	198	856	624					
Mix of special waste with saw dust (C	TJ	18	106	124	105	97					
Other biomass	TJ	NO	NO	NO	NO	5.7					
Plastics	TJ	NO	15	158	233	347					
Sewage sludge (dried)	TJ	9.4	128	333	494	477					
Solvents and residues from distillation	TJ	2.5	1.6	3.8	8.8	11					
Waste oil	TJ	NO	NO	NO	NO	NO					
Waste tyres and rubber	TJ	89	112	114	174	227					
Wood waste	TJ	NO	322	NO	NO	292					

<b>Cement industry (part of 1A2f)</b>	<b>Unit</b>	<b>2012</b>	<b>2013</b>	<b>2014</b>	<b>2015</b>	<b>2016</b>	<b>2017</b>	<b>2018</b>	<b>2019</b>	<b>2020</b>	<b>2021</b>
Total fuel consumption	TJ	11'462	11'866	12'339	11'348	11'583	11'476	11'474	11'478	11'248	11'609
Cement fossil without waste	TJ	5'406	5'512	5'847	4'917	4'544	4'354	3'965	3'736	3'500	3'617
Gas oil	TJ	0.10	88	75	87	50	56	63	106	54	61
Residual fuel oil	TJ	297	86	58	45	90	59	NO	63	35	52
Petroleum coke	TJ	920	815	1'052	622	658	574	542	552	591	583
Other bituminous coal	TJ	3'097	3'203	1'713	1'267	826	938	938	831	528	587
Lignite	TJ	1'081	1'283	2'912	2'856	2'881	2'694	2'367	2'120	2'266	2'304
Natural gas	TJ	11	38	37	41	39	34	56	65	26	28
Cement, waste derived fuel	TJ	6'056	6'354	6'492	6'431	7'039	7'122	7'509	7'743	7'748	7'992
Other fossil fuels	TJ	3'635	3'923	3'884	3'895	4'486	4'393	4'645	4'885	4'861	4'834
Industrial waste	TJ	NO									
Mix of special waste with saw dust (C	TJ	23	23	25	20	26	21	20	16	0.043	0.58
Other fossil waste fuels	TJ	36	25	19	12	11	5.7	5.4	NO	NO	13
Plastics	TJ	803	963	1'016	887	890	1'071	1'319	1'246	1'558	1'688
Solvents and residues from distillation	TJ	1'247	1'345	1'193	1'194	1'397	1'254	1'238	1'456	1'155	1'107
Waste coke from coke filters	TJ	NO	NO	NO	NO	NO	66	61	48	52	48
Waste oil	TJ	822	848	884	1'083	1'469	1'215	1'239	1'359	1'353	1'253
Waste tyres	TJ	704	719	746	699	694	760	763	760	743	726
Biomass	TJ	2'421	2'432	2'608	2'536	2'553	2'729	2'864	2'858	2'887	3'158
Agricultural waste	TJ	28	NO	NO	NO	NO	9.2	NO	NO	NO	NO
Animal meal	TJ	572	479	457	412	409	470	522	475	441	454
Mix of special waste with saw dust (C	TJ	77	73	78	60	72	57	53	43	0.12	1.6
Other biomass	TJ	17	32	21	42	7.9	5.6	5.4	31	36	147
Plastics	TJ	289	336	343	290	281	327	403	381	476	516
Sewage sludge (dried)	TJ	527	418	428	420	479	499	519	512	553	572
Solvents and residues from distillation	TJ	46	70	80	98	137	144	142	167	133	127
Waste oil	TJ	18	27	39	60	98	96	98	107	107	99
Waste tyres and rubber	TJ	260	266	276	259	257	281	282	281	275	269
Wood waste	TJ	586	732	886	896	811	840	840	861	867	973

## Lime (1A2f)

In Switzerland there is only one plant producing lime. Fossil fuels are used for the burning process (calcination) of limestone. From 1990 to 1993, other bituminous coal was the primary fuel. Between 1994 and 2012, bituminous coal was replaced by residual fuel oil. In 2013, the main kiln has been switched to natural gas.

### **Container glass (1A2f)**

Today, there exists only one production plant for container glass in Switzerland. Fuel consumption has drastically decreased over the reporting period due to a reduction in production. Until 2003, only residual fuel oil was used. From 2004 onwards, the share of natural gas has increased, reaching a stable share between 2006 and 2012. In autumn 2013, the plant has switched its glass kiln completely to natural gas.

### **Tableware glass (1A2f)**

Today, there exists only one production plant for tableware glass in Switzerland. Fuel consumption for tableware glass currently includes only liquefied petroleum gas, as residual fuel oil was eliminated in 1995. Since 1990, fuel consumption has strongly decreased because of the closure of one production plant in 2006.

### **Glass wool (1A2f)**

Glass wool is produced in two plants. Currently, fuel consumption for glass wool production includes only natural gas. Production of glass wool has increased since 1990.

### **Fine ceramics (1A2f)**

In Switzerland, the main production of fine ceramics is sanitary ware produced by one big and some small companies. In earlier years, also other ceramics were produced as for example glazed ceramic tiles, electrical porcelain and earthenware. Since 2001, only sanitary ware is produced.

Until 2001, the fuel mix consisted of natural gas and gas oil. Since then, gas oil consumption decreased continuously, so that from 2010 onwards, only natural gas is consumed.

Compared to the production of other fine ceramics, the production of sanitary ware is more energy-intensive. Therefore, the specific energy use per tonne of produced fine ceramics increased considerably between 1990 and 2001. This results in a lower reduction of fuel consumption compared to the reduction in production between 1990 and 2021.

### **Brick and tile (1A2f)**

In Switzerland there are about 20 plants producing bricks and tiles. Mainly fossil fuels but also paper production residues, animal grease and wood are used for drying and burning of the clay blanks.

#### *Emission factors*

The CO<sub>2</sub> emission factors for wood and animal grease are based on a study of Cemsuisse (Cemsuisse 2010a), see Table 3-53, whereas the one for paper production residues is taken from a German study on secondary fuels (UBA 2006) as documented in the EMIS database (EMIS 2023/1A2f Ziegeleien).

For CH<sub>4</sub> and N<sub>2</sub>O, emission factors of paper production residues and animal grease default values for wood waste and other liquid fuels, respectively, according to IPCC 2006 are used. For wood, the CH<sub>4</sub> emission factor according to the energy model for wood combustion

(automatic chip boiler >500 kW, w/o wood processing companies), see chp. 3.2.4.5.2, and the default N<sub>2</sub>O emission factor from IPCC 2006 are used.

#### *Activity data*

Since 2013, plant-specific activity data – except for biomass – are available from monitoring reports of the Swiss ETS. Fuels used in the brick and tile production in 2021 are almost exclusively natural gas and very little gas oil. Apart from a production recovery in the years around 2004, the production has gradually decreased since 1990, which is also represented in the overall fuel consumption decrease. Regarding the fuels used, there has been a considerable shift from residual fuel oil to natural gas from 1990 onwards as well as to a lesser extent, a shift from liquefied petroleum gas and gas oil to natural gas from 2004 onwards. Small amounts of paper production residues, wood and animal grease were used from 2000 onwards and reported up to 2017, 2012 and 2020, respectively.

#### **Rock wool (1A2f)**

In Switzerland there is one single producer of rock wool. Cupola furnaces are used for the melting of rocks at a temperature of 1500°C.

Currently, other bituminous coal and natural gas are used in the production process. Until 2004, also gas oil and liquefied petroleum gas were used. In 2005, these fuels were substituted by natural gas.

#### **Mixed goods (1A2f)**

The production of mixed goods mainly includes the production of bitumen for road paving. A total of 110 production sites are producing mixed goods at stationary production sites. The main fuels used are gas oil and increasingly also natural gas.

#### **3.2.6.2.8. Other (1A2g stationary)**

##### **Methodology (1A2g stationary)**

Source category 1A2g<sub>iv</sub> Wood and wood products includes fuel consumption of fibreboard production. Fibreboards were produced in two companies in Switzerland until 2019, where thermal energy is used for heating and drying processes. Since 2020 only one plant is left.

Source category 1A2g<sub>viii</sub> Other covers fossil fuel combustion in boilers not further specified in manufacturing industries and construction, as well as combustion of wood, wood waste, biogas and sewage gas in all manufacturing industries. Methodologically, the fossil fuel consumption in boilers of 1A2g<sub>viii</sub> represents the residual entities of the industry installations that could not be allocated to any other source categories in 1A2a–f.

For more detailed descriptions on methodologies of biogas and sewage gas, see source categories 5B Biological treatment of solid waste (chp. 7.3) and 5D Wastewater treatment and discharge (chp. 7.5), respectively.

This source category accounts for nearly 40 % of the overall fuel consumption in 2021 of 1A2 Manufacturing industries and construction (stationary).

### **Emission factors (1A2g stationary)**

The CO<sub>2</sub> emission factors for wood waste and animal grease in 1A2giv Wood and wood products are based on a study by Cemsuisse (2010a), see Table 3-53. For wood waste, the respective CH<sub>4</sub> and N<sub>2</sub>O emission factors of the energy model for wood combustion, see chp. 3.2.4.5.2, and IPCC 2006, respectively, are taken, whereas for animal grease, the default values of IPCC 2006 for other liquid biofuels are used. For biogas and sewage gas in 1A2gviii Other Boilers and Engines Industry, the same emission factors as for natural gas are assumed.

### **Activity data (1A2g stationary)**

#### *1A2giv Wood and wood products*

In source category 1A2giv Wood and wood products, mainly wood waste as well as natural gas are used (Table 3-55). Since 1990, the production of fibreboard and thus the fuel consumption have increased significantly. The fuel mix has strongly shifted from fossil fuels to biomass (wood waste) between 1990 and 2021. Between 2001 and 2013, also animal grease was used for fibreboard production. Since 2004, data on annual fuel consumption is taken from monitoring reports of the industry as documented in the EMIS database (EMIS 2023/1A2giv).

#### *1A2gviii Other Boilers and Engines Industry*

Activity data for wood combustion is based on Swiss wood energy statistics (SFOE 2022b) whereas sewage and biogas consumption is based on data from the Swiss renewable energy statistics (SFOE 2022a) and the Statistics on combined heat and power generation in Switzerland (SFOE 2022c). Further information on wood energy consumption is provided in chp. 3.2.4.5.2.

Since 1990, the consumption of residual fuel oil and liquefied petroleum gas has decreased, and since 2005 also that of gas oil. Solid fossil fuel consumption remained quite stable with fluctuations, whereas biomass and natural gas consumption increased significantly.

Table 3-55 Activity data fuel consumption in 1A2giv Wood and wood products and 1A2gviii Other (stationary).

1A2giv: Wood and wood products, 1A2gviii: Other (stationary)	Unit	1990	1995	2000	2005	2010					
Total fuel consumption	TJ	22'345	28'343	30'406	33'013	36'316					
Gas oil	TJ	7'431	11'657	13'542	14'531	12'707					
Residual fuel oil	TJ	5'298	3'749	199	26	122					
Liquefied petroleum gas	TJ	3'091	3'288	4'164	3'116	2'855					
Petroleum coke	TJ	765	914	15	383	318					
Other bituminous coal	TJ	205	140	12	88	11					
Lignite	TJ	NO	NO	NO	4.7	111					
Natural gas	TJ	1'000	2'607	5'423	6'077	8'116					
Other fossil fuels	TJ	NO	NO	NO	NO	NO					
Biomass	TJ	4'555	5'988	7'050	8'786	12'076					

1A2giv: Wood and wood products, 1A2gviii: Other (stationary)	Unit	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Total fuel consumption	TJ	33'278	32'904	29'846	30'892	31'622	32'025	30'479	30'665	29'214	32'488
Gas oil	TJ	10'239	10'377	7'050	7'342	7'788	6'913	6'568	5'534	4'831	4'791
Residual fuel oil	TJ	109	22	0.33	2.8	7.9	4.3	2.2	2.4	3.7	2.8
Liquefied petroleum gas	TJ	2'162	2'165	1'949	1'977	1'615	1'860	1'814	1'738	1'667	1'758
Petroleum coke	TJ	405	181	108	104	155	113	168	169	65	21
Other bituminous coal	TJ	49.7	110	105	134	125	102	140	58	101	18
Lignite	TJ	95	75	189	204	197	182	153	141	144	138
Natural gas	TJ	7'980	7'313	7'878	8'453	8'229	8'907	8'374	9'220	8'564	9'876
Other fossil fuels	TJ	NO									
Biomass	TJ	12'239	12'660	12'566	12'675	13'505	13'944	13'259	13'803	13'837	15'883

### 3.2.6.3. Uncertainties and time-series consistency for 1A2 (stationary)

The uncertainty of emission estimates for source category 1A2 (stationary) is described in the general uncertainty assessment of source category 1A Fuel combustion in chp. 3.2.4.7.

Time series for 1A2 Manufacturing industries and construction are all considered consistent.

### 3.2.6.4. Category-specific QA/QC and verification for 1A2 (stationary)

The general QA/QC procedures are described in chp. 1.5. Furthermore QA/QC procedures conducted for all 1A source categories are listed in chp. 3.2.4.8.

### 3.2.6.5. Category-specific recalculations for 1A2 (stationary)

The following recalculations were implemented in submission 2023. Major recalculations, which contribute significantly to the total differences in GHG emissions of sector 1 Energy between the latest and the previous submissions are presented also in chp. 10.1.2.1.

- 1A2: According to the Swiss energy statistic there was a reallocation of natural gas use from source category 1A1a Public electricity and heat production to end users in 1A2 Manufacturing industries and construction and 1A4a Commercial/institutional in the years 2013 to 2020. This does not lead to a change in total gas consumption but it leads to recalculations for natural gas in all source-categories with stationary combustion in 1A2 Manufacturing industry and construction for these years.
- 1A2a–g: Recalculation in all source categories 1A2a to 1A2gviii due to reallocations of natural gas and gas oil use in these sub-categories of 1A2 Manufacturing industries and construction in the year 2020. The reason is that during the surveys for the most recent year, the reports from the previous year are reviewed again and, if necessary, adjusted retroactively. This does not affect the total amount of gas and gas oil used in 1A2 Manufacturing industries and construction for that year.

- 1A2f: In 1A2f Cement, the following combustibles are a mix of biogenic and fossil waste: waste oil, solvents and residues from distillation, waste tyre and rubber, plastics, mix of special waste with saw dust (CSS). Previously, the total activity data were used while the biogenic and fossil shares were reflected using specific emission factors for CO<sub>2</sub> fossil and biogenic. From now on, the fossil and biogenic shares are reflected in the activity data. Specific activity data and emission factors have been created for the fossil and biogenic contributions, for each of these combustibles. Due to rounding issues small deviations from previous emission values may occur, up to 5%. Values for emission factors and activity data have substantially changed (up to 70%) while the sum of emissions for all fuels has not changed by more than 5%. All years are affected. Before the change, the activity data for CSS was fully reported within Biomass and for all the other reorganised resources, within Other fuels.
- 1A2gviii: Activity data (wood, wood waste) of combustion installations in source category 1A2gviii have been revised for 1990–2020 due to recalculations in the Swiss wood energy statistics (SFOE 2022b). The biggest changes were in automatic boilers >50 kW after 2015.
- 1A2gviii: An error in the country-specific emission factor model for wood energy combustion was corrected resulting in revised CH<sub>4</sub> emission factors of log wood dual chamber boilers for the entire time series.
- 1A2gviii: Since more residual fuel oil was consumed in the years 2020 and 2021 according to direct bottom-up information from the industry than was declared in total sales in the same year, stock transfers must be made. This leads to additional stockpiling in 2008–2010 and therefore to changes for residual fuel oil used in not further defined boilers in 1A2gviii Other. Stockpiling can only be performed in the years in which more residual fuel oil was sold according to total energy statistics than was consumed according to bottom-up information. Therefore, the years 2008–2010 were chosen to add residual fuel oil to stocks to cover the additional bottom-up consumption in the years 2020 and 2021.
- 1A2gviii: Due to revised activity data of liquefied petroleum gas in source category 1A3bi Passenger cars, also the statistical difference and not further defined use of liquefied petroleum gas in boilers of source category 1A2gviii Other changed for the years 2011 to 2020.

#### **3.2.6.6. Category-specific planned improvements for 1A2 (stationary)**

A new model for stationary engines and gas turbines within 1A Fuel combustion will be implemented. This model bases on new data collection and more detailed emission modelling.

### 3.2.7. Source category 1A4 – Stationary combustion in other sectors (commercial, residential, agriculture and forestry)

#### 3.2.7.1. Source category description for 1A4 Stationary combustion in other sectors (commercial, residential, agriculture and forestry)

Table 3-56 Key categories of 1A4 Other sectors. Combined KCA results, level for 2021 and trend for 1990–2021, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC category	Gas	Identification criteria
1A4a	Commercial; Gaseous fuels	CO2	L1, T1, L2, T2
1A4a	Commercial; Liquid fuels	CO2	L1, T1
1A4b	Residential; Gaseous fuels	CO2	L1, T1, L2, T2
1A4b	Residential; Liquid fuels	CO2	L1, T1
1A4c	Agriculture and forestry; Liquid fuels	CO2	L1, T1

Each of the source categories 1A4a, 1A4b, 1A4c contain the sum of emissions of stationary and mobile sources – the above statements on key categories hold for the aggregated emissions of 1A4a etc. only. The CO<sub>2</sub> emissions of 1A4a and 1A4b from Liquid Fuels are vastly dominated by the stationary sources, which means that the emissions of 1A4aii and 1A4bii only play a minor role within category 1A4a and 1A4b. For 1A4c, however, the emissions of 1A4cii are more important than those of 1A4ci (see also chp. 3.2.10.1.)

Table 3-57 Specification of source category 1A4 Other sectors.

1A4	Source category	Specification
1A4ai	Commercial/institutional: Stationary	Emissions from stationary fuel combustion in commercial and institutional buildings, including boilers, engines, turbines and different wood combustion installations
1A4bi	Residential: Stationary	Emissions from stationary fuel combustion in households, including boilers, engines, turbines and different wood combustion installations
1A4ci	Agriculture/Forestry/Fishing: Stationary	Emissions from stationary fuel combustion in agriculture, including different wood combustion installations, engines with biogas, heating of greenhouses and grass drying

### **3.2.7.2. Methodological issues for 1A4 Stationary combustion in other sectors (commercial, residential, agriculture and forestry)**

#### **Methodology (1A4 stationary)**

CO<sub>2</sub> emissions from stationary combustion in source categories 1A4ai, 1A4bi and 1A4ci are estimated based on country-specific emission factors using a Tier 2 approach according to the decision tree for stationary combustion of the IPCC Guidelines (IPCC 2006, Volume 2 Energy, chp. 2 Stationary Combustion, Figure 2.1) for liquid, solid, gaseous fuels, biogas, wood consumption in bonfires and animal grease. For wood biomass, a Tier 3 approach using country-specific emission factors is applied.

A Tier 1 approach is applied with IPCC default emission factors for CH<sub>4</sub> emissions of residual fuel oil and gas oil for boilers and N<sub>2</sub>O emissions of all fuels and technologies (IPCC 2006). CH<sub>4</sub> emissions of gas oil used in engines, gaseous fuels and biogas are calculated by a Tier 2 approach using country-specific emission factors. CH<sub>4</sub> emissions of wood biomass are calculated by a Tier 3 approach using country-specific emission factors. In 1A4ci Grass drying, also small amounts of crop residues are used as fuel; their emissions are calculated with default IPCC emission factors (IPCC 2006).

For the calculation of the emissions from the use of gas oil and natural gas the following sources are differentiated: (a) heat only boilers, (b) combined heat and power production in turbines and (c) combined heat and power production in engines.

Emissions from 1A4ci Other sectors (stationary) – Agriculture/Forestry/Fishing originate from fuel combustion for the heating of greenhouses and grass drying, as well as from wood combustion for heating in agriculture and forestry. For grass drying, information is provided by the Swiss association of grass drying plants (VSTB). For greenhouses, information is provided by the Energy Agency of the Swiss Private Sector (EnAW).

## Emission factors (1A4 stationary)

Table 3-58 Emission factors for stationary combustion in 1A4ai Other sectors commercial/institutional in 2021. Emission factors that are highlighted in green are described in chp. 3.2.4.4.

1A4ai Other sectors:	CO <sub>2</sub> fossil	CO <sub>2</sub> biog.	CH <sub>4</sub>	N <sub>2</sub> O	NO <sub>x</sub>	NMVOC	SO <sub>2</sub>	CO
	t/TJ							
Gas oil (weighted average)	73.7	NA	10	0.6	32	6	5.6	6
Gas oil heat only boilers	73.7	NA	10	0.6	32	6	5.6	5.9
Gas oil engines	73.7	NA	2	0.6	40	8	5.6	30
Natural gas (weighted average)	55.9	NA	2.1	0.1	17.9	1.9	0.5	11.6
NG heat only boilers	55.9	NA	1	0.1	16	2	0.5	8.9
NG turbines	55.9	NA	2	0.1	19	0.1	0.5	4.8
NG engines	55.9	NA	20	0.1	50	1	0.5	54.7
Biomass (weighted average)	NA	99.8	17.5	3.99	112.3	39.1	5.4	544
Biomass (wood)	NA	99.9	17.5	4	112.4	39.1	5.4	545
Biogas (heat only boilers)	NA	55.9	1	0.1	15.9	2.0	0.5	8.9

Table 3-59 Emission factors for stationary combustion in 1A4bi Other sectors residential in 2021. Emission factors that are highlighted in green are described in chp. 3.2.4.4.

1A4bi Other sectors: Residential	CO <sub>2</sub> fossil	CO <sub>2</sub> biog.	CH <sub>4</sub>	N <sub>2</sub> O	NO <sub>x</sub>	NMVOC	SO <sub>2</sub>	CO
	t/TJ							
Gas oil (weighted average)	73.7	NA	10	0.6	33	6	5.6	11
Gas oil heat only boilers	73.7	NA	10	0.6	33	6	5.6	11
Gas oil engines	73.7	NA	2	0.6	40	8	5.6	30
Natural gas (weighted average)	55.9	NA	1.2	0.1	14.9	4	0.5	12.2
NG heat only boilers	55.9	NA	1	0.1	15	4	0.5	12
NG turbines	NO	NA	NO	NO	NO	NO	NO	NO
NG engines	55.9	NA	20	0.1	29	1	0.5	54.7
Other bituminous coal	92.7	NA	300	1.5	65	100	350	1'000
Biomass (wood, charcoal, bonfires)	NA	100	46	3.99	95	104	7.8	1'331
Wood	NA	100	43	4	96	99	7.8	1'304
Use of charcoal	NA	112	200	1	50	600	11	4'000
Bonfires	NA	100	300	4	50	600	11	4'000

Table 3-60 Emission factors for stationary combustion in 1A4ci Agriculture/forestry/fishing in 2021. Emission factors that are highlighted in green are described in chp. 3.2.4.4.

1A4ci Agriculture/forestry/fishing	CO <sub>2</sub> fossil	CO <sub>2</sub> biog.	CH <sub>4</sub>	N <sub>2</sub> O	NO <sub>x</sub>	NMVOC	SO <sub>2</sub>	CO
	t/TJ							
Grass drying (fossil, biogenic) (weighted average)	59	99	2.0	0.89	65	88	73	501
Gas oil	74	NA	3	0.6	NA	NA	NA	NA
Residual fuel oil	NO	NA	NO	NO	NA	NA	NA	NA
Natural gas	55.9	NA	1	0.1	NA	NA	NA	NA
Biomass	NA	99	4.4	3.7	NA	NA	NA	NA
Heating of greenhouses (weighted average)	61	NA	1.6	0.3	22	2	2.1	6.6
Gas oil	73.7	NA	3	0.6	30.9	2	5.6	5.9
Natural gas	55.9	NA	1	0.1	18.5	2	0.5	6.9
Other biomass combustion (weighted average)	NA	73	16	1.6	51	8.7	2.5	218
Biogas heat only boilers	NA	55.9	1	0.1	16	2	0.5	8.9
Biogas engines	NA	55.9	20	0.1	20	1	0.5	54.7
Wood combustion	NA	99.9	10	4	103	21	5.7	487

### Charcoal and bonfires

Emission factors concerning CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O emissions of charcoal use in the residential source categories (1A4bi) are taken from the IPCC Guidelines (IPCC 2006). Default emission factors according to the guidelines are also applied for CH<sub>4</sub> and N<sub>2</sub>O emissions resulting from bonfires. The CO<sub>2</sub> emission factor for bonfires is based on the value for wood

combustion; see chp. 3.2.4.4. Emission factors of precursors are taken from the EMEP/EEA guidebook (2019) (Table 3.39).

### Activity data (1A4 stationary)

#### General energy sources

Activity data about the energy sources gas oil, residual fuel oil, natural gas and biomass are calculated by the Swiss energy model (see chp. 3.2.4.3 for further information). For other energy sources such as other bituminous coal, activity data is provided directly by the Swiss overall energy statistics (SFOE 2022). Grass drying activities for source category 1A4ci are reported by the Swiss association of grass drying plants (VSTB) (as standard tonne of dried grass) as documented in the EMIS database (EMIS 2023/1A4ci Grastrocknung). The fuel consumption for the heating of greenhouses is extrapolated from the information provided by the Energy Agency of the Swiss Private Sector (EnAW) as documented in the EMIS database (EMIS 2023/1A4ci Gewächshäuser).

Table 3-61 Activity data in 1A4a Commercial/Institutional (stationary).

1A4ai Other sectors (stationary): Commercial/institutional	Unit	1990	1995	2000	2005	2010
Total fuel consumption	TJ	72'354	80'123	76'795	83'379	79'430
Gas oil	TJ	52'977	54'379	48'777	51'197	46'525
Gas oil heat only boilers	TJ	52'953	54'204	48'426	50'880	46'406
Gas oil engines	TJ	24	175	351	318	119
Natural gas	TJ	16'399	21'843	23'552	26'732	25'307
NG heat only boilers	TJ	16'123	20'672	21'815	24'699	23'602
NG turbines	TJ	85	78	NO	28	23
NG engines	TJ	192	1'093	1'737	2'004	1'681
Biomass (total)	TJ	2'978	3'901	4'466	5'450	7'599
Biomass (wood)	TJ	2'939	3'869	4'438	5'403	7'495
Biogas (heat only boilers)	TJ	39	32	27	46	104

1A4ai Other sectors (stationary): Commercial/institutional	Unit	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Total fuel consumption	TJ	71'902	77'299	60'985	66'966	70'299	67'761	61'196	61'675	58'792	67'362
Gas oil	TJ	39'750	42'727	32'993	35'153	36'440	34'222	30'879	30'273	27'596	31'349
Gas oil heat only boilers	TJ	39'656	42'640	32'910	35'071	36'358	34'140	30'797	30'191	27'514	31'267
Gas oil engines	TJ	94	86	82	82	82	82	82	82	82	82
Natural gas	TJ	24'733	26'351	20'247	23'112	24'336	23'967	21'176	21'759	21'054	24'120
NG heat only boilers	TJ	23'180	24'854	18'811	21'676	22'900	22'531	19'740	20'323	19'618	22'684
NG turbines	TJ	5	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3
NG engines	TJ	1'548	1'490	1'429	1'429	1'429	1'429	1'429	1'429	1'429	1'429
Biomass (total)	TJ	7'420	8'221	7'745	8'701	9'522	9'572	9'141	9'643	10'142	11'892
Biomass (wood)	TJ	7'344	8'162	7'698	8'679	9'498	9'548	9'128	9'628	10'127	11'877
Biogas (heat only boilers)	TJ	76	59	47	21	24	24	13	14	15	16

Table 3-62 Activity data in 1A4b Residential (stationary).

1A4bi Other sectors (stationary): Residential	Unit	1990	1995	2000	2005	2010					
Total fuel consumption	TJ	185'308	189'291	170'485	186'056	182'062					
Gas oil	TJ	136'887	133'548	116'295	124'024	111'731					
Gas oil heat only boilers	TJ	136'887	133'544	116'242	123'961	111'695					
Gas oil engines	TJ	0.59	4.5	53	63	36					
Natural gas	TJ	25'864	34'088	36'261	42'633	48'229					
NG heat only boilers	TJ	25'804	33'830	35'822	42'103	47'723					
NG turbines	TJ	NO	NO	NO	NO	NO					
NG engines	TJ	60	258	439	530	506					
Other bituminous coal	TJ	630	460	130	400	400					
Biomass (wood, charcoal, bonfires)	TJ	21'926	21'195	17'799	19'000	21'702					
Wood	TJ	21'455	20'744	17'347	18'526	21'198					
Use of charcoal	TJ	311	291	292	313	344					
Bonfires	TJ	160	160	160	160	160					

1A4bi Other sectors (stationary): Residential	Unit	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Total fuel consumption	TJ	161'282	172'581	135'085	144'791	150'953	144'838	133'078	133'971	124'475	139'280
Gas oil	TJ	94'103	99'373	75'136	79'406	81'340	76'113	67'901	66'642	59'375	66'048
Gas oil heat only boilers	TJ	94'072	99'344	75'109	79'379	81'312	76'085	67'874	66'615	59'348	66'021
Gas oil engines	TJ	32	29	27	27	27	27	27	27	27	27
Natural gas	TJ	47'043	50'977	42'377	46'106	48'835	48'345	45'925	47'585	47'215	53'086
NG heat only boilers	TJ	46'577	50'529	41'947	45'676	48'405	47'915	45'496	47'155	46'786	52'656
NG turbines	TJ	NO									
NG engines	TJ	466	448	430	430	430	430	430	430	430	430
Other bituminous coal	TJ	300	300	200	200	200	100	100	100	100	100
Biomass (wood, charcoal, bonfires)	TJ	19'836	21'931	17'372	19'079	20'579	20'281	19'151	19'645	17'785	20'045
Wood	TJ	19'331	21'428	16'858	18'565	20'084	19'747	18'637	19'159	17'221	19'846
Use of charcoal	TJ	344	343	354	354	334	374	354	325	404	40
Bonfires	TJ	160	160	160	160	160	160	160	160	160	160

Table 3-63 Activity data in 1A4ci Agriculture/forestry/fishing (stationary).

1A4ci Other sectors (stationary): Agriculture/forestry/fishing	Unit	1990	1995	2000	2005	2010					
Total fuel consumption	TJ	6'378	6'103	5'798	5'524	5'650					
Drying of grass	TJ	1'895	1'544	1'223	994	739					
Gas oil	TJ	1'156	942	746	607	451					
Residual fuel oil	TJ	NO	NO	NO	NO	NO					
Natural gas	TJ	739	602	477	388	288					
Biomass	TJ	NO	NO	NO	NO	NO					
Heating of greenhouses	TJ	4'000	4'000	4'000	3'735	3'677					
Gas oil	TJ	3'490	3'490	3'490	3'133	1'803					
Natural gas	TJ	510	510	510	601	1'874					
Other biomass combustion	TJ	484	559	575	795	1'235					
Biogas heat only boilers	TJ	39	32	27	46	104					
Biogas engines	TJ	16	15	35	82	394					
Wood combustion	TJ	428	513	513	666	738					

1A4ci Other sectors (stationary): Agriculture/forestry/fishing	Unit	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Total fuel consumption	TJ	5'803	5'294	4'758	4'933	5'438	5'957	5'483	5'819	5'928	6'347
Drying of grass	TJ	685	458	524	431	492	610	545	684	721	630
Gas oil	TJ	418	106	104	89	86	118	116	124	148	94
Residual fuel oil	TJ	NO	17	20	22	18	25	13	NO	NO	NO
Natural gas	TJ	267	220	264	233	279	338	296	427	435	410
Biomass	TJ	NO	114	136	88	109	129	120	132	138	126
Heating of greenhouses	TJ	3'671	3'389	2'800	2'900	2'899	3'238	2'754	2'732	2'537	2'753
Gas oil	TJ	1'647	1'496	1'095	1'165	1'066	1'145	930	916	788	861
Natural gas	TJ	2'025	1'893	1'705	1'735	1'834	2'093	1'824	1'816	1'749	1'892
Other biomass combustion	TJ	1'447	1'448	1'435	1'602	2'046	2'109	2'184	2'403	2'670	2'963
Biogas heat only boilers	TJ	76	59	47	21	24	24	13	14	15	16
Biogas engines	TJ	599	754	880	1'020	1'168	1'248	1'390	1'597	1'747	1'893
Wood combustion	TJ	772	635	507	562	854	837	781	792	909	1'055

### Charcoal and bonfires

Besides the main fuels, also charcoal use and bonfires are accounted for in source category 1A4bi Other sectors (Stationary) – Residential. Charcoal is only used for charcoal grills. The total charcoal consumption under 1A4bi Other sectors (Stationary) – Residential is very small

compared to other fuels used for heating purposes. The activity data are the sum of Swiss charcoal production as reported under 1A1c Manufacture of solid fuels and other energy industries and net imports provided by the Swiss overall energy statistics (SFOE 2022).

As the Swiss wood energy statistics (SFOE 2022b) cover wood used for heating and energy purposes only, no figures are available on wood burnt in source category 1A4bi Bonfires. The activity data of bonfires are thus expert judgements based on a per capita consumption. Two types of bonfires are considered: (public) traditional bonfires such as on national day and (private) bonfires for barbecuing. The number of traditional bonfires has declined, as fewer communities are holding national day bonfires. With the increasing use of gas barbecues, there has also been a decrease in bonfires for barbecuing. Overall, a constant wood consumption was therefore assumed for bonfires due to the declining per capita consumption and increasing population (EMIS 2023/1A4bi Lagerfeuer).

### **3.2.7.3. Uncertainties and time-series consistency for 1A4 Stationary combustion in other sectors (commercial, residential, agriculture and forestry)**

The uncertainty of emission estimates for source category 1A4 (stationary) is described in the general uncertainty assessment of source category 1A Fuel combustion in chp. 3.2.4.7.

Time series for 1A4 Other sectors are all considered to be consistent.

### **3.2.7.4. Category-specific QA/QC and verification for 1A4 Stationary combustion in other sectors (commercial, residential, agriculture and forestry)**

The general QA/QC procedures are described in chp. 1.5. Furthermore QA/QC procedures conducted for all 1A source categories are listed in chp. 3.2.4.8.

### **3.2.7.5. Category-specific recalculations for 1A4 Stationary combustion in other sectors (commercial, residential, agriculture and forestry)**

The following recalculations were implemented in submission 2023. Major recalculations which contribute significantly to the total differences in GHG emissions of sector 1 Energy between the latest and the previous submissions are presented also in chp. 10.1.2.1.

- 1A4: An error in the country-specific emission factor model for wood energy combustion was corrected resulting in revised CH<sub>4</sub> emission factors of log wood single-room furnaces and dual chamber boilers for the entire time series.
- 1A4a: According to the Swiss energy statistic there was a reallocation of natural gas use from source category 1A1a Public electricity and heat production to end users in 1A2 Manufacturing industries and construction and 1A4a Commercial/institutional in the years 2013 to 2020. This does not lead to a change in total gas consumption.
- 1A4ai, 1A4bi, 1A4ci: Activity data (wood, wood waste) of combustion installations in source categories 1A4ai, 1A4bi and 1A4ci have been revised for 1990–2020 due to recalculations in the Swiss wood energy statistics (SFOE 2022b). The biggest changes were in automatic boilers >50 kW after 2015.
- 1A4ci: The CH<sub>4</sub> emission factor for crop residues in source category 1A4ci Grass drying has been adjusted from 300 g/GJ to 30 g/GJ for 2013 to 2020. It is now based on Table 2.3 instead of Table 2.5 of 2006 IPCC Guidelines (vol. 2, chp. 2.).

### 3.2.7.6. Category-specific planned improvements for 1A4 Stationary combustion in other sectors (commercial, residential, agriculture and forestry)

A new model for stationary engines and gas turbines within 1A Fuel combustion will be implemented. This model bases on new data collection and more detailed emission modelling.

### 3.2.8. Source category 1A2 – Manufacturing industries and construction (mobile 1A2gvii)

#### 3.2.8.1. Source category description for 1A2 Manufacturing industries and construction (mobile 1A2gvii)

Note for Key categories 1A2: See chp. 3.2.6 and note that source category 1A2 contains the sum of emissions of stationary and mobile sources – the statement on key categories holds for the aggregated emission only. The CO<sub>2</sub> emissions of 1A2 from Liquid Fuels are dominated by the stationary sources. Only 41 % (2021) of the CO<sub>2</sub> emissions of Liquid Fuels from 1A2 stem from mobile sources 1A2gvii.

Table 3-64 Specification of source category 1A2 Manufacturing industries and construction (mobile).

1A2	Source category	Specification
1A2gvii	Mobile Combustion in manufacturing industries and construction	Industry sector: forklifts and snow groomers etc. construction machines: excavators, loaders, dump trucks, mobile compressors etc.

#### 3.2.8.2. Methodological issues for 1A2 Manufacturing industries and construction (mobile 1A2gvii)

##### Methodology (1A2gvii)

Based on the decision tree Fig. 3.3.1 in chp. “3. Mobile Combustion” in IPCC (2006) the emissions of industry and construction vehicles and machinery are calculated by a Tier 3 method with the non-road transportation model described in chp. 3.2.4.5.1.

CO<sub>2</sub> emissions from lubricants of gasoline 2-stroke engines are calculated by using the IPCC default CO<sub>2</sub> emission factor for lubricants, 73.3 t/TJ (IPCC 2006). However, these emissions are reported under source category 2D1 Lubricant use (see chp. 4.5.2.1). In contrast, CH<sub>4</sub> and N<sub>2</sub>O emissions from lubricant use in 2-stroke engines are reported in source category 1A2gvii, since the emission factors are based on measurements including 2-stroke engines.

##### Emission factors (1A2gvii)

- The CO<sub>2</sub> emission factors applied for the time series 1990–2021 for diesel oil, gasoline, liquefied petroleum gas and biodiesel and bioethanol are country-specific and are given in Table 3-13.

- The CH<sub>4</sub> and N<sub>2</sub>O emission factors are country-specific and are shown in Table 3-65 to Table 3-67 for diesel oil, gasoline and liquefied petroleum gas engines for all emission standards.
- For SO<sub>2</sub> from diesel oil, gasoline, gas oil and liquefied petroleum gas see Table A – 15 in Annex A5.1.4.
- The emission factors for precursors are country-specific and are given in FOEN (2015j).
- NMVOC is not modelled bottom-up. The NMVOC emissions are calculated as the difference between VOC and CH<sub>4</sub> emissions.
- The implied emission factors 2021 are shown in Table 3-68.

All emission factors (GHG, precursors) can be downloaded by query from the online non-road database INFRAS (2015a). They can be queried by vehicle type, fuel type, power class and emission standard either at aggregated or disaggregated levels.

Table 3-65 Emission factors CH<sub>4</sub> and N<sub>2</sub>O for industry and construction vehicles with diesel oil engines by emission standards including the year of entry into force.

Gas	Power class	PreEU-A	PreEU-B	EU-I	EU-II	EU-III A	EU-III B	EU-IV
	kW	<1996	1996	2002/03	2002/04	2006/08	2011/12	2014
		g/kWh						
CH <sub>4</sub>	<18	0.0547	0.0547	0.0384	0.0240	0.0142	0.0142	0.0142
CH <sub>4</sub>	18–37	0.0578	0.0578	0.0221	0.0134	0.0089	0.0089	0.0089
CH <sub>4</sub>	37–56	0.0319	0.0319	0.0156	0.0110	0.0079	0.0055	0.0058
CH <sub>4</sub>	56–75	0.0319	0.0319	0.0156	0.0110	0.0079	0.0031	0.0031
CH <sub>4</sub>	75–130	0.0218	0.0218	0.0108	0.0084	0.0067	0.0031	0.0031
CH <sub>4</sub>	130–560	0.0218	0.0218	0.0103	0.0072	0.0053	0.0031	0.0031
CH <sub>4</sub>	>560	0.0218	0.0218	0.0103	0.0072	0.0053	0.0031	0.0031
N <sub>2</sub> O	0–3000	0.035	0.035	0.035	0.035	0.035	0.035	0.035

Table 3-66 Emission factors CH<sub>4</sub> and N<sub>2</sub>O for industry and construction vehicles with gasoline engines by emission standards including the year of enforcement.

Gas	Power class	PreEU-A	PreEU-B	PreEU-C	EU-I	EU-II
	ccm	<1996	1996	2000	2004	2005/09
		g/kWh				
CH <sub>4</sub>	<66	2.040	2.040	2.040	1.394	1.394
CH <sub>4</sub>	66–100	1.360	1.360	1.360	1.088	1.088
CH <sub>4</sub>	100–225	0.680	0.680	0.680	0.408	0.408
CH <sub>4</sub>	>225	0.680	0.680	0.680	0.340	0.306
N <sub>2</sub> O	0–3000	0.03	0.03	0.03	0.03	0.03

Table 3-67 Emission factors CH<sub>4</sub> and N<sub>2</sub>O for industry and construction vehicles with liquefied petroleum gas engines (for all years).

Gas	without catalyst	with catalyst
	g/kWh	
CH <sub>4</sub>	0.552	0.035
N <sub>2</sub> O	0.05	0.05

Table 3-68 Implied emission factors 2021 for industry and construction vehicles.

1A2gvii Non-road vehicles and other machinery	CO <sub>2</sub>	CH <sub>4</sub>	N <sub>2</sub> O	NO <sub>x</sub>	NMVOC	SO <sub>2</sub>	CO
	t/TJ	kg/TJ					
Gasoline	73.8	34.4	1.1	100	617	0.26	19'716
Diesel oil	73.3	0.45	3.3	196	19	0.33	97
Liquefied petroleum gas	65.5	0.67	2.3	96	8.8	NA	24
Biodiesel	73.3	0.39	2.8	168	17	0.28	83
Bioethanol	73.8	7.8	0.79	46	220	0.17	12'058

### Activity data (1A2gvii)

Activity data for non-road (1A2gvii) are described in chp. 3.2.4.5.1 (non-road transportation model). Values are taken from FOEN (2015j). Data on biofuels are provided by the statistics of renewable energies (SFOE 2015a). Activity data are shown in Table 3-69 and in Annex A5.1.3. Detailed data can be downloaded from the non-road database (INFRAS 2015a). Underlying activity data (vehicle stock, operating hours) of mobile non-road sources can also be downloaded by query from the online non-road database (INFRAS 2015a). They can be queried by vehicle type, fuel type, power class and emission standard either at aggregated or disaggregated levels.

Table 3-69 Activity data for industry and construction vehicles.

1A2gvii Non-road vehicles and other machinery	Unit	1990	1995	2000	2005	2010
Total fuel consumption	TJ	5'721	6'852	7'636	8'169	8'779
Gasoline	TJ	196	224	227	225	220
Diesel oil	TJ	5'359	6'380	7'106	7'626	8'254
Liquefied petroleum gas	TJ	165	248	294	290	269
Biodiesel	TJ	NO	NO	9.2	28	36
Bioethanol	TJ	NO	NO	NO	NO	0.0047

1A2gvii Non-road vehicles and other machinery	Unit	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Total fuel consumption	TJ	8'843	8'875	8'906	8'938	8'944	8'949	8'955	8'960	8'966	8'991
Gasoline	TJ	206	198	191	184	180	177	174	171	168	167
Diesel oil	TJ	8'312	8'341	8'370	8'399	8'380	8'361	8'342	8'323	8'304	8'296
Liquefied petroleum gas	TJ	252	243	235	226	215	203	192	180	168	163
Biodiesel	TJ	73	91	110	128	166	205	243	282	320	360
Bioethanol	TJ	0.51	0.76	1.02	1.3	2.0	2.7	3.3	4.0	4.7	5.4

### 3.2.8.3. Uncertainties and time-series consistency for 1A2gvii (mobile)

The uncertainty of emission estimates for source category 1A2gvii (mobile) is described in the general uncertainty assessment of source category 1A Fuel combustion in chp. 3.2.4.7. Uncertainties by fuel type are given in Table 3-26.

### 3.2.8.4. Category-specific QA/QC and verification for 1A2gvii (mobile)

The general QA/QC procedures are described in chp. 1.5. Furthermore, QA/QC procedures conducted for all 1A source categories are listed in chp. 3.2.4.8.

### 3.2.8.5. Category-specific recalculations for 1A2gvii (mobile)

There were no recalculations implemented in submission 2023.

### 3.2.8.6. Category-specific planned improvements for 1A2gvii (mobile)

No category-specific improvements are planned.

## 3.2.9. Source category 1A3 – Transport

### 3.2.9.1. Source category description for 1A3

Table 3-70 Key categories of 1A3 Transport. Combined KCA results, level for 2021 and trend for 1990–2021, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC category	Gas	Identification criteria
1A3a	Domestic aviation; Kerosene fossil	CO2	T1
1A3b	Road transportation; Diesel oil	CO2	L1, T1, L2, T2
1A3b	Road transportation; Diesel oil	N2O	T1
1A3b	Road transportation; Gasoline	CO2	L1, T1
1A3b	Road transportation; Gasoline	CH4	T1, T2
1A3b	Road transportation; Gasoline	N2O	T1, T2

Table 3-71 Specification of source category 1A3 Transport.

1A3	Source category	Specification
1A3a	Domestic aviation	LTO and Cruise; Large (jet, turboprop) and small (piston) aircrafts, helicopters
1A3bi	Road Transportation	Passenger cars
1A3bii		Light duty trucks
1A3biii		Heavy duty trucks and buses
1A3biv		Motorcycles
1A3bv		Other
1A3c	Railways	Diesel locomotives
1A3d	Domestic navigation	Passenger ships, motor and sailing boats on the Swiss lakes and the river Rhine
1A3e	Other transportation - Pipeline compressors	Compressor station in Ruswil, Lucerne

For information on international bunker fuel emissions from international aviation and navigation, see chp. 3.2.2.

### 3.2.9.2. Methodological issues for 1A3

#### 3.2.9.2.1. Domestic aviation (1A3a)

##### Methodology (1A3a)

The emissions of domestic aviation are modelled by a Tier 3A method (IPCC 2006, Volume 2, chp. 3 Mobile Combustion, Table 3.6.2 and figure 3.6.2) developed by FOCA (2006) and based on origin and destination of single movements by aircraft type according to detailed movement statistics. LTO emissions are modelled based on the individual engine type. The

emissions of domestic aviation are modelled together with the international aviation reported in 1D1 (aviation bunker, see chp. 3.2.2.2.1).

FOCA is represented in the emissions technical working group (Committee on Aviation Environmental Protection CAEP, WG3) and in the modelling and database group (CAEP MDG) of the International Civil Aviation Organisation (ICAO). FOCA is directly involved in the development of ICAO guidance material for the calculation of aircraft emissions and in the update of the IPCC Guidelines (via the secretariat of ICAO CAEP). The Tier 3A method applied for the emission modelling is in line with the methods developed in the working groups mentioned. The modelling scheme for domestic aviation refers to aircraft basic data, activity data and emission factors that result in calculated emissions. Respective values are ultimately imported into the EMIS database as shown in Figure 3-23.

The Tier 3A method follows standard modelling procedures at the level of single aircraft movements based on detailed movement statistics. The primary key for all calculations is the aircraft tail number, which allows to calculate on the most precise level, namely on the level of the individual aircraft and engine type. Every aircraft is linked to the FOCA engine data base containing emission factors for more than 800 individual engine types with different power settings. Emissions in the landing/take-off (LTO) cycle are calculated with aircraft category dependent flight times and corresponding power settings. Cruise emissions are calculated based on the individual aircraft type with individual engine model (since 2021) and the trip distance for every flight. For piston-engine powered aircraft and helicopters, to the knowledge of FOCA, it has been the only provider of publicly available engine data and a full methodology. All piston engine data and study results have been published in 2007 (FOCA 2007a). The guidance on the determination of helicopter emissions has been published in 2009 (FOCA 2009a) and updated in 2015 (FOCA 2015a).

The movement database from Swiss airports registers the departure and destination airports of each flight. With this information, all flights from and to Swiss airports are differentiated into domestic and international flights prior to the emission calculation. The emissions of domestic flights are reported under 1A3a Domestic Aviation, the emissions of international flights are reported under 1D1 international aviation (international bunkers).

The emission factors used are either country-specific or taken from the ICAO engine emissions databank, from EMEP/EEA guidebook (EMEP/EEA 2019), Swedish Defence Research Agency (FOI) and Swiss FOCA measurements (precursors). Cruise emission factors are generally calculated from the values of the ICAO engine emissions databank, aircraft performance tables and from confidential airline data. Pollutant emission factors are adjusted to cruise conditions by using the Boeing Fuel Flow Method 2. For N<sub>2</sub>O, the IPCC default emission factor of 2 kg/TJ is used (IPCC 2006). For the methane split of unburnt hydrocarbons, the 10 % methane share for the LTO, given in IPCC 2006 is used. For cruise emissions, no methane is reported.

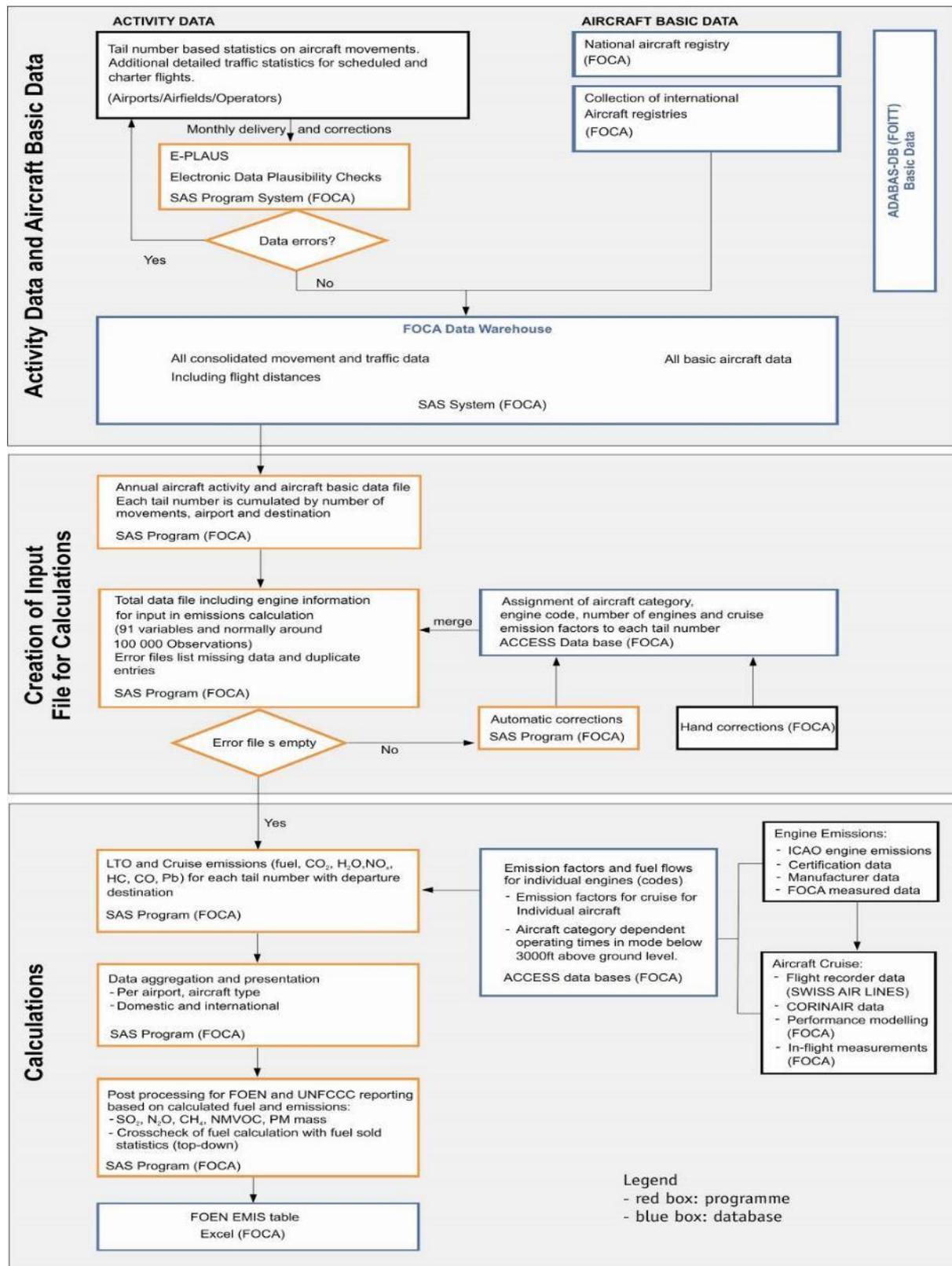


Figure 3-23 Modelling scheme (activity data, emission factors, emissions) for domestic aviation.

A complete emission modelling (LTO and cruise emissions for domestic and international flights) has been carried out by FOCA for 1990, 1995, 2000, 2002, 2004–2021. The results of the emission modelling have been transmitted from FOCA to FOEN in an aggregated form (FOCA 2006a, 2007–2022). FOEN calculated the implied emission factors 1990, 1995, 2000,

2002, 2004 and carried out a linear interpolation for the years in-between. The interpolated implied emission factors were multiplied with the annual fuel sold from Swiss overall energy statistics (SFOE in respective years), providing the missing emissions of domestic aviation for the years 1991–1994, 1996–1999, 2001 and 2003.

Details of emission factors and activity data follow below. Further tables containing more information are also given in Annex A5.1.1, more detailed descriptions of the emission modelling may be found in FOCA (2006).

## Emission factors (1A3a)

### *Landing/take-off (LTO) cycle*

The FOCA engine emissions database consists of more than 800 individual engine data sets. Jet engine factors for engines above 26.7 kN thrust (emission certificated) are identical to the ICAO engine emissions database. Emission factors for lower thrust engines, piston engines and helicopters were taken from manufacturers or from own measurements. Emission factors for turboprops could be obtained in collaboration with the Swedish Defence Research Agency (FOI).

### *Cruise*

The fuel flows of the whole Airbus fleet (which produces a great portion of the Swiss inventory) have been modelled on the basis of real operational aircraft data from flight data recorders (FDR) of Swiss International Airlines. GHG emission factors have been modelled on the basis of the ICAO engine databank and corrected to cruise conditions using FDR engine parameters and the Boeing Fuel Flow Method 2. For older aircraft types (pre-2003), part of the cruise emission factors were taken from the EMEP/EEA guidebook (EMEP/EEA 2019) and from former CROSSAIR (FOCA 1991). For new aircraft type entries, the FOCA models the cruise emission factors based on the aircraft type characteristics and the engine models fitted to the aircraft. The model uses proprietary aircraft information as well as public information from the ICAO engine database. For those aircraft types, which dominate the fuel consumption in Switzerland, flight data recorder information has been used to calibrate emission factors. The factors are updated periodically to take account of flight operational improvements, as well. Calculation results for international aviation emissions are periodically compared to Eurocontrol results. For piston engine aircraft and helicopters, Swiss FOCA has produced its own data, which were taken under real flight conditions (2005 data, FOCA 2009a, FOCA 2015a).

In 2015 and 2016, the FOCA Helicopter Emissions Calculation Guidance has been updated and implemented in the emissions calculation for the 2015 and 2016 emission inventory (FOCA 2015a, 2016a). Since then, FOCA uses engine power specific emission factors for most helicopters, taking into account lower power requirement per engine, if engines are installed in a twin-engine configuration. On top of the few non-public manufacturer data sources, FOCA introduced 80 individual helicopter engine models replacing most of the generic engine assignments.

## Gases

- CO<sub>2</sub>: the emission factor for jet kerosene is country-specific and is based on measurements and analyses of fuel samples (see Table 3-13 and Table 3-72)

- CH<sub>4</sub>, NMVOC (country-specific; CORINAIR): VOC emissions (see section “Precursors” below) of jet kerosene are split into CH<sub>4</sub> and NMVOC by a constant share of 0.1 (CH<sub>4</sub>) and 0.9 (NMVOC) for LTO. For cruise flights, the VOC emissions do not contain CH<sub>4</sub>. The implied emission factor for CH<sub>4</sub> for 2021 is shown in Table 3-72.
- The N<sub>2</sub>O emission factor for jet kerosene corresponds to the default value given by the 2006 IPCC Guidelines (IPCC 2006, Table 3.6.5), see Table 3-72. It is assumed that the emission factor for international cruise is sufficient for all kind of flight periods (LTO and cruise) and remains constant over the entire time period 1990–2021.

*Precursors (further details see Switzerland's Informative Inventory Report (FOEN 2023b))*

- Assignment of emission factors for 1990 and 1995: The fleet that operated in and from Switzerland during those years has been analysed. The corresponding most frequent engines within an aircraft category (ICAO Code) have been assigned to every aircraft type.
- Assignment of emission factors for the year 2000, 2002 and 2004 to 2021: the actual engine of every single aircraft operating in and from Switzerland has been assigned. FOCA uses the aircraft tail number as the key variable which links activity data and individual aircraft engine information (see Annex A5.1.1 Table A – 9 Aircraft Engine Combinations).

FOCA determines the emission factors of different gases as given in Table 3-72.

Table 3-72 Implied emission factors of 1A3a in 2021. Emission factors that are highlighted in green are described in chp. 3.2.4.4.

1A3a/1D1 Civil aviation	CO <sub>2</sub> fossil	CO <sub>2</sub> biogenic	CH <sub>4</sub>	N <sub>2</sub> O	NO <sub>x</sub>	NMVOC	SO <sub>2</sub>	CO
	kg/TJ							
1A3a Domestic aviation								
1A3a Domestic aviation, LTO, Kerosene fossil	72'800	NA	19	2.0	208	175	18	5'254
1A3a Domestic aviation, CR, Kerosene fossil	72'800	NA	NA	2.0	252	85	22	832
1D1 International aviation (not part of national total)								
1D1 International aviation, LTO, Kerosene fossil	72'800	NA	2.9	2.0	332	26	23	280
1D1 International aviation, LTO, Kerosene biogenic	NA	72'800	2.5	2.0	358	23	23	258
1D1 International aviation, CR, Kerosene fossil	72'800	NA	NA	2.0	427	4.2	23	47
1D1 International aviation, CR, Kerosene biogenic	NA	72'800	NA	2.0	454	3.7	23	41

### Activity data (1A3a)

The statistical basis has been extended after 1996. Therefore, the modelling details are not exactly the same for the years 1990/1995 as for the subsequent years. The source for the 1990 and 1995 modelling are the movement statistics, which record information for every movement on airline, number of seats, Swiss airport, arrival/departure, origin/destination, number of passengers, distance. From 1996 onwards, every movement in the FOCA statistics also contains the individual aircraft tail number (aircraft registration). This is the key variable to connect airport data and aircraft data. The FOCA activity data contain both, instrument flight rules (IFR) traffic and visual flight rules (VFR) traffic. As visual flight rules

traffic dominates the domestic flight activity, a complete inclusion of visual flight rules traffic is important. The statistics may contain more than one million records with individual tail numbers. All annual aircraft movements recorded are split into domestic and international flights. There are 191'219 aircraft movements in the total of scheduled and charter traffic in 2021 (FSO 2022j). The number of aircraft movements in 2020 and 2021 was clearly lower than usual due to the COVID-19 pandemic (e.g. 2019: 469'667, 2020: 166'758 movements), which also leads to a strong reduction of fuel consumption from civil aviation (see Table 3-73).

#### *Handling of small aircraft and helicopters*

- Airports and most of the airfields report individual aircraft data (aircraft registration). FOCA may therefore compute the inventory for small aircraft with a Tier 3A method, too. However, for 1990 and 1995, the emissions data for non-scheduled, non-charter and General Aviation (helicopters etc.) could not be calculated with a Tier 3A method. Its fuel consumption is estimated to be 10 % of the domestic fuel consumption. Data were taken from two FOCA studies (FOCA 1991, FOCA 1991a). For 2000–2007, all movements from airfields are known, which allows a more detailed modelling of the emissions (FOCA 2007a).
- Helicopter flights which do not take off from an official airport or airfield such as transport flights, flights for lumbering, animal transports, supply of alpine huts, heli-skiing and flight trainings in alpine regions cannot be recorded with the movement data base from airports and airfields. These emissions are taken into account using the statistics of the Swiss Helicopter Association (Unternehmensstatistik der Schweizer Helikopterunternehmen). These statistics are officially collected by FOCA and updated annually (see FOCA 2004 as illustrative example for all subsequent years). In this case, emissions are calculated based on operating hours of the helicopters, with emission factors taken from the helicopter study (see FOCA 2015a).
- Since 2007, the data of these helicopter statistics are included electronically in the data warehouse of the model and undergo first some plausibility checks (E-plaus software). In order to distinguish between single engine helicopters and twin-engine helicopters a fix split of 87 % for single engine helicopters and 13 % for twin engine helicopters has been applied for the entire commitment period until 2014 based on investigations in 2004 (FOCA 2004). Since 2015, the statistics allows to assign the individual helicopters to the helicopter companies. All emissions from helicopter flights without using an official airport or an official airfield are considered domestic emissions.

#### *Fuel consumption*

Table 3-73 summarises the activity data for 1A3a Civil aviation. It also includes international aviation, which belongs to the memo items, international bunkers/aviation (1D1, see also chp. 3.2.2). In order to split the fuel consumption for domestic and international flights, the FOCA calculates the fuel for each domestic and international flight bottom-up. A first validation of this calculation can be done top down for the sum of all flights: The total annual aviation fuel sold known from robust energy statistics in a country should correspond very closely (within a few percent) to the modelled total fuel consumption of domestic and international flights together. In 2021 and 2020, in contrast to the years before, the modelled total fuel consumption in Switzerland was clearly higher than the fuel sold value (2021: 9.8 %), so the model showed a clear overestimation. For domestic aviation, the statistical data did not show systematic changes, which could have caused differences to the modelling of pre 2020 years. However, for international aviation, which is dominated by large and scheduled aircraft in Switzerland, FOCA investigation revealed a much lower load factor in

2020 and 2021 due to the COVID-19 pandemic. The model fully accounts for the individual aircraft flying but calculates the fuel burn of normally loaded aircraft. In fact, many aircraft were flying lighter than usual, thus burning less fuel than usual on a given distance, which explains the 9.8 % difference observed in 2021. A small additional effect reported by a Swiss carrier were more direct routes in Europe due to the low traffic volume, especially in 2020. A cross comparison for the modelled difference for international aviation was done with Eurocontrol calculations for Switzerland's international flights, where the same phenomenon (overestimation by the model) was observed by Eurocontrol. For domestic flights, FOCA takes every movement including the smallest aircraft into account and applies conservative emission factors. An indication of this is the fact that Eurocontrol calculations for Switzerland's domestic flight fuel consumption is usually only around half the value reported by Switzerland. In summary, Switzerland reports the domestic fuel consumption according to the modelled value, whereas the international fuel consumption (bunker) is scaled downwards so that the sum of domestic and international fuel consumption becomes identical with the fuel sold, as reported in the Swiss overall energy statistics.

Since 2021, sustainable aviation fuels (SAF) are reported from Zurich airport and attributed to international flights. The amount is very small compared to the amount of fossil jet fuel.

Table 3-73 Fuel consumption of civil aviation in TJ separated for domestic/international and LTO/cruise. Domestic consumption and the corresponding emissions are reported under 1A3a, international consumption is reported under Memo items, international bunkers. Sustainable aviation fuels (SAF) are referred to as kerosene biogenic. (FOCA 2007, 2007a, 2008–2022).

1A3a/1D1 Civil aviation	1990	1995	2000	2005	2010
	Fuel consumption in TJ				
1A3a Domestic aviation	3'450	3'075	2'541	1'702	1'694
1A3a Domestic aviation, LTO, Kerosene fossil	1'050	935	773	518	464
1A3a Domestic aviation, CR, Kerosene fossil	2'401	2'139	1'768	1'184	1'230
1D1 International aviation (not part of national total)	41'884	49'918	63'726	47'775	58'334
1D1 International aviation, LTO, Kerosene fossil	4'277	5'097	6'507	4'878	5'643
1D1 International aviation, LTO, Kerosene biogenic	NO	NO	NO	NO	NO
1D1 International aviation, CR, Kerosene fossil	37'608	44'821	57'219	42'896	52'691
1D1 International aviation, CR, Kerosene biogenic	NO	NO	NO	NO	NO
Total 1A3a/1D1 Civil aviation	45'334	52'993	66'267	49'477	60'028
1990 = 100%	100%	117%	146%	109%	132%

1A3a/1D1 Civil aviation	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
	Fuel consumption in TJ									
1A3a Domestic aviation	1'875	1'817	1'921	1'887	1'932	1'641	1'579	1'571	1'056	811
1A3a Domestic aviation, LTO, Kerosene fossil	504	494	525	387	421	384	346	321	170	183
1A3a Domestic aviation, CR, Kerosene fossil	1'371	1'323	1'396	1'500	1'511	1'257	1'234	1'250	886	628
1D1 International aviation (not part of national total)	63'903	64'709	65'006	67'333	70'603	72'824	77'214	78'196	28'194	31'872
1D1 International aviation, LTO, Kerosene fossil	6'226	6'208	6'142	6'459	6'529	6'728	6'953	6'963	2'395	2'718
1D1 International aviation, LTO, Kerosene biogenic	NO	NO	NO	NO	NO	NO	NO	NO	NO	2.0
1D1 International aviation, CR, Kerosene fossil	57'677	58'501	58'864	60'874	64'073	66'096	70'261	71'233	25'799	29'129
1D1 International aviation, CR, Kerosene biogenic	NO	NO	NO	NO	NO	NO	NO	NO	NO	24
Total Civil aviation	65'778	66'526	66'927	69'220	72'534	74'465	78'793	79'767	29'250	32'683
1990 = 100%	145%	147%	148%	153%	160%	164%	174%	176%	65%	72%

### 3.2.9.2.2. Road transportation (1A3b)

#### Methodology (1A3b)

##### *Choice of method*

- The CO<sub>2</sub> emissions are calculated by a Tier 2 method based on the decision tree Fig. 3.2.2 in chp. 3. Mobile Combustion in IPCC (2006).
- The CH<sub>4</sub> and the N<sub>2</sub>O emissions are calculated by a Tier 3 method based on the decision tree Fig. 3.2.3 in chp. 3. Mobile Combustion in IPCC (2006).
- The use of urea in urea-based catalysts is reported in chp. 4.5.2.2 under Urea use in SCR catalysts of diesel engines (2D3d) as recommended in the reporting table's footnotes.
- CO<sub>2</sub> emissions from the use of lubricants as an additive in 2-stroke motorcycles are reported in chp. 4.5.2.1 under 2D1 Non-energy products from fuels and solvent use / lubricant use. Non-CO<sub>2</sub> emissions are reported under 1A3biv.

##### *Connections between road model, non-road model and Swiss overall energy statistics*

For the source categories related to transport, INFRAS developed a territorial emission model for 1A3b Road transportation and a model for non-road vehicles and machinery (mobile sources categories 1A2gvii, 1A3c, 1A3d, 1A4aii, 1A4bii, 1A4cii, 1A5b excl. military aviation). The general method of the road transportation model is described in the following paragraphs and Annex A5.1.2 (INFRAS 2017c, INFRAS 2019a, Matzer et al. 2019, Notter et al. 2022).

Due to fluctuating fuel price differences in the vicinity of the national borders, gas stations sell varying amounts of fuels to foreign car owners. This amount of fuel is referred to as “fuel tourism”. Fuel tourism is not captured by the territorial road transportation model.

The Swiss overall energy statistics (SFOE 2022) provide information on the total amount of fuel sold, i.e. the sum of territorial consumption **and** fuel tourism. From the amount of fuel sold, the consumption modelled by the territorial road and non-road models – i.e. fuel used – is subtracted. The resulting difference represents the amount of fuel tourism plus statistical differences. The amount of fuel tourism is regularly estimated in ex-post analyses, latest update by SFOE (2022e). The results for fuel tourism clearly show that the difference between fuels sales and fuels determined by the traffic model tend to overestimate the “true” fuel tourism. It is concluded that the difference also contains potential underestimation of the mileage and other statistical biases. Therefore, the difference between fuel sold and fuel used in the traffic model is indicated in the NID as “fuel tourism and statistical differences”. The value for fuel tourism can be negative (in case of net fuel imports – e.g. the case for diesel oil in the years 2015–2021 since it was cheaper in the neighbouring countries) or positive (in case of net fuel exports – the case for gasoline in most years, since it is cheaper in Switzerland). It is assumed that no fuel tourism takes place with non-road vehicles and therefore the fuel tourism and the statistical difference is attributed to 1A3b Road transportation for gasoline, diesel oil, natural gas, bioethanol and biodiesel (see Figure 3-9, Figure 3-16 and Figure 3-19). The statistical difference for biogas is attributed to 1A4ai Other sectors (stationary) – commercial/institutional (see Figure 3-18) and the one from liquefied petroleum gas to 1A2gvii Other (boilers) (see Figure 3-13). In the reporting tables, activity data and emissions from fuel tourism and statistical difference are reported in the most appropriate categories. In submission 2023, the CRF reporter produced an error due to negative values in some source categories for some years for CH<sub>4</sub>. The negative values

occurred because of the way the fuel tourism and statistical difference was integrated in the reporting tables (CRF Table 1.A(a)s3). Therefore, the distribution of fuel tourism amongst the source categories 1A3bi, 1A3bii and 1A3biii had to be changed. The new distribution is not intuitive for diesel oil and gaseous fuels, but there is currently no other solution which does not lead to an error from the CRF reporter. The distribution of fuel tourism and statistical differences does not affect total fuels sold and has no effect on the total emissions reported. The distribution is conducted as follows:

- Emissions from gasoline: fuel tourism and statistical difference is proportionally distributed amongst source categories 1A3bi, 1A3bii and 1A3biii according to annual consumption data within these categories.
- Emissions from diesel oil: fuel tourism and statistical difference is distributed amongst source categories 1A3bi and 1A3biii. The distribution is conducted in proportion to annual consumption data within these two source categories, but due to negative CH<sub>4</sub> emission values, 25 % of the fuel tourism had to be reallocated from source category 1A3biii to category 1A3bi for all years.
- Emissions from gaseous fuels: fuel tourism and statistical difference is completely allocated to source category 1A3biii.
- Emissions from biomass: fuel tourism and statistical difference is proportionally distributed amongst source categories 1A3bi, 1A3bii and 1A3biii according to annual consumption data within these categories.

Figure 3-24 shows how the models and the Swiss overall energy statistics are linked to determine the GHG emissions from road and non-road transportation:

- CO<sub>2</sub> emissions are calculated by using fuel sales and country-specific CO<sub>2</sub> emission factors.
- CH<sub>4</sub> and N<sub>2</sub>O emissions are calculated in three steps (the same procedure also applies to precursor gases):
  - From fuel used and country-specific CH<sub>4</sub> and N<sub>2</sub>O emission factors, the territorial emissions are calculated.
  - The differences between fuels sold and fuels used (territorial) are interpreted as fuel tourism and statistical differences. These amounts of gasoline and diesel oil are multiplied with implied CH<sub>4</sub> and N<sub>2</sub>O emission factors, which are deduced from the territorial road transportation model (including weighted averages over all vehicle categories), to form the CH<sub>4</sub> and N<sub>2</sub>O emissions resulting from fuel tourism and statistical differences.
  - The sum of CH<sub>4</sub> and N<sub>2</sub>O emissions from the territorial model and CH<sub>4</sub> and N<sub>2</sub>O from fuel tourism and statistical differences represents the total CH<sub>4</sub> and N<sub>2</sub>O emissions as reported in 1A3b Road transportation.

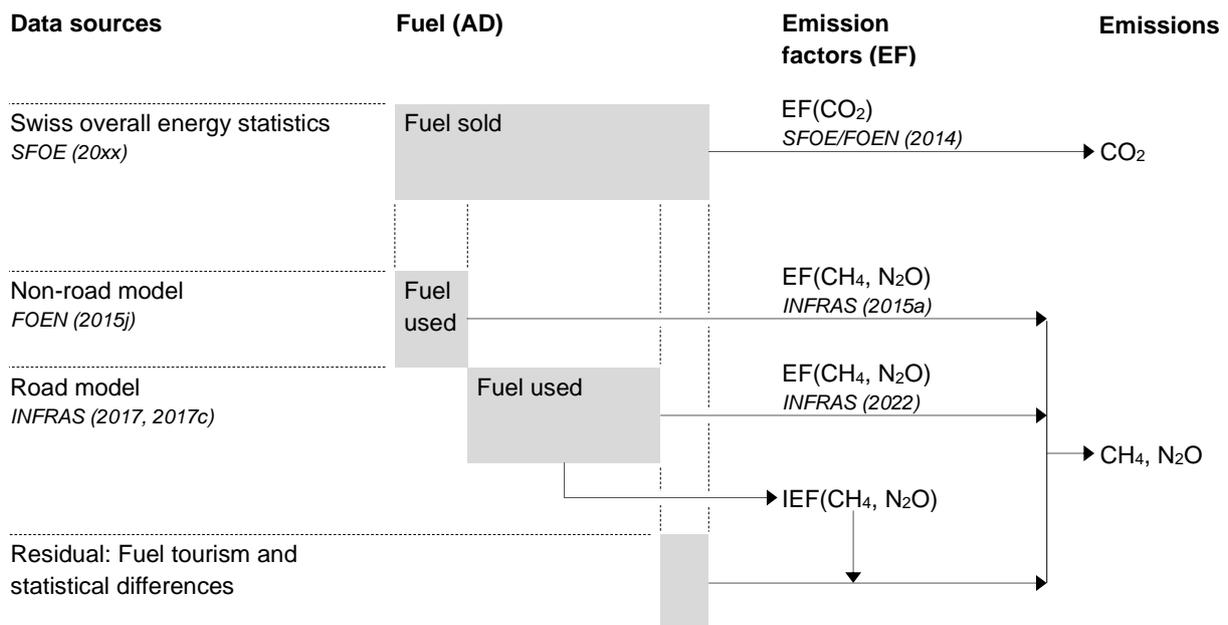


Figure 3-24 Connections between fuel sold and fuel used for road and non-road transportation. Fuel sold is provided by the Swiss overall energy statistics (minus Liechtenstein's gasoline and diesel oil consumption and bunker fuels for navigation). Fuel used results from the territorial road and non-road models. The residual fuel consists of fuel tourism and statistical differences. Its emissions are calculated by means of implied emission factors deduced from the territorial road model. The diagram holds separately for gasoline and diesel oil. SFOE (20xx) stands for the latest Swiss overall energy statistics.

#### Methodology of the territorial road transportation model

The emission computation is based on two sets of data:

- Emission factors: specific emissions in grams per activity data unit.
- Traffic activity data:
  - vehicle kilometres travelled (hot emissions, evaporative losses during operation)
  - number of starts/stops
  - vehicle stock (cold start, evaporative losses from gasoline passenger cars, light duty vehicles and motorcycles)
  - fuel consumption per vehicle category

Emissions are calculated as follows:

- Hot emissions:  $E_{hot} = VKT \cdot EF_{hot}$
- Cold start excess emissions:  $E_{start} = N_{start} \cdot EF_{start}$
- Evaporation soak and diurnal VOC emissions:  $E_{evap,i} = N_{evap,i} \cdot EF_{evap,i}$ ,
- Evaporation running VOC losses:  $E_{evap-RL} = VKT \cdot EF_{Evap-RL}$

with

- $EF_{hot}$ ,  $EF_{start}$ ,  $EF_{evap,i}$ ,  $EF_{evap-RL}$ : Emission factors for ordinary driving conditions (hot engine), cold start excess emissions, and evaporative (VOC) emissions (after stops, diurnal losses, and running losses)
- $VKT$ : Vehicle km travelled

- $N_{start}$ : Number of starts
- $N_{evap,i}$ : Number of stops, or number of vehicles.  $i$  runs over two evaporation categories:
  - a) evaporation soak emissions, i.e. emissions after stopping when the engine is still hot; and
  - b) evaporation diurnal emissions, i.e. emissions due to daily air temperature differences. For a) the corresponding activity is the number of stops, for b) it is the number of vehicles.

Emission factors are differentiated for all fuel types: Gasoline (4-stroke), gasoline (2-stroke), diesel oil, liquefied petroleum gas bioethanol, biodiesel, gas (CNG), biogas. In terms of vehicle categories, the emission factors are weighted according to the fleet composition in Switzerland (within HBEFA).

CO<sub>2</sub> emissions from lubricant use in 2-stroke engines are calculated from the gasoline consumption of 2-stroke motorcycles, assuming a lubricant content of 2 % in the gasoline. Note that the road transportation model distinguishes 2-stroke (including 2 % lubricant) and 4-stroke gasoline (without lubricant). It is assumed that the whole amount of lubricant is being oxidised. The resulting CO<sub>2</sub> emissions are reported in source category 2D1 Lubricant use. In contrast, CH<sub>4</sub> and N<sub>2</sub>O emissions from lubricant use are reported in source category 1A3biv, since the emission factors are deduced from measurements on motorcycles including 2-stroke engines.

Cold start excess emissions for N<sub>2</sub>O were originally not accounted for in the model described. During the in-country review in 2016, the ERT identified a potential underestimation. Switzerland therefore estimated N<sub>2</sub>O cold start excess emissions for passenger cars and light duty vehicles by means of emission factors from the EMEP/EEA guidebook, as recommended by the ERT. The corresponding emission factors per Euro class are documented in the EMEP/EEA guidebook on p. 72 ff. (EMEP/EEA 2019).

## Emission factors (1A3b)

### CO<sub>2</sub>

- The country-specific CO<sub>2</sub> emission factors are described in chp. 3.2.4.4.2. Values are shown in Table 3-13 (gasoline, diesel oil, biofuels) and in Table 3-14 (natural gas, biogas). The values in 2021 are also shown in Table 3-74.
- The same emission factors are also applied for the calculation of the emissions resulting from fuel tourism and statistical differences.
- Emission factors for 2-stroke gasoline: For the gasoline part of the fuel, the CO<sub>2</sub> emission factor for gasoline according to Table 3-13 is applied. For the lubricant part of the fuel, the IPCC default CO<sub>2</sub> emission factor for lubricants is applied (see Table 4-38, IPCC 2006). The resulting emissions from the gasoline part are reported under 1A3biv, the emissions from the lubricant part, however, under source category 2D1 Lubricant use (see chp. 4.5.2.1).

### CH<sub>4</sub>

- Country-specific emission factors are applied. For details including data sources see below ("*Country-specific emission factors*"). Emission factors are applied based on HBEFA 4.2 (INFRAS 2022).

- CH<sub>4</sub> emissions from fuel tourism and statistical difference: From the territorial model, implied emission factors for CH<sub>4</sub> are derived per fuel type corresponding to mean emission factors for Switzerland including all vehicle categories (see Figure 3-24). These factors are then applied to calculate the emissions resulting from fuel tourism. This approach has been verified by comparing implied emission factors with the neighbouring countries (see chp. 3.2.9.4).
- For biofuels, no country-specific emission factors for CH<sub>4</sub> are available. Therefore, the same emission factors as for fossil fuels have been used (e.g. emission factor for gasoline was used for bioethanol, and emission factor for diesel oil for biodiesel).

## N<sub>2</sub>O

- N<sub>2</sub>O emissions from territorial traffic under hot operating condition: Country-specific emission factors are used, details see below (INFRAS 2022).
- Cold start N<sub>2</sub>O emission factors for gasoline, diesel oil, natural gas and liquefied petroleum gas vehicles are based on the EMEP/EEA guidebook (EMEP/EEA 2019) (see Annex A5.1.2 for details).
- N<sub>2</sub>O emissions from fuel tourism and statistical difference: The same approach as for CH<sub>4</sub> is applied (see paragraph above) by means of mean emission factors (country-specific).
- For biofuels no country-specific emission factors for N<sub>2</sub>O are available. Therefore, the same emission factors as for fossil fuels have been used (e.g. emission factor for gasoline was used for bioethanol, and emission factor for diesel oil for biodiesel).

### *Country-specific emission factors*

Emission factors for gases other than CO<sub>2</sub> are derived from “emission functions” which are determined from a compilation of measurements from various European countries with programmes using similar driving cycles (legislative as well as standardized real-world cycles, like “Common Artemis Driving Cycle” (CADC)). The method was developed in 1990–1995 and has been extended and updated in 2000, 2004, 2010, 2017, 2019 and latest 2022. These emission factors are compiled in the “Handbook of Emission Factors for Road Transport” (HBEFA, see INFRAS 2022). The latest version 4.2 is presented on the website (<http://www.hbefa.net/>) and documented in Notter et al. 2022. Further descriptions can also be found in the former publication INFRAS (2017c), INFRAS (2019a) and Matzer et al. (2019). The emission factors are differentiated by so-called “traffic situations”, which represent characteristic patterns of driving behaviour determined by road type, speed limit, area type (rural/urban), traffic density, and road gradient. They serve as a key to the disaggregation of the activity data. The underlying database contains dynamic fleet compositions simulating the release of new exhaust technologies and the fading out of old technologies. Further details are shown in Annex A5.1.2.

### *Implied emission factors for GHG and precursors*

The following Table 3-74 presents mean emission factors for GHG and precursors in 2021 in kg per TJ fuel consumption. More or less pronounced decreases of the emission factors have occurred in the last years due to new emission regulations and subsequent new exhaust technologies (optimized combustion, use of catalytic converters, particle filters, lower limits for sulphur content in diesel fuels). Early models of catalytic converters represented substantial sources of N<sub>2</sub>O, leading to an emission increase of this gas until 1998. More

recent converter technologies have overcome this problem resulting in a decrease of the (mean) emission factor.

Table 3-74 Implied emission factors in 2021 for road transportation. For more details see Annex A5.1.2. The implied emission factors in the reporting tables (CRF) are slightly different because of the distribution of fuel tourism and statistical differences in the reporting tables (see chapter 3.2.9.2.2).

<b>1A3b Road Transportation Gasoline / Bioethanol</b>		<b>CO<sub>2</sub></b>	<b>CH<sub>4</sub></b>	<b>N<sub>2</sub>O</b>	<b>NO<sub>x</sub></b>	<b>NM VOC</b>	<b>SO<sub>2</sub></b>	<b>CO</b>
		kg/TJ						
1A3bi	Passenger cars	73'800	3.8	0.63	32	46	0.26	545
1A3bii	Light duty vehicles	73'800	10	2.3	86	121	0.26	2535
1A3biii	Heavy duty vehicles	73'800	19	0.81	781	552	0.26	666
1A3biv	Motorcycles	73'800	55	1.2	73	248	0.26	1911
1A3bv	Other, gasoline evaporation	NO	NO	NO	NO	24	NO	NO
1A3bi-iii	Fuel tourism and statistical differences	73'800	5.9	0.68	35	80	0.26	627
<b>1A3b Road Transportation Diesel oil / Biodiesel</b>		<b>CO<sub>2</sub></b>	<b>CH<sub>4</sub></b>	<b>N<sub>2</sub>O</b>	<b>NO<sub>x</sub></b>	<b>NM VOC</b>	<b>SO<sub>2</sub></b>	<b>CO</b>
		kg/TJ						
1A3bi	Passenger cars	73'300	4.0	3.7	239	3.7	0.33	46
1A3bii	Light duty vehicles	73'300	1.6	2.5	281	1.7	0.33	47
1A3biii	Heavy duty vehicles	73'300	0.06	3.9	137	2.6	0.33	55
1A3biv	Motorcycles	NO	NO	NO	NO	NO	NO	NO
1A3bv	Other, gasoline evaporation	NO	NO	NO	NO	NO	NO	NO
1A3bi-iii	Fuel tourism and statistical differences	73'300	2.4	3.5	210	3.0	0.33	48
<b>1A3b Road Transportation Natural gas / Biogas</b>		<b>CO<sub>2</sub></b>	<b>CH<sub>4</sub></b>	<b>N<sub>2</sub>O</b>	<b>NO<sub>x</sub></b>	<b>NM VOC</b>	<b>SO<sub>2</sub></b>	<b>CO</b>
		kg/TJ						
1A3bi	Passenger cars	55'900	15	4.5	27	1.3	NA	167
1A3bii	Light duty vehicles	55'900	7.1	14	14	0.62	NA	1283
1A3biii	Heavy duty vehicles	55'900	25	NE	207	2.2	NA	64
1A3biv	Motorcycles	NO	NO	NO	NO	NO	NO	NO
1A3bv	Other, gasoline evaporation	NO	NO	NO	NO	NO	NO	NO
1A3bi-iii	Fuel tourism and statistical differences	55'900	19	3.5	103	1.6	NA	232
<b>1A3b Road Transportation Liquefied petroleum gas</b>		<b>CO<sub>2</sub></b>	<b>CH<sub>4</sub></b>	<b>N<sub>2</sub>O</b>	<b>NO<sub>x</sub></b>	<b>NM VOC</b>	<b>SO<sub>2</sub></b>	<b>CO</b>
		kg/TJ						
1A3bi	Passenger cars	65'500	1.1	1.2	24	1.8	NA	327
1A3bii	Light duty vehicles	NO	NO	NO	NO	NO	NO	NO
1A3biii	Heavy duty vehicles	NO	NO	NO	NO	NO	NO	NO
1A3biv	Motorcycles	NO	NO	NO	NO	NO	NO	NO
1A3bv	Other, gasoline evaporation	NO	NO	NO	NO	NO	NO	NO
1A3bi-iii	Fuel tourism and statistical differences	NO	NO	NO	NO	NO	NO	NO

### Activity data (1A3b)

#### *Energy-related activity data (basis for modelling the CO<sub>2</sub> emissions)*

The Swiss overall energy statistics (SFOE 2022) provides the amount of liquid fuels (gasoline, diesel oil) and gaseous fuels (CNG) sold in Switzerland for road transportation. From the amount of liquid fuels sold, Liechtenstein's sales, Switzerland's non-road consumption, bunker fuel emissions and fugitive emissions from transmission, storage and fuelling of gasoline (reported under 1B2av Distribution of oil products) are subtracted. Amounts of liquefied petroleum gas used for road transportation are very small and not provided in the Swiss overall energy statistics. Therefore, the liquefied petroleum gas consumption for road transportation is entirely based on the road transportation model.

The consumption of biofuels is based on the Swiss overall energy statistics (SFOE 2022), the Swiss renewable energy statistics (SFOE 2022a) and the Federal Office for Customs and Border Security (FOCBS 2022). The NCV of biogas is assumed to be equal to the NCV of

natural gas since the raw biogas is treated to reach the same quality level including its energetic properties as natural gas (see NCV time series for natural gas and biogas in Table 3-11).

Table 3-75 shows the split of fuel sales into territorial road transportation model, the territorial non-road transportation model and fuel tourism including statistical differences.

- The relevant numbers for 1A3b Road transportation are given as two different contributions in the rows “on road fuel consumption (model)” and “fuel tourism and statistical differences”.
- Consumption of biofuels for road transportation (biodiesel, bioethanol and biogas) starts in Switzerland in 1997.

Table 3-75 Split of fuel sales between territorial “on-road consumption (model)”, “non-road consumption (models)” and “fuel tourism and statistical differences” (residual value to sold amounts) for gasoline, diesel oil, natural gas (CNG), liquefied petroleum gas, and biofuels (vegetable/waste oil is included in the numbers of Biodiesel) in PJ. Numbers may not add to totals due to rounding.

Activity data for on-road and non-road categories	Source category	1990	1995	2000	2005	2010					
		PJ									
<b>Gasoline</b>											
on-road consumption (model)	1A3b	137	135	147	136	120					
fuel tourism and statistical differences	1A3b	16	14	19	13	12					
non-road consumption (models)	1A2gvii; 1A3dii; 1A4aii,bii,cii; 1A5b	2.4	2.4	2.3	2.1	1.9					
Gasoline sold in Switzerland		156	151	168	152	134					
<b>Diesel oil</b>											
on-road consumption (model)	1A3b	38	41	47	60	81					
fuel tourism and statistical differences	1A3b	-2.0	-6.0	-5.8	-1.9	1.5					
non-road consumption (models)	1A2gvii; 1A3c,dii; 1A4cii; 1A5b	11	12	14	14	15					
Diesel oil sold in Switzerland		47	48	55	73	98					
<b>Natural gas</b>											
on-road consumption (model)	1A3b	NO	NO	NO	0.052	0.54					
fuel tourism and statistical differences	1A3b	NO	NO	NO	0.038	0.17					
non-road consumption (models)		NO	NO	NO	NO	NO					
Natural gas sold in on- and non-road categories in Switzerland		NO	NO	NO	0.090	0.71					
<b>Liquefied petroleum gas (LPG)</b>											
on-road consumption (model)	1A3b	NO	NO	NO	NO	NO					
non-road consumption (models)	1A2gvii	0.17	0.25	0.29	0.29	0.27					
Liquefied petroleum gas sold in on- and non-road categories in Switzerland		0.17	0.25	0.29	0.29	0.27					
<b>Biodiesel</b>											
on-road consumption (model)	1A3b	NO	NO	0.042	0.18	0.30					
non-road consumption (models)	1A2gvii; 1A3c,dii; 1A4cii; 1A5b	NO	NO	0.017	0.050	0.064					
Biodiesel sold in Switzerland		NO	NO	0.060	0.23	0.37					
<b>Bioethanol</b>											
on-road consumption (model)	1A3b	NO	NO	NO	0.019	0.055					
non-road consumption (models)	1A2gvii; 1A3dii; 1A4bii; cii; 1A5b	NO	NO	NO	NO	0.000037					
Bioethanol sold in Switzerland		NO	NO	NO	0.019	0.055					
<b>Biogas</b>											
on-road consumption (model)	1A3b	NO	NO	NO	0.030	0.13					
non-road consumption (models)		NO	NO	NO	NO	NO					
Biogas sold in Switzerland		NO	NO	NO	0.030	0.13					

Activity data for on-road and non-road categories	Source category	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
		PJ									
<b>Gasoline</b>											
on-road consumption (model)	1A3b	111	106	102	97	94	91	89	87	77	79
fuel tourism and statistical differences	1A3b	11	11	10	6.5	7.0	6.1	6.7	7.7	6.8	6.5
non-road consumption (models)	1A2gvii; 1A3dii; 1A4aii,bii,cii; 1A5b	1.8	1.8	1.7	1.7	1.7	1.6	1.6	1.6	1.6	1.6
Gasoline sold in Switzerland		124	119	114	106	102	99	98	97	86	88
<b>Diesel oil</b>											
on-road consumption (model)	1A3b	90	96	100	103	106	107	106	107	98	102
fuel tourism and statistical differences	1A3b	1.50	1.2	0.0	-5.1	-7.0	-7.6	-5.5	-6.3	-3.5	-6.0
non-road consumption (models)	1A2gvii; 1A3c,dii; 1A4cii; 1A5b	15	15	15	15	15	15	15	15	15	15
Diesel oil sold in Switzerland		107	111	114	113	114	114	115	115	109	110
<b>Natural gas</b>											
on-road consumption (model)	1A3b	0.39	0.39	0.40	0.39	0.41	0.39	0.41	0.40	0.34	0.37
fuel tourism and statistical differences	1A3b	0.29	0.31	0.27	0.24	0.19	0.18	0.18	0.18	0.18	0.17
non-road consumption (models)		NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Natural gas sold in on- and non-road categories in Switzerland		0.68	0.70	0.67	0.63	0.60	0.57	0.59	0.58	0.52	0.54
<b>Liquefied petroleum gas (LPG)</b>											
on-road consumption (model)	1A3b	0.015	0.015	0.015	0.018	0.020	0.021	0.020	0.019	0.021	0.021
non-road consumption (models)	1A2gvii	0.25	0.24	0.23	0.23	0.21	0.20	0.19	0.18	0.17	0.16
Liquefied petroleum gas sold in on- and non-road categories in Switzerland		0.27	0.26	0.25	0.24	0.23	0.22	0.21	0.20	0.19	0.18
<b>Biodiesel</b>											
on-road consumption (model)	1A3b	0.29	0.23	0.50	1.2	2.5	4.2	5.9	6.0	5.4	4.2
non-road consumption (models)	1A2gvii; 1A3c,dii; 1A4cii; 1A5b	0.13	0.16	0.19	0.23	0.29	0.36	0.43	0.49	0.56	0.63
Biodiesel sold in Switzerland		0.42	0.39	0.70	1.5	2.8	4.5	6.3	6.4	5.9	4.8
<b>Bioethanol</b>											
on-road consumption (model)	1A3b	0.093	0.078	0.162	0.58	0.79	0.97	1.2	1.3	1.3	1.7
non-road consumption (models)	1A2gvii; 1A3dii; 1A4bii; cii; 1A5b	0.0043	0.0065	0.0086	0.011	0.017	0.023	0.029	0.035	0.041	0.046
Bioethanol sold in Switzerland		0.097	0.08	0.170	0.59	0.80	1.00	1.2	1.4	1.3	1.7
<b>Biogas</b>											
on-road consumption (model)	1A3b	0.10	0.12	0.11	0.12	0.12	0.13	0.12	0.12	0.13	0.13
non-road consumption (models)		NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Biogas sold in Switzerland		0.10	0.12	0.11	0.12	0.12	0.13	0.12	0.12	0.13	0.13

*Mileage-related activity data (basis for modelling of the non-CO<sub>2</sub> emissions by means of a traffic model)*

The activity data are derived from different data sources:

- Vehicle stock: The federal vehicle registration database IVZ (run by the Federal Roads Office FEDRO) contains vehicle stock data including all parameters needed for the emission modelling (vehicle category, engine capacity, fuel type, total weight, vehicle age and exhaust technology). The data are not public, but the overall vehicle stock numbers are published by the Federal Statistical Office (FSO 2022e). With the help of a fleet turnover model, the vehicle categories are assigned emission standards based on age and thereby split up into “sub-segments”, which are used to link with the specific emission factors of the same categorisation (vehicle category, size class, fuel type, emission standard [“Euro classes”]).
- The specific mileage per vehicle category is an input from the Federal Statistical Office (FSO 2022e, 2022f). It is based on periodical surveys/Mikrozensus (ARE 2002, ARE/SFSO 2005, 2012, 2017). By means of the vehicle stock data (see paragraph above), the specific mileage per vehicle category can be derived (FSO 2022e, SFOE 2022e, INFRAS 2017).
- Numbers of starts/stops: Derived from vehicle stock and periodical surveys/Mikrozensus (ARE/SFSO 2005, 2012, 2017).

The total mileage of each vehicle category is differentiated by “traffic situations” (characteristic patterns of driving behaviour) and gradients, which serve as a key to select the appropriate emission factors, which are also available per traffic situation and gradient. The relative shares of the traffic situations and gradients are derived from a national road traffic model (operated by the Federal Office of Spatial Development, see ARE 2016). The traffic model is based on an origin-destination matrix that is assigned to a network of about 20'000 road segments. The model is calibrated partly bottom-up and partly top-down: bottom-up by a number of traffic counts from the national traffic-counter network, and top-down by the total of the mileage per vehicle category. The assignment of traffic situations and gradients to the modelled mileage is described in INFRAS (2017). The traffic model in combination with consumption factors (per vehicle category, size class, fuel type, emissions standard and per traffic situation) allows to calculate the territorial road traffic consumption of gasoline and diesel oil.

Table 3-76 shows the time series of the mileage per vehicle category. The total mileage has constantly been increasing since 1995. This trend was halted in 2020 and 2021, as total mileages decreased compared to the years before due to the restrictions related to the COVID-19 pandemic. In 2021 total mileages increased again compared to 2020, but were still lower than before 2020. The major part of vehicle kilometres was driven by passenger cars over the whole period. In the same period, on-road fuel consumption increased less strongly, indicating improved fuel efficiency. This effect is also reflected in Table 3-77 that shows the specific fuel consumption per vehicle-km. Average consumption and the specific consumption for most of the vehicle categories have decreased in the period 1990–2021.

Table 3-76 Mileages in millions of vehicle kilometres. PC: passenger cars, LDV: light duty vehicles, HDV: heavy duty vehicles).

Veh. category	1990	1995	2000	2005	2010
	million vehicle-km				
PC	42'649	41'324	45'613	48'040	52'066
LDV	2'600	2'746	2'957	3'228	3'502
HDV	1'992	2'107	2'273	2'120	2'226
Coaches	108	110	99	106	118
Urban Bus	174	192	200	229	244
2-Wheelers	2'025	1'563	1'700	1'785	1'852
Sum	49'548	48'043	52'841	55'507	60'009
(1990=100%)	100%	97%	107%	112%	121%

Veh. category	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
	million vehicle-km									
PC	53'721	54'695	55'641	56'620	57'737	58'735	59'344	59'833	52'840	56'057
LDV	3'776	3'874	3'998	4'129	4'269	4'392	4'530	4'668	4'809	4'809
HDV	2'229	2'243	2'236	2'235	2'235	2'242	2'238	2'226	2'203	2'248
Coaches	124	125	128	131	134	136	139	142	131	135
Urban Bus	254	262	267	272	281	280	291	300	295	300
2-Wheelers	1'899	1'904	1'920	1'937	1'976	2'008	2'046	2'068	2'152	2'152
Sum	62'004	63'102	64'188	65'324	66'631	67'793	68'588	69'237	62'430	65'701
(1990=100%)	125%	127%	130%	132%	134%	137%	138%	140%	126%	133%

Table 3-77 Specific fuel consumption of road transport, excluding fuel tourism and statistical differences. Numbers include additional fuel consumption by cold starts.

Veh. Category	Fuel	1990	1995	2000	2005	2010
		MJ / veh-km				
PC	Gasoline	3.15	3.23	3.29	3.21	3.07
	Diesel oil	3.34	3.16	3.05	2.75	2.72
	Liquefied petroleum gas	NO	NO	NO	NO	NO
	CNG	NO	NO	NO	NO	2.04
LDV	Gasoline	3.85	3.75	3.65	3.62	3.54
	Diesel oil	4.54	4.51	4.33	3.98	3.77
	CNG	NO	NO	NO	NO	2.40
HDV	Gasoline	NO	NO	NO	NO	NO
	Diesel oil	11.3	11.6	11.6	12.2	11.9
	CNG	NO	NO	NO	10.5	13.2
Coach	Diesel oil	12.7	12.6	12.3	12.0	11.5
Urban Bus	Gasoline	NO	NO	NO	NO	NO
	Diesel oil	16.3	16.7	16.8	16.8	16.2
	CNG	NO	NO	NO	NO	16.7
2-Wheeler	Diesel oil	1.49	1.66	1.48	1.59	1.52
Average (1990=100%)		3.53	3.66	3.68	3.55	3.37
		100%	104%	104%	101%	96%

Veh. Category	Fuel	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
		MJ / veh-km									
PC	Gasoline	2.95	2.88	2.81	2.73	2.65	2.57	2.50	2.44	2.39	2.33
	Diesel oil	2.70	2.68	2.66	2.62	2.58	2.53	2.49	2.49	2.50	2.52
	Liquefied petroleum gas	2.96	2.95	2.93	2.86	2.84	2.82	2.82	2.81	2.81	2.79
	CNG	1.97	1.88	1.89	1.81	1.84	1.76	1.80	1.75	1.65	1.66
LDV	Gasoline	3.45	3.40	3.35	3.29	3.23	3.15	3.05	3.01	2.96	2.89
	Diesel oil	3.71	3.71	3.69	3.66	3.61	3.53	3.43	3.40	3.36	3.36
	CNG	2.69	2.55	2.56	2.45	2.48	2.38	2.40	2.34	2.22	2.24
HDV	Gasoline	9.15	9.16	9.15	9.10	9.10	9.07	9.04	8.99	8.95	8.89
	Diesel oil	11.8	11.7	11.6	11.5	11.4	11.1	10.9	10.8	10.8	10.8
	CNG	13.0	12.5	12.7	12.3	12.7	12.2	10.9	10.7	9.4	10.2
Coach	Diesel oil	10.6	10.5	10.4	10.3	10.1	9.92	9.67	9.64	9.43	9.54
Urban Bus	Gasoline	NO	NO	NO	NO	NO	NO	9.4	9.39	9.38	9.34
	Diesel oil	16.1	16.0	15.9	15.6	15.4	15.0	14.9	14.8	14.8	14.7
	CNG	16.4	15.8	15.7	15.2	15.6	15.2	15.8	15.6	14.9	15.2
2-Wheeler	Diesel oil	1.55	1.53	1.58	1.62	1.59	1.59	1.61	1.62	1.61	1.57
Average (1990=100%)		3.26	3.21	3.15	3.08	3.02	2.94	2.87	2.84	2.85	2.81
		92%	91%	89%	87%	85%	83%	81%	80%	81%	80%

For modelling of evaporative emissions, the stock, the mileage and the number of stops of gasoline passenger cars, light duty vehicles and motorcycles are used. For modelling cold start excess emissions, also the numbers of starts of passenger cars and light duty vehicles are used as activity data. The corresponding numbers are summarised in Table 3-78. Vehicle stock figures correspond to registration data. The starts and stops per vehicle are based on specific surveys (ARE/SFSO 2005, 2012, 2017).

Table 3-78 Vehicle stock numbers (gasoline vehicles only – relevant for diurnal evaporation) and average number of starts per vehicle per day (gasoline, diesel oil, and CNG vehicles).

Veh. Category	1990	1995	2000	2005	2010
	stock in 1000 veh. (gasoline/bioeth.)				
PC	2'839	3'049	3'305	3'263	2'956
LDV	167	164	148	112	77
2-Wheelers	764	688	712	746	765
starts per veh. per day					
PC	2.94	2.68	2.91	2.52	2.56
LDV	1.97	1.97	1.96	1.96	1.96

Veh. Category	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
	stock in 1000 veh. (gasoline/bioeth.)									
PC	2'873	2'831	2'782	2'738	2'688	2'687	2'701	2'706	2'767	2'791
LDV	69	64	61	58	56	54	51	52	54	52
2-Wheelers	779	792	801	812	820	839	860	866	879	870
starts per veh. per day										
PC	2.53	2.54	2.55	2.55	2.56	2.58	2.59	2.59	2.27	2.40
LDV	1.96	1.96	1.96	1.96	1.96	1.96	1.94	2.05	2.03	1.95

Further details are given in Annex A5.1.2.

### 3.2.9.2.3. Railways (1A3c)

#### Methodology (1A3c)

As mentioned in chp. 3.2.4.5.1, the emissions are calculated by the non-road transportation model. The following methods are used:

- Tier 2 for CO<sub>2</sub> (based on decision tree Fig. 3.4.1 in IPCC 2006)
- Tier 3 for CH<sub>4</sub>, N<sub>2</sub>O and precursors (based on decision tree Fig. 3.4.2 in IPCC 2006).

The entire Swiss railway system is electrified. Electric locomotives are used in passenger as well as freight railway traffic. Diesel locomotives are used for shunting purposes in marshalling yards and for construction activities only.

Emissions are calculated for the years 1990, 1995, 2000, 2005 etc. up to 2021 based on fuel used. For the years in-between, the emissions are interpolated linearly.

#### Emission factors (1A3c)

Only diesel oil is being used as fuel, therefore all emission factors refer to diesel oil.

- The CO<sub>2</sub> emission factor applied for the time series 1990–2021 for diesel oil is country-specific and is given in Table 3-13.
- The CH<sub>4</sub> and N<sub>2</sub>O emission factors of diesel locomotives are shown in Table 3-79.
- The emission factors for precursors are country-specific and are given in FOEN (2015j). More details concerning the emission factor for SO<sub>2</sub> are shown in Table A – 15 (row diesel oil). NMVOC emissions are calculated as the difference between VOC and CH<sub>4</sub> emissions.
- Implied emission factors 2021 are shown in Table 3-80.

All emission factors (GHG, precursors) can be downloaded by query from the online non-road database INFRAS (2015a). They can be queried by vehicle type, fuel type, power class and emission standard either at aggregated or disaggregated levels (see INFRAS (2015a)).

Table 3-79 CH<sub>4</sub> and N<sub>2</sub>O emission factors for rail vehicles

Gas	Power class	Rail vehicles with diesel oil engines				
		PreEU <2000	UIC1 2000	UIC2 2003	EU3a 2006	EU3b 2012
		g/kWh				
CH <sub>4</sub>	<18	0.0547	0.0384	0.024	0.0142	0.0142
CH <sub>4</sub>	18–37	0.0578	0.0221	0.0134	0.0089	0.0089
CH <sub>4</sub>	37–56	0.0319	0.0156	0.011	0.0079	0.0055
CH <sub>4</sub>	56–75	0.0319	0.0156	0.011	0.0079	0.0031
CH <sub>4</sub>	75–130	0.0218	0.0108	0.0084	0.0067	0.0031
CH <sub>4</sub>	>130	0.0218	0.0103	0.0072	0.0053	0.0031
N <sub>2</sub> O	all	0.035	0.035	0.035	0.035	0.035

Table 3-80 Implied emission factors 2021 for rail vehicles. Emission factors that are highlighted in green are described in chp. 3.2.4.4.

1A3c Railways	CO <sub>2</sub> fossil	CO <sub>2</sub> biog.	CH <sub>4</sub>	N <sub>2</sub> O	NO <sub>x</sub>	NMVOC	SO <sub>2</sub>	CO
	kg/TJ							
Diesel oil	73'300	NA	1.3	3.6	937	110	0.33	520
Biodiesel	NA	73'300	1.1	3.0	801	94	0.28	445

### Activity data (1A3c)

Activity data for non-road, including 1A3c Railways, are described in chp. 3.2.4.5.1 (non-road transportation model). Values are taken from FOEN (2015j). Data on biofuels are provided by the statistics of renewable energies (SFOE 2015a). Activity data are shown in Table 3-81 and in Annex A5.1.3.

Underlying activity data (vehicle stock, operating hours) of mobile non-road sources can be downloaded by query from the online non-road database INFRAS (2015a). They can be queried by vehicle type, fuel type, power class and emission standard either at aggregated or disaggregated levels (see INFRAS (2015a)).

Table 3-81 Activity data (diesel oil consumption) for railways.

1A3c Railways	Unit	1990	1995	2000	2005	2010
Diesel oil	TJ	390	441	455	472	492
Biodiesel	TJ	NO	NO	0.59	1.7	2.1
Total Railways	TJ	390	441	456	474	494
1990 = 100%		100%	113%	117%	121%	127%

1A3c Railways	Unit	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Diesel oil	TJ	451	431	410	390	388	387	385	383	382	380
Biodiesel	TJ	3.7	4.4	5.2	5.9	7.7	9.4	11	13	15	16
Total Railways	TJ	455	435	416	396	396	396	396	396	396	396
1990 = 100%		117%	112%	107%	102%	102%	102%	102%	102%	102%	102%

### 3.2.9.2.4. Domestic navigation (1A3d)

#### Methodology (1A3d)

Based on the decision tree Fig. 3.5.1 Box 1 of the 2006 IPCC Guidelines (IPCC 2006) the emissions of navigation are calculated by a Tier 2 method with the non-road transportation model described in chp. 3.2.4.5.1.

There are passenger ships, dredgers, fishing boats, motor and sailing boats on the lakes and rivers of Switzerland. The emissions are calculated for the years 1990, 1995, 2000, 2005 etc. up to 2021 based on fuel used. For the years in-between, the emissions are linearly interpolated.

On the river Rhine as well as on Lake Geneva and Lake Constance, some of the boats cross the border. Fuels bought in Switzerland but used for international navigation are therefore reported as bunker fuels (memo items, chp. 3.2.2.).

CO<sub>2</sub> emissions from lubricants of gasoline 2-stroke engines are calculated by using the IPCC default CO<sub>2</sub> emission factor for lubricants, 73.3 t/TJ (IPCC 2006). However, these emissions are reported in source category 2D1 Lubricant use (see chp. 4.5.2.1). In contrast, CH<sub>4</sub> and N<sub>2</sub>O emissions from lubricant use are reported in source category 1A3d Domestic navigation, since the emission factors are deduced from measurements including 2-stroke engines.

#### Emission factors (1A3d)

- The CO<sub>2</sub> emission factor applied for the time series 1990–2021 for diesel oil, gasoline and gas oil are country-specific and are given in Table 3-13.
- The CH<sub>4</sub> and N<sub>2</sub>O emission factors are country-specific and are shown below in Table 3-82 to Table 3-84 for all fuel types and emission standards.
- For SO<sub>2</sub> the emission factors are country-specific. See also Table A – 15 in Annex A5.1.4 rows diesel oil, gasoline, gas oil.
- The emission factors for precursors are country-specific and are given in FOEN (2015j).
- NMVOC is not modelled bottom-up. The NMVOC emissions are calculated as the difference between VOC and CH<sub>4</sub> emissions.
- The implied emission factors 2021 are shown in Table 3-85.

All emission factors (GHG, precursors) can be downloaded by query from the online non-road database INFRAS (2015a). They can be queried by vehicle type, fuel type, power class and emission standard either at aggregated or disaggregated levels (see INFRAS (2015a)).

Table 3-82 CH<sub>4</sub> and N<sub>2</sub>O emission factors for ships with diesel engines.

Gas	Power class	Ships with diesel oil engines				
		Pre SAV (<1995)	SAV 1995	EU-I 2003	EU-II 2008	EU-III 2009
		g/kWh				
	kW					
CH <sub>4</sub>	<18	0.0547	0.0547	0.0384	0.0240	0.0142
CH <sub>4</sub>	18–37	0.0578	0.0578	0.0221	0.0134	0.0089
CH <sub>4</sub>	37–56	0.0319	0.0319	0.0156	0.0110	0.0079
CH <sub>4</sub>	56–75	0.0319	0.0319	0.0156	0.0110	0.0079
CH <sub>4</sub>	75–130	0.0218	0.0218	0.0108	0.0084	0.0067
CH <sub>4</sub>	>130	0.0218	0.0218	0.0103	0.0072	0.0053
N <sub>2</sub> O	all	0.035	0.035	0.035	0.035	0.035

Table 3-83 CH<sub>4</sub> and N<sub>2</sub>O emission factors for ships with gasoline engines by emission standards including the year of enforcement.

Gas	Power class	Boats with 2-stroke gasoline engines			Boats with 4-stroke gasoline engines		
		Pre SAV <1995	SAV 1995	SAV/EU 2007	Pre SAV <1995	SAV 1995	SAV/EU 2007
		g/kWh			g/kWh		
	kW						
CH <sub>4</sub>	<18	18.2	1.54	1.75	1.25	1.10	1.25
CH <sub>4</sub>	18–37	18.2	0.84	0.91	1.00	0.60	0.65
CH <sub>4</sub>	37–56	18.2	0.42	0.56	1.00	0.30	0.40
CH <sub>4</sub>	56–75	18.2	0.42	0.56	1.00	0.20	0.30
CH <sub>4</sub>	75–130	18.2	0.42	0.56	1.00	0.17	0.25
CH <sub>4</sub>	130–560	18.2	0.42	0.56	1.00	0.10	0.25
N <sub>2</sub> O	0–300	0.01	0.01	0.01	0.03	0.03	0.03

Table 3-84 CH<sub>4</sub> and N<sub>2</sub>O emission factors for steamboats by the year of enforcement.

Gas	Steamboats		
	<2000	2000-2004	>2004
	g/kWh		
CH <sub>4</sub>	0.0218	0.0103	0.0072
N <sub>2</sub> O	0.035	0.035	0.035

Table 3-85 Implied emission factors 2021 for navigation. Emission factors that are highlighted in green are described in chp. 3.2.4.4.

1A3d Navigation	CO <sub>2</sub> fossil	CO <sub>2</sub> biog.	CH <sub>4</sub>	N <sub>2</sub> O	NO <sub>x</sub>	NM VOC	SO <sub>2</sub>	CO
	kg/TJ							
Gasoline	73'800	NA	23	1.9	545	416	0.26	8'751
Diesel oil	73'300	NA	1.3	3.4	764	216	0.33	498
Gas oil	73'700	NA	0.24	0.73	26	1.6	4.7	6.9
Biodiesel	NA	73'300	1.1	2.9	653	185	0.28	426
Bioethanol	NA	73'800	13	1.3	351	256	0.17	5'540

### Activity data (1A3d)

Activity data for navigation (1A3d) are described in chp. 3.2.4.5.1 (non-road transportation model). Values are taken from FOEN (2015j). Data on biofuels are provided by the statistics

of renewable energies (SFOE 2015a). Activity data are shown in Table 3-86 and in Annex A5.1.3.

Underlying activity data (vehicle stock, operating hours) of mobile non-road sources can be downloaded by query from the online non-road database INFRAS (2015a). They can be queried by vehicle type, fuel type, power class and emission standard either at aggregated or disaggregated levels (INFRAS 2015a).

Table 3-86 Fuel consumption of (domestic) navigation.

1A3d Domestic navigation	Unit	1990	1995	2000	2005	2010					
Gasoline	TJ	701	654	616	565	535					
Diesel oil	TJ	738	724	792	800	868					
Gas oil	TJ	110	139	147	150	159					
Biodiesel	TJ	NO	NO	1.0	2.9	3.8					
Bioethanol	TJ	NO	NO	NO	NO	0.013					
Total Navigation	TJ	1'550	1'517	1'556	1'518	1'565					
1990 = 100%		100%	98%	100%	98%	101%					

1A3d Domestic navigation	Unit	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Gasoline	TJ	526	522	518	514	512	511	509	508	506	505
Diesel oil	TJ	872	874	876	878	873	867	862	857	851	847
Gas oil	TJ	156	154	153	151	150	149	148	147	146	145
Biodiesel	TJ	7.6	9.5	11	13	17	21	25	29	33	37
Bioethanol	TJ	1.6	2.3	3.1	3.9	6.3	8.6	11	13	16	18
Total Navigation	TJ	1'563	1'562	1'561	1'560	1'559	1'557	1'556	1'554	1'552	1'551
1990 = 100%		101%	101%	101%	101%	101%	100%	100%	100%	100%	100%

### 3.2.9.2.5. Other transportation (1A3e)

#### Methodology (1A3e)

The emissions are calculated with a Tier 2 method (the 2006 IPCC Guidelines (IPCC 2006) do not contain a decision tree to determine the Tier level specifically).

Source 1A3e includes only pipeline transportation (1A3ei) from a compressor station located in Ruswil. Emissions of CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, NO<sub>x</sub>, CO, NMVOC and SO<sub>2</sub> are reported. The compressor station uses a centrifugal compressor according to Transitgas AG (the company operating the compressor station and the pipeline network).

#### Emission factors (1A3e)

- The CO<sub>2</sub> emission factor applied for the time series 1990–2021 for natural gas is country-specific and is given in Table 3-14.
- The CH<sub>4</sub> emission factor corresponds to the one used for gas turbines in Switzerland (SAEFL 2000) as suggested by expert judgement. The CH<sub>4</sub> emission factor is assumed to be 5 g/GJ up to 1995 and 2 g/GJ from 2000 onwards, with linear interpolation in between. This corresponds with the fact that a catalyst was fitted to the system, which reduced the CH<sub>4</sub> emissions of the gas turbine.
- For N<sub>2</sub>O emission factors the IPCC 2006 default value (Table 3-17) is used as displayed in Table 3-87.
- The emission factors for precursors are mostly country-specific. The NO<sub>x</sub> emission factor stems from the Factsheet Emission Factors Furnaces (FOEN 2015k). NMVOC and SO<sub>x</sub> emission factors stem from section “Gasturbinen; Erdgas” in SAEFL (2000). More details

concerning the emission factor for SO<sub>2</sub> are shown in Table A – 15(row natural gas). The CO emission factor is a default factor from the EMEP/EEA guidebook (EMEP/EEA 2019).

- The emission factors 2021 are shown in Table 3-87.

Table 3-87 Emission factors of 1A3ei Pipeline transportation / compressor station located in Ruswil in 2021. Emission factors that are highlighted in green are described in chp. 3.2.4.4.

1A3e Other transportation	CO <sub>2</sub> fossil	CH <sub>4</sub>	N <sub>2</sub> O	NO <sub>x</sub>	NMVOC	SO <sub>2</sub>	CO
	kg/TJ						
Gas	55'900	2.0	0.10	19	0.10	0.50	4.8

### Activity data (1A3e)

The data on fuel consumption for the operation of the compressor station in Ruswil is based on the Swiss overall energy statistics (SFOE 2022; Table 17).

Table 3-88 Activity data of 1A3e.

1A3ei Pipeline transport	Unit	1990	1995	2000	2005	2010
Natural gas	TJ	560	310	340	1'070	830
1990=100%		100%	55%	61%	191%	148%

1A3ei Pipeline transport	Unit	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Natural gas	TJ	810	410	830	760	340	470	490	600	540	120
1990=100%		145%	73%	148%	136%	61%	84%	88%	107%	96%	21%

### 3.2.9.3. Uncertainties and time-series consistency for 1A3

The uncertainty of emission estimates for source category 1A3 is described in the general uncertainty assessment of source category 1A Fuel combustion in chp. 3.2.4.7. Uncertainties by fuel type are given in Table 3-26.

Time series for 1A3 Transport are all considered consistent.

### 3.2.9.4. Category-specific QA/QC and verification for 1A3

#### General

The general QA/QC measures are described in chp. 1.5. Furthermore, QA/QC procedures conducted for all 1A source categories are listed in chp. 3.2.4.8.

#### Specific: Domestic aviation (1A3a)

##### Emissions

Total calculated emissions for domestic and international flights have been compared between different years. The development of total emissions with time is consistent with a fleet renewal of former Swissair in the early nineties, the technological improvements and changes in fleet composition.

### *Emission factors*

- From total fuel consumption, total distance, number of passengers (without freight) per aircraft type, the fuel consumption per 100 passenger km has been calculated (backward calculation). The result of 2 to 10 kg fuel per 100 passenger km is in line with expectations for 1990 passenger fleets. Current modern fleets are in the order of 2.5 kg fuel per 100 passenger km. During the COVID-19 pandemic, the seat load factor was exceptionally low and therefore, a calculation of the fuel consumption per 100 passenger km is not representative.
- The implied emission factors were calculated for 2021 and compared with previous years.

### *Activity data*

- In an independent Tier 3B calculation, EUROCONTROL performed a fuel calculation for Switzerland's international flights, based on collected Instrument Flight Rules flight plan data and single movements. The results for the years 2004, 2005 and 2007 matched the FOCA calculations by more than 97.4 %. The FOCA results were generally 1 % to 2 % higher but included the total number of actual flight movements of all flights, including visual flight rules and non-scheduled flights such as helicopter movements in alpine regions.
- Comparison between total movement numbers in the calculation and in the corresponding published statistics. Example: In 1990 calculation, FOCA considered all flights for which there was a form 'Traffic report to the airport authorities' filled in (total heavy aircraft). The total number of movements in 1990 is 263'951 (without Basel). The published number of movements for scheduled and charter flights in 1990 is: 263'952 (without Basel).
- The bottom-up calculation of total fuel matches the total fuel sold within a few percent, except for 2020 and 2021, where the difference is larger due to the COVID-19 pandemic.
- Real-world fuel consumption was compared with modelled consumption for selected aircraft of four Swiss airlines. The difference between the two methods was smaller than 1 %.

### **Specific: Road transportation (1A3b)**

Comparison between the 2006 IPCC Guideline's default (IPCC 2006) and Switzerland's emission factors:

- CO<sub>2</sub> (see also Table 3-27): IPCC default value for gasoline is 69.3 t/TJ and for diesel oil 74.1 t/TJ (IPCC 2006, Table 3.2.1). Switzerland's emission factors vary between 73.8 and 73.9 t/TJ for gasoline – 6 % higher than IPCC – and between 73.3 and 73.6 t/TJ for diesel oil – about 1 % below IPCC default value (IPCC 2006).
- CH<sub>4</sub>: The IPCC default emission factor for gasoline motors with oxidation catalysts is 25 kg/TJ with an uncertainty range from 7.5 to 86 kg/TJ (IPCC 2006, Table 3.2.2). Switzerland's emission factor for gasoline passenger cars varied between 27.5 kg/TJ and 3.8 kg/TJ throughout the time series and is therefore in the lower part of and below IPCC's uncertainty range. For diesel oil, the IPCC default emission factors lie in the range of 1.6–9.5 kg/TJ (IPCC 2006), whereas Switzerland's range is on a lower level (0.8–4.0 kg/TJ).
- N<sub>2</sub>O: The IPCC default emission factor for gasoline motors with oxidation catalysts lies in the uncertainty range 2.6–24 kg/TJ (IPCC 2006, Table 3.2.2). Switzerland's emission factor for gasoline passenger cars varied between 5.4 kg/TJ and 0.6 kg/TJ and is therefore in the lower part of and below IPCC's uncertainty range. For diesel oil the IPCC

default emission factors lies in the range of 1.3–12 kg/TJ (IPCC 2006), whereas Switzerland's range is lower (0.2–3.7 kg/TJ).

The international project for the update of the emission factors for road vehicles is overseen by a group of external national and international experts that guarantees an independent quality control. For the update of the modelling of Switzerland's road transport emissions, which has last been carried out comprehensively between 2019–2020 in the framework of the update of Switzerland's energy perspectives, several experts from the federal administration have accompanied the project (INFRAS 2019a). The results have undergone extensive plausibility checks and comparisons with earlier estimates. A light update of the emission factors took place in 2022 (Notter et al. 2022).

The emission factors CH<sub>4</sub> and N<sub>2</sub>O used for the modelling of 1A3b Road Transportation are taken from version 4.2 of the Handbook Emission Factors for Road Transport (HBEFA) (INFRAS 2022), which is also applied in Germany, Austria, Netherlands, and Sweden. The Swiss emission factors for CH<sub>4</sub> and N<sub>2</sub>O used in 1A3b Road transportation were additionally compared with those shown in the CRF from Germany and a good match was found. Possible small differences might result from a varying fleet composition.

Use of implied emission factors from the territorial model to calculate emissions for fuel tourism: This approach has been verified by comparing implied emission factors with the neighbouring countries. The differences turned out to be small between Switzerland, Austria, and Germany because all three countries used the same emission factors (INFRAS 2010), whereas there were some differences when comparing with France and Italy that use other emission factors (COPERT, EEA 1997). Nevertheless, the use of the implied Swiss emission factors seemed to be the consistent approach. It must be noted, that this comparison was carried out with version 3.1 of the "Handbook of Emission Factors for Road Transport", whereas the current emissions are based on version 4.2. It is expected that an update of this comparison would result in similarly low differences with the neighbouring countries, since the underlying measurement data in the inventory models are the same (given the neighbouring countries also work with an eventually updated COPERT version).

The activity data for gasoline and diesel oil of the road transportation model (consumption without tank tourism and statistical difference) is verified due to the fact that more than 90 % of the gasoline and diesel oil sold 2021 in Switzerland, as reported by the Swiss overall energy statistic (SFOE 2022), is consumed by the road transportation model (see Table 3-75).

### **3.2.9.5. Category-specific recalculations for 1A3**

The following recalculations were implemented in submission 2023. Major recalculations, which contribute significantly to the total differences in emissions of sector 1 Energy between the latest and the previous submissions are presented also in chp. 10.1.2.1.

- 1A3a/1D1: An update of activity data in 1A3ai Domestic aviation and 1D1 International aviation for the year 2020 leads to a recalculation of all greenhouse gas emissions for the year 2020.
- 1A3b: Based on newest available statistics updates in the activity data (mileage) for different vehicle categories have been done. This recalculation leads to changes in all greenhouse gas emissions for the years 1990–2020.

- 1A3b: The revision of the model for determining NMVOC emissions at gasoline stations in 1B2a Fugitive emissions from oil distribution leads to changes in total gasoline losses as the NMVOC lost are equivalent to gasoline losses. This amount of gasoline lost is part of the total amount of gasoline consumption reported in the Swiss overall energy statistics. To keep consistency with this total amount of gasoline consumption a respective adjustment of activity data of gasoline consumption in 1A3b Road transportation was required.
- 1A3b: The emission factors in 1A3b Road transportation were adjusted to the HBEFA version 4.2 published in February 2022. This leads to a recalculation of all greenhouse gas emissions for the years 1990–2020.

#### **3.2.9.6. Category-specific planned improvements for 1A3**

No category-specific improvements are planned.

### 3.2.10. Source category 1A4 – Other non-road machinery sources in residential, commercial, agriculture and forestry sectors

#### 3.2.10.1. Source category description for 1A4 – Other non-road machinery sources in residential, commercial, agriculture and forestry sectors

##### Key categories 1A4

See key categories mentioned in chp. 3.2.7.1, Table 3-56.

Table 3-89 Specification of source category 1A4 – Other non-road machinery sources in residential, commercial, agriculture and forestry sectors (1A4a, 1A4b, 1A4c).

1A4	Source category	Specification
1A4a	Commercial/ institutional	Emission from non-road vehicles (professional gardening) and motorised equipment
1A4b	Residential	Emissions from mobile machinery (hobby, gardening) and motorised equipment
1A4c	Agriculture/forestry	Emissions from non-road vehicles and machinery in agriculture and forestry

#### 3.2.10.2. Methodological issues for 1A4 – Other non-road machinery sources in residential, commercial, agriculture and forestry sectors

##### Methodology (1A4 – Other non-road machinery sources in residential, commercial, agriculture and forestry sectors)

Based on the decision tree Fig. 3.3.1 in chp. “3. Mobile Combustion” in the 2006 IPCC Guidelines (IPCC 2006), the emissions of vehicles and machinery in 1A4 are calculated by a Tier 3 method with the non-road transportation model described in chp. 3.2.4.5.1.

CO<sub>2</sub> emissions from lubricants of gasoline 2-stroke engines are calculated by using the IPCC default CO<sub>2</sub> emission factor for lubricants, 73.3 t/TJ (IPCC 2006). However, these emissions are reported under source category 2D1 Lubricant use (see chp. 4.5.2.1). In contrast, CH<sub>4</sub> and N<sub>2</sub>O emissions from lubricant use in 2-stroke engines are reported in the corresponding source category in 1A4 Other non-road machinery sources in residential, commercial, agriculture and forestry sectors, since the emission factors are based on measurements including 2-stroke engines.

##### Emission factors (1A4 – Other non-road machinery sources in residential, commercial, agriculture and forestry sectors)

In Off-road vehicles and other machinery in categories 1A4a Commercial/institutional and 1A4b Residential, only gasoline (and a small share of bioethanol) is being used as fuel. In category 1A4c Agricultural/forestry/fishing, mainly diesel oil is consumed (more than 85 %, see Table 3-91) and only a small amount (less than 15 %) of gasoline (e.g. chainsaws) or biodiesel/bioethanol.

- The CO<sub>2</sub> emission factors applied for the time series 1990–2021 are country-specific and are given in Table 3-13.
- The CH<sub>4</sub> and N<sub>2</sub>O emission factors are country-specific and are shown in Table 3-65 and Table 3-66 for diesel oil and gasoline engines for all emission standards.

- For SO<sub>2</sub> the emission factors are country-specific. See also Table A – 15 in Annex A5.1.4 for diesel oil, gasoline, gas oil.
- The emission factors for precursors are country-specific and are given in FOEN (2015j).
- NMVOC is not modelled bottom-up. The NMVOC emissions are calculated as the difference between VOC and CH<sub>4</sub> emissions.
- Implied emission factors 2021 are shown in Table 3-90.

All emission factors (GHG, precursors) can be downloaded by query from the online non-road database INFRAS (2015a). They can be queried by vehicle type, fuel type, power class and emission standard either at aggregated or disaggregated levels (see INFRAS (2015a)).

Table 3-90 Implied emission factors 2021 for 1A4 – Other non-road machinery sources in residential, commercial agriculture and forestry sectors(1A4aii – 1A4cii mobile). Emission factors that are highlighted in green are described in chp. 3.2.4.4.

1A4 Non-road machinery	CO <sub>2</sub> fossil	CO <sub>2</sub> biog.	CH <sub>4</sub>	N <sub>2</sub> O	NO <sub>x</sub>	NMVOC	SO <sub>2</sub>	CO
	kg/TJ							
1A4aii Gardening professional								
Gasoline	73'800	NA	83	1.2	178	1'317	0.26	26'732
Bioethanol	NA	73'800	15	1.0	75	434	0.17	15'853
1A4bii Gardening								
Gasoline	73'800	NA	41	1.4	146	852	0.26	25'475
Bioethanol	NA	73'800	15	1.0	85	432	0.17	15'867
1A4cii Forestry and agriculture								
Gasoline	73'800	NA	80	1.2	177	1'379	0.26	24'656
Diesel oil	73'300	NA	1.0	3.0	348	40	0.33	201
Biodiesel	NA	73'300	0.8	2.5	298	34	0.28	172
Bioethanol	NA	73'800	19	0.92	76	529	0.17	15'083

### Activity data (1A4 – Other non-road machinery sources in residential, commercial, agriculture and forestry sectors)

Activity data are described in chp. 3.2.4.5.1 (non-road transportation model) and are shown in Table 3-91 and in Annex A5.1.3.

Underlying activity data (vehicle stock, operating hours) of mobile non-road sources can be downloaded by query from the online non-road database INFRAS (2015a). They can be queried by vehicle type, fuel type, power class and emission standard either at aggregated or disaggregated levels (see INFRAS 2015a).

Table 3-91 Activity data for non-road vehicles and machinery in 1A4 – Other non-road machinery sources in residential, commercial, agriculture and forestry sectors.

1A4 Non-road machinery	Unit	1990	1995	2000	2005	2010
1A4aii Gardening professional						
Gasoline	TJ	191	245	295	295	287
Bioethanol	TJ	NO	NO	NO	NO	0.0039
1A4bii Gardening						
Gasoline	TJ	142	155	165	166	163
Bioethanol	TJ	NO	NO	NO	NO	0.0034
1A4cii Forestry and agriculture						
Gasoline	TJ	1'160	1'070	963	824	689
Diesel oil	TJ	4'269	4'604	4'920	4'802	4'882
Biodiesel	TJ	NO	NO	6.4	17	21
Bioethanol	TJ	NO	NO	NO	NO	0.012
Total 1A4 non-road machinery	TJ	5'761	6'073	6'349	6'103	6'042
Relative values 1A4 (1990 = 100%)		100%	105%	110%	106%	105%

1A4 Non-road machinery	Unit	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
1A4aii Gardening professional											
Gasoline	TJ	273	266	260	253	251	250	248	247	245	243
Bioethanol	TJ	0.48	0.72	0.95	1.19	1.9	2.6	3.3	4.0	4.7	5.4
1A4bii Gardening											
Gasoline	TJ	160	159	158	156	155	154	153	152	151	150
Bioethanol	TJ	0.43	0.64	0.85	1.06	1.7	2.3	2.9	3.6	4.2	4.8
1A4cii Forestry and agriculture											
Gasoline	TJ	641	616	592	568	551	535	519	503	486	473
Diesel oil	TJ	4'870	4'864	4'859	4'853	4'835	4'817	4'800	4'782	4'764	4'742
Biodiesel	TJ	42	53	63	74	96	118	140	162	184	205
Bioethanol	TJ	1.31	2.0	2.6	3.3	4.8	6.4	8.0	9.6	11	12
Total 1A4 non-road machinery	TJ	5'989	5'962	5'936	5'909	5'898	5'886	5'874	5'862	5'851	5'836
Relative values 1A4 (1990 = 100%)		104%	103%	103%	103%	102%	102%	102%	102%	102%	101%

### 3.2.10.3. Uncertainties and time-series consistency for 1A4 – Other non-road machinery sources in residential, commercial, agriculture and forestry sectors

The uncertainty of emission estimates for source category 1A4 Other sectors (mobile) is described in the general uncertainty assessment of source category 1A Fuel combustion in chp. 3.2.4.7. Uncertainties by fuel type are given in Table 3-26.

### 3.2.10.4. Category-specific QA/QC and verification for 1A4 – Other non-road machinery sources in residential, commercial, agriculture and forestry sectors

The general QA/QC procedures are described in chp. 1.5. Furthermore QA/QC procedures conducted for all 1A source categories are listed in chp. 3.2.4.8.

### 3.2.10.5. Category-specific recalculations for 1A4 – Other non-road machinery sources in residential, commercial, agriculture and forestry sectors

There were no recalculations implemented in submission 2023.

### 3.2.10.6. Category-specific planned improvements for 1A4 – Other non-road machinery sources in residential, commercial, agriculture and forestry sectors

No category-specific improvements are planned.

### 3.2.11. Source category 1A5b – Other (mobile)

#### 3.2.11.1. Source category description for 1A5b (mobile)

Table 3-92 Key categories of 1A5b – Other (mobile). Combined KCA results, level for 2021 and trend for 1990–2021, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Source category 1A5b – Other (mobile) is not a key category.

All of the Swiss source categories of 1A5 refer to mobile sources of military activities (1A5b). Stationary activities (1A5a) are not occurring.

Table 3-93 Specification of Swiss source category 1A5 Other.

1A5	Source category	Specification
1A5bi	Military aviation	Emissions from military aircrafts
1A5bii	Military non-road vehicles and machines	Emissions from machines like power generators, tanks, bulldozers, boats etc.

#### 3.2.11.2. Methodological issues for 1A5b Other (mobile)

##### 3.2.11.2.1. Military aviation (1A5bi)

##### Methodology (1A5bi Other, military aviation)

To calculate the emissions from military aviation, a Tier 2 method is used for CO<sub>2</sub>, while a Tier 1 method is used for CH<sub>4</sub> and N<sub>2</sub>O.

##### Emission factors (1A5bi Other, military aviation)

- The CO<sub>2</sub> emission factor applied for the time series 1990–2021 for kerosene is country-specific and is given in Table 3-13.
- CH<sub>4</sub>: Because there is no split in LTO and cruise flights in military aviation, the CH<sub>4</sub> emission factor of 1A3a Civil aviation (see chp. 3.2.9.2.1) cannot be applied. Therefore, the Tier 1 emission factor from IPCC 2006, table 3.6.5 is used.
- N<sub>2</sub>O: As for 1A3a Civil aviation, the Tier 1 IPCC default value is used (IPCC 2006, table 3.6.5).
- NO<sub>x</sub>, NMVOC, CO: average emission factors for military aircraft are calculated by the Federal Office of Civil Aviation (FOCA) based on collaborative measurement efforts of FOCA and the Federal Department of Defence, Civil Protection and Sport (DDPS) and the FOCA aircraft engine data bank. The fuel consumption per aircraft type in the year 2016–2017 is provided by DDPS (DDPS 2018b). The emission factors stay constant for the whole time series from 1990 onwards.
- SO<sub>2</sub>: the emission factor is taken from the EMEP/EEA guidebook (EMEP/EEA 2019, Table 3.11, row “Switzerland/CCD” (where: CCD means: climb/cruise/descent)) and is assumed to be constant over the period 1990–2021.
- Implied emission factors 2021 are shown in Table 3-94.

Table 3-94 Implied emission factors 1A5bi military aviation in 2021. Emission factors that are highlighted in green are described in chp. 3.2.4.4.

1A5bi Other: Military aviation	CO <sub>2</sub> fossil	CH <sub>4</sub>	N <sub>2</sub> O	NO <sub>x</sub>	NM VOC	SO <sub>2</sub>	CO
	kg/TJ						
Jet kerosene	72'800	0.50	2.0	231	33	23	235

### Activity data (1A5bi Other, military aviation)

Fuel consumption data for 1990–2021 is available on an annual basis (VTG 2011, DDPS 2022). A very small fraction of fuel is consumed for training abroad and might be allocated under “International aviation” (assumed to be less than 3 % of total military aviation consumption). Since the exact numbers for the fuels used abroad is not known, it is not subtracted from the total consumption but included under national military aviation, as recommended by the 2006 IPCC Guidelines (IPCC 2006, chp. 3.6.1.4).

Table 3-95 Activity data (fuel consumption) for military aviation.

1A5bi Other: Military aviation	Unit	1990	1995	2000	2005	2010
Jet kerosene	TJ	2'733	1'955	1'794	1'624	1'592

1A5bi Other: Military aviation	Unit	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Jet kerosene	TJ	1'527	1'542	1'615	1'567	1'627	1'469	1'457	1'303	1'365	1'301

### 3.2.11.2.2. Military non-road vehicles (1A5bii Other, military machinery)

#### Methodology (1A5bii Other, military machinery)

Emissions are calculated as part of the non-road transportation model (chp. 3.2.4.5.1) corresponding to a Tier 3 according to the decision tree Fig. 3.3.1 in chp. 3. Mobile Combustion in IPCC (2006).

CO<sub>2</sub> emissions from lubricants of gasoline 2-stroke engines are calculated by using the IPCC default CO<sub>2</sub> emission factor for lubricants, 73.3 t/TJ (IPCC 2006). However, these emissions are reported under source category 2D1 Lubricant use (see chp. 4.5.2.1). In contrast, CH<sub>4</sub> and N<sub>2</sub>O emissions from lubricant use in 2-stroke engines are reported in source category 1A5bii, since the emission factors are based on measurements including 2-stroke engines.

#### Emission factors (1A5bii Other, military machinery)

- The CO<sub>2</sub> emission factors applied for the time series 1990–2021 for diesel oil, gasoline and biofuels are country-specific as shown in Table 3-13.
- The CH<sub>4</sub> and N<sub>2</sub>O emission factors are country-specific and are shown in Table 3-65 and Table 3-66 for diesel oil and gasoline engines for all emission standards.
- For SO<sub>2</sub> the emission factors are country-specific. See Table A – 15 in Annex A5.1.4, rows diesel oil, gasoline.
- The emission factors for precursors are country-specific and are given in FOEN (2015j).
- NMVOC is not modelled bottom-up. The NMVOC emissions are calculated as the difference between VOC and CH<sub>4</sub> emissions.
- Implied emission factors 2021 are shown in Table 3-96.

All emission factors (GHG, precursors) can be downloaded by query from the online non-road database INFRAS (2015a). They can be queried by vehicle type, fuel type, power class and emission standard either at aggregated or disaggregated levels (see INFRAS (2015a)).

Table 3-96 Implied emission factors 1A5bii military non-road vehicles 2021. Emission factors that are highlighted in green are described in chp. 3.2.4.4.

1A5bii Military non-road	CO <sub>2</sub> fossil	CO <sub>2</sub> biog.	CH <sub>4</sub>	N <sub>2</sub> O	NO <sub>x</sub>	NMVOC	SO <sub>2</sub>	CO
	kg/TJ							
Gasoline	73'800	NA	38	1.5	126	701	0.26	24'654
Diesel oil	73'300	NA	0.63	3.0	289	26	0.33	133
Biodiesel	NA	73'300	0.54	2.6	247	22	0.28	113
Bioethanol	NA	73'800	10	1.1	65	279	0.17	15'629

### Activity data (1A5bii Other, military machinery)

Activity data for military non-road vehicles (1A5bii) are described in chp. 3.2.4.5.1 (non-road transportation model). Values are taken from FOEN (2015j). Data on biofuels are provided by the statistics of renewable energies (SFOE 2015a). Activity data are shown in Table 3-97 and in Annex A5.1.3.

Underlying activity data (vehicle stock, operating hours) of mobile non-road sources can be downloaded by query from the public part of the non-road database INFRAS (2015a). They can be queried by vehicle type, fuel type, power class and emission standard either at aggregated or disaggregated levels (see INFRAS 2015a).

Table 3-97 Activity data (fuel consumption) for military non-road vehicles.

1A5bii Military non-road	Unit	1990	1995	2000	2005	2010
Total fuel consumption	TJ	239	248	252	257	275
Gasoline	TJ	19	19	19	19	18
Diesel oil	TJ	220	228	233	238	256
Biodiesel	TJ	NO	NO	0.30	0.86	1.1
Bioethanol	TJ	NO	NO	NO	NO	0.00038

1A5bii Military non-road	Unit	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Total fuel consumption	TJ	275	275	275	275	274	273	272	271	270	269
Gasoline	TJ	18	17	17	17	17	16	16	16	16	16
Diesel oil	TJ	255	255	254	254	252	250	248	246	244	243
Biodiesel	TJ	2.2	2.8	3.3	3.9	5.0	6.1	7.2	8.3	9.4	11
Bioethanol	TJ	0.046	0.069	0.092	0.11	0.18	0.25	0.31	0.38	0.45	0.51

### 3.2.11.3. Uncertainties and time-series consistency for 1A5b Other (mobile)

The uncertainty of emission estimates for source category 1A5b Other (mobile) is described in the general uncertainty assessment of source category 1A Fuel combustion in chp. 3.2.4.7.

Uncertainties by fuel type are given in Table 3-26.

### 3.2.11.4. Category-specific QA/QC and verification for 1A5b Other (mobile)

The general QA/QC measures are described in chp. 1.5. Furthermore, QA/QC procedures conducted for all 1A source categories are listed in chp. 3.2.4.8.

The activity data of military aviation (1A5b), kerosene consumption, is provided by the Federal Department of Defence, Civil Protection and Sport. For a compatibility check with the

emission database of civil aviation, they are sent to the FOCA (office of the Federal Department of the Environment, Transport, Energy and Communications).

#### **3.2.11.5. Category-specific recalculations for 1A5b Other (mobile)**

There were no recalculations implemented in submission 2023.

#### **3.2.11.6. Category-specific planned improvements for 1A5b Other (mobile)**

No category-specific improvements are planned.

### 3.3. Source category 1B – Fugitive emissions from fuels

#### 3.3.1. Source category description for 1B

Table 3-98 Key categories of 1B Fugitive emissions from fuels. Combined KCA results, level for 2021 and trend for 1990–2021, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC category	Gas	Identification criteria
1B2b	Natural gas; All fuels	CH4	L1, T1, L2, T2

The only relevant source categories of fugitive emissions in Switzerland are:

- Oil (1B2a)
- Natural gas (1B2b)
- Venting and flaring (1B2c)

#### 3.3.2. Source category 1B1 – Solid Fuels

Coal mining is not occurring in Switzerland. There are no greenhouse gas emissions from coal handling.

#### 3.3.3. Source category fugitive emissions from 1B2a – Oil

##### 3.3.3.1. Source category description for 1B2a

In Switzerland, oil production is not occurring. Fugitive emissions in the oil industry result exclusively from the refineries and several fuel handling stations. At the beginning of 2015, one of the two refineries ceased operation. The extents of the two existing oil pipelines in Switzerland are approximately 40 km and 70 km, respectively. The pipelines are mainly laid underground.

Table 3-99 Specification of source category fugitive emissions from 1B2a Oil in Switzerland.

1B2	Source category	Specification
1B2aiii	Fugitive emissions oil: Transport	Emissions only stem from pipeline transport
1B2aiv	Fugitive emissions oil: Refining / storage	Emissions from oil refining process
1B2av	Fugitive emissions oil: Distribution of oil products	Distribution of oil products (from gasoline storage tanks and gasoline stations) (only precursor emissions NMVOC)

##### 3.3.3.2. Methodological issues for 1B2a

###### Methodology (1B2a)

According to the decision tree for crude oil transport, refining and upgrading, Switzerland estimates 1B2a fugitive emissions from oil based on a Tier 3 (for 1B2aiii Fugitive emissions

oil: Transport) and a Tier 2 (for 1B2aiv Fugitive emissions oil: Refining / storage, 1B2av Fugitive emissions oil: Distribution of oil products) approach (IPCC 2006, Volume 2 Energy, chp. 4 Fugitive Emissions, Figure 4.2.3 and for precursors EMEP/EEA 2019, Figure 3-1).

For source 1B2a fugitive emissions from oil, fugitive emissions of CH<sub>4</sub> are reported. They occur only in 1B2aiii Transport and 1B2aiv Refining/storage. Indirect CO<sub>2</sub> emissions resulting from CH<sub>4</sub> and NMVOC emissions in this source category are included in CRF Table6 as documented in chp. 9. As no CO emissions occur in source category 1B2a, from this source category no indirect CO<sub>2</sub> emissions from CO are included in CRF Table6 as documented in chp. 9.

### Emission factors (1B2a)

Crude oil transportation (1B2aiii): In Switzerland crude oil is transported by underground pipelines only. According to experts from the pipeline operator, there are no emissions along the pipelines but only at the pig trap. There is one pig trap per pipeline and one pipeline per refinery. Based on expert estimates 0.5 m<sup>3</sup> air saturated with VOC are emitted per week and pig trap. This leads to CH<sub>4</sub> emissions of 1–2 kg per year. The CH<sub>4</sub> to NMVOC ratio is assumed to be 1:10.

For oil refining and storage (1B2aiv), country-specific emission factors for CH<sub>4</sub> and NMVOC are used. The emission factors for CH<sub>4</sub> are delineated from an emission estimation project in one of the refineries in 1992 called CRISTAL (Raffinerie de Cressier 1992). The emission factor from the other refinery is assumed to be twice as high, because the technology of the plant is older. Then a weighted mean based on the quantity of crude oil used in both refineries was calculated (for further details see the internal documentation of the EMIS database, EMIS 2023/1B2aiv). This emission factor is used for all the years until 1995. For the years 2007–2019, total NMVOC emissions from 1A1b, 1B2aiv and 1B2c correspond to those reported in the Swiss Pollutant Release and Transfer Register (PRTR) from the two refineries. For 2021, the emission factor is the same as for 2019, because data from PRTR is not available during data collection for the inventory. Therefore, emission factors in 1B2aiv are adapted to reach the total NMVOC emissions as reported in the Swiss Pollutant Release and Transfer Register. Between the years 1995 and 2007, the emission factors are interpolated linearly. The ratio between CH<sub>4</sub> and NMVOC stays at 1:10 for all the years.

The emission factors for SO<sub>x</sub> emissions from Claus units in refineries are country-specific and based on measurements and data from industry and expert estimates.

For the distribution of oil products in gasoline stations (1B2av): The emission factors of NMVOC from 1B2av are country-specific and based on a bottom-up model (Luftkollektiv 2022) that sums up the different processes generating fugitive gasoline emissions, i.e. transport to the gasoline station, unloading to the tank at the gasoline station, opening the manhole, pressure equalisation, vapour recovery and finally refuelling of the vehicles. The bottom-up model developed was applied to the state of the years 1990, 2002, 2010 and 2030 and the respective emission factors were determined. In between, the emission factors are linearly interpolated.

For the distribution of oil products in gasoline and kerosene storage tank facilities (1B2av): Emission factors for storage tanks are estimated by Carbura based on two studies, one for gasoline storage tanks (Carbura 2021) and one for kerosene storage tanks (Carbura 2022). NMVOC emissions were estimated on the basis of information on tank volumes, tank

equipment, throughput quantities and maintenance. For gasoline storage tanks, detailed information is available for all historical reporting years. For kerosene storage tanks, historical data is available since 2000. Due to lack of data for earlier years, the emission factor for 1990 is the same as the one calculated for 2000 and kept constant in between. It should be noted that the storage and handling of kerosene causes significantly lower NMVOC emissions than gasoline due to the significantly lower vapour pressure.

Table 3-100 Emission factors for fugitive emissions of source category 1B2a Oil in 2021.

1B2a Fugitive emissions attributed to oil	Per amount of	Unit	CO <sub>2</sub>	CH <sub>4</sub>	N <sub>2</sub> O	NO <sub>x</sub>	NMVOC	SO <sub>2</sub>	CO
1B2ai Exploration		g/t	NO	NO	NO	NO	NO	NO	NO
1B2aii Production		g/t	NO	NO	NO	NO	NO	NO	NO
1B2aiii Transport of crude oil by pipelines	Number of refineries	g/No.	NA	1'000	NA	NA	10'000	NA	NA
1B2aiv Refining/Storage of crude oil	Crude oil imported	g/t	NA	7	NA	NA	75	5	NA
1B2av Distribution of oil products: Gasoline storage tank	Gasoline sold	g/GJ	NA	NA	NA	NA	0.83	NA	NA
1B2av Distribution of oil products: Gasoline station	Gasoline sold	g/GJ	NA	NA	NA	NA	22.4	NA	NA
1B2av Distribution of oil products: Kerosene storage tank	Kerosene imported	g/GJ	NA	NA	NA	NA	0.12	NA	NA

### Activity data (1B2a)

As crude oil is transported per pipeline to the refineries in Switzerland, activity data for oil transport (1B2aiii) reflects the number of pipelines, which is equal to the number of refineries. Activity data for oil refining and storage (1B2aiv) is the amount of crude oil imported. This data is provided by Avenegy Suisse (Avenegy 2022) in their annual statistics and also reported in the Swiss overall energy statistics (SFOE 2022).

For oil distribution from storage tanks and gasoline stations (1B2av), gasoline sales based on the Swiss overall energy statistics (SFOE 2022), corrected for consumption of Liechtenstein, are used as activity data.

Table 3-101 Activity data for fugitive emissions from 1B2a Oil.

1B2a Oil products	Amount of	Unit	1990	1995	2000	2005	2010						1990 vs. 2021 (%)	
1B2aiii Transport of crude oil by pipelines	Number of refineries	No.	2	2	2	2	2							
1B2aiv Refining/Storage	Crude oil imported	kt	3'127	4'657	4'649	4'877	4'546							
1B2av Gasoline distribution	Gasoline sold	TJ	156'516	151'672	168'353	152'182	134'129							
1B2av Kerosene distribution	Kerosene imported and produced	TJ	48'160	54'739	68'310	51'004	61'815							
1B2a Oil products	Amount of	Unit	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	1990 vs. 2021 (%)	
1B2aiii Transport of crude oil by pipelines	Number of refineries	No.	2	2	2	1	1	1	1	1	1	1	-50%	
1B2aiv Refining/Storage	Crude oil imported	kt	3'455	4'935	4'975	2'836	3'006	2'889	3'076	2'789	2'857	2'339	-25%	
1B2av Gasoline distribution	Gasoline sold	TJ	124'386	118'717	113'956	105'664	102'367	99'223	97'654	96'850	85'769	87'628	-44%	
1B2av Kerosene distribution	Kerosene imported and produced	TJ	67'513	69'248	68'219	70'857	73'853	75'027	80'262	83'698	34'816	31'736	-34%	

### 3.3.3.3. Uncertainties and time-series consistency for 1B2a

Based on expert judgement, a preliminary uncertainty assessment of all sources in source category 1B2a results in medium confidence in the emissions estimate (see Table 1-8).

Time series for 1B2a Oil are all considered consistent.

### 3.3.3.4. Category-specific QA/QC and verification for 1B2a

The general QA/QC measures are described in chp. 1.5 and partly also in chp. 3.2.4.8. No further source-specific activities undertaken for fugitive emissions from oil (1B2a).

### 3.3.3.5. Category-specific recalculations for 1B2a

There were no recalculations implemented in submission 2023.

For recalculations relating to indirect CO<sub>2</sub> emissions resulting from NMVOC emissions, please refer to recalculations reported in chp. 3 on Energy in Switzerland's Informative Inventory Report 2023 (FOEN 2023b).

### 3.3.3.6. Category-specific planned improvements for 1B2a

No category-specific improvements are planned.

## 3.3.4. Source category fugitive emissions from 1B2b – Natural gas

### 3.3.4.1. Source category description for 1B2b

Emissions from natural gas production (1B2bii) are only occurring for the years of operation of the single production plant in Switzerland from 1985–1994. Other emissions in this source category occur from natural gas transmission (1B2biv) and distribution (1B2bv). Emissions from accidents in the gas pipeline system are reported under source category 1B2bvi Other Leakage.

Table 3-102 Specification of source category fugitive emissions from 1B2b Natural gas in Switzerland.

1B2	Source category	Specification
1B2bii	Fugitive emissions attributed to natural gas: Production	Emissions from natural gas production (1990-1994 only).
1B2biv	Fugitive emissions attributed to natural gas: Transmission	Emissions from natural gas transmission.
1B2bv	Fugitive emissions attributed to natural gas: Distribution	Emissions from natural gas distribution.
1B2bvi	Fugitive emissions attributed to natural gas: Other Leakage	Emissions from other leakage (accident events, so far one in 2010 and one in 2011).

### 3.3.4.2. Methodological issues for 1B2b

#### Methodology (1B2b)

According to the decision tree for natural gas systems (IPCC 2006, Volume 2 Energy, chp. 4 Fugitive Emissions, Figure 4.2.1), Switzerland follows a Tier 1 approach for fugitive emissions concerning 1B2bii Production and a Tier 2 approach for fugitive emissions attributed to 1B2biv Transmission and storage as well as 1B2bv Distribution.

Emissions from source category 1B2 are key (see Table 3-98). However, the contribution from 1B2bii is small and therefore the use of a Tier 1 method for this source category is justified. The emissions from source category 1B2bii are calculated based on annual production data and default emission factors (IPCC Tier 1 approach). Production data under 1B2bii occur for the years 1990–1994 only because the single production site was closed in 1994.

For emission calculations from source category 1B2biv, 1B2bv and 1B2bvi, country-specific emission factors and activity data are available. Emissions are calculated with a country-

specific method which first assesses the losses of natural gas in the gas network including pipelines, fittings and gas devices, as these data represent the activity data. Based on the gas losses, CO<sub>2</sub>, CH<sub>4</sub> and NMVOC emissions are calculated with country-specific emission factors which reflect the composition of the gas lost.

Emissions from gas transmission (source category 1B2biv) include emissions from transport pipelines including the transit pipeline and the single compressor station. Emissions comprise leakages from gas pipelines, small-scale damages, maintenance work and leakages of pipeline fittings. Gas storages are considered as components of the distribution network and the respective emissions are included in source category 1B2bv.

Source category 1B2bv Distribution covers emissions from the gas distribution pipelines and network components (e.g. control units, fittings and gas meters) as well as fugitive emissions at the end users. Emission calculations for the gas distribution network are based on the length, material and pressure of the gas pipelines. Fugitive emissions at the end users arise from on-site and indoor pipelines and the permanent leakiness of the different gas appliances in households, industry and natural gas fuelling stations. In the calculations, the number and kind of end users and connected gas appliances are considered.

Indirect CO<sub>2</sub> emissions resulting from CH<sub>4</sub> and NMVOC emissions in this source category are included in CRF Table6 as documented in chp. 9. As no CO emissions occur in source category 1B2b, from this source category no indirect CO<sub>2</sub> emissions from CO are included in CRF Table6 as documented in chp. 9.

### Emission factors (1B2b)

For natural gas production, CO<sub>2</sub>, CH<sub>4</sub> and NMVOC default emission factors are taken from the 2006 IPCC Guidelines (IPCC 2006) as documented in the internal emission database documentation (EMIS 2023/1B2b Diffuse Emissionen Erdgas).

Emission factors for transmission, distribution and other leakages (source categories 1B2biv, 1B2bv, and 1B2bvi) are calculated based on the weighted average CO<sub>2</sub>, CH<sub>4</sub>, and NMVOC concentrations and net calorific values of natural gas as annually reported by the Swiss Gas and Water Industry Association (SGWA) for the different import stations (see Quantis 2014 and EMIS 2023/1B2b Diffuse Emissionen Erdgas).

Table 3-103 Emission factors for fugitive emissions of source category 1B2b Natural gas in 2021.

1B2b Natural gas	Per amount of	Unit	CO <sub>2</sub>	CH <sub>4</sub>	N <sub>2</sub> O	NO <sub>x</sub>	NMVOC	SO <sub>2</sub>	CO
1B2bii Production	Natural gas	g/GJ	NO	NO	NO	NO	NO	NO	NO
1B2biv Transmission, losses	Natural gas	g/GJ	435	18'328	NA	NA	1'409	NA	NA
1B2bv Distribution, losses	Natural gas	g/GJ	435	18'328	NA	NA	1'409	NA	NA
1B2bvi Other Leakage, losses	Natural gas	g/GJ	NO	NO	NO	NO	NO	NO	NO

### Activity data (1B2b)

Activity data for fugitive emissions from gas production (1B2bii) are the actual gas production data for the years 1990–1994 (SFOE 2022).

For gas transmission (1B2biv), distribution (1B2bv), and other leakage (1B2bvi), the activity data have been reassessed in a study by Quantis (2014) and the corresponding calculation model is updated regularly. The activity data represent the amount of natural gas lost from the gas network and are shown in Table 3-104.

For source categories 1B2biv and 1B2bv, information regarding the gas transport and distribution network from the Swiss Gas and Water Industry Association (SGWA) is used to derive the activity data (see Quantis 2014 and EMIS 2023/1B2b Diffuse Emissionen Erdgas).

For transmission pipelines a constant emission factor per pipeline length is applied accounting for losses from purging and cleaning flows, pipeline damages and leaky fittings and mountings. For the one compressor station a constant emission rate based on the physical power of the turbines is employed including emissions due to shutting down and starting of the gas turbines, leakages at regulating valves and fittings, maintenance and gasometry work.

The calculation of losses from source category 1B2bv Distribution follows a detailed country-specific approach that considers losses from the pipeline network as well as losses at the end users.

The calculated gas losses from the pipeline network depend on the length, material and pressure of the pipelines. Gas losses due to permanent leakiness, small-scale damages, network maintenance and the network components are evaluated separately. As no applicable loss rates are available for the network compounds in Switzerland (installed control units, fittings, storage systems and gas meters), a fixed percentage is applied to the permanent gas losses.

Regarding the end users, gas losses from on-site and indoor pipelines as well as gas losses due to the permanent leakiness of gas appliances are evaluated. Pipeline loss rates apply to the number of households, industrial users and gas fuelling stations separately. Regarding the gas appliances, different loss rates are assigned to the number of gas heating systems, gas cooking stoves and gas fuelling stations.

For some (earlier) years in the time series, sufficient input data are not available to calculate the gas losses. For these years, polynomial interpolations are applied to assess the activity data.

For significant emission events due to accidents the Swiss Pollutant Release and Transfer Register is considered, and emissions are attributed to source category 1B2bvi Other Leakage. So far, two events have been reported by the transit pipeline operator, one in 2010 and one in 2011.

Fugitive emissions from pipelines are the major emission source in source category 1B2b. Fugitive emissions from damages and ruptures of the pipelines, maintenance of the pipelines and the components are very small (Quantis 2014). Total CH<sub>4</sub> emissions from gas transmission and distribution decreased due to gradual replacement of cast-iron pipes with polyethylene pipes.

Table 3-104 Activity data (amount of gas lost) for fugitive emissions from 1B2b Natural gas.

1B2b Natural Gas	Amount of	Unit	1990	1995	2000	2005	2010						
1B2bii Production	Natural gas	GJ	130'000	NO	NO	NO	NO						
1B2biv Transmission, losses	Natural gas	GJ	28'226	30'874	32'571	33'491	34'595						
1B2bv Distribution, losses	Natural gas	GJ	710'246	817'028	655'267	512'036	449'418						
1B2bvi Other Leakage, losses	Natural gas	GJ	NO	NO	NO	NO	35'444						
1B2b Natural Gas	Amount of	Unit	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	1990 vs. 2021 (%)
1B2bii Production	Natural gas	GJ	NO	-100%									
1B2biv Transmission, losses	Natural gas	GJ	34'483	34'852	35'125	35'468	35'743	35'884	35'809	36'096	36'007	35'784	27%
1B2bv Distribution, losses	Natural gas	GJ	435'545	399'993	389'310	388'251	390'185	383'203	377'827	376'657	374'028	371'708	-48%
1B2bvi Other Leakage, losses	Natural gas	GJ	NO	-									

### 3.3.4.3. Uncertainties and time-series consistency for 1B2b

According to the assessment by Quantis (2014), an uncertainty of 30 % is estimated for fugitive CH<sub>4</sub> emissions from natural gas pipelines in Switzerland.

A preliminary uncertainty assessment of all other sources in source category 1B2 based on expert judgement results in medium confidence in the emissions estimate (see Table 1-8).

Time series for 1B2b Natural gas are all considered consistent.

### 3.3.4.4. Category-specific QA/QC and verification for 1B2b

The general QA/QC measures are described in chp. 1.5.

As suggested by the 2006 IPCC Guidelines (IPCC 2006), the gas industry was involved in the reassessment of fugitive emissions from the natural gas system in 2014 (Quantis 2014) and 2016 (EMIS 2023/1B2b Diffuse Emissionen Erdgas).

### 3.3.4.5. Category-specific recalculations for 1B2b

The following recalculations were implemented in submission 2023. Major recalculations which contribute significantly to the total differences in emissions of sector 1 Energy between the latest and the previous submissions are presented also in chp. 10.1.2.1.

- 1B2b: Small recalculation, as fewer decimal places were used for activity rate and emission factors of CH<sub>4</sub> and NMVOC to calculate fugitive emissions from natural gas distribution network for all years.

### 3.3.4.6. Category-specific planned improvements for 1B2b

No category-specific improvements are planned.

## 3.3.5. Source category 1B2c – Venting and flaring

### 3.3.5.1. Source category description for 1B2c

In Switzerland, oil production is not occurring, and only one production site for natural gas production was operational from 1985–1994. Therefore, emissions from flaring result primarily from the torches, which were operational at the two refineries (1B2ci Flaring). Since 2015, there is only one refinery in operation. In addition, CO<sub>2</sub> emissions from H<sub>2</sub> production in one of the two refineries are also reported under 1B2c.

Table 3-105 Specification of source category 1B2c Venting and flaring in Switzerland.

1B2	Source category	Specification
1B2ci	Fugitive emissions attributed to venting and flaring: Flaring oil	The combustion of excess gas at the oil refinery (flaring) only.
1B2ci	Fugitive emissions attributed to venting and flaring: H <sub>2</sub> production	Emissions from H <sub>2</sub> production (butane and natural gas).
1B2cii	Fugitive emissions attributed to venting and flaring: Flaring gas	Emissions from gas production (1990-1994 only).

### 3.3.5.2. Methodological issues for 1B2c

#### Methodology (1B2c)

For source category 1B2ci Flaring, Oil, emissions of CO<sub>2</sub> as well as CH<sub>4</sub>, N<sub>2</sub>O, NO<sub>x</sub>, CO and NMVOC are considered. According to the decision tree for crude oil transport, refining and upgrading, Switzerland follows a Tier 3 method for CO<sub>2</sub> emissions and a Tier 2 method for all further pollutants attributed to 1B2ci Flaring, Oil in order to estimate fugitive emissions under 1B2c fugitive emissions from venting and flaring (IPCC 2006, Volume 2 Energy, chp. 4 Fugitive Emissions, Figure 4.2.3). For CO<sub>2</sub> emission calculations, country-specific CO<sub>2</sub> emission factors and activity data are available from the refining industry.

Emissions from gas production are calculated by a Tier 1 method according to 1B2c fugitive emissions from venting and flaring according to the decision tree for natural gas systems (IPCC 2006, Volume 2 Energy, chp. 4 Fugitive Emissions, Figure 4.2.1). For source category 1B2cii Flaring, Gas, emissions of CO<sub>2</sub> as well as CH<sub>4</sub>, N<sub>2</sub>O and NMVOC are considered.

One of the refining plants produces H<sub>2</sub>. Until 2017, butane was used for the production of H<sub>2</sub>, leading to process emissions of CO<sub>2</sub>. During 2017, additionally to butane, the refinery started to use natural gas in its hydrogen production unit. Emissions are estimated based on plant-specific data (Tier 3 method).

Since the CO<sub>2</sub> emission factors assume an oxidation of 100 %, no indirect emissions need to be accounted for. Therefore, no indirect emissions from this source category are included in CRF Table6 as documented in chp. 9.

#### Emission factors (1B2c)

Emission factors concerning flaring of refinery gas during the refining process are documented in the internal emission database documentation (EMIS 2023/1B2c Raffinerie Abfackelung). The emission factor for CO<sub>2</sub> is based on a study from Frischknecht et al. (1996), the emission factor for N<sub>2</sub>O is based on the expert estimate in the German NIR 2019 (UBA 2019), and those for the other greenhouse gases and precursors base on a study from USEPA (1995b) and data from the refining industry.

Since 2005 (with the exception of 2012), the refining industry provides annual data on the CO<sub>2</sub> emissions from flaring under the Federal Act on the Reduction of CO<sub>2</sub> Emissions (Swiss Confederation 2011) based on daily measurements of CO<sub>2</sub> emission factors of the flared gases. From these data, annual emission factors are derived. Since 2005, the evolution of the other emission factors (CH<sub>4</sub>, N<sub>2</sub>O, NO<sub>x</sub>, CO and NMVOC) is assumed to vary proportionally to the CO<sub>2</sub> emission factor. Emission factors are considered confidential and are available to reviewers on request.

The emissions from flaring in the gas production facility are calculated based on default emission factors provided in the 2006 IPCC Guidelines.

CO<sub>2</sub> emission factors for H<sub>2</sub> production are confidential. Data are available to reviewers on request.

Table 3-106 Emission factors for 1B2c Venting and flaring in 2021.

1B2c Fugitive emissions attributed to venting and flaring	Per amount of	Unit	CO <sub>2</sub>	CH <sub>4</sub>	N <sub>2</sub> O	NO <sub>x</sub>	NM VOC	SO <sub>2</sub>	CO
1B2ci H2 production refinery	Butane	g/GJ	NO	NA	NA	NA	NA	NA	NA
1B2ci H2 production refinery	Natural gas	g/GJ	C	NA	NA	NA	NA	NA	NA
1B2cii1 Flaring Oil	Crude oil imported	g/t	C	C	C	C	C	C	C
1B2cii2 Flaring gas	Natural gas produced	g/GJ	NO	NO	NO	NA	NO	NA	NA

### Activity data (1B2c)

Before 2005, the amount of flared gas during the refining process is assumed to be proportional to the amount of crude oil processed in the refineries. Avenergy Suisse (formerly the Swiss petroleum association EV) provides data on the use of crude oil on an annual basis (Avenergy 2022). Between 2001 and 2004, one of the two refineries made major changes to their installations (new cracker, new flaring installation) and their standard operation process. Therefore, emissions from flaring decreased significantly thereafter. Since 2005, the industry provides data on the amount of gas flared.

For gas production, the amount flared is estimated based on the amount of gas produced.

For H<sub>2</sub> production in one of the refining plants, annual data on butane and natural gas consumption are provided by the industry since 2005, when the H<sub>2</sub> production unit was installed. Data are confidential and they are available to reviewers on request.

Table 3-107 Activity data for 1B2c Venting/flaring.

1B2c Venting and flaring	Amount of	Unit	1990	1995	2000	2005	2010
1B2ci: H2 production in refinery	Butane and natural gas	GJ	NO	NO	NO	C	C
1B2cii1 Flaring Oil	Crude oil imported	kt	C	C	C	C	C
1B2cii2 Flaring Gas	Natural gas produced	GJ	130'000	NO	NO	NO	NO

1B2c Venting and flaring	Amount of	Unit	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
1B2cii1 Flaring Oil	Crude oil imported	kt	C	C	C	C	C	C	C	C	C	C
1B2ci: H2 production in refinery	Butane and natural gas	GJ	C	C	C	C	C	C	C	C	C	C
1B2cii2 Flaring Gas	Natural gas produced	GJ	NO									

### 3.3.5.3. Uncertainties and time-series consistency for 1B2c

A preliminary uncertainty assessment of all sources in source category 1B2 based on expert judgement results in medium confidence in the emissions estimate (see Table 1-8).

Consistency: Time series for 1B2c Venting and flaring are all considered consistent.

### 3.3.5.4. Category-specific QA/QC and verification for 1B2c

The general QA/QC measures are described in chp. 1.5. No category-specific QA/QC activities were undertaken.

### 3.3.5.5. Category-specific recalculations for 1B2c

The following recalculations were implemented in submission 2023. Major recalculations which contribute significantly to the total differences in emissions of sector 1 Energy between the latest and the previous submissions are presented also in chp. 10.1.2.1.

- 1B2c: The calculation method for the CO<sub>2</sub> emissions from flaring in refineries has been changed for the year 2012.
- 1B2c: Small recalculation due to rounding of emission factors of N<sub>2</sub>O for 1B2c Flaring oil for the years 2016–2020.

#### **3.3.5.6. Category-specific planned improvements for 1B2c**

No category-specific improvements are planned.

### **3.4. Source category 1C – CO<sub>2</sub> transport and storage**

CO<sub>2</sub> transport and storage is not occurring in Switzerland.

## 4. Industrial processes and product use (IPPU)

Responsibilities for sector Industrial processes and product use (IPPU)	
Overall responsibility	Sabine Schenker (FOEN)
Method updates & authors	Sabine Schenker (FOEN), Cornelia Stettler (Carbotech; F-gases)
EMIS database operation	Anouk-Aimée Bass (FOEN; F-gases), Sabine Schenker (FOEN)
Annual updates (NID text, tables, figures)	Dominik Egli (Meteotest), Lukas Meyer (Meteotest), Beat Rihm (Meteotest), Cornelia Stettler (Carbotech; F-gases)
Quality control (NID annual updates)	Gavin Roberts (Carbotech; F-gases), Regine Röhliberger (FOEN), Adrian Schilt (FOEN), Felix Weber (INFRAS)
Internal review	Stefan Reimann (EMPA; F-gases), Regine Röhliberger (FOEN), Sabine Schenker (FOEN), Adrian Schilt (FOEN; F-gases), Loïc Schmidely (FOEN, SF6)

### 4.1. Overview

This chapter provides information on the estimation of the GHG emissions from sector 2 Industrial processes and product use. The following source categories are reported:

- 2A Mineral industry
- 2B Chemical industry
- 2C Metal industry
- 2D Non-energy products from fuels and solvent use
- 2E Electronics industry
- 2F Product uses as substitutes for ozone-depleting substances (ODS)
- 2G Other product manufacture and use
- 2H Other

Emissions within this sector comprise GHG emissions as by-products from industrial processes and also emissions of F-gases during production, use and disposal. Emissions from fuel combustion in industry are reported in source category 1A2 under sector 1 Energy.

According to the 2006 IPCC Guidelines this sector provides also information on the GHG emissions from solvent and product use. CO<sub>2</sub> emissions from solvent and partly from product use are due to post-combustion of NMVOC in order to reduce NMVOC in exhaust gases. The disposal of solvents is reported in the waste energy sector (waste derived fuels, chp. 3.2.6).

Indirect CO<sub>2</sub> emissions resulting from fossil CH<sub>4</sub>, CO and NMVOC emissions as well as indirect N<sub>2</sub>O emissions resulting from NO<sub>x</sub> and NH<sub>3</sub> emissions are included in CRF Table6 as documented in chp. 9. However, indirect CO<sub>2</sub> emissions are taken into account when calculating the key categories of sector 2 (see Figure 4-4). Since the CO<sub>2</sub> emissions from the cracker reported in source category 2B8b Ethylene, from 2C1 Secondary steel production, electric arc furnace and from 2C3 Primary aluminium production are based on carbon mass balances, their emissions of CO (from source categories 2C1 and 2C3) and NMVOC (from source categories 2B8b and 2C1) are not accounted for in the calculation of the indirect CO<sub>2</sub>

emissions. Biogenic CO and NMVOC emissions occur in source category 2H2 Food and beverages and 2G4 tobacco consumption and are not reported as indirect CO<sub>2</sub> emissions.

For several industrial processes within source categories 2A Mineral industry, 2B Chemical industry, 2C Metal industry and 2G Other product manufacture and use, data and information on emission factors and activity data are classified as confidential (C), because they refer to a single enterprise. For reviewers, there is an additional version of chp. 4 Industrial processes and product use (IPPU) available, including all confidential data and information.

Figure 4-1 shows the evolution of greenhouse gas emissions in sector 2 between 1990 and 2021.

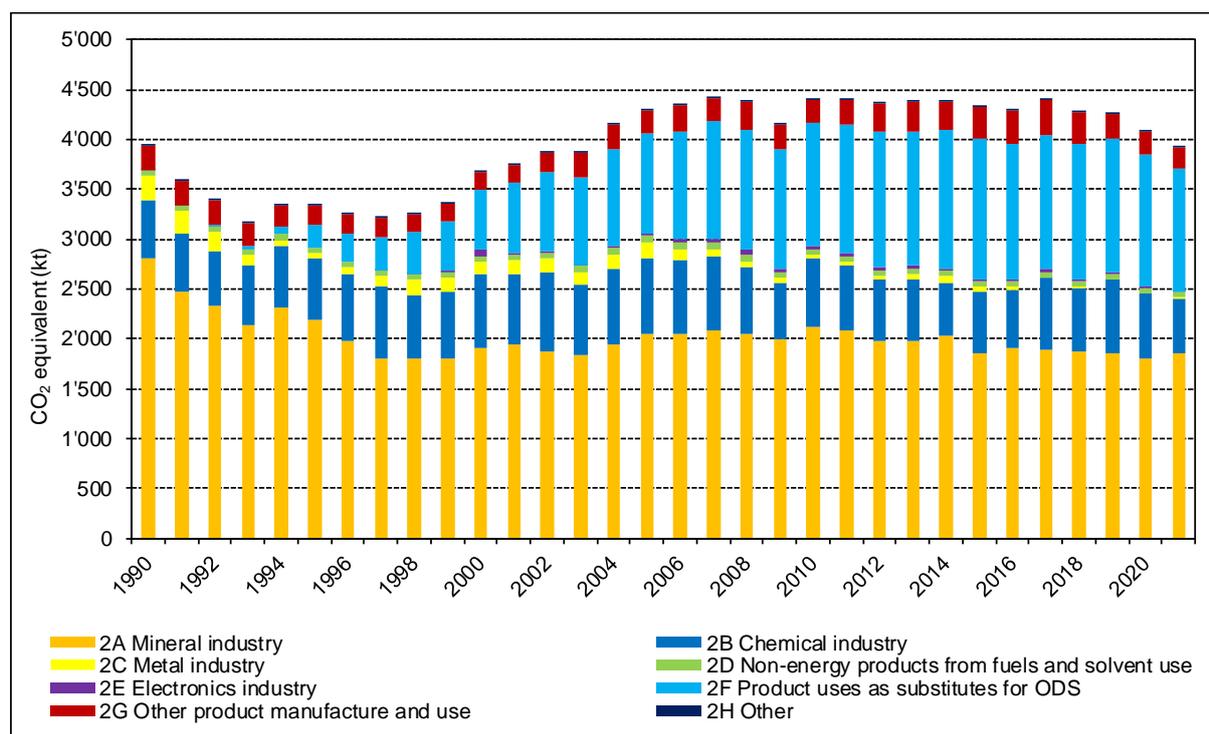


Figure 4-1 Switzerland's greenhouse gas emissions of sector 2 Industrial processes and product use.

2A Mineral industry remains the dominant source of sector 2, accounting for around 50 % of the GHG emissions in 2021 although absolute emissions have decreased since 1990. 2B Chemical industry accounts for a share of around 10 % and shows no clear trend since 1990. 2C Metal industry shows a strong decreasing trend and accounts only for a negligibly small share in 2021. 2D Non-energy products have also only a minor contribution in 2021.

2F Product uses as substitutes for ozone depleting substances (ODSs) is of considerable importance: The emissions have increased from 1990 to 2015 due to the replacement of CFCs and other ODSs by HFCs in many technical applications. However, the emissions are gradually decreasing over the past years due to restrictions of HFC use in mobile air-conditioning and stationary refrigeration. They account for almost one third of total GHG emissions in sector 2 in 2021. 2G Other product manufacture and use shows, after an increase between 2000 and 2017, a decrease in emissions since then. 2E Electronic industry and 2H Other are of little importance with regard to the overall GHG emissions of sector 2.

In Table 4-1, the development of GHG emissions in sector 2 Industrial processes and product use is given by gases. Dominant gases are CO<sub>2</sub>, F-gases and N<sub>2</sub>O in 2021 whereas CH<sub>4</sub> has only a minor contribution. The relative trend of these gases referring to the base year 1990 is shown in Figure 4-2 and Figure 4-3.

Table 4-1 GHG emissions of sector 2 Industrial processes and product use by gases in CO<sub>2</sub> equivalent (kt).

Gas	1990	1995	2000	2005	2010
	CO <sub>2</sub> equivalent (kt)				
CO <sub>2</sub>	3'153	2'420	2'208	2'372	2'369
CH <sub>4</sub>	4.0	6.6	5.8	7.0	7.8
N <sub>2</sub> O	535	570	639	661	564
F-gases	246	339	815	1'253	1'447
Sum	3'938	3'336	3'668	4'293	4'388

Gas	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
	CO <sub>2</sub> equivalent (kt)									
CO <sub>2</sub>	2'201	2'201	2'255	2'085	2'148	2'124	2'110	2'096	2'022	2'102
CH <sub>4</sub>	7.6	5.9	6.4	6.3	7.9	7.9	8.4	7.8	7.2	6.8
N <sub>2</sub> O	523	516	439	511	469	606	523	610	538	417
F-gases	1'637	1'650	1'680	1'732	1'670	1'660	1'637	1'550	1'513	1'399
Sum	4'368	4'373	4'381	4'333	4'296	4'398	4'278	4'263	4'081	3'925

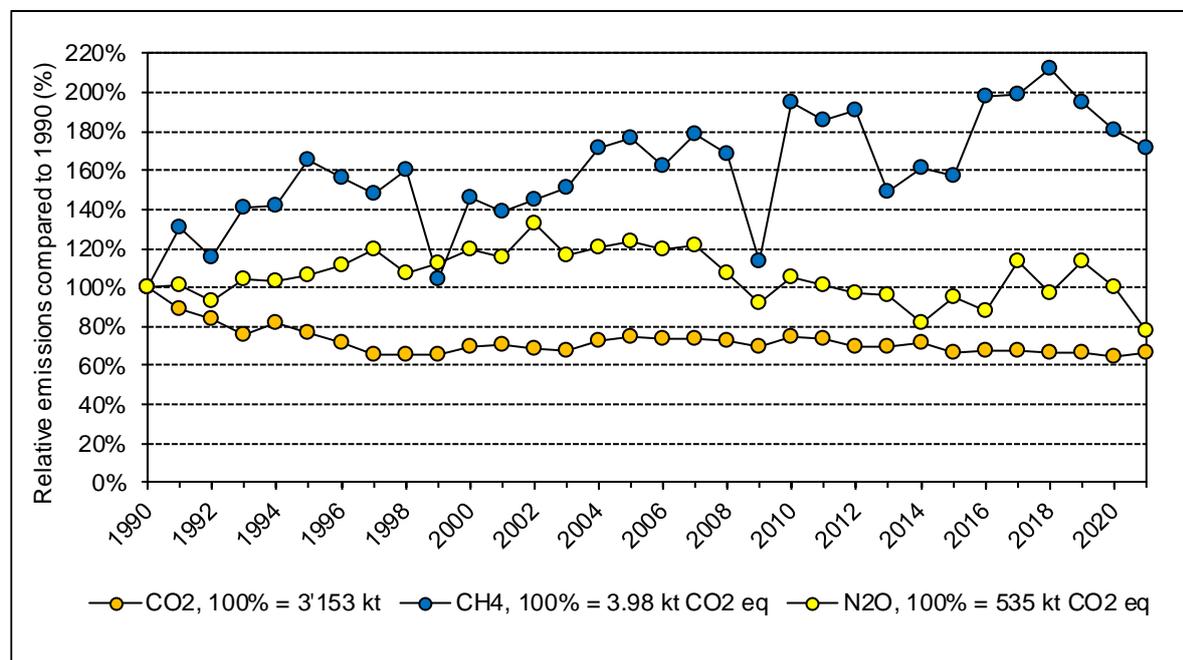


Figure 4-2 Relative trends of the greenhouse gas emissions (without F-gases, see Figure 4-3) of sector 2 Industrial processes and product use. The base year 1990 represents 100 %.

Figure 4-2 shows that the emissions of CO<sub>2</sub> decreased between 1990 and 1997 and since then, they have remained at a constant level. Emissions of N<sub>2</sub>O have increased slowly between 1990 and 2002 and decreased afterwards until 2014. Since 2014 there has been an increasing trend again with even higher emissions in 2017, 2019 and 2020 than in 1990; 2021 however, has the lowest N<sub>2</sub>O emissions ever. Emissions of CH<sub>4</sub> have an increasing

trend with considerable interannual fluctuations. However, absolute emissions are very small compared to CO<sub>2</sub> and N<sub>2</sub>O.

Figure 4-3 shows a large increase in emissions of F-gases compared to the year 1990. Main contributions in the inventory 1990 result from the PFC emissions in the smelting process of aluminium production (chp. 4.4.2.2) and from the use of SF<sub>6</sub> in electrical equipment and sound proof windows (chp. 4.8.2.1 and chp. 4.8.2.2). The increase between 1995 and 2012 is due to the increasing product uses of HFCs as substitutes for ODS (chp. 4.6) in refrigeration and air conditioning. Since 2012, total F-gas emissions have remained at a constant level with a visible drop after 2018. The main driver are the restrictions of HFC use in mobile air-conditioning and the progressing limitation of HFCs with a high GWP for stationary refrigeration. Most relevant and main source of F-gases emissions in 2021 is the use of HFC in refrigeration and air conditioning.

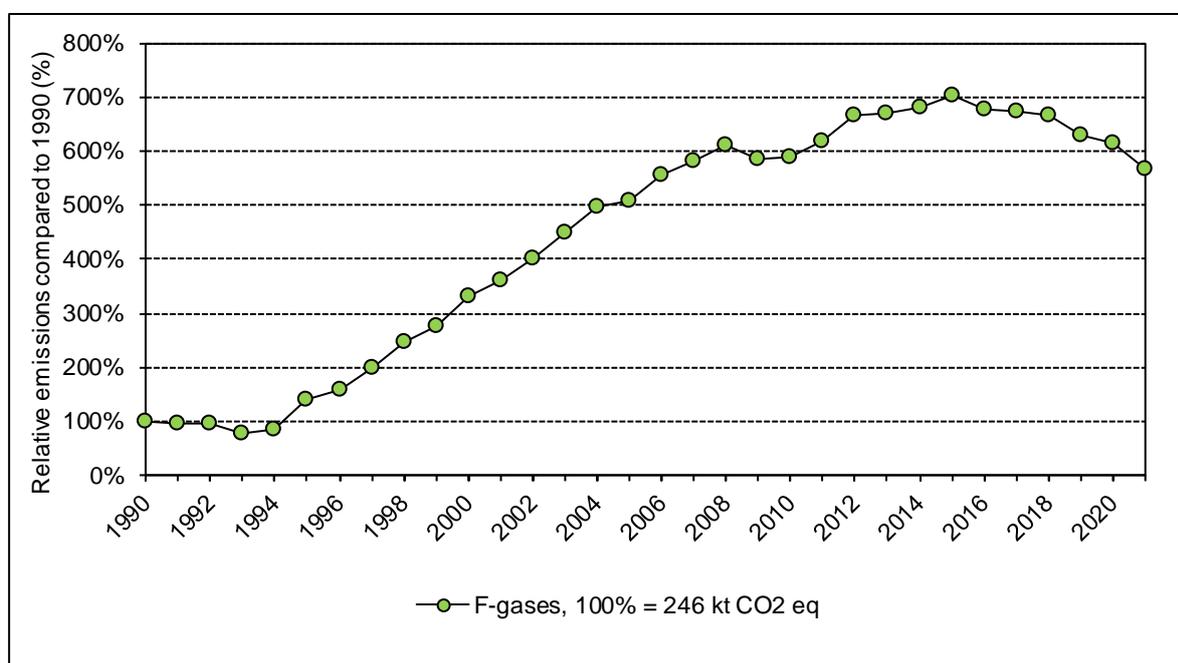


Figure 4-3 Relative trends in emissions of F-gases in sector 2 Industrial processes and product use. The base year 1990 represents 100 %.

There are a total of eight key categories identified in sector 2 IPPU, thereof six key categories with direct greenhouse gas emissions and two key categories with indirect CO<sub>2</sub> emissions (see Figure 4-4).

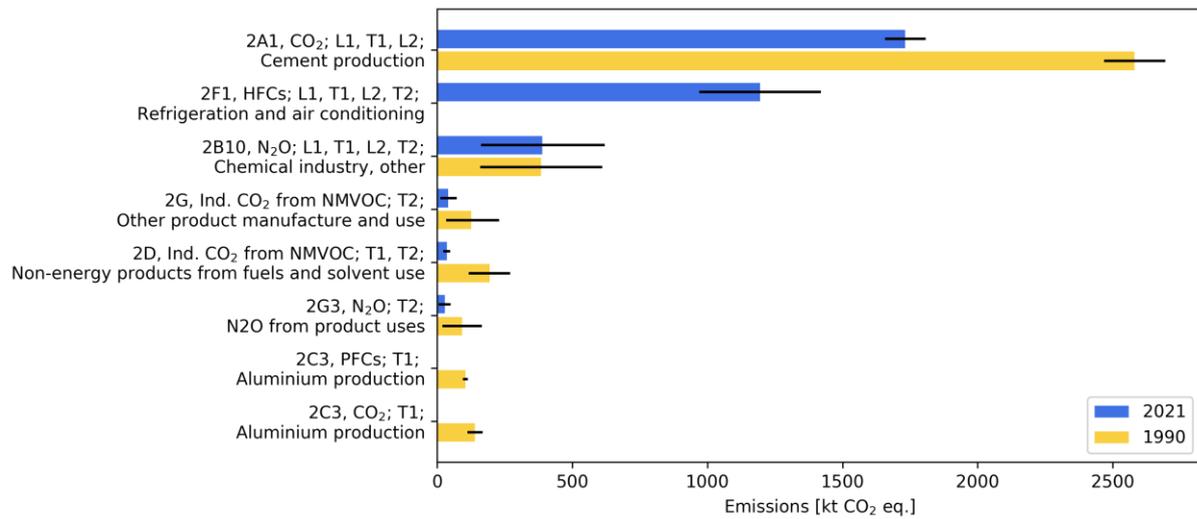


Figure 4-4 Key categories in the Swiss GHG inventory from sector 2 IPPU, including indirect CO<sub>2</sub> emissions (Ind. CO<sub>2</sub>), determined by the key category analyses, approaches 1 and 2. Categories are set out in order of decreasing emissions in 2021. L1: key category according to approach 1 level in 2021; L2: same for approach 2; T1: key category according to approach 1 trend 1990–2021; T2: same for approach 2. Black uncertainty bars represent the narrowest 95 % confidence interval obtained by Monte Carlo simulations (see chp. 1.6 for details).

## 4.2. Source category 2A – Mineral industry

### 4.2.1. Source category description

Table 4-2 Key categories of 2A Mineral industries. Combined KCA results, level for 2021 and trend for 1990–2021, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC category	Gas	Identification criteria
2A1	Cement Production	CO2	L1, T1, L2

Table 4-3 Specification of source category 2A Mineral industry.

2A	Source category	Specification
2A1	Cement production	Geogenic CO <sub>2</sub> emissions from calcination process in cement production; Emissions of CO <sub>2</sub> , NO <sub>x</sub> , CO, NMVOC and SO <sub>2</sub> from blasting operations
2A2	Lime production	Geogenic CO <sub>2</sub> emissions from calcination process in lime production; Emissions of CO <sub>2</sub> , NO <sub>x</sub> , CO, NMVOC and SO <sub>2</sub> from blasting operations
2A3	Glass production	Geogenic CO <sub>2</sub> emissions from production of container and tableware glass, and glass wool
2A4	Other process uses of carbonates	Geogenic CO <sub>2</sub> emissions from production of fine ceramics, bricks and tiles and rockwool; Geogenic CO <sub>2</sub> emissions from use of carbonates for sulphur oxide removal in municipal solid waste incineration plants, a combined heat and power plant that burns all classes of wood waste and cellulose production (ceased in 2008); Geogenic CO <sub>2</sub> emissions from use of sodium bicarbonate; Emissions of CO <sub>2</sub> , NO <sub>x</sub> , CO, NMVOC and SO <sub>2</sub> from blasting operations in plaster production

### 4.2.2. Methodological issues

#### 4.2.2.1. Cement production (2A1)

In Switzerland, there are six plants producing clinker and cement. The Swiss plants are rather small and do not exceed a capacity of 3'000 tonnes of clinker per day. All of them use modern dry process technology.

Emissions of geogenic CO<sub>2</sub> occur during the production of clinker, which is an intermediate component in the cement manufacturing process. During the production of clinker, limestone, which is mainly calcium carbonate (CaCO<sub>3</sub>), is heated (calcined) to produce lime (CaO) and CO<sub>2</sub> as by-product. The CaO reacts subsequently with minerals in the raw materials and yields clinker. During this reaction step no further CO<sub>2</sub> is emitted. Clinker is then mixed with other components such as gypsum to make cement.

Blasting operations in the limestone quarries are another source of emissions for both CO<sub>2</sub> and precursor greenhouse gases such as NO<sub>x</sub>, CO, NMVOC and SO<sub>2</sub>.

Indirect CO<sub>2</sub> emissions resulting from CO and NMVOC emissions in this source category are included in CRF Table6 as documented in chp. 9.

## Methodology

### *Calcination process*

The geogenic CO<sub>2</sub> emissions from the calcination process in cement production are determined by a Tier 2 method according to the decision tree Fig. 2.1. of 2006 IPCC Guidelines (IPCC 2006, vol. 3, chp. 2.1 Cement production).

In Switzerland, no long wet or long dry kilns are used. Only modern preheater or precalciner kilns are used and also no so-called low-alkali cement is produced. Therefore, there is no land-filling of calcined cement dust (cement kiln dust, CKD) in Switzerland. In the cement plants all the filter dust is collected in high performance electrostatic precipitator or bag filters (having an efficiency of more than 99.999 %) and being recycled to the kiln feed. In some cases, small portions of the CKD are added directly to the cement as filler. Due to the kiln technology used in Switzerland the degree of decarbonization of the CKD is almost equal to that of the kiln feed, meaning, that this CKD has not been decarbonised yet.

### *Blasting operations*

Emissions resulting from blasting operations during the digging of limestone are calculated by a Tier 2 method according to the EMEP/EEA guidebook (EMEP/EEA 2019, chp. 2A1, Fig. 3.1) using country-specific emission factors. The CO<sub>2</sub> emissions from "blasting" are related only to the usage of explosives in the quarries and not to the fuel consumption of construction machinery such as bulldozers etc.

The CO<sub>2</sub> emission factor for the use of blasting agents amounts to 600 kg CO<sub>2</sub>/t of blasting agent (EMIS 2023/2A1 Zementwerke übriger Betrieb). The amount of used explosives is reported to be 0.13 kg/t cement on average, based on measurement data of four Swiss cement plants in 2002. Since these covered more than 60 % of the production, the value is considered representative for cement plants in Switzerland.

Total emissions reported for the production of cement are the sum of emissions from calcination process and blasting operations. The share of CO<sub>2</sub> emissions from blasting operations in limestone quarries is well below one tenth of a percent of the geogenic CO<sub>2</sub> emissions from the calcination process.

## Emission factors

### *Calcination process*

The emission factor of CO<sub>2</sub> from calcination is provided per tonne of clinker. It accounts for geogenic emissions from the carbonate containing raw material, emissions from organic carbon content of the raw material and from cement kiln dust (CKD).

The base emission factor of 525 kg CO<sub>2</sub>/t clinker used in the Swiss ETS corresponds to the value provided by the Cement Sustainability Initiative (CSI) in its report "CO<sub>2</sub> and Energy Accounting and Reporting Standard for the Cement Industry – The Cement CO<sub>2</sub> and Energy Protocol" (see method B1, p. 9 in CSI 2011). Data from the Swiss cement industry for the years 2008–2011 showed that CaO contents in clinker typically varied between 63 % and

66 %, while MgO contents were around 2 %. This resulted in an emission factor that varied from 529 to 532 kg CO<sub>2</sub>/t clinker for those years (weighted average from the values of the six cement plants). However, these contents already contained fractions deriving from non-carbonate sources. Therefore, it was decided in the ETS to define the base emission factor as described in the CSI Protocol and then add a share for non-carbonate C and CKD. In submission 2017, the emission factor was revised in order to establish a consistent time series from 1990 to 2015 and also to achieve consistency between the Swiss ETS and the greenhouse gas inventory (CSI 2011).

The emissions from the organic carbon content of the raw material are assumed to be a constant share of 0.2 % of the raw material (i.e. 11.37 kg CO<sub>2</sub>/t clinker). The emission factor of CKD is estimated based on plant-specific data available for 2013–2016 that were provided by the cement industry association (cemsuisse). From this data, an average emission factor of CO<sub>2</sub> from CKD is calculated (0.35 kg CO<sub>2</sub>/t clinker). As the CKD represents only an insignificant proportion of the total EF, no annual update is provided.

Based on these three partial emission factors (base, non-carbonate C and CKD) a total emission factor per ton of clinker is calculated. This results in a country-specific emission factor of 536.7 kg CO<sub>2</sub>/t clinker. It is assumed constant for the entire time period. Given that the cement plants have not changed the source of their raw material, it is justified to assume a constant emission factor over the entire time period.

Table 4-4 CO<sub>2</sub> emission factor for calcination in 2A1 Cement Production 1990 to 2021.

2A1 Cement production	Unit	1990–2021
Calcination, CO <sub>2</sub>	kg/t clinker	537

### *Blasting operations*

The emission factors are country-specific based on emission factors of civil explosives and information on the specific consumption of explosives in the quarries as documented in the Handbook on emission factors for stationary sources (SAEFL 2000) as documented in the EMIS database (EMIS 2023/2A1 Zementwerke übriger Betrieb). They are assumed to be constant over the entire time period and are given per tonne of clinker.

Table 4-5 Emission factors for CO<sub>2</sub>, NO<sub>x</sub>, CO, NMVOC and SO<sub>2</sub> from blasting operations in g/t clinker from source category 2A1 Cement Production in 2021.

2A1 Cement production	Unit	CO <sub>2</sub>	NO <sub>x</sub>	CO	NMVOC	SO <sub>2</sub>
Blasting operations	g/t clinker	34	3.3	3.3	8.6	0.14

### **Activity data**

Since 1990, data on annual clinker production are provided by the industry association cemsuisse as documented in the EMIS database (EMIS 2023/2A1\_Zementwerke Rohmaterial). From 2008 onwards they are based on plant-specific annual monitoring reports from the Swiss Emissions Trading Scheme (ETS).

Table 4-6 Activity data of clinker production.

2A1 Cement production	Unit	1990	1995	2000	2005	2010					
Clinker production	kt	4'808	3'706	3'214	3'442	3'642					
2A1 Cement production	Unit	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Clinker production	kt	3'368	3'415	3'502	3'195	3'296	3'279	3'239	3'227	3'129	3'227

#### 4.2.2.2. Lime production (2A2)

During the production of lime, calcium carbonate ( $\text{CaCO}_3$ ) is heated (calcined) yielding burnt lime ( $\text{CaO}$ ) and  $\text{CO}_2$  as by-product. In Switzerland, there is only one plant producing lime.

There is no industry in Switzerland producing lime for its own requirements, except for sugar production. A request to both sugar producing plants confirmed that indeed they produce lime from limestone in own shaft kilns. However, the  $\text{CO}_2$  is re-captured in the sugar production process and thus no  $\text{CO}_2$  emissions occur.

Blasting operations in quarries are another source of emissions for both  $\text{CO}_2$  and precursor emissions such as  $\text{NO}_x$ , CO, NMVOC and  $\text{SO}_2$ .

Indirect  $\text{CO}_2$  emissions resulting from CO and NMVOC emissions in this source category are included in CRF Table6 as documented in chp. 9.

### Methodology

#### *Calcination process*

Since 2013, the geogenic  $\text{CO}_2$  emissions from the calcination process in lime production are determined by a Tier 3 method using plant-specific emission factors according to the decision tree Fig. 2.2. of the IPCC Guidelines (IPCC 2006, vol. 3, chp. 2.2 Lime production). Between 1990 and 2012, a Tier 2 method is applied.

#### *Blasting operations*

Emissions resulting from blasting operations during the digging of limestone are calculated by a Tier 2 method according to the EMEP/EEA Guidebook (EMEP/EEA 2019, chp. 2A2, Fig. 3.1) using country-specific emission factors. The  $\text{CO}_2$  emissions from "blasting" are related only to the usage of explosives in the quarries and not to fuel consumption of e.g. bulldozers etc.

Total emissions reported for the production of lime are the sum of emissions from calcination process and blasting operations.  $\text{CO}_2$  emissions from blasting operations in limestone quarries account only for a small share of the total emissions.

### Emission factors

#### *Calcination process*

The emission factor for  $\text{CO}_2$  from calcination of limestone depends both on the purity of the limestone and the degree of calcination (i.e. amount of  $\text{CO}_2$  remaining in the lime produced). A plant-specific value has been calculated based on industry declaration and it is assumed to be constant for the years 1990–2012 (EMIS 2023/2A2 Kalkproduktion, Rohmaterial). The value is confidential and is available to reviewers on request. Since 2013, emission factors

are derived from annual monitoring reports from the Swiss Emissions Trading Scheme (ETS).

Table 4-7 CO<sub>2</sub> emission factor for calcination process in lime production in kg/t lime for 1990–2021 are documented in the confidential NID, which is available to reviewers on request.

### *Blasting operations*

The emission factors are country-specific as documented in EMIS 2023/2A2 Kalkproduktion, übriger Betrieb. The values are confidential and they are available to reviewers on request.

Table 4-8 CO<sub>2</sub> emission factor for the calcination process in lime production in kg/t lime and emission factors for CO<sub>2</sub>, NO<sub>x</sub>, CO, NMVOC and SO<sub>2</sub> from blasting operations in g/t lime in 2021.

2A2 Lime production	Unit	CO <sub>2</sub>	NO <sub>x</sub>	CO	NMVOC	SO <sub>2</sub>
Calcination	kg/t	C	NA	NA	NA	NA
Blasting operations	g/t	C	C	C	C	C

### Activity data

Activity data on annual lime production are provided by the only existing plant in Switzerland, as documented in the EMIS database (EMIS 2023/2A2 Kalkproduktion, Rohmaterial and EMIS 2023/2A2 Kalkproduktion übriger Betrieb). Since 2009 they are based on plant-specific annual monitoring reports from the Swiss Emissions Trading Scheme (ETS).

Detailed activity data are not reported since they are considered confidential.

Table 4-9 In the confidential NID, the respective table with activity data on lime production are separately reported and available to reviewers.

### 4.2.2.3. Glass production (2A3)

Source category 2A3 Glass production comprises geogenic CO<sub>2</sub> emissions from the carbonate containing raw materials, i.e. soda ash, limestone and dolomite. In Switzerland, the following three glass types are produced: container glass, tableware glass and glass wool. Today, there is only one production plant remaining for container glass and tableware glass after the other plants closed in 2002 and 2006, respectively. Glass wool is produced in two plants.

### Methodology

For determination of geogenic CO<sub>2</sub> emissions from glass production, a Tier 2 method according to the decision tree Fig. 2.3 of IPCC 2006 (vol. 3, chp. 2.4 Glass production) is used. For glass production in Switzerland this results in the following formula:

$$\text{CO}_2 \text{ Emissions} = M_{\text{Glass type}} \cdot \text{EF}_{\text{Glass type}} \cdot (1 - \text{cullet ratio})$$

The cullet ratio describes the share of recycled glass material which is used in the production. The melting of cullet causes no geogenic CO<sub>2</sub> emissions.

From 2005 onwards, the geogenic CO<sub>2</sub> emissions from container glass production is determined according to a Tier 3 method based on the amount of carbonate containing raw materials used, i.e. soda, dolomite and limestone and their effective carbonate content.

For the two plants producing glass wool, the amount of soda ash used as raw material is available from 2013 and 2021 onwards, respectively. Accordingly, the geogenic CO<sub>2</sub> emission factor corresponds to a Tier 3 method from 2021 onwards. For the years 2013 to 2020, the emission factor is thus based on a Tier 3 method of one plant and a Tier 2 method of the other one.

### Emission factors

The emission factors for glass production in Switzerland are taken from IPCC 2006 (vol.3, chp. 2.4 Glass production, Table 2.6). For the production of container glass (1990–2004), tableware glass and glass wool (1990–2020) the values for glass type container, tableware and fibreglass are taken, respectively. As the emission factors are material properties, they remain constant over time.

From 2005 onwards, effective amounts of carbonate containing raw materials (soda ash, dolomite and limestone) are available from ETS monitoring reports for the container glass production and thus the corresponding default CO<sub>2</sub> emission factors are taken from IPCC 2006 (vol. 3, chp. 2.1, Table 2.1). As these emission factors are material properties, they remain constant over time. Whereas for the two plants producing glass wool, the amounts of soda ash are available from ETS monitoring reports from 2013 and 2021 onwards, respectively.

Table 4-10 Geogenic CO<sub>2</sub> emission factor for glass production in g/t glass and g/t carbonate containing raw material (IPCC 2006).

2A3 Glass production	Unit	CO <sub>2</sub> geogenic	
		1990–2020	2013–2021
Glass (speciality tableware)	g/t	100'000	
Glass wool (fibre glass insulation)	g/t	250'000	
Soda use	g/t soda		414'920
		1990–2004	2005–2021
Container glass	g/t	210'000	
Soda use	g/t soda		414'920
Dolomite use	g/t dolomite		477'320
Limestone use	g/t limestone		439'710

Table 4-11 In the confidential NID, a comparison of implied CO<sub>2</sub> emission factors based on Tier 2 and Tier 3 approaches is provided for container glass production in g/t glass for the time period 2005–2011.

Figure 4-5 In the confidential NID, a comparison of Tier 2 and Tier 3 methods for deriving emission factors of geogenic CO<sub>2</sub> from 2A3 Container glass production is provided for the years between 2005 and 2011.

### Activity data and cullet ratios

Source category 2A3 Glass production is dominated by the emissions from the production of container glass and glass wool.

For glass wool production, activity data are based on data from the two glass wool production plants in Switzerland. Since 2008, activity data are based on plant-specific annual monitoring reports (EMIS 2023/2A3 Glaswolle Produktion Rohprodukt).

Activity data of tableware and container glass production are based on data from Swiss glass producers (EMIS 2023/2A3 Hohlglas Produktion, EMIS 2023/2A3 Glas übrige Produktion). For container glass, they are based on ETS monitoring reports from 2005 onward.

Detailed information on activity data for container glass production and tableware production is confidential as there is only one production plant for container glass and tableware glass, respectively. Data are available to the reviewers on request.

Table 4-12 Activity data of glass production in Switzerland and cullet ratio in % as well as consumption of carbonate containing raw materials in container glass production

2A3 Glass production	Unit	1990	1995	2000	2005	2010						
Container glass												
Production	kt	C	C	C	C	C						
Cullet ratio	%	C	C	C	NA	NA						
Soda use	kt	NA	NA	NA	C	C						
Dolomite use	kt	NA	NA	NA	C	C						
Limestone use	kt	NA	NA	NA	C	C						
Glass (speciality tableware)												
Production	kt	C	C	C	C	C						
Cullet ratio	%	C	C	C	C	C						
Glass wool												
Production	kt	24	24	31	37	36						
Cullet ratio	%	21	45	69	65	71						
Soda use	kt	NA	NA	NA	NA	NA						
2A3 Glass production	Unit	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	
Container glass												
Production	kt	C	C	C	C	C	C	C	C	C	C	
Cullet ratio	%	NA										
Soda use	kt	C	C	C	C	C	C	C	C	C	C	
Dolomite use	kt	C	C	C	C	C	C	C	C	C	C	
Limestone use	kt	C	C	C	C	C	C	C	C	C	C	
Glass (speciality tableware)												
Production	kt	C	C	C	C	C	C	C	C	C	C	
Cullet ratio	%	C	C	C	C	C	C	C	C	C	C	
Glass wool												
Production	kt	39	33	32	31	32	36	40	47	40	49	
Cullet ratio	%	61	C	C	C	C	C	C	C	C	NA	
Soda use	kt	NA	C	C	C	C	C	C	C	C	2.7	

#### 4.2.2.4. Other process uses of carbonates (2A4)

Source category 2A4 Other process uses of carbonates comprises geogenic CO<sub>2</sub> emissions from production of fine ceramics (2A4a), bricks and tiles (2A4a) and rock wool (2A4d), from use of carbonates for sulphur oxide removal in municipal solid waste incineration plants (2A4d) and cellulose production (ceased in 2008) (2A4d), and from use of sodium bicarbonate (2A4d) as well as emissions of CO<sub>2</sub>, NO<sub>x</sub>, CO, NMVOC and SO<sub>2</sub> from blasting operations in plaster production (2A4d). The limestone use in cupola furnaces of iron foundries has been reallocated from source category 2A4d to 2C1.

Indirect CO<sub>2</sub> emissions resulting from CO and NMVOC emissions in this source category are included in CRF Table6 as documented in chp. 9.

## Ceramics (2A4a)

Source category 2A4a Ceramics consists of the production of fine ceramics and brick and tile.

### Fine ceramics (2A4a)

In Switzerland, the main production of fine ceramics is sanitary ware. The carbonate containing raw materials limestone and dolomite as well as small amounts of soda ash are used in product glazes only. All information on the fine ceramics production is documented in EMIS 2023/2A4a Feinkeramik Produktion.

#### Methodology

The geogenic CO<sub>2</sub> emissions from fine ceramics production are determined by a Tier 2 method according to the decision tree Fig. 2.4 of IPCC 2006 (vol. 3, chp. 2.5 Other process uses of carbonates).

For fine ceramics production in Switzerland, this results in the following formula:

$$\text{CO}_2 \text{ Emissions} = (M_{\text{Limestone}} \cdot EF_{\text{Limestone}}) + (M_{\text{Dolomite}} \cdot EF_{\text{Dolomite}}) + (M_{\text{Soda Ash}} \cdot EF_{\text{Soda Ash}})$$

#### Emission factors

The CO<sub>2</sub> emission factors of limestone, dolomite and soda ash are taken from IPCC 2006 (vol. 3, chp. 2.1, Table 2.1). As these emission factors are material properties, they remain constant over time.

Table 4-13 Geogenic CO<sub>2</sub> emission factors used for fine ceramics and the production of brick and tile in g/t carbonate containing raw material and g/t product, respectively.

2A4a Ceramics	Unit	CO <sub>2</sub> geogenic								
Fine ceramics		1990–2021								
Limestone use	g/t limestone	439'710								
Dolomite use	g/t dolomite	477'320								
Soda use	g/t soda	414'920								
		1990–2012	2014	2015	2016	2017	2018	2019	2020	2021
Brick and tile production	g/t	117'000	110'000	103'000	112'000	113'000	107'000	107'000	103'000	113'000

#### Activity data

Activity data for carbonate containing raw materials (i.e. limestone, dolomite and soda ash) used in the glazes of the fine ceramics production are extrapolated values based on industry data from the largest production plant in Switzerland. Detailed activity data are considered confidential. They are available to the reviewers on request.

### Brick and tile production (2A4a)

In Switzerland, there are about 20 plants producing bricks and tiles. The manufacturing process uses limestone containing clay as main raw material.

### *Methodology*

The brickearth used in Switzerland for the production of bricks and tiles does not consist of pure and defined contents of clay minerals but its clay content is varying depending on the individual pit, comprising other minerals such as calcite, dolomite and quartz. Compared to other countries, the fraction of carbonate containing raw material is relatively high. Detailed data on the composition of carbonate containing raw materials from the Swiss brick and tile industry were not available before 2013. Therefore, for the period 1990 until 2012 data from a comparison of geogenic CO<sub>2</sub> emissions based on representative analyses of the carbonate content of the clay used for brick and tile production in a number of plants in Switzerland and the European Union are applied. This study was carried out by the Swiss association of brick and tile industry (Verband Schweizerische Ziegelindustrie, VSZ) in 2012 (see EMIS 2023/2A4a Ziegeleien).

Since 2013, the Swiss brick and tile production plants are legally obliged to report geogenic emissions from carbonate containing raw materials annually (Federal Act on the Reduction of CO<sub>2</sub> Emissions, Swiss Confederation 2011 and Ordinance for the Reduction of CO<sub>2</sub> Emissions, Swiss Confederation 2012). The emissions are estimated from analyses of the carbonate content of the raw materials and an assumed calcination factor of 100 %. This procedure corresponds to a Tier 3 method according to the decision tree Fig. 2.4 of IPCC 2006 (vol. 3, chp. 2.5 Other process uses of carbonates). Between 1990 and 2012 a Tier 2 method is applied.

### *Emission factors*

According to the above-mentioned study, bricks emit a weighted average of 13.2 % of geogenic CO<sub>2</sub> (variation range 5.4–24 %) and roof tiles have a weighted average of 8.6 % (variation range 5.6–13 %). Based on the production shares of the largest Swiss brick producer, a production ratio for bricks to tiles of 2:1 was assumed for the whole period from 1990 to 2012. This resulted in an average geogenic CO<sub>2</sub> emission factor of 117 kg CO<sub>2</sub>/t brick and tile, which was assumed constant for the time period 1990 to 2012.

Since 2013, a production weighted emission factor is derived based on the plant-specific monitoring data of the geogenic CO<sub>2</sub> emissions from the carbonate containing raw materials. For emission factors see Table 4-13.

### *Activity data*

Activity data are based on production data from the Swiss association of brick and tile industry (VSZ) and are presented in Table 4-14 (EMIS 2023/2A4). Since 2011 they are based on plant-specific annual monitoring reports from the Swiss Emissions Trading Scheme (ETS).

Table 4-14 Activity data for the production of fine ceramics including the use of limestone, soda and dolomite in the glazes, brick and tile, rock wool and plaster as well as other use of carbonates (sodium bicarbonate).

<b>2A4a Ceramics</b>	<b>Unit</b>	<b>1990</b>	<b>1995</b>	<b>2000</b>	<b>2005</b>	<b>2010</b>					
Fine ceramics production	kt	C	C	C	C	C					
Limestone use	kt	C	C	C	C	C					
Dolomite use	kt	C	C	C	C	C					
Soda use	kt	C	C	C	C	C					
Brick and tile production	kt	1'271	1'115	959	1'086	879					
<b>2A4d Other</b>											
Rock wool production	kt	C	C	C	C	C					
Carbonate use in waste incineration plants	kt	0.71	0.76	0.82	0.61	NO					
Limestone use in cellulose production	kt	8.5	9.4	9.3	8.3	NO					
Other use of carbonates	kt	5.9	5.4	7.0	7.3	6.9					
Plaster production	kt	319	304	288	327	335					
<b>2A4a Ceramics</b>	<b>Unit</b>	<b>2012</b>	<b>2013</b>	<b>2014</b>	<b>2015</b>	<b>2016</b>	<b>2017</b>	<b>2018</b>	<b>2019</b>	<b>2020</b>	<b>2021</b>
Fine ceramics production	kt	C	C	C	C	C	C	C	C	C	C
Limestone use	kt	C	C	C	C	C	C	C	C	C	C
Dolomite use	kt	C	C	C	C	C	C	C	C	C	C
Soda use	kt	C	C	C	C	C	C	C	C	C	C
Brick and tile production	kt	792	785	765	726	660	622	581	554	531	484
<b>2A4d Other</b>											
Rock wool production	kt	C	C	C	C	C	C	C	C	C	C
Carbonate use in waste incineration plants	kt	NO	2.7	1.9	6.5	6.6	6.8	7.2	7.0	7.0	7.8
Limestone use in cellulose production	kt	NO									
Other use of carbonates	kt	7.6	6.1	7.5	6.7	6.8	6.5	7.4	7.8	7.9	9.2
Plaster production	kt	271	213	166	140	148	146	152	149	122	C

### Other uses of soda ash (2A4b)

Soda ash is mainly used in the glass production, which is reported separately in source category 2A3 Glass production. A very small amount of soda ash is also applied in glazes of fine ceramics and is thus accounted for in source category 2A4a Ceramics (see Table 4-13). Based on a study investigating carbonate use in industry (INFRAS 2015), it is concluded that there are no known other uses of soda ash (2A4b) in Switzerland. No soda ash is used in flue gas or wastewater treatment. It was concluded that there is no other relevant emissive soda ash use and thus, reported as not occurring in the inventory so far.

During the in-depth review in 2019, the ERT raised the question about potential other uses of soda ash in Switzerland. Based on net imports of soda ash and the known uses in the production of glass (assuming for glass wool and speciality tableware glass the same soda ash content of carbonate raw materials as for container glass) and fine ceramics, an amount of about 11.6 kt resulted for 2017, of which it is not clear whether its use is emissive or not. In a conservative estimate, this would yield a maximum of about 4.8 kt of CO<sub>2</sub> emissions (default emission factor of 0.41492 t CO<sub>2</sub>/t soda ash, IPCC 2006), which corresponds to 0.01 % of the national total (excluding LULUCF) in 2017. Considering the entire time series, the share of the national total was largest in 1990 (0.02 %) and has remained about constant (0.01 %) since 2003. In accordance with decision 24/CP.19, annex I, paragraph 37(b), this is below the significance threshold and thus, the ERT recommended that Switzerland reports CO<sub>2</sub> emissions from source category 2A4b Other use of soda ash as not estimated ("NE") in its inventory, which was implemented in the submission 2021.

## Other (2A4d)

### Rock wool production (2A4d)

In Switzerland, there is one single producer of rock wool. The plant uses carbonate containing raw materials like dolomite, basalt, cement and further additives as documented in the EMIS database (EMIS 2023/2A4d Steinwolle Produktion).

#### Methodology

Since 2013, rock wool manufacturers are legally obliged to report geogenic CO<sub>2</sub> emissions from carbonate containing raw material annually. For the years 2005–2011 and 2013 plant-specific data on raw material consumption and emission factors is available from monitoring reports of the Swiss ETS. From this information, data for the other years are interpolated for calculating an implied emission factor.

The geogenic CO<sub>2</sub> emissions from rock wool production are determined by a Tier 3 method according to IPCC 2006 (vol. 3, chp. 2.5 Other process uses of carbonates). Before 2004, a Tier 2 method was applied.

#### Emission factors

For rock wool production in Switzerland, the CO<sub>2</sub> emission factor is based on measurements of the oxides (CaO, MgO, Na<sub>2</sub>O, K<sub>2</sub>O, MnO) of the carbonate containing raw materials and the product for the years 2005 to 2011 as well as since 2013. Based on the difference in the oxide content in the raw material and the products, the total geogenic CO<sub>2</sub> emissions are determined. Consequently, the emission factor is specified as g/t rock wool. Since data on the carbonate content are missing for the years 1990 to 2004 and 2012 the mean value of the years 2005–2011 and 2013 is applied for these years.

The CO<sub>2</sub> emission factors are confidential. They are available to reviewers on request.

Table 4-15 Geogenic CO<sub>2</sub> emission factors used for rock wool production and other carbonate uses, CO<sub>2</sub> fossil, NO<sub>x</sub>, CO, NMVOC and SO<sub>2</sub> emission factors for plaster production in g/t carbonate containing raw material and g/t product, respectively for 2021.

2A4d Other	Unit	CO <sub>2</sub> geogenic	CO <sub>2</sub> fossil	NO <sub>x</sub>	CO	NMVOC	SO <sub>2</sub>
Rock wool production	g/t	C	NA	NA	NA	NA	NA
Carbonate use in waste incineration plants	g/t	523'880	NA	NA	NA	NA	NA
Other carbonate uses	g/t	523'880	NA	NA	NA	NA	NA
Plaster production	g/t rocks	NA	C	C	C	C	C

Table 4-16 In the confidential NID, the respective table with geogenic CO<sub>2</sub> emission factors used for rock wool production is separately reported and available to reviewers.

#### Activity data

Activity data are based on industry data from the single rock wool production plant in Switzerland (monitoring reports of the Swiss ETS) and are therefore confidential. They are available to reviewers on request.

### Other carbonate uses (2A4d)

In 2014, an assessment was carried out in order to identify sources of CO<sub>2</sub> emissions from carbonate use for sulphur oxide removal and acid neutralization, which were not considered in the Swiss greenhouse gas inventory so far (INFRAS 2015). The survey among selected potentially relevant industrial plants, industry associations, Swiss cantons and the Swiss customs administration (EZV) comprised the following substances: limestone (CaCO<sub>3</sub>), dolomite (CaMg(CO<sub>3</sub>)<sub>2</sub>), sodium bicarbonate (NaHCO<sub>3</sub>) and soda ash (Na<sub>2</sub>CO<sub>3</sub>).

Besides applications of calcium hydroxide and sodium hydroxide in flue gas treatment also a few applications of limestone and sodium bicarbonate for sulphur oxide removal could be identified in Switzerland. Limestone had been used in the cellulose production up to 2008, when the plant was closed, and in one municipal solid waste incineration plant up to 2005. Since 2013, several waste incineration plants and one combined heat and power plant that burns all classes of wood waste (from 2021 onwards) are using sodium bicarbonate.

In cupola furnaces of iron foundries limestone is also used as flux. The resulting geogenic CO<sub>2</sub> emissions are reported in 2C1 Iron and steel production. Limestone is also used to neutralize acid wastewater in one chemical production plant. These emissions are reported in source category 2B10 Limestone pit.

Additionally, it is assumed, that all other applications of sodium bicarbonate result in a complete conversion to CO<sub>2</sub>. Since there is no production of sodium bicarbonate in Switzerland, the annual emissions can be estimated based on the net import.

#### *Methodology*

The method for calculating the geogenic CO<sub>2</sub> emissions from the use of limestone and sodium bicarbonate in all the source categories mentioned above – except in waste incineration plants from 1994 onwards – corresponds to a Tier 2 method according to the decision tree Fig. 2.4 of IPCC 2006 (vol. 3, chp. 2.5 Other process uses of carbonates).

The method for calculating the geogenic CO<sub>2</sub> emissions from the use of limestone and sodium bicarbonate in waste incineration plants from 1994 onwards corresponds to a Tier 3 method according to the decision tree Fig. 2.4 of IPCC 2006 (vol. 3, chp. 2.5 Other process uses of carbonates).

#### *Emission factors*

The emission factors of limestone and sodium bicarbonate are based on the stoichiometry of CaCO<sub>3</sub> (IPCC 2006, vol. 3 chp. 2.1, table 2.1, IPCC 2006) and NaHCO<sub>3</sub> (CRC 2004), respectively, see Table 4-15. A conversion factor of 100 % is assumed for all applications of both carbonates.

#### *Activity data*

Activity data on limestone use in flue gas treatment in cellulose production are based on expert estimates on the specific consumption of limestone per tonne of cellulose as documented in the EMIS database (EMIS 2023/1A2d Zellulose Produktion).

The activity data of limestone and sodium bicarbonate use in waste incineration plants and a combined heat and power plant fuelled with all classes of wood waste are provided by the

industry as documented in the EMIS database (EMIS 2023/1A1a Kehrlichtverbrennungsanlagen).

The activity data of sodium bicarbonate correspond to difference between the net import of sodium bicarbonate and the amount of sodium bicarbonate used in waste incineration plants and a wood waste plant. The net import data are provided by the Swiss customs administration as documented in the EMIS database (EMIS 2023/2A4d Karbonatanwendung weitere). For activity data see Table 4-14.

## Plaster production (2A4d)

### *Methodology*

There were two plaster production sites in Switzerland. In August 2020, one of the two sites was closed. Therefore, data on plaster production are confidential from 2021 onwards.

The emissions stem mainly from blasting operations. They are determined by a country-specific method analogous to a Tier 2 method of the EMEP/EEA guidebook (EMEP/EEA 2019).

### *Emission factors*

As there are no specific emission factors for gypsum mining, the emission factors for cement raw material mining are taken instead (with a rough estimate that 1.5 t of raw material are required for production of 1 t of cement). This method is documented in EMIS 2023/2A4d Gips-Produktion übriger Betrieb. For emission factors see Table 4-15. Emission factors for Plaster production are confidential but available to reviewers on request.

### *Activity data*

The activity data of the annual amount of raw material processed in the plaster production are based on industry data and expert estimates as documented in EMIS 2023/2A4d Gips-Produktion übriger Betrieb (see Table 4-14). Activity data for Plaster production are confidential from 2021 onwards but available to reviewers on request.

## 4.2.3. Uncertainties and time-series consistency

For all source categories in 2A, emitting CO<sub>2</sub>, an uncertainty of 2 % is assumed for activity data, since data at plant level are available and assumed to be fully representative. This is in agreement with the default range of 1 % to 3 % (IPCC 2006, vol. 3, chp. 2, p. 2.39).

For source category 2A1 Cement production, an uncertainty of 4 % is assumed for the CO<sub>2</sub> emission factor, which consists of an average emission factor per tonne of clinker for calcination of the carbonate containing raw material (FOEN 2020k chp. G.7) and a correction for the content of organic carbon and cement kiln dust.

The uncertainty of the CO<sub>2</sub> emission factor is estimated to be 3 % for 2A2 Lime production, which is the upper value of the default range for Tier 3 (IPCC 2006, vol. 3, chp. 2, p. 2.31, suggested range of 1 % to 3 %).

For 2A3 Glass production, the uncertainty of the CO<sub>2</sub> emission factor is estimated to be 3 %, which is the upper value of the default range for Tier 3 (IPCC 2006, vol. 3, chp. 2, p. 2.31, suggested range of 1 % to 3 %).

For CO<sub>2</sub> emissions in source category 2A4 Other process uses of carbonates, most of the data are provided by industrial plants participating in the Swiss ETS, which requires that the uncertainty in the emissions does not exceed a given limit (1.5 % to 7.5 %, depending on the amount of emissions resulting from a given source) and from the Swiss Federal Customs Administration. For the emission factor, the chosen value of 2 % is also in agreement with the default range of 1 % to 5 % (IPCC 2006, vol. 3, chp. 2, p. 2.39).

Consistency: Time series for 2A Mineral industry are all considered consistent.

#### **4.2.4. Category-specific QA/QC and verification**

The general QA/QC measures are described in chp. 1.5.

For submission 2017, implied emission factors of 2A3 container glass production were assessed by both a Tier 2 and Tier 3 method for the years 2005–2011. This comparison provides an indication of the differences caused by the switch in the Tier level from Tier 2 (1990–2004) to Tier 3 (2005–2015).

#### **4.2.5. Category-specific recalculations**

The following recalculations were implemented in submission 2023. Major recalculations which contribute significantly to the total differences in GHG emissions of sector 2 IPPU between the latest and the previous submissions are also presented in chp. 10.1.2.2.

- 2A3: The geogenic CO<sub>2</sub> emission factor from 2A3 Glass wool production was revised for the years 2013–2020 based on monitoring reports from the Swiss emissions trading system. For one of the two plants the factor in 2013–2020 is based on soda consumption and for the other on cullet ratio and the default factor from IPCC 2006.

#### **4.2.6. Category-specific planned improvements**

There are no category-specific planned improvements.

## 4.3. Source category 2B – Chemical industry

### 4.3.1. Source category description

Table 4-17 Key categories of 2B Chemical industry. Combined KCA results, level for 2021 and trend for 1990–2021, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC category	Gas	Identification criteria
2B10	Chemical industry, other	N2O	L1, T1, L2, T2

Table 4-18 Specification of source category 2B Chemical industry.

2B	Source category	Specification
2B1	Ammonia production	Emissions of CO <sub>2</sub> and NMVOC are reported in 2B8b Ethylene production
2B2	Nitric acid production	Emissions of N <sub>2</sub> O and NO <sub>x</sub> from the production of nitric acid (ceased in 2018)
2B5	Carbide production	Emissions of CO <sub>2</sub> , CH <sub>4</sub> , CO and SO <sub>2</sub> from the production of silicon carbide and graphite
2B8	Petrochemical and carbon black production	Emissions of CO <sub>2</sub> and NMVOC from ethylene production. In Switzerland there is only ethylene production under this source category
2B10	Other	Emissions of CO <sub>2</sub> , CH <sub>4</sub> , CO and NMVOC from acetic acid production; CO <sub>2</sub> emissions from limestone pit; CO <sub>2</sub> , N <sub>2</sub> O, NO <sub>x</sub> and CO emissions from niacin production; NMVOC emissions from PVC production (ceased in 1996); SO <sub>2</sub> emissions from sulphuric acid production

### 4.3.2. Methodological issues

#### 4.3.2.1. Ammonia production (2B1)

Ammonia (NH<sub>3</sub>) is produced in one single plant in Switzerland by catalytic reaction of nitrogen and synthetic hydrogen (see Figure 4-6). Ammonia is not produced in an isolated reaction plant but is part of an integrated production chain (see Figure 4-6).

The starting production process is the thermal cracking of liquefied petroleum gas and light virgin naphtha yielding ethylene (ethene, C<sub>2</sub>H<sub>4</sub>), and a series of by-products such as e.g. synthetic hydrogen and methane, which are used as educts for further production steps. According to the Swiss ammonia producer it is not possible to split and allocate the emissions of the cracking process (CO<sub>2</sub> and NMVOC) to every single product such as, e.g., ethylene, acetylene (ethyne, C<sub>2</sub>H<sub>2</sub>), cyanic acid or ammonia. Therefore, all CO<sub>2</sub> and NMVOC emissions of the cracking process are allocated to the ethylene production and are reported under the category 2B8b Ethylene production. Thus, for source category 2B1 Ammonia production, CO<sub>2</sub> and NMVOC emissions are reported as included elsewhere (IE). All information on the ammonia production and the cracking process is documented in EMIS 2023/2B1 Ammoniak-Produktion and EMIS 2023/2B8b Ethen-Produktion, respectively.

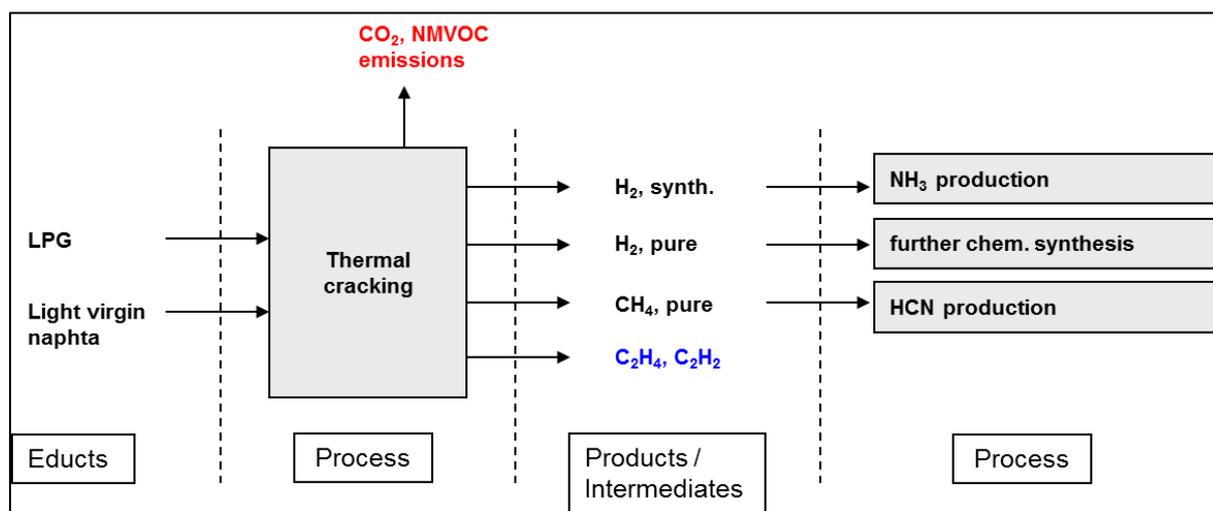


Figure 4-6 Process flow chart for the production of ethylene (C<sub>2</sub>H<sub>4</sub>) and acetylene (C<sub>2</sub>H<sub>2</sub>) by thermal cracking of liquefied petroleum gas (LPG) and light virgin naphtha. The intermediate product H<sub>2</sub>, synth. is used as educt in the ammonia production in the same plant.

Table 4-19 Activity data for ammonia production in Switzerland are documented in the confidential NID, which is available to reviewers on request.

#### 4.3.2.2. Nitric acid production (2B2)

In Switzerland, there was one single plant producing nitric acid (HNO<sub>3</sub>) which stopped production in spring 2018. Nitric acid was produced by catalytic oxidation of ammonia (NH<sub>3</sub>) with air. At temperatures of 800°C nitric monoxide (NO) is formed. During cooling, nitrogen monoxide reacted with excess oxygen to form nitrogen dioxide (NO<sub>2</sub>). The nitrogen dioxide reacted with water to form 60 % nitric acid (HNO<sub>3</sub>). Today, two types of processes are used for nitric acid production: single pressure or dual pressure plants. In Switzerland a dual pressure plant was installed.

During this process, nitrous oxide (N<sub>2</sub>O) can be formed as an unintentional by-product. In addition, also some nitrogen oxide (NO<sub>x</sub>) is produced. In the Swiss production plant abatement of NO<sub>x</sub> was done by selective catalytic reduction (SCR, installed in 1988), which reduced NO<sub>x</sub> to N<sub>2</sub> and O<sub>2</sub> (the SCR in this plant was also used for treatment of other flue gases and was not installed for the HNO<sub>3</sub> production specially). In 1990, an automatic control system for the dosing of ammonia to the SCR process was installed. A new catalyst installed in 2013 reduced the N<sub>2</sub>O emissions.

No additional abatement technique is installed to destroy N<sub>2</sub>O. A decomposition of N<sub>2</sub>O occurs, to some extent, simultaneously in the NO<sub>x</sub> reduction process.

#### Methodology

According to decision tree Fig. 3.2 of IPCC 2006 (vol. 3, chp. 3.3 Nitric acid production), the N<sub>2</sub>O emissions from nitric acid production are determined by a Tier 2 method during the time period 1990–2012 and by a Tier 3 method between 2013 and the end of production in 2018 based on direct measurements. The NO<sub>x</sub> emissions are calculated by a Tier 2 method according to the decision tree Fig. 3.1 in EMEP/EEA guidebook (EMEP/EEA 2019, chp. 2B Chemical industry) using a plant-specific emission factor.

## Emission factors

The N<sub>2</sub>O and NO<sub>x</sub> emission factors for nitric acid production in Switzerland are based on measurements from the single nitric acid production plant.

The measurement of N<sub>2</sub>O was carried out in 2009 according to the guideline VDI-Richtlinie 2469/Blatt 1 (Messen gasförmiger Emissionen – Messen von Distickstoffmonoxid – Manuelles gaschromatographisches Verfahren) and is the only plant-specific measurement of N<sub>2</sub>O emissions. The test gas is sucked in via a heated titanium sensor and then treated with a solution of potassium permanganate and hydrogen peroxide in order to remove nitrogen oxides and further disturbing components. The N<sub>2</sub>O concentration is then measured using a gas chromatograph with an electron capture detector. The measurement uncertainty is ±20 % (minimum ±0.5 mg/m<sup>3</sup>). On repeated enquires the plant confirmed that since a denitrification system and an automatic control system for the ammonia addition were installed in 1988 and 1990, respectively, no modifications were made in the production line until 2012. Therefore, a constant N<sub>2</sub>O-emission factor is assumed for this time period. A new catalyst installed in 2013 reduced the N<sub>2</sub>O emissions, which are measured online by NDIR photometry between 2013 and 2018.

The NO<sub>x</sub> emission factor is the mean value based on three plant-specific measurements in 2007, 2009 and 2012. Since no modifications were made in the production line between 1990 and 2012, a constant emission factor is assumed for this time period. In 2013, the volume of the SCR-plant was doubled. This modification together with the new catalyst in the production line slightly reduced the NO<sub>x</sub> emission factor. The values are documented in EMIS 2023/2B2 Salpetersäure Produktion.

Table 4-20 Emission factors for N<sub>2</sub>O for nitric acid production in Switzerland in kg/t nitric acid for 1990–2021 are provided in the confidential NID, which is available to reviewers on request.

## Activity data

Activity data on annual production of nitric acid (100 %) are provided annually by the Swiss production plant for the entire time period 1990–2018. Since 2013, activity data of the annual nitric acid production is taken from annual monitoring reports from the Swiss Emissions Trading Scheme (ETS). The data are confidential but available to reviewers (see EMIS 2023/2B2 Salpetersäure Produktion).

Table 4-21 Activity data for the production of nitric acid (100 %) in Switzerland are documented in the confidential NID, which is available to reviewers on request.

### 4.3.2.3. Carbide production (2B5)

In Switzerland, there is one single plant producing carbide. The plant produces silicon carbide, which is used in abrasives, refractories, metallurgy and anti-skid flooring. Silicon carbide is produced together with graphite in a coupled process in an electric furnace at temperatures above 2000 °C using the Acheson process. The starting materials are quartz sand (SiO<sub>2</sub>), petroleum coke and anthracite (C) which yield silicon carbide (SiC) and carbon monoxide (CO). The CO is converted to CO<sub>2</sub> in excess oxygen and released to the atmosphere. Petroleum coke and anthracite – although to a lower portion – may contain

volatile organic compounds, which can form methane (CH<sub>4</sub>) as an unintended by-product. There is no abatement techniques installed which could capture the CO<sub>2</sub> or CH<sub>4</sub> emissions.

Indirect CO<sub>2</sub> emissions resulting from CH<sub>4</sub> and CO emissions in this source category are included in CRF Table6 as documented in chp. 9.

### Methodology

According to decision tree Fig. 3.5 of IPCC 2006 (vol. 3, chp. 3.6 Carbide production), the CO<sub>2</sub> and CH<sub>4</sub> emissions from silicon carbide production are determined by a Tier 2 method. The CO and SO<sub>2</sub> emissions are calculated by a Tier 2 method according to the decision tree Fig. 3.1 in EMEP/EEA guidebook (EMEP/EEA 2019, chp. 2B Chemical industry) using plant-specific emission factors.

### Emission factors

The CO<sub>2</sub>, CH<sub>4</sub>, CO and SO<sub>2</sub> emission factors are confidential and available to reviewers on request. The values are partly based on data from the single silicon carbide production plant and are documented in EMIS 2023/2B5 Graphit und Siliziumkarbid Produktion.

The CO<sub>2</sub>, CO and SO<sub>2</sub> emission factors are based on data from the production plant. For CO<sub>2</sub> and CO, they are calculated based on the carbon mass balance of the production process and CO exhaust measurements from 2001 onwards. The SO<sub>2</sub> emission factor is derived from the sulphur content of the feedstocks, i.e. petroleum coke and anthracite. The CO<sub>2</sub> emission factors for the entire time series are listed in the following table.

Table 4-22 In the confidential NID, a respective table with emission factors of fossil CO <sub>2</sub> in kg/t silicon carbide are provided. Data are available to reviewers on request.
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Table 4-23 Emission factors for CO <sub>2</sub> , CH <sub>4</sub> , CO and SO <sub>2</sub> for carbide production in kg/t silicon carbide in Switzerland for 2020 are provided in the confidential NID, which is available for reviewers upon request.
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### Activity data

Activity data on annual production of silicon carbide (and graphite) are provided annually from 1995 onwards by the production plant. For the time period 1990–1994 they are based on industry data.

The data are confidential but available to reviewers on request (see EMIS 2023/2B5 Graphit und Siliziumkarbid Produktion).

Table 4-24 In the confidential NID, the respective table with activity data on silicon carbide production in Switzerland is separately reported and available to reviewers.
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#### 4.3.2.4. Petrochemical and carbon black production (2B8)

##### Ethylene (2B8b)

Ethylene (ethene, C<sub>2</sub>H<sub>4</sub>) is produced by a single plant in Switzerland by thermal cracking of liquefied petroleum gas and virgin naphtha. Ethylene is not produced in an isolated process but is co-processed together with several other products such as H<sub>2</sub>, CH<sub>4</sub>, and C<sub>2</sub>H<sub>2</sub> (see flow chart in Figure 4-6 in chp. 4.3.2.1). From the thermal cracking process, emissions of CO<sub>2</sub> and NMVOC are released. They are both allocated entirely to the production of ethylene, which is the first product within the integrated production chain. CH<sub>4</sub> emissions to the atmosphere do not occur since CH<sub>4</sub> is completely used as an educt in the downstream production of cyanic acid (HCN) in the same facility (again, see Figure 4-6 and for further information see EMIS 2023/2B8b Ethen-Produktion). Therefore, CH<sub>4</sub> emissions are reported as NA for ethylene production and only CO<sub>2</sub> and NMVOC emissions are reported.

The CO<sub>2</sub> emissions from the cracker reported in source category 2B8b Ethylene production are based on a mass balance considering all feedstocks, products and by-products. Therefore, the NMVOC emissions are not included in the calculation of the indirect CO<sub>2</sub> emissions from sector 2 IPPU in order to avoid double counting.

##### Methodology

According to decision trees Fig. 3.8 of IPCC 2006 (vol. 3, chp. 3.9 Petrochemical and carbon black production) and Fig. 3.1 of the EMEP/EEA guidebook (EMEP/EEA 2019, chp. 2B Chemical industry), the CO<sub>2</sub> and NMVOC emissions, respectively, from ethylene production are determined by a Tier 2 method using plant-specific emission factors (EMIS 2023/2B8b Ethylene production).

##### Emission factors

The CO<sub>2</sub> and NMVOC emission factors for ethylene production are based on industry data from the single ethylene production plant in Switzerland. Annual emission data were only available from the year 2000 onwards. For the period 1990–1999 constant emission factors, i.e. the mean emission factors of the years 2000–2009 were assumed.

The emission factors for ethylene production are considered confidential; however, they are available to reviewers on request.

Table 4-25 Emission factors for CO<sub>2</sub> and NMVOC in ethylene production, NMVOC in acetic acid production, CO<sub>2</sub> in limestone pit, CO<sub>2</sub>, N<sub>2</sub>O, NO<sub>x</sub> and CO in niacin production and SO<sub>2</sub> in sulphuric acid production for 2021 in kg/t product.

2B8 Petrochemical and carbon black production	Unit	CO <sub>2</sub>	N <sub>2</sub> O	NO <sub>x</sub>	CO	NMVOC	SO <sub>2</sub>
2B8b Ethylene	kg/t	C	NA	NA	NA	C	NA
2B10 Other							
Acetic acid production	kg/t	NA	NA	NA	NA	C	NA
Limestone pit	kg/t	C	NA	NA	NA	NA	NA
Niacin production	kg/t	C	C	C	C	NA	NA
Sulphuric acid production	kg/t	NA	NA	NA	NA	NA	C

Table 4-26 CO<sub>2</sub> fossil emission factors in 2B8b Ethylene are documented in the confidential NID, which is available to reviewers on request.

### Activity data

Activity data on the annual production of ethylene are provided annually by the single ethylene production plant in Switzerland. Since 2013, activity data are taken from annual monitoring reports from the Swiss Emissions Trading Scheme (ETS). The data are considered confidential but available to reviewers on request.

Table 4-27 Activity data for the production of ethylene, acetic acid, niacin, PVC and sulphuric acid as well as for limestone pit in Switzerland in kt.

	Unit	1990	1995	2000	2005	2010					
<b>2B8 Petrochemical and carbon black production</b>											
2B8b Ethylene	kt	C	C	C	C	C					
<b>2B10 Other</b>											
Acetic acid production	kt	30	27	24	8.4	20					
Limestone pit	kt	C	C	C	C	C					
Niacin production	kt	C	C	C	C	C					
PVC production	kt	43	43	NO	NO	NO					
Sulphuric acid production	kt	C	C	C	C	C					
	Unit	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
<b>2B8 Petrochemical and carbon black production</b>											
2B8b Ethylene	kt	C	C	C	C	C	C	C	C	C	C
<b>2B10 Other</b>											
Acetic acid production	kt	12	C	C	C	C	C	C	C	C	C
Limestone pit	kt	C	C	C	C	C	C	C	C	C	C
Niacin production	kt	C	C	C	C	C	C	C	C	C	C
PVC production	kt	NO									
Sulphuric acid production	kt	C	C	C	C	C	C	C	C	C	C

#### 4.3.2.5. Other (2B10)

Source category 2B10 Other comprises emissions from production of acetic acid, sulphuric acid, niacin and PVC (ceased in 1996) as well as from limestone pits.

#### Acetic acid production (2B10)

In Switzerland, there is only one plant producing acetic acid (CH<sub>3</sub>COOH) remaining after the other one stopped its production by the end of 2012. The still existing plant emits NMVOC only whereas from the latter one also emissions of CO<sub>2</sub>, CH<sub>4</sub> and CO occurred.

Indirect CO<sub>2</sub> emissions resulting from CH<sub>4</sub>, CO and NMVOC emissions in this source category are included in CRF Table6 as documented in chp. 9.

#### Methodology

In order to determine emissions of CO<sub>2</sub> and CH<sub>4</sub> from acetic acid a country-specific method analogous to a Tier 2 method according to IPCC 2006 (vol. 3) is used. The CO and NMVOC emissions are calculated by a Tier 2 method according to the decision tree Fig. 3.1 in the EMEP/EEA guidebook (EMEP/EEA 2019, chp. 2B Chemical industry).

### *Emission factors*

The emission factors for CO<sub>2</sub>, CH<sub>4</sub>, CO and NMVOC from acetic acid production in Switzerland are plant-specific and based on data from industry and expert estimates documented in EMIS 2023/2B10 Essigsäure-Produktion.

In the plant which ceased production by the end of 2012 process emissions had been treated in a flue gas incineration. Thus, the reported emissions of CH<sub>4</sub>, CO and NMVOC only occurred in case of malfunction, which resulted in strongly fluctuating plant-specific emission factors. In addition, the resulting implied emission factors based on the emissions of both plants are modulated by considerable production fluctuations of one of the plants from 2000 onwards.

The emission factors for acetic acid production are confidential but available to reviewers on request.

Table 4-28 In the confidential NID, the respective table with emission factors for CO<sub>2</sub> and CH<sub>4</sub> in acetic acid production are separately reported and available to reviewers.

### *Activity data*

The annual amount of produced acetic acid is based on data from industry and from the Swiss industry association for the chemical, pharmaceutical and biotech industry (scienceindustries) documented in EMIS 2023/2B10 Essigsäure-Produktion (see Table 4-27).

The data for acetic acid production since 2013 are confidential, since there is only one manufacturer remaining. The data are available for reviewers on request.

## **Limestone pit (2B10)**

In one chemical plant acids are neutralized in a so-called limestone pit yielding geogenic CO<sub>2</sub> emissions.

### *Methodology*

According to decision tree Fig. 2.4 of IPCC 2006 (vol. 3, chp. 2.5 Other process uses of carbonates), the CO<sub>2</sub> emissions from the limestone pit are determined by Tier 2 method using plant-specific emission factors.

### *Emission factors*

The CO<sub>2</sub> emission factor is considered confidential but available to reviewers on request.

### *Activity data*

Activity data of annual consumption of calcium carbonate are provided by the chemical plant from 1999 onwards as documented in EMIS 2023/2B10 Kalksteingrube. For the years 2005–2011 and since 2013 they are based on monitoring reports of the Swiss ETS. Since no data are available of the limestone pit for the time period 1990–1998, the annual activity is derived from the average annual consumption between 1999 and 2015.

Activity data is considered confidential but available to reviewers on request.

### **Niacin production (2B10)**

In Switzerland, there is one plant producing niacin that emits CO<sub>2</sub>, N<sub>2</sub>O, NO<sub>x</sub> and CO. In the production process nitric acid is used as oxidizing agent. Since the nitric acid production plant was closed in spring 2018 the required nitric acid is directly produced within the niacin production plant using a so-called ammonia burner. In autumn 2021, a catalytic converter was installed to treat the non-absorbed gas components of the production plant (including ammonia burner). The nitrogen oxides are denitrified with ammonia, and nitrous oxide, hydrocyanic acid and carbon monoxide are decomposed to nitrogen, water and carbon dioxide.

#### *Methodology*

In order to determine emissions of CO<sub>2</sub> and N<sub>2</sub>O from niacin production, a country-specific method analogous to a Tier 2 method according to IPCC 2006 (vol. 3) is used. The NO<sub>x</sub> and CO emissions are calculated by a Tier 2 method based on the decision tree Fig. 3.1 in the EMEP/EEA guidebook (EMEP/EEA 2019, chp. 2B Chemical industry) using plant-specific emission factors.

#### *Emission factors*

The emission factors of CO<sub>2</sub>, N<sub>2</sub>O, NO<sub>x</sub> and CO are plant-specific based on measurement data from industry. For CO<sub>2</sub> and CO, they are based on measurements in 2018 and 2021 before and after the production process was modified (i.e. including the ammonia burner) and after the installation of the catalytic converter, respectively. For N<sub>2</sub>O, the emission factor is derived from measurements in 2018 after the modification of the production process but with and without operating the ammonia burner and in 2021 (after catalytic converter installation). For NO<sub>x</sub>, the emission factor is based on measurements in 2017 and 2018 (after process modification) and 2021 (after converter installation). Due to lack of emission measurements in previous years, constant emission factors are assumed between 1990 and 2017 as documented in the EMIS database (EMIS 2023/2B10 Niacin-Produktion) The emission factors are considered confidential but available to reviewers on request.

Table 4-29 In the confidential NID, the respective table with emission factors for CO <sub>2</sub> and N <sub>2</sub> O emission factors for 2B10 Niacin production are separately reported and available to reviewers.
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#### *Activity data*

Activity data of annual niacin production were provided by the Swiss production plant for the entire time period as documented in EMIS 2023/2B10 Niacin-Produktion. For the years 2005–2011 and since 2013 they are based on monitoring reports of the Swiss ETS.

Activity data are considered confidential but available to reviewers on request.

## PVC and sulphuric acid production (2B10)

Sulphuric acid ( $\text{H}_2\text{SO}_4$ ) is produced by one plant only in Switzerland. From this production process  $\text{SO}_2$  is emitted. Until 1996, also PVC was produced in Switzerland releasing NMVOC emissions.

Indirect  $\text{CO}_2$  emissions resulting from NMVOC emissions in this source category are included in CRF Table6 as documented in chp. 9.

### *Methodology*

In order to determine NMVOC and  $\text{SO}_2$  emissions from sulphuric acid and PVC production, respectively, a Tier 2 method according to the decision tree Fig. 3.1 in the EMEP/EEA guidebook (EMEP/EEA 2019, chp. 2B Chemical industry) with plant-specific emission factors is used.

### *Emission factors*

The emission factor for  $\text{SO}_2$  from sulphuric acid production in Switzerland is plant-specific and based on measurement data from industry and expert estimates documented in the EMIS database (EMIS 2023/2B10 Schwefelsäure-Produktion).

The  $\text{SO}_2$  emission factor is confidential but available to reviewers on request.

For PVC production the NMVOC emission factor was based on industry information and expert estimates (EMIS 2023/2B10 PVC-Produktion).

### *Activity data*

The annual amount of sulphuric acid and PVC produced is based on data from industry and expert estimates documented in EMIS 2023/2B10 Schwefelsäure-Produktion and EMIS 2023/2B10 PVC-Produktion (see Table 4-27). The activity data for sulphuric acid production are confidential but available to reviewers on request.

## 4.3.3. Uncertainties and time-series consistency

For all source categories in 2B, the activity data are based on plant level data and the corresponding uncertainties are therefore considered small and estimated to be 2 %.

For  $\text{N}_2\text{O}$  emissions from 2B2 Nitric acid production, the combined uncertainty is assumed to be 7.5 % (from 2013 – 2018) since the Swiss ETS requires that an uncertainty of 7.5 % is not exceeded for emission estimations based on continuous  $\text{N}_2\text{O}$  measurements. The uncertainty for the emission factor is derived using the activity data uncertainty of 2 %. For 1990 an uncertainty of 60 % is assumed for the emission factor, based on the uncertainty rating given in EMEP/EEA (2019) (part A, chp. 5, Table 2-2, rating B) since the calculated emissions are based on a single  $\text{N}_2\text{O}$  emission measurement in 2009.

For 2B5 Silicon carbide production, the uncertainty of the  $\text{CO}_2$  emission factor is set at 10 %, which is the default value according to IPCC 2006 (vol. 3, chp. 3, p. 3.45). For  $\text{CH}_4$ , the uncertainty of the emission factor is set at 20 %.

For 2B8b Ethylene production, the uncertainty of the  $\text{CO}_2$  emission factor is 10 % according to the default value for a Tier 2 methodology (IPCC 2006, vol. 3, chp. 3, p. 3.87).

The uncertainties for the CO<sub>2</sub> and N<sub>2</sub>O emission factors from 2B10 Niacin production are assumed to be 60 % according to the uncertainty rating given in EMEP/EEA (2019) (part A, chp. 5, Table 2-2, rating B) since the calculated emissions are based on (spot) measurement data from industry in 2018 and 2021 only.

Consistency: Time series for 2B Chemical industry are all considered consistent.

#### 4.3.4. Category-specific QA/QC and verification

The general QA/QC measures are described in chp. 1.5.

#### 4.3.5. Category-specific recalculations

There were no recalculations implemented in submission 2023.

#### 4.3.6. Category-specific planned improvements

No category-specific improvements are planned.

### 4.4. Source category 2C – Metal industry

#### 4.4.1. Source category description

Table 4-30 Key categories of 2C Metal industry. Combined KCA results, level for 2021 and trend for 1990–2021, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC category	Gas	Identification criteria
2C3	Aluminium production	CO <sub>2</sub>	T1
2C3	Aluminium production	PFCs	T1

Table 4-31 Specification of source category 2C Metal industry.

2C	Source category	Specification
2C1	Iron and steel production	Emissions of CO <sub>2</sub> , NO <sub>x</sub> , CO, NMVOC and SO <sub>2</sub> from the production of iron and steel; Geogenic CO <sub>2</sub> emissions from use of limestone in iron-foundries (cupola furnaces)
2C2	Ferroalloys production	Production is not occurring in Switzerland
2C3	Aluminium production	Emissions of PFC, CO <sub>2</sub> , NO <sub>x</sub> , CO, NMVOC, and SO <sub>2</sub> from the production of primary aluminium (ceased in 2006); Emissions from use of SF <sub>6</sub> in aluminium foundries
2C4	Magnesium production	Emissions from use of SF <sub>6</sub> in magnesium foundries
2C7	Other	Emissions of CO and NMVOC from non-ferrous metal foundries; Emissions of CO <sub>2</sub> , NO <sub>x</sub> , CO and SO <sub>2</sub> from battery recycling

## 4.4.2. Methodological issues

### 4.4.2.1. Iron and steel production (2C1)

There is no primary iron and steel production in Switzerland. Only secondary steel production occurs, which is steel production from recycled steel scrap. After closing down of two steel plants in 1994, there remain two plants in Switzerland. Both plants use electric arc furnaces (EAF) with a carbon electrode for melting the steel scrap. During the melting process CO<sub>2</sub> emissions occur mainly from scrap, electrodes and carburization coal whereas the produced steel, filter dust and slag act as carbon sinks. Emissions of precursors such as NO<sub>x</sub>, CO, NMVOC and SO<sub>2</sub> occur as well.

In Switzerland, no production of pig iron occurs but iron is processed in foundries only. Today, there exist about 14 iron foundries in Switzerland. About 75 % of the iron is processed in induction furnaces and 25 % in cupola furnaces. From induction furnaces only precursors are emitted. In cupola furnaces also CO<sub>2</sub> emissions from other bituminous coal and limestone occur. Other bituminous coal acts first of all as fuel but also as carburization material and reductant. Therefore it was decided to report those CO<sub>2</sub> emissions in source category 1A2a. This ensures consistency with the reported use of other bituminous coal as fuel in the Swiss overall energy statistics (SFOE 2022). In cupola furnaces of iron foundries, limestone is also used as flux as documented in the EMIS database (EMIS 2023/1A2a 2C1 Eisengiessereien Kupolöfen). The resulting geogenic CO<sub>2</sub> emissions are reported in 2C1.

The CO<sub>2</sub> emissions from 2C1 Secondary steel production, electric arc furnace are based on a carbon mass balance considering all carbon sources and sinks of the process. Therefore, the emissions of CO and NMVOC are not included in the calculation of the indirect CO<sub>2</sub> emissions from sector 2 IPPU in order to avoid a double counting.

### Methodology

For determination of CO<sub>2</sub> emission from EAF in secondary steel production a mixture of a Tier 2 (before 2005 and for 2012) and a Tier 3 method (2005–2011 and since 2013) according to decision tree Fig. 4.7 of IPCC 2006 (vol. 3, chp. 4.2 Iron & steel and metallurgical coke production) is used. For the years 2005–2011 and from 2013 onwards plant-specific data on the carbon mass balance is available from monitoring reports of the Swiss ETS, since under the Ordinance for the Reduction of CO<sub>2</sub> Emissions (Swiss Confederation 2012) the plants are required to report their emissions annually (Tier 3). From this information, data for the other years are interpolated for calculating an implied emission factor. In Switzerland, no CH<sub>4</sub> emissions occur in the EAF process.

The method for calculating geogenic CO<sub>2</sub> emissions from limestone use in cupola furnaces of iron foundries corresponds to a Tier 2 method according to the decision tree Fig. 2.4 of IPCC 2006 (vol. 3, chp. 2.5 Other process uses of carbonates).

Emissions of all precursors are determined by a Tier 2 method based on the decision tree Fig. 3.1 in chapter 2C1 in the EMEP/EEA guidebook (EMEP/EEA 2019) using country-specific emission factors (EMIS 2023/2C1).

## Emission factors

The emission factors for EAF in secondary steel production in Switzerland are country-specific and are based on measurements from industry and expert estimates documented in the EMIS database (EMIS 2023/2C1 Stahl-Produktion Elektroschmelzöfen).

The electrode consumption in the two Swiss plants differs. For the calculations all carbon sources (graphite electrodes, steel scrap, alloy coal, etc.) and carbon sinks (steel, filter dust and slag) for the years 2005–2011 and from 2013 onwards were taken into account. Based on these carbon mass balances, a mean plant-specific CO<sub>2</sub> emission factor results. The reported CO<sub>2</sub> emission factor for Swiss steel industry is the production-weighted average. Therefore, from this source category no indirect emissions are included in CRF Table6 as documented in chp. 9.

The plant-specific data are confidential but available to reviewers on request.

Table 4-32 CO<sub>2</sub> emission factor of electric arc furnaces in 2C1 Steel production in kg/t.

2C1 Steel production	Unit	1990	1995	2000	2005	2010
CO <sub>2</sub>	kg/t	8.3	8.0	7.7	8.8	7.6

2C1 Steel production	Unit	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
CO <sub>2</sub>	kg/t	7.3	7.4	7.5	6.4	6.2	6.6	6.2	5.8	5.6	5.5

Emission factors for all precursors emitted from steel production are based on air pollution control measurements of the steel plants. For submission 2016, emission factors of NO<sub>x</sub>, CO, NMVOC, and SO<sub>2</sub> have been revised based on air pollution control measurements at the electric arc furnaces of the two plants in 1999, 2005 and 2010 and in 1998, 2009 and 2014, respectively.

The emission factor of geogenic CO<sub>2</sub> from limestone use in cupola furnaces of iron foundries is based on the stoichiometry of CaCO<sub>3</sub> (IPCC 2006, vol. 3 chp. 2.1, table 2.1), see Table 4-33. A conversion factor of 100 % is assumed. The emission factors of the precursors from induction furnaces of iron foundries are provided by the Swiss foundry association (GVS).

Table 4-33 Emission factors for CO<sub>2</sub>, NO<sub>x</sub>, CO and NMVOC in iron production, for CO<sub>2</sub>, NO<sub>x</sub>, CO, NMVOC and SO<sub>2</sub> in steel production, for CO and NMVOC in non-ferrous metal production and for CO<sub>2</sub>, NO<sub>x</sub>, CO and SO<sub>2</sub> in battery recycling for 2021.

2C Metal industry	Unit	CO <sub>2</sub>	NO <sub>x</sub>	CO	NMVOC	SO <sub>2</sub>
2C1 Iron production	kg/t	NA	0.01	4.1	4.0	NA
2C1 Limestone use in iron foundries (cupola furnaces)	kg/t	439.71	NA	NA	NA	NA
2C1 Steel production	kg/t	5.5	0.14	0.7	0.1	0.014
2C7a Non-ferrous metals	kg/t	NA	NA	0.24	0.05	NA
2C7c Battery recycling	kg/t	C	C	C	C	C

## Activity data

Activity data on annual production of iron and steel are provided annually by the Swiss foundry association (Giesserei-Verband Schweiz, GVS) and the steel plants, respectively. Since 2009, activity data of the annual steel production is taken from annual monitoring reports from the Swiss Emissions Trading Scheme (ETS).

The amount of limestone used as flux in iron foundries (cupola furnaces) is estimated by GVS to be in the range of 30–50 % of the coal consumed. Therefore, an average share of 40 % is assumed to calculate the activity data of limestone use (EMIS 2023/1A2a\_2C1 Eisengiessereien Kupolöfen).

Table 4-34 Production of iron, steel, aluminium and non-ferrous metals as well as amount of batteries recycled in Switzerland in kt.

2C Metal industry	Unit	1990	1995	2000	2005	2010					
2C1 Iron production	kt	170	130	120	67	53					
2C1 Limestone use in iron foundries (cupola furnaces)	kt	6.2	4.1	3.8	2.3	0.98					
2C1 Steel production	kt	1'108	716	1'022	1'159	1'218					
2C3 Aluminium production	kt	87	21	36	45	NO					
2C7a Non-ferrous metals	kt	60	56	53	33	20					
2C7c Battery recycling	kt	NO	C	C	C	C					
2C Metal industry	Unit	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
2C1 Iron production	kt	46	45	43	37	34	35	34	24	20	22
2C1 Limestone use in iron foundries (cupola furnaces)	kt	0.86	0.86	0.82	0.70	0.65	0.67	0.65	0.45	0.38	0.41
2C1 Steel production	kt	1'252	1'231	1'315	1'296	1'238	1'270	1'291	1'130	1'125	1'294
2C3 Aluminium production	kt	NO									
2C7a Non-ferrous metals	kt	6.6	6.4	9.5	8.9	9.0	8.0	6.8	6.4	5.1	7.5
2C7c Battery recycling	kt	C	C	C	C	C	C	C	C	C	C

#### 4.4.2.2. Aluminium production (2C3)

##### Methodology

The last production site for primary aluminium in Switzerland closed down in April 2006. According to IPCC 2006 (vol. 3, chp. 4.4, fig. 4.11), CO<sub>2</sub> emissions are calculated by a Tier 2 method using a country-specific emission factor. For PFC emissions, a more specific Tier 3 method with facility-specific data according to the Guidelines (IPCC 2006) was used. Operating smelter emissions have been monitored periodically by the industry for selected years.

FOEN import statistics indicate in the year 2003 part of the SF<sub>6</sub> imports to be related to the aluminium industry, referring to cleaning processes in foundries. The 2006 IPCC Guidelines mention use of SF<sub>6</sub> in aluminium production for magnesium alloys on a low scale but do not provide further information for evaluation. Accordingly, the same evaluation methodology as for magnesium foundries with an emission factor based on a Tier 2 method is applied.

##### Emission factors

The emission factor for CO<sub>2</sub> of 1.6 tonnes per tonne of aluminium is country-specific. It is based on measurements and data from industry and expert estimates, as documented in the EMIS database (EMIS 2023/2C3 Aluminium Produktion). CO<sub>2</sub> emissions from aluminium production stem from the oxidation of the anode in the electrolysis process. In Switzerland, only prebake anode technology was used. For the anode consumption, a constant mean value of 0.43 tonnes per tonne of aluminium was applied. It is assumed that the anode consisted completely of carbon and that it was fully oxidized during the process. Therefore, no indirect CO<sub>2</sub> emissions resulting from CO emissions from primary aluminium production are included in CRF Table6 as documented in chp. 9. However, the NMVOC emissions solely originate from the production of the electrodes at the plants. Accordingly, the

respective indirect CO<sub>2</sub> emissions resulting from NMVOC in this source category are included in CRF Table6 as documented in chp. 9.

Before the close down of the only Swiss primary aluminium factory in 2006, PFC emission factors of operating smelters have been monitored periodically. Measurements made in 1990, 1999 and 2000 reported emission factors of 0.17, 0.06 and 0.04 kg per tonne, respectively, for those three years (Alcan 2003). This was reported to be lower than the European averages, by factors of 4.0, 4.7 and 4.0, respectively. For other years no measurements have been made in Switzerland; thus, European Union (EU) average emission factors have been used, multiplied by a factor of 0.25 (Alcan 2002).

Figure 4-7 shows the resulting development of the emission factor for PFC over time. The European average has decreased by over 75 % from 0.68 kg PFC per tonne of aluminium to 0.16 kg PFC per tonne of aluminium between 1990 and 2000 (European Aluminium 2019).

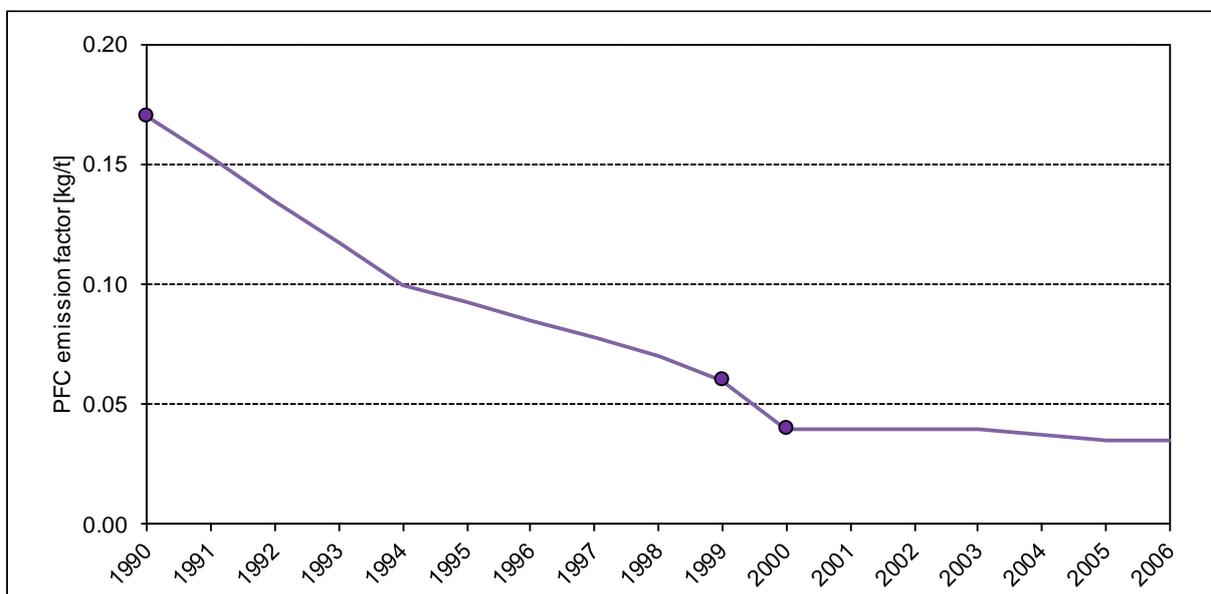


Figure 4-7 Extrapolation of PFC emission factor based on measurements in 1990, 1999 and 2000. The path for the reduction between measurements and the stagnation after the last measurements reflects the observed development of average emission factors in the European Union.

There is no documentation of the measurements. Due to the close down in 2006 it is not possible to redo any measurements or to collect any information about the process details retroactively. Measurement results and development of emission factors are assumed to be plausible because the factory used point feed prebake (PFPB) technology which is known for the lowest emissions per tonne of aluminium. The resulting emission factors for Switzerland are within the uncertainty range according to the 2006 IPCC Guidelines (variations by a factor of 10 using same technologies). The comparison with data from IAI (2005) on global PFC emissions from aluminium production showed that the monitored emissions from the smelter in Switzerland were lower by a factor of about 4.

Table 4-35 PFC emission factors for aluminium production in Switzerland. Aluminium production in Switzerland ceased in 2006.

Gas	Unit	1990	1995	2000	2005	2006	2007-2021
CF <sub>4</sub>	kg/t	0.15	0.083	0.036	0.032	0.032	NO
C <sub>2</sub> F <sub>6</sub>	kg/t	0.017	0.0093	0.0040	0.0035	0.0035	NO

There are no measurements of SF<sub>6</sub> emissions available from aluminium foundries to identify the fraction of SF<sub>6</sub> destroyed or transformed in the cleaning process. For SF<sub>6</sub> used in aluminium foundries (2C3) it is therefore assumed that the total imported amount is emitted, in accordance with the default emission factor (1'000 kg per tonne of imported substance) of the IPCC Guidelines (IPCC 2006).

### Activity data

In 2006, the last primary aluminium production site in Switzerland was closed. Activity data on aluminium production from 1997 to 2006 are based on annual data published by the Swiss Aluminium Association. For earlier years, data were provided directly by the aluminium industry. Activity data for aluminium production in Switzerland are given in Table 4-34.

Activity data on SF<sub>6</sub> used in aluminium foundries (2C3) is derived from import data from FOEN statistics. Import companies indicated in the year 2003 a portion of SF<sub>6</sub> imports for foundries to be used for aluminium cleaning. For the activity data of any particular year, the mean value of the imports in the present and the previous year is used to account for possible time lag between import and consumption (e.g. for 2004 the mean value of 2003 and 2004 import data are used). In 2011, a study was carried out among members of the Swiss Foundry Association (GVS), confirming that SF<sub>6</sub> is not used any more in aluminium foundries. As no details on the imported amount are available for the time period 2003–2011, a steady decrease of the import amount of SF<sub>6</sub> is assumed from 2003 until the final elimination of SF<sub>6</sub> for aluminium cleaning in 2011. This assumption is based on the above-mentioned survey and on information obtained on applications within the category 'others' from FOEN import statistics.

#### 4.4.2.3. Magnesium production (2C4)

##### Use of SF<sub>6</sub> in magnesium foundries (2C4)

SF<sub>6</sub> was used in Swiss magnesium foundries in the time period 1997 to 2016. There have been two magnesium foundries known to be using SF<sub>6</sub>. In 2007 one of them closed down. A survey carried out 2011 among members of the Swiss Foundry Association (GVS) confirmed that only one company was using SF<sub>6</sub>.

The import of SF<sub>6</sub> for magnesium foundries has been prohibited in Switzerland since 2017.

### Methodology

SF<sub>6</sub> was used in magnesium foundries in the cleaning process as inert gas to fill casting forms. The Swiss Foundry Association (GVS) has not provided information on emission factors and hence a Tier 2 method is used.

## Emission factors

There are no measurements of SF<sub>6</sub> emissions available to identify the fraction of SF<sub>6</sub> destroyed or transformed in the process. For SF<sub>6</sub> used in magnesium foundries (2C4) it is therefore assumed that the total imported amount is emitted, in accordance with the default emission factor (1'000 kg per tonne of imported substance) of the 2006 IPCC Guidelines (IPCC 2006).

## Activity data

Activity data on SF<sub>6</sub> used in magnesium foundries (2C4) are based on import data from FOEN statistics. For the activity data of any particular year, the mean value of the imports in the present and the previous year is used to account for possible time lag between import and consumption (e.g. for 2016 the mean value of 2015 and 2016 import data are used). The import of SF<sub>6</sub> ceased in 2016. Part of the import of the preceding year were considered for the phase-out 2016.

One of the magnesium foundries reported on the SF<sub>6</sub> consumption between 2008 to 2015 to the Swissmem statistics. The information is in accordance with import data obtained for FOEN statistics.

### 4.4.2.4. Other (2C7)

#### Battery recycling and non-ferrous metal foundries (2C7)

There is one battery recycling plant in Switzerland which started operation in 1992. The recycling is done by applying the Sumitomo process. The batteries are first pyrolysed at temperatures of 700°C in a reducing atmosphere in a shaft kiln. The gas with the carbonised components then goes to a post-combustion step where it is completely oxidised at temperatures of 1000°C. The flue gas is then directed to a flue gas treatment installation. The metal fraction from the pyrolysis goes to a melting furnace where it is reduced by addition of coal and magnesium oxide. As reducing agent coke and Carburit is used.

In Switzerland, there are one large company and several small plants operating non-ferrous metal foundries producing mainly copper alloys. During the melting process emissions of CO and NMVOC occur.

Indirect CO<sub>2</sub> emissions resulting from CO and NMVOC emissions in this source category are included in CRF Table6 as documented in chp. 9.

## Methodology

To determine emissions of CO<sub>2</sub>, NO<sub>x</sub>, CO and SO<sub>2</sub> from battery recycling and of CO and NMVOC from non-ferrous metal foundries, Tier 2 methods according to the EMEP/EEA Guidebook (EMEP/EEA 2019, chp. 2C7c and 2C7a) with country-specific emission factors are used.

### Emission factors

The emission factors of CO<sub>2</sub>, NO<sub>x</sub>, SO<sub>2</sub>, CO from battery recycling between 1992 and 2002 are based on measurements in 2003 as well as mass balances of the single recycling site and are assumed constant. Since 2003 they are based on air pollution control measurements from 2003 and 2012 and are assumed constant during this time period. Emission factors of NMVOC are also based on air pollution control measurements from 2003 and 2012 and are assumed constant for the entire time period (EMIS 2023/2C7 Batterie-Recycling).

Emission factors of CO and NMVOC from non-ferrous metal foundries in Switzerland are country-specific and based on measurements from industry and expert estimates documented in the EMIS database (EMIS 2023/2C7 Buntmetallgiessereien Elektroöfen) (see Table 4-33). Emission factors are confidential. They are available to reviewers on request.

### Activity data

The annual amount of recycled batteries and produced non-ferrous metals in Switzerland is reported from industry (including monitoring reports of the Swiss ETS from 2006 onwards for the large non-ferrous metal company) and the foundry association as documented in the EMIS database (EMIS 2023/2C7 Batterie-Recycling and EMIS 2023/2C7 Buntmetallgiessereien Elektroöfen). Activity data are confidential. They are available to reviewers on request.

#### 4.4.3. Uncertainties and time-series consistency

Production data of the steel industry have a high confidence and its uncertainty is estimated at 2 %. The uncertainty for the CO<sub>2</sub> emission factor is estimated at 5 %, which is the default value for a Tier 3 method (IPCC 2006, vol. 4, Table 4.4 p. 4.30). Since the geogenic CO<sub>2</sub> emissions from the limestone use in cupola furnaces (iron foundries) are comparatively small their contribution to the uncertainty calculation was neglected.

For source category 2C3 Aluminium production (1990–2006), the uncertainty of the activity data is estimated to be 5 %. The uncertainty of the CO<sub>2</sub> emission factor is estimated to be 20 %. For PFCs, the combined uncertainty is estimated to be 9 %.

For the emissions of SF<sub>6</sub> from the use in 2C4 Magnesium production (1990–2016), the combined uncertainty is estimated at 27.7 %.

For CO<sub>2</sub> emissions from source category 2C7 Other, the uncertainty of the activity data is set at 2 % because plant level data are available. The uncertainty of the CO<sub>2</sub> emission factor is estimated to be 20 % (expert estimate based on the observed variability in the available data).

Consistency: Time series for 2C Metal industry are all considered consistent.

#### 4.4.4. Category-specific QA/QC and verification

The general QA/QC measures are described in chp. 1.5.

#### 4.4.5. Category-specific recalculations

The following recalculations were implemented in submission 2023. Major recalculations which contribute significantly to the total differences in GHG emissions of sector 2 IPPU between the latest and the previous submissions are also presented in chp. 10.1.2.2.

- 2C1: The CO<sub>2</sub> emission factor from 2C1 Secondary steel production, electric arc furnace was revised for the years 2012–2020 based on newly available data on carbon contents of various material flows (scrap, alloying carbon, steel, slag and filter dust) of the two plants in connection with the monitoring under the emissions trading scheme.

#### 4.4.6. Category-specific planned improvements

No category-specific improvements are planned.

### 4.5. Source category 2D – Non-energy products from fuels and solvent use

#### 4.5.1. Source category description

Table 4-36 Key categories of 2D Non-energy products from fuels and solvent use. Combined KCA results, level for 2021 and trend for 1990–2021, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Direct emissions of Source category 2D Non-energy products from fuels and solvent use are not a key category. Indirect emissions are documented in chp. 9.

Table 4-37 Specification of source category 2D Non-energy products from fuels and solvent use in Switzerland.

2D	Source category	Specification
2D1	Lubricant use	Emissions of CO <sub>2</sub> from primary usage of lubricants in machinery and vehicles and from fully oxidised lubricants blended into gasoline for 2-stroke engines
2D2	Paraffin wax use	Emissions of CO <sub>2</sub> from primary usage of paraffin waxes
2D3a	Solvent use	Emissions of NMVOC from coating applications, degreasing, dry cleaning and chemical products as well as emissions of CO <sub>2</sub> resulting from post-combustion of NMVOC in exhaust gases of these sources
2D3b	Road paving with asphalt	Emissions of NMVOC from road paving with asphalt
2D3c	Asphalt roofing	Emissions of CO and NMVOC from asphalt roofing
2D3d	Urea use in SCR catalysts of diesel engines	Emissions of CO <sub>2</sub> from urea use in SCR catalysts of diesel engines

#### 4.5.2. Methodological issues

##### 4.5.2.1. Lubricant use (2D1) and Paraffin wax use (2D2)

Lubricants are mostly used in industrial and transportation applications. They can be subdivided into motor oils, industrial oils and greases, which differ in terms of physical characteristics, commercial applications and environmental fate. Lubricants in engines of road and non-road vehicles are primarily used for their lubricating properties and associated

GHG emissions are therefore considered as non-combustion emissions reported in 2D1 Lubricant use. Only lubricants blended into gasoline for 2-stroke engines are assumed to be fully oxidised.

The source category 2D2 Paraffin wax use includes products such as petroleum jelly, paraffin waxes and other waxes, including mixtures of saturated hydrocarbons, solid at ambient temperature. Paraffin waxes are separated from crude oil during the production of light (distillate) lubricating oils. Emissions from the use of waxes occur primarily when the waxes or derivatives of paraffins are combusted during use (e.g. candles).

### Methodology

CO<sub>2</sub> emissions from the use of lubricants in 2-stroke engines (road and non-road vehicles) are calculated by a Tier 1 method and default emission factor according to the decision trees in IPCC 2006, vol. 2, chp. 3, Figure 3.2.2 and Figure 3.2.3) assuming that the lubricants are fully oxidised (as described in chp. 3.2.9.2.2). CH<sub>4</sub> and N<sub>2</sub>O emissions from lubricant use in 2-stroke engines are reported in sector 1 Energy since these emissions are included in the CH<sub>4</sub> and N<sub>2</sub>O emission factors of the respective 2-stroke engines (1A2gvii, 1A3biv, 1A3dii, 1A4aii, 1A4bii, 1A4cii and 1A5b).

CO<sub>2</sub> emissions from oxidation of all other lubricants and paraffin wax are calculated by a Tier 1 method according to the 2006 IPCC Guidelines applying the IPCC default oxidation fraction of 0.2 (IPCC 2006, vol. 3, chp. 5.2 and 5.3).

### Emission factors

The CO<sub>2</sub> emission factor for lubricants used in 2-stroke vehicles is based on the default emission factor and the net calorific value from IPCC 2006 (vol. 2, chp. 2 Stationary combustion, Table 2.2 and chp.1, Table 1.2, respectively), see Table 4-38 and EMIS 2023/2D 1\_Schmiermittel-Verbrauch B2T. Non-CO<sub>2</sub> emissions from lubricant use in 2-stroke engines are included in the road and the non-road transportation model, since the emission factors are deduced from measurements on motorcycles including 2-stroke engines (see chp. 3.2.9.2.2).

The emission factors of CO<sub>2</sub> from all other lubricant and paraffin wax use in Switzerland are based on default IPCC values for NCV, carbon content and oxidation fraction documented in vol. 2, chp.1 and vol. 3, chp. 5.2 and 5.3, respectively, of IPCC 2006, see also EMIS 2023/2D1 Lubricant use and EMIS 2023/2D2 Paraffin wax use.

Table 4-38 CO<sub>2</sub> emission factor of 2D1 Lubricant use and 2D2 Paraffin wax use for 2021.

	Unit	CO <sub>2</sub>
<b>2D1 Lubricant use</b>		
in two-stroke engines	kg/t	2'947
unspecified	kg/t	590
<b>2D2 Paraffin wax use</b>	kg/t	590

## Activity data

The annual amount of lubricant and paraffin wax used in Switzerland is derived from Avenergy Suisse (formerly Swiss petroleum association) (Avenergy 2022). The consumption of lubricants of Liechtenstein, which forms a customs union with Switzerland, is subtracted from the consumption reported by Avenergy Suisse. The resulting amount is further differentiated between application in 2-stroke engines and unspecified use. The amount of lubricants corresponds to 2 % of total gasoline consumption of all 2-stroke engines based on the road and non-road transportation models (INFRAS 2022, INFRAS 2015a).

Table 4-39 Use of lubricants and paraffin waxes.

	Unit	1990	1995	2000	2005	2010					
<b>2D1 Lubricant use</b>											
in two-stroke engines	kt	0.61	0.42	0.49	0.36	0.29					
unspecified	kt	79	61	62	72	55					
<b>2D2 Paraffin wax use</b>	kt	11	10	12	10	5.0					
	Unit	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
<b>2D1 Lubricant use</b>											
in two-stroke engines	kt	0.27	0.26	0.23	0.21	0.23	0.22	0.23	0.22	0.20	0.21
unspecified	kt	51	53	53	51	51	50	45	44	40	42
<b>2D2 Paraffin wax use</b>	kt	3.3	3.8	4.5	3.8	3.4	4.0	4.2	3.4	3.3	3.9

### 4.5.2.2. Other (2D3)

#### Solvent use (2D3a)

Since the 2006 IPCC Guidelines (IPCC 2006, vol. 3, chp. 5.5) refer to the EMEP/EEA guidebook regarding methodologies for estimating NMVOC emissions from solvent use, the respective NFR codes are indicated as reference as well. Within 2D3a Solvent use, the NMVOC emissions from coating applications (2D3d NFR), degreasing (2D3e NFR), dry cleaning (2D3f NFR) as well as production and processing of chemical products (2D3g NFR) are reported. Paint application on wood, paint application in construction, industrial and non-industrial paint application, production of fine chemicals and other industrial cleaning account for the largest share of NMVOC emissions from 2D3a in 2021. Indirect CO<sub>2</sub> emissions resulting from NMVOC emissions in this source category are included in CRF Table6 as documented in chp. 9.

#### Methodology

For the determination of NMVOC emissions from solvent use in coating applications (2D3d NFR), degreasing (2D3e NFR), dry cleaning (2D3f NFR) as well as production and processing of chemical products (2D3g NFR) a Tier 2 method according to the EMEP/EEA guidebook (EMEP/EEA 2019) is used. For coating applications the emissions are based on the consumption of paints, lacquers, glazes, thinners etc. and their solvent content, for degreasing and dry cleaning on the solvent consumption and for production and processing of chemical products on the products manufactured or processed. Switzerland's Informative Inventory Report (FOEN 2023b, chp. 4.5.2.4–4.5.2.7) contains a detailed description of the country-specific emission factors and activity data of these four NFR source categories.

### **Post-combustion of NMVOC from solvent use (2D3a)**

Due to the obligations of the Ordinance on Air Pollution Control (Swiss Confederation 1985) and Ordinance on the Incentive Tax on Volatile Organic Compounds (Swiss Confederation 1997) several industrial plants use facilities and equipment to reduce NMVOC in exhaust gases and room ventilation output. Often this implies the feeding of air with high NMVOC content into the burning chamber of boilers or other facilities to incinerate NMVOC. These CO<sub>2</sub> emissions from post-combustion of NMVOC are estimated based on industry data and expert estimates (Carbotech 2022a).

#### *Methodology*

The CO<sub>2</sub> emissions from post-combustion of NMVOC are calculated by a Tier 2 method using country-specific emission factors. Emissions are calculated based on the amount of NMVOC (and their carbon content) destroyed in the respective combustion facility of industrial plants (Carbotech 2022a). Post-combustion facilities are applied in source categories 2D3a Solvent use (industrial paint applications (2D3d NFR), metal degreasing (2D3e NFR) and chemical products, manufacture and processing (2D3g NFR)) and 2G4 Other. In 2018, the source category allocation of all post-combustion plants was verified. For the ten largest facilities (within 2D3a and 2G4), which are responsible for about 70 % of the emissions, the NMVOC quantities and respective carbon contents based on the composition of the solvents were updated annually whereas all the others every five years. For the previous submission, a complete update of all facilities was carried out by means of a survey of all cantonal air pollution control authorities, in addition, with VOC balances. If no information of the solvent composition is available, mean source category-specific values were applied for the carbon content.

Source categories coating applications (2D3d NFR) and degreasing (2D3e NFR) comprise nine facilities each, whereas chemical products, manufacture and processing (2D3g NFR) comprise about 80 facilities. Not all facilities have been in use for the entire period 1990–2021. There was a significant increase in total number of facilities from 32 in the year 1990 to 115 in 2002. Since then, the number fluctuates around 120.

The amounts of NMVOC eliminated by post-combustion are also declared in the respective VOC balances of the industrial plants and are thus not included as NMVOC emissions. When deriving the NMVOC emission factors for these source categories, the amount of NMVOC destroyed in post-combustion facilities is taken into account, i.e. the NMVOC emission factor is reduced accordingly.

#### *Emission factors*

CO<sub>2</sub> emission factors are derived based on the composition of the solvents (carbon content) destroyed in each post-combustion installation. For the ten most important installations (within 2D3a and 2G4), amount and composition of solvents destroyed were updated annually whereas for all others at least every five years. In between, the values were kept constant (see Table 4-40). For installations with no information on the solvent composition, mean industry-specific values are applied. The emission factors given in Table 4-40 are (source category specific) implied emission factors that depend both on carbon content and respective amount of the destroyed NMVOC. Thus, the implied emission factors of source categories with large post-combustion facilities may vary significantly over the years, due to changes in solvent compositions and amounts, starting-up or shutting down of facilities, etc.

Table 4-40 CO<sub>2</sub> emission factors for post-combustion of NMVOC in 2D3a Solvent use.

2D3a Solvent use	Unit	CO <sub>2</sub>				
<b>Post-combustion of NMVOC</b>		<b>1990</b>	<b>1995</b>	<b>2000</b>	<b>2005</b>	<b>2010</b>
Coating applications (2D3d NFR)	t/t NMVOC	2.78	2.75	2.72	2.78	2.78
Degreasing (2D3e NFR)	t/t NMVOC	NO	2.63	2.63	2.64	2.65
Chemical products, manufacture and processing (2D3g NFR)	t/t NMVOC	2.02	1.71	1.96	1.97	2.23

2D3a Solvent use	Unit	CO <sub>2</sub>									
<b>Post-combustion of NMVOC</b>		<b>2012</b>	<b>2013</b>	<b>2014</b>	<b>2015</b>	<b>2016</b>	<b>2017</b>	<b>2018</b>	<b>2019</b>	<b>2020</b>	<b>2021</b>
Coating applications (2D3d NFR)	t/t NMVOC	2.79	2.79	2.78	2.27	2.25	2.24	2.25	2.25	2.05	2.05
Degreasing (2D3e NFR)	t/t NMVOC	2.65	2.64	2.40	2.37	2.35	2.35	2.34	2.34	2.34	2.34
Chemical products, manufacture and processing (2D3g NFR)	t/t NMVOC	2.33	2.33	2.36	2.33	2.31	2.26	2.20	2.14	2.09	2.09

### Activity data

Activity data are the amounts of NMVOC destroyed in post-combustion installations and are provided by the industry, VOC balances and cantonal air pollution control authorities. For the ten most important installations (within 2D3a and 2G4), they were updated annually whereas for all others at least every five years.

Table 4-41 Activity data of NMVOC post-combustion in 2D3a Solvent use.

2D3a Solvent use	Unit	1990	1995	2000	2005	2010
<b>Post-combustion of NMVOC</b>						
Coating applications (2D3d NFR)	t NMVOC	443	662	756	986	1'104
Degreasing (2D3e NFR)	t NMVOC	NO	749	749	576	898
Chemical products, manufacture and processing (2D3g NFR)	t NMVOC	1'199	4'501	5'677	8'237	5'490

2D3a Solvent use	Unit	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
<b>Post-combustion of NMVOC</b>											
Coating applications (2D3d NFR)	t NMVOC	1'102	1'076	1'048	1'083	1'113	1'126	1'076	1'064	1'061	1'061
Degreasing (2D3e NFR)	t NMVOC	974	972	665	663	855	817	976	922	882	882
Chemical products, manufacture and processing (2D3g NFR)	t NMVOC	4'920	5'038	5'078	4'574	5'232	5'345	5'406	5'267	5'587	5'587

## Road paving with asphalt (2D3b)

### Methodology

Asphalt road surfaces are composed of compacted aggregate and asphalt binder. From road surfacing operations only NMVOC emissions occur. Based on the decision tree Fig. 3.1 in chapter 2D3b in the EMEP/EEA guidebook (EMEP/EEA 2019), the NMVOC emissions from 2D3b Road paving with asphalt are determined by a Tier 2 method based on country-specific emission factors as documented in EMIS 2023/2D3b NFR.

### Emission factors

The emission factor for NMVOC emissions from 2D3b Road paving with asphalt comprises NMVOC emissions from the use of prime coatings and from the bitumen content in asphalt products (about 5 %). The NMVOC content in the bitumen has decreased considerably between 1990 and 2010. The values are based on industry data from 1990, 1998, 2007, 2010 and 2013. All other years are interpolated and complemented with expert estimates documented in the EMIS database.

Table 4-42 Emission factors of 2D3b Road paving with asphalt, 2D3c Asphalt roofing and 2D3d Urea use in SCR catalysts (AdBlue) for 2021.

	Unit	CO <sub>2</sub>	CO	NM VOC
<b>2D3b Road paving</b>	kg/t asphalt concrete	NA	NA	0.54
<b>2D3c Asphalt roofing</b>	kg/t asphalt sealing	NA	0.0059	4.9
<b>2D3d Urea use in SCR catalysts</b>	t/t urea solution	0.238	NA	NA

### Activity data

Activity data on the amount of asphalt products (so-called mixed goods) used for road paving is based on annual data from the association of asphalt production industry (SMI) for 1990 and from 1998 onwards and expert estimates for the years between.

Table 4-43 Activity data for road paving with asphalt, asphalt roofing and urea use in SCR catalysts.

	Unit	1990	1995	2000	2005	2010
<b>2D3b Road paving with asphalt</b>						
Asphalt concrete	kt	5'500	4'800	5'170	4'780	5'250
<b>2D3c Asphalt roofing</b>						
Asphalt sealing sheeting	kt	54	56	58	51	68
<b>2D3d Urea use in SCR catalysts</b>						
AdBlue	kt	NO	NO	NO	0.27	20

	Unit	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
<b>2D3b Road paving with asphalt</b>											
Asphalt concrete	kt	4'770	4'770	5'260	4'850	4'710	5'260	5'180	5'210	4'910	4'960
<b>2D3c Asphalt roofing</b>											
Asphalt sealing sheeting	kt	74	75	75	75	76	76	76	77	77	77
<b>2D3d Urea use in SCR catalysts</b>											
AdBlue	kt	25	27	28	29	31	33	35	37	37	38

## Asphalt roofing (2D3c)

### Methodology

This source category comprises emissions from production and use of asphalt roofing materials (saturated felt, roofing and siding shingles, roll roofing and sidings). These products are used in roofing and other building applications. From 2D3c Asphalt roofing only precursors such as CO and NMVOC arise. CO is emitted during the production process of asphalt roofing materials whereas NMVOC emissions are released during the entire production and laying processes (primers included). Based on the decision tree Fig. 3.1 in chapter 2D3c in the EMEP/EEA guidebook (EMEP/EEA 2019), the emissions of NMVOC from Asphalt roofing are determined by a Tier 2 method based on country-specific emission factors as documented in the EMIS database (EMIS 2023/2D3c Dachpappen Produktion und Verlegung). Emissions of CO are determined based on a Tier 1 method using the default emission factor for the production process from the EMEP/EEA guidebook (EMEP/EEA 2019, chp. 2D3c, Table 3.1).

Indirect CO<sub>2</sub> emissions resulting from CO and NMVOC emissions in this source category are included in CRF Table6 as documented in chp. 9.

### Emission factors

The NMVOC emission factors from asphalt roofing are based on information from the industry association, literature and expert estimates as documented in the EMIS database.

Tier 1 emission factor of CO for the production process is taken from the EMEP/EEA guidebook (EMEP/EEA 2019, chp. 2D3c, Table 3.1) (see Table 4-42).

#### *Activity data*

Activity data is based on data from industry and expert estimates as documented in the EMIS database (see Table 4-43).

### **Urea use in SCR catalysts of diesel engines (2D3d)**

This source category encompasses CO<sub>2</sub> emissions from the use of urea containing AdBlue in diesel engines with SCR-catalysts in road transportation (Euro V/VI and Euro 5/6).

#### *Methodology*

In accordance with the 2006 IPCC Guidelines, the consumption of Ad Blue is reported following a methodology suggested in the EMEP/EEA guidebook (EMEP/EEA 2016; part B, chp. 1.A.3.b.i-iv, page 48). A specific percentage of the fuel consumption of SCR-vehicles in road transportation according to their Euro class is applied for AdBlue consumption estimates. Emissions are calculated according to following formula:

$$\text{CO}_2 \text{ Emissions} = \text{EF} \cdot \text{FC} \cdot \text{Share of SCR vehicles mileage} \cdot \text{Specific urea share}$$

“FC” relates to the fuel consumption in tonnes of the entire vehicle category. “Share of SCR vehicles mileage” implies the mileage share of SCR-vehicles in the entire vehicle category and “Specific urea share” comprises the percentage of fuel consumption, which relates to AdBlue (urea solution) consumption.

#### *Emission factors*

The emission factor for CO<sub>2</sub> emissions from urea use in SCR-catalysts in vehicles is a default value from the EMEP/EEA guidebook (EMEP/EEA 2019, chp. 1.A.3.b.i-iv, page 46) considering the molecular mass conversion of urea into CO<sub>2</sub> during the reaction with water and the content of 32.5 % of the aqueous AdBlue urea solution (see Table 4-42).

#### *Activity data*

Activity data on AdBlue consumption as well as annual mileage are provided by INFRAS (INFRAS 2017, INFRAS 2022) on a yearly basis as documented in EMIS 2023/2D3d NFR Urea (AdBlue) Einsatz Strassenverkehr. For activity data see Table 4-43.

### **4.5.3. Uncertainties and time-series consistency**

The uncertainty of total CO<sub>2</sub> emissions from the entire source category 2D – Non-energy products from fuels and solvent use is estimated to be 14 % (expert estimate). This is the combined uncertainty according to uncertainty propagation assuming 10 % uncertainty of activity data and 10 % uncertainty for emission factors.

Consistency: Time series for 2D Non-energy products from fuels and solvent use are all considered consistent.

#### 4.5.4. Category-specific QA/QC and verification

The general QA/QC measures are described in chp. 1.5.

#### 4.5.5. Category-specific recalculations

The following recalculations were implemented in submission 2023. Major recalculations which contribute significantly to the total differences in direct and indirect CO<sub>2</sub> emissions of sector 2 IPPU between the latest and the previous submissions are presented also in chp. 10.1.2.2.

- 2D1: The activity data of 2D1 Lubricant use in two-stroke engines changed for the years 1991, 1996 and 1998–2020 due to recalculations in the gasoline consumption of two-stroke motorcycles (1A3biv). Consequently, the activity data of 2D1 Lubricant use unspecified has also changed for the same years.  
The recalculation of activity data in sector 1A3b Road transportation was due to new available statistics of activity data (mileage) for the different vehicle categories for all years 1990–2020.

#### 4.5.6. Category-specific planned improvements

There are no planned improvements.

### 4.6. Source category 2E – Electronics industry

#### 4.6.1. Source category description

Table 4-44 Key categories of 2E Electronics industry. Combined KCA results, level for 2021 and trend for 1990–2021, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Source category 2E Electronics industry is not a key category.
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Source category 2E Electronics industry comprises HFC, PFC, NF<sub>3</sub> and SF<sub>6</sub> emissions from consumption of the applications listed in Table 4-45.

Table 4-45 Specification of source category 2E Electronics industry in Switzerland.

2E	Source category	Specification
2E1	Integrated Circuit or Semiconductor	Etching and cleaning processes in the production of IC and semiconductors (similar cleaning services for printed wiring boards included in the evaluation)
2E2	TFT flat panel display	No production of TFT flat panel displays in Switzerland, activities contained in the production of displays for watches
2E3	Photovoltaics	Emissions from photovoltaic manufacturing
2E4	Heat transfer fluids	No application in Switzerland assumed*
2E5	Other	Test activities (for example related to printed wiring boards), research activities

\* Heat transfer fluids subject of research, for example ORC systems. Alternative products available with low GWP as for example Novec 649 and 7000

## 4.6.2. Methodological issues

Emission calculations are based on import data from FOEN statistics for etching and cleaning processes of the electronics industry, covering different source categories as listed in Table 4-45 (until 2010 import declarations for electronic industry under solvents). Process-specific transformation and emission rates are used. A survey within the electronics industry was carried out for the submission in 2015 to distribute the imported substances to the different source categories of electronic industry and to obtain information on waste air treatment. Information was obtained on the type of substance used in different source categories, but no information on emission factors and type of efficiency of exhaust treatment. More information are available from Carbotech (2023).

### Methodology

A Tier 2a approach with specific parameters for each gas is used for emission calculations. IPCC default values for the gas-specific transformation rate of different processes and general values for the exhaust treatment efficiency are applied according to the 2019 Refinement to the 2006 IPCC Guidelines (IPCC 2019). The Tier 2a method is for semiconductor sub-sector with revised emission factors, also accounting for additional precursors and by-products.

For the inventory report 2011 (FOEN 2011) interviews were conducted with the industry to get in-depth information on allocation of imported PFC volumes to different applications and to obtain process-specific information from consumers. Until 2010, most PFC imports declared as 2F5 Solvents or 2F6 Other were related to the electronics industry (2E). Since 2011, PFC import declarations have been improved and information is provided for the source category 2E separately. A survey was carried out for the submission in 2015 to determine contributions of different source categories 2E1–2E5 in Table 4-45 (Carbotech 2023). As a result, the peak of  $\text{NF}_3$  imports (and corresponding emissions) between 2009 and 2011 was found to be related to photovoltaic manufacture.

### Emission factors

Default emission factors according to the 2019 Refinement to the 2006 IPCC Guidelines are used for production and waste-air treatment (IPCC 2019). An exhaust treatment is assumed probable for most applications, in agreement with the requirements of the Chemical Risk Reduction Ordinance (Swiss Confederation 2005) to minimize emissions and in particular

with the 5 % threshold for semiconductor production. Based on information available to the FOEN from several companies, a compliance with these requirements of close to 100 % can be expected (Wöhrenschiimmel and Schmidely 2023). Therefore, for the purposes of calculating emissions, full compliance was assumed for 2021. In former years, a compliance of >60 % had been assumed, based on declarations from companies confirming the presence of exhaust treatment in a survey.

### **Activity data**

Activity data are based on FOEN import statistics and industry information.

### **4.6.3. Uncertainties and time-series consistency**

The uncertainty for the emissions from the use of HFC, PFC, SF<sub>6</sub>, and NF<sub>3</sub> in 2E Electronics industry was estimated based on a Monte Carlo simulation. The obtained distribution types and numeric values for the emission uncertainties are reported in Annex A2.1. More information is available from Carbotech (2023).

Consistency: Time series for 2E Electronics industry are all considered consistent.

### **4.6.4. Category-specific QA/QC and verification**

The entire time series are compared between the latest and the previous submissions. The general QA/QC measures are described in chp. 1.5.

### **4.6.5. Category-specific recalculations**

No recalculations were implemented in submission 2023.

### **4.6.6. Category-specific planned improvements**

No category-specific improvements are planned.

## 4.7. Source category 2F – Product uses as substitutes for ozone depleting substances

### 4.7.1. Source Category Description

Table 4-46 Key categories of 2F Product uses as substitutes for ozone depleting substances. Combined KCA results, level for 2021 and trend for 1990–2021, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC category	Gas	Identification criteria
2F1	Refrigeration and air conditioning	HFCs	L1, T1, L2, T2

Source category 2F Product uses as substitutes for ozone depleting substances comprises HFC and PFC emissions from consumption of the applications listed in Table 4-47.

Table 4-47 Specification of source category 2F Product uses as substitutes for ozone depleting substances in Switzerland.

2F	Source category	Specification
2F1	Refrigeration and air conditioning	Emissions from refrigeration and air conditioning (inclusive heat pumps and tumble dryers)
2F2	Foam blowing agents	Emissions from foam blowing, incl. polyurethan spray
2F4	Aerosols	Emissions from use as aerosols, incl. metered dose inhalers
2F5	Solvents	Emissions from use as solvents

The following graph shows HFC and PFC emissions from different applications in source category 2F. In 2021, stationary and mobile refrigeration and air conditioning equipment accounted by far for the highest emissions with a share of 98 % of the total emissions in source category 2F. Further, emissions are dominated by HFCs and only a minor contribution comes from PFCs (less than 1 %).

From 2015 onwards there is a decline in emissions as a result of the regulations from the Chemical Risk Reduction Ordinance (Swiss Confederation 2005). The regulations contain restrictions of F-gas import, limitation of HFCs with a high GWP for stationary refrigeration and a registration of equipment with more than 3 kg of refrigerants. Regarding the prefilled imported equipment, there is an effect of EU F-gas regulation and planned phase-out due to the Kigali Amendment. The results of EU regulations are a complete replacement of HFC in imported equipment for mobile air-conditioning and a lower HFC content in stationary refrigeration and air-conditioning equipment. Overall, this results in a decline of HFC emissions with a certain delay replacing the current stock of HFC in equipment. New substances such as hydrofluoroolefins (HFOs) and HFO blends are replacing formerly used refrigerants with higher GWP and are also used as substitutes of HFC and PFC in other applications such as foams, solvents or semiconductors.

Additional factors for a decline are effects of monitoring of equipment and education and training. Some retailers maintain a monitoring program of refrigerant stock and emissions confirming improvements over time.

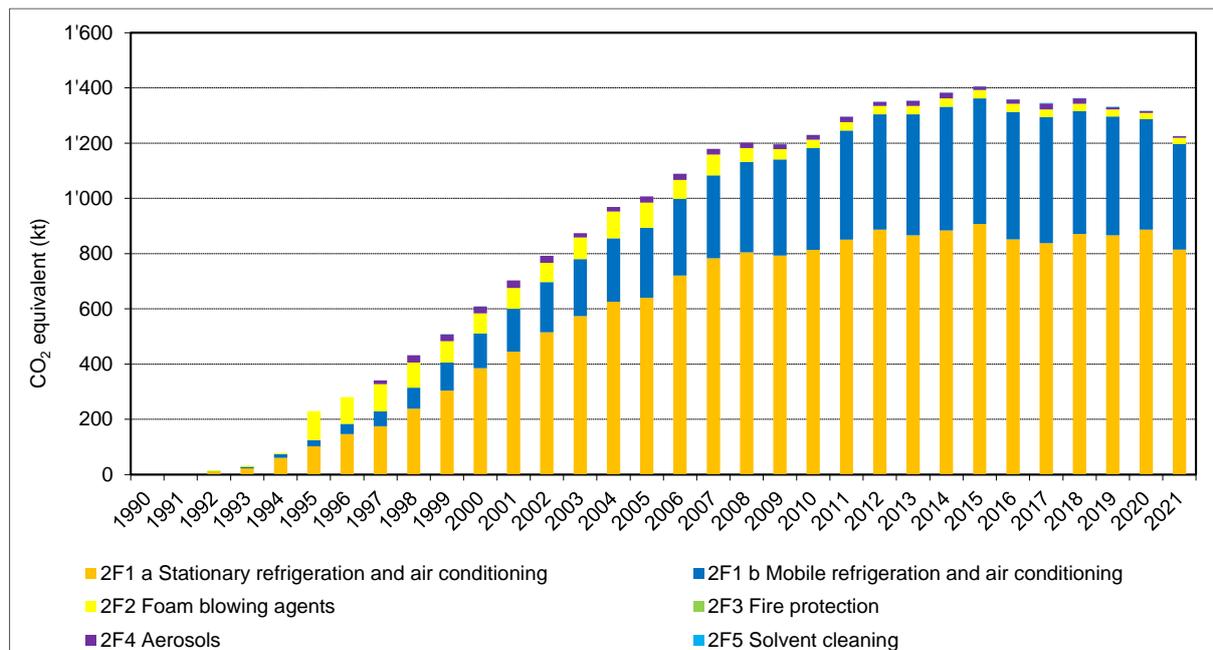


Figure 4-8 Development of emissions under source category 2F Product uses as substitutes for ozone depleting substances. HFC and small amounts of PFC are used as substitutes for ozone depleting substances. Most relevant today are emissions from the refrigerant stock in refrigeration and air conditioning equipment (2F1).

#### 4.7.2. Methodological issues

The data models used for source category 2F are complex and therefore a comprehensive documentation of all relevant model parameters is not possible within the NID. Most relevant is the contribution of 2F1 refrigeration and air conditioning. Calculations are carried out for different applications separately.

##### 2F1a Stationary refrigeration and air conditioning

- Domestic refrigeration
- Commercial refrigeration
- Industrial refrigeration
- Stationary air conditioning, heat pumps and tumble dryers

##### 2F1b Mobile refrigeration and air conditioning

- Mobile air conditioning in different vehicle types
- Transport refrigeration for different vehicle types

Annex A5.2 shows an illustrative example of the model structure and parameters used for calculating emissions from mobile air conditioning in cars. The most important assumptions for the data model are documented in Table 4-48. More information of the individual data and models is available from Carbotech (2023) as well as related background documents. This information is considered confidential, but it will be made available for consultation by reviewers on request.

### 4.7.2.1. Refrigeration and air conditioning (2F1)

#### Methodology

The inventory under source category 2F1 includes different applications and equipment types. For each individual emission, models are used for calculating actual emissions as per the 2006 IPCC Guideline's Tier 2a approach (emission factor approach). In order to obtain the most reliable data for the calculations, two different approaches are applied to get the stock data needed for the model calculations. For the following applications a bottom-up approach is applied relying on statistics, product information and expert estimations:

- Domestic refrigeration
- Mobile air conditioning for different vehicle types (example illustrated in Annex A5.2)
- Transport refrigeration for different vehicles types
- Stationary air conditioning (direct and indirect systems)
- Heat pumps
- Tumble dryers

On the other hand, a top-down approach is applied for the calculation of the stock in commercial and industrial equipment starting with the total imported amount of refrigerant. To determine the portion used for commercial and industrial refrigeration, the refrigerant consumption of other applications is subtracted from the import amount. Consumption for the production and maintenance is based on the bottom-up calculations of stock as given in the example of mobile air conditioning in Annex A5.2. A comparison to neighbouring countries shows higher stock and emissions from mobile air-conditioning in Switzerland. Model parameters were checked and a higher rate of air-conditioning of >95 % in vehicles is assumed plausible and is confirmed by companies dismantling vehicles.

Commercial and industrial refrigeration were evaluated together in former years. To obtain separate models the total bulk refrigerant used for commercial and industrial application is split considering the typical use of refrigerant blends and information on commercial and industrial equipment provided to FOEN (Carbotech 2023). Parameters for commercial and industrial applications are given in Table 4-48. Furthermore, HFC-245fa, included under commercial and industrial refrigeration, was found to be used for organic rankine cycles (ORC).

The combination of bottom-up with top-down calculations leads to more comprehensive results than using just a single approach. Noteworthy, in the hypothetical but possible case of incomplete bottom-up evaluations, the remaining imported refrigerant would be attributed to the production and maintenance of industrial and commercial refrigeration equipment. This might be the reason why the resulting refrigerant stock of commercial and industrial refrigeration, which serves as the residual, tends to be higher than in neighbouring countries.

The import data as reported to FOEN are adjusted for imported substances to be used in Liechtenstein. This is to eliminate double counting with the inventory data of Liechtenstein. The split factor is based on the proportion of employees in the industrial and service sector (share of import for Liechtenstein <1 %). The adjustment does not affect the bottom-up calculations and leads to an adjustment of commercial and industrial refrigeration mainly.

Figure 4-9 shows the required data for the model calculation of refrigeration and air conditioning.

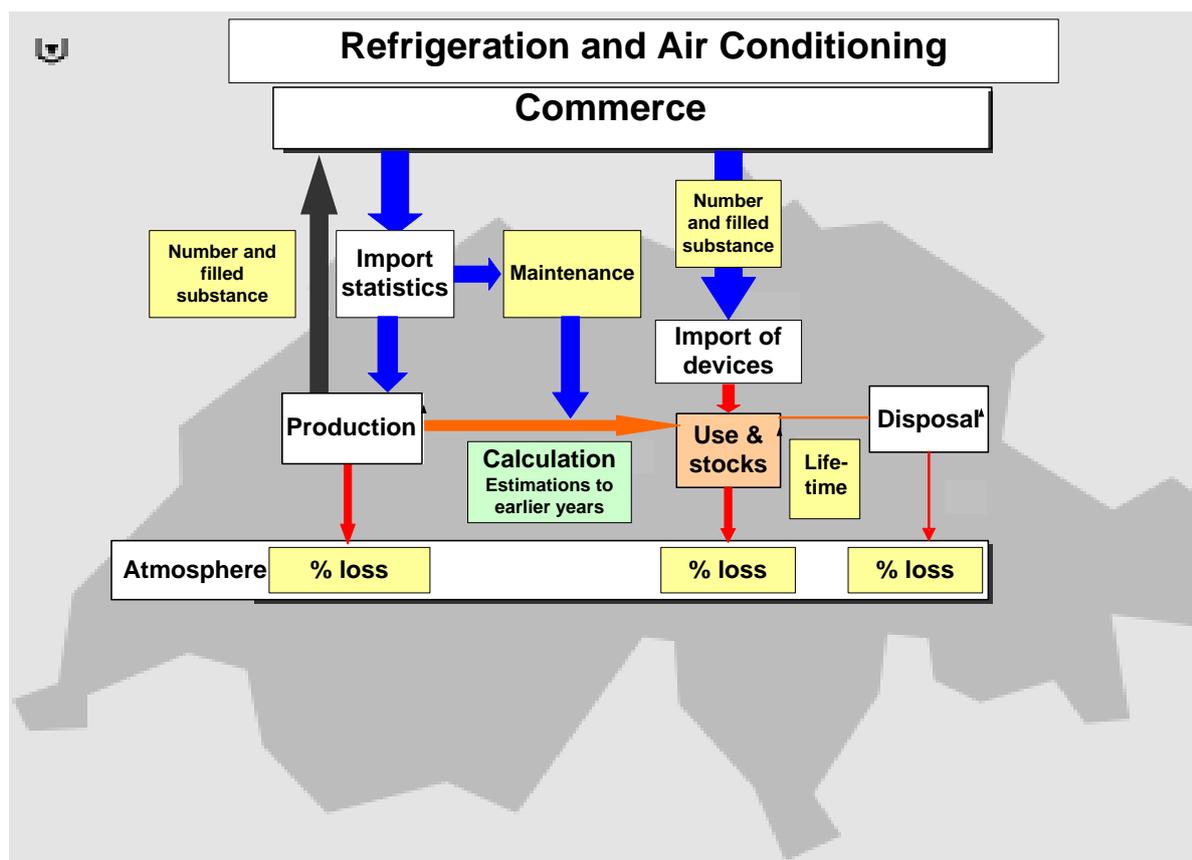


Figure 4-9 Required data for the model to calculate emissions from refrigeration and air conditioning in Switzerland.

Since 2008, operators handling equipment containing more than 3 kg of HFCs have been obligated to provide information to FOEN on the date of operation start, type of equipment, type and amount of refrigerant and date of disposal. This data source provides valuable information and is applied to improve the estimates used for modelling emissions under source category 2F and for the split of commercial and industrial equipment. However, it does not allow to directly draw the stock data or emission factors for the national inventory.

### Emission factors

Emission factors related to manufacturing, product life and disposal as well as average product lifetime are established on the basis of expert judgement and literature. Direct monitoring of the product life emission factors is only done at the company level for internal use and has been used partly for the verification of the quality (confidential data from retailers and other industries). The product life factors and further parameters (i.e. re-filling frequency, handling losses and reuse of refrigerant) are used to allocate imported F-gases to new products and maintenance activities.

Table 4-48 displays the detailed model parameters used for the present submission and values used in the early period of HFC use (1990 to 1995). For product life emission factors of some equipment types, a dynamic model is applied, which implies that emissions decreased linearly between 1995 and 2015 due to improved production technologies and the continuous sensitisation of service technicians. The start/end values are based on expert statements (UBA 2005, UBA 2007, Schwarz 2001, Schwarz and Wartmann 2005). The

charge at the end of life for different applications has been analysed considering the technical minimal charge of the equipment and the expected frequency of the maintenance (UBA/Ökorecherche 2012). Disposal losses are calculated based on expert assumptions on the portion of broken equipment (100 % loss) and on assumptions on disposal losses for professional recovery on site or waste treatment by specialized companies.

Table 4-48 Typical values of lifetime, charge and emission factors used in the model calculations for 1990 to 2021 for refrigeration and air conditioning equipment. Changes of model parameters within this time period are indicated giving the initial value considered in the early time period of F-gas use around 1995 and the value used for modelling for 2021. The reduction of charge and losses is the result of improvement of technology and handling of equipment.

	Product life time	HFC Stock 2021	Composition of stock HFC/PFC	Initial charge of new product	Manufacturing emission factor	Product life emission factor	Disposal loss emission factor	Charge at end of life *)	Export of retiring equipment **)
	[a]	[t]	Main products	[kg]	[% of initial charge]	[% per annum]	[% of remaining charge]	[% of initial charge of new product]	[% of retiring equipment]
Domestic refrigeration	16	1	HFC134a	0.1	NO	0.5	19 ****)	92	<3
Commercial refrigeration	8	1'850	R404a, R407C, R449a, R410a, R507, R422d, R448a	NR	0.5	1995: 12.5 2021: 7.8	24	80-90	NE
Industrial refrigeration	15	490	HFC134a, R410a, R407c, R404a, R422d, R507	NR	0.5	1995: 10 2021: 5	15	75-90	NE
Transport refrigeration: trucks/vans	10	60	R404a, R134a	1.8-7.8	1.5	15	28	86	90
Transport refrigeration: wagons	16			NR	NO	10	28	100	NE
Stationary air conditioning: direct cooling systems	15	2'480	R410a, HFC134a, R407c, R404a, HFC32, R517a	NR	1995: 3 2005: 1	1995:10 2021:4	28	74-89	NE
Stationary air conditioning: indirect cooling systems	15			NR	1	1995: 6 2021: 4	19	85-89	NE
Stationary air conditioning: heat pumps	15			1995: 4.7-7.5 2021: 2.8-4.5	1995: 3 2021: 1	2	19	86	NE
Stationary air conditioning: tumble dryers	15		HFC134a, R407c	0.4	0.5	2	19	74	NE
Mobile air conditioning: cars	15	2'370	HFC134a	1995: 0.84 2021: 0.55	NO	8.5	50	58	1995: 31-72 2021: 48
Mobile air conditioning: truck/van cabins	12			1.1	NO	1995: 10 2021: 8.5	50	69-73	90 trucks / 50 vans
Mobile air conditioning: buses	12			7.5	NO	1995: 20 2021:15	45	78	50
Mobile air conditioning: trains	16			20	NO	5.5	20	100	50

\*) Calculated value taking into account annual loss and portion refilled over the whole product life where applicable.

\*\*\*) Allocation of disposal losses to export country (export for reselling and secondhand use)

\*\*\*\*) Calculated value taking into account share of total refrigerant loss and emission factor of professional disposal. Disposal losses occur from 2000 onwards (introduction of HFCs and PFCs starting 1991 and 8 to 16 years lifetime of equipment). The value of 50 % for mobile air conditioning is based on UBA 2005 and expert assumptions on share of total refrigerant loss, e.g. due to road accident.

\*\*\*\*\*) Takes into account HFC-134a content in foams, based on information from the recycling organisation SENS.

NR = Not relevant as only aggregate data is used

NO = Not occurring (only import of charged units)

NE = Not estimated

## Activity data

Activity data are taken from industry information and national statistics such as for admission of new cars, buses, vans and trucks. Stock data is modelled dynamically. Due to the large number of sub-models used for modelling the total emissions for source category 2F1, no table on time series of activity data is provided here. For illustration, Annex A5.2 shows the detailed calculation model for car air conditioning including the time series for the activity

data for this particular sub-model. Mobile air conditioning accounts for approx. 33 % of the total emissions (CO<sub>2</sub> eq) of source category 2F1 Refrigeration and air conditioning in the inventory 2020.

For the NIR 2012 (FOEN 2012) a cross check has been performed for results from model calculation and FOEN statistics on disposal and recycling of HFCs. This has indicated a significant gap with higher disposal values in model calculations compared to the FOEN disposal statistics. Some of the gap is explained by the onsite reuse and recycling of refrigerants, which is not reflected in the FOEN statistics and by other factors as e.g. the not accounted export of refrigeration equipment for second-hand use. Export rates used in model calculations are given in Table 4-48.

The registered refrigerant import is assumed to cover the consumption of Switzerland and Liechtenstein. To avoid double counting with the inventory data of Liechtenstein, the activity data for the equipment type commercial and industrial refrigeration is reduced by 0.9 %, based on the share of imports of substances to be used in Liechtenstein. The reduction factor is based on the proportion of employees in the industrial and service sector in these two countries. For other equipment types no scope for double counting with the inventory of Liechtenstein was identified and therefore no correction factor is applied.

#### **4.7.2.2. Foam blowing agents (2F2)**

##### **Methodology**

In Switzerland no production of open cell foam based on HFCs is reported by the industry. Therefore, only closed cell PU and XPS foams, PU spray applications and further closed cell applications as sandwich elements are relevant under source category 2F2.

The emission model (Tier 2a) for foam blowing has been developed top down based on import statistics for products, industry information and expert assumptions for market volumes and emission factors. Emissions from further not specified applications of foam production have been calculated (Tier 1a) as residual balance between FOEN import statistics and consumption in PU spray, PU and XPS foams.

Desktop research on HFC-245fa use in neighbouring countries was carried out for the inventory 2019 to identify the relevance of HFC-245fa emissions from the import of foam products. HFC-245fa has not been used for foam blowing in Switzerland, but measurements at the Jungfrauoch site by Empa (see chp. 4.7.4 and Annex A6.1) indicate emissions probably related to the import of foam products. Due to the low relevance, lacking data and the decreasing use in neighbouring countries since 2005 (partly through bans) the model calculations were not extended with HFC-245fa (Carbotech 2023).

##### **Emission factors**

For the emission factors and the lifetimes of XPS and PU foams, expert estimates and default values according to the 2006 IPCC Guidelines (IPCC 2006, Volume 3, p. 7.37) are used. For PU sprays, expert estimates and specific default values according to the 2006 IPCC Guidelines (IPCC 2006, Volume 3, p. 7.37) are used. Unknown applications are evaluated following the Gamlen model recommended in the 2006 IPCC Guidelines (IPCC 2006). First-year losses are allocated to the country of production.

Table 4-49 Typical values on lifetime, charge and emission factors used in model calculations for foam blowing.

Product	Product lifetime	Charge of new product	Manufacturing emission factor	Product life emission factor	Charge at end of life
Foam type	years	% of product weight	% of initial charge	% per annum	% charge of new product
PU foam	50	4.5	NR	NR	Calculated charge minus emissions over lifetime (so far not relevant, products still in use)
XPS foam HFC-134a	50	6.5	NR	NR / 0.7**	
XPS foam HFC-152a				100 / 0**	
PU spray all HFC	50	13.6 / 0 *	<1%	95 / 2.5 **	
Unknown use:					
HFC 134a, HFC 227ea, HFC 365 mfc	20	NR	10	10 / 4.5 **	
HFC 152a			100	100 / 0 **	

\* The first value represents the charge of HFC 1995 (start of HFC use as substitutes for ozone depleting substances). The HFC amount was reduced continuously between 1995 and 2008. Since 2009 the production of PU spray is HFC free in Switzerland.

\*\* Data for 1st year / following years (HFC-152a all emissions allocated to production)

NR Not relevant (PU foam: no substances according to this protocol have been used; XPS foam: emissions occur outside Switzerland; unknown use: calculations are based on the remaining propellant import amount).

### Activity data

HFCs have been used until 2008 in the Swiss production of PU spray. The export rate of PU spray from Swiss production was about 96.5 % of the total production volume in the time period of the HFC use. About one third of the PU spray sold in Switzerland originates from local production, the rest is imported. For PU rigid foams no HFCs are used as foam blowing agent (only pentane and CO<sub>2</sub>). There has been no production of XPS in Switzerland with HFCs. XPS foams were 100 % imported until 2010. In 2011 a new production facility was started which, however, does not use HFCs. The HFC import not related to the main applications above has been allocated to further unknown applications (possible use in the production of sandwich elements and pipe insulation mentioned by an import company of foam blowing agents has not been confirmed).

Without additional measurements the release of F-gases from the disposal of foam product stock is assumed to occur approximately from 2050 onwards, resulting in an emission peak.

Detailed activity data for this source category are considered confidential, but are available to reviewers on request.

#### 4.7.2.3. Fire protection (2F3)

No emissions occur in source category 2F3 within Switzerland. The application of HFCs, PFCs and SF<sub>6</sub> in fire extinguishers is prohibited by law.

#### 4.7.2.4. Aerosols (2F4)

##### Methodology

The Tier 2a emission model for Aerosol / metered dose inhalers is based on a top-down approach using import statistics for HFCs.

##### Emission factors

A manufacturing emission factor of 1 % is applied. The model then assumes prompt emissions, i.e. 50 % of the remaining substance is emitted in the first year and the rest in the second year, in line with the 2006 IPCC Guidelines (IPCC 2006).

##### Activity data

In most aerosol applications, HFCs have been replaced already in the past years. According to the information of companies filling aerosol bottles for use in households, e.g. cosmetics, cloth care and paint, no HFC is being used. For special technical applications – especially metered dose inhalers (MDI) – HFC is still in use. Compared to the total amount of aerosol applied, the HFC use for MDI is considered to be irrelevant.

Activity data are based on import statistics. The export and import of filled products is unknown, but assumed to be in a similar range.

#### 4.7.2.5. Solvents (2F5)

##### Methodology

HFCs and PFCs have been used as solvents until 2020. Emissions are calculated according to a Tier 1a method according to the 2006 IPCC Guidelines on basis of a top-down approach using import statistics and industry information on allocation of the imported HFC and PFC amounts to different applications.

The import data as reported to FOEN cover imported substances to be used in Switzerland and Liechtenstein, and are therefore split in proportion of inhabitants of the two countries to avoid double counting.

##### Emission factors

In line with the 2006 IPCC Guidelines prompt emissions are assumed, i.e. half of the initial amount is emitted in the first year, the other half in the second year.

##### Activity data

Activity data are based on import statistics. Imports before 2011 were included under solvents. Therefore, the model for allocation of imported PFC volumes was adjusted accordingly for substances related to the electronics industry. Since 2011 imports for semiconductors manufacturing and further etching processes of electronics industry are registered as separate category in FOEN import statistics.

To avoid double counting with the inventory data of Liechtenstein, the import data reported to FOEN which is assigned to source category 2F5 in the inventory of Switzerland is reduced

by 0.5 %. The reduction factor is based on the proportion of inhabitants in these two countries.

In 2021 no import for solvent use has been declared, a complete replacement with HFC-free options is assumed.

#### 4.7.2.6. Other applications (2F6)

There are no further applications of substitutes for ozone depleting substances in Switzerland.

#### 4.7.3. Uncertainties and time-series consistency

For refrigeration equipment, air conditioning equipment as well as for foam blowing, a Monte Carlo analysis according to IPCC Good Practice Guidance (IPCC 2000) for the evaluation of uncertainties of model calculations according to Tier 1 and 2 has been carried out. The Monte Carlo analysis was performed on the inventory data of the latest GHG inventory (submission 2023), using the Cristal Ball Add-in for Excel. For the purpose of the Monte Carlo analysis, the uncertainty of all relevant parameters (e.g. initial appliance charge, product life emission factor, import and export volumes, etc.) used in the emission models for the applications as per Table 4-50 below has been characterised using the following statistical distributions:

- Triangular distribution (defined by the three parameters: minimum, maximum and most likely value)
- Uniform distribution (same probability for the whole spectrum)
- Normal or lognormal distribution (defined by mean and standard deviation, and, if necessary, additional minimum and maximum cut-off values).

The analysis was carried out with 10'000 cycles. Details on the distributions of parameters used (i.e. type of distribution, minimum, maximum, most likely value) are available from background documents at FOEN (Carbotech 2023).

For the submission 2006 the uncertainty for the import statistic data had been estimated for the first time. Discussions with the persons responsible for data collection in the years 1997–2015 led to the estimations of standard deviation and minimal and maximal values given in Table 4-50. A normal distribution is used in the Monte Carlo analysis and the standard deviation, minimal and maximal values applied to define the probability ranges.

Table 4-50 Estimated uncertainty for the data of the imported substances.

Year	Std. Dev.	Minimal	Maximal	Remarks
Up to 1999	20%	50%	50%	Data can be incomplete or possible double declaration
2000 – 2003	20%	20%	20%	Data can be incomplete or possible double declaration
2004 – 2021	10%	20%	20%	Data can be incomplete or possible double declaration

The probability range of parameters applied in the model calculation is defined based on the variation given in expert interviews and the literature. Table 4-51 illustrate the definition of ranges for the example of commercial refrigeration.

Table 4-51 Assumptions on probability ranges for the example of commercial refrigeration.

Parameter	applied "likeliest"	Minimal	Maximal	Remarks
Initial charge of product	NR	NR	NR	Not relevant, calculated value
Manufacturing emission factor	1%	0%	3%	Triangular distribution
Prefilled import	25%	10%	40%	Normal distribution, StdDev5%
Product life emission factor 1990	13%	5%	20%	Normal distribution, StdDev5%
Product life emission factor 2021	7.8%	5%	15%	Lognormal distribution, StdDev2%
Recharge of product life emissions	80%	70%	100%	Triangular distribution
Product lifetime	8	7	15	Triangular distribution
Charge at end of life	NR	NR	NR	Not relevant, calculated value
Disposal loss emission factor (professional disposal)	10%	1%	19%	Normal distribution, StdDev10%
Professional disposal	85%	75%	95%	Normal distribution, StdDev5%

Table 4-52 summarises the results for the application-specific emission models. The “value 2020” represents the reported emissions in kt CO<sub>2</sub> eq for the specific application for the year 2019. The uncertainty values stem from the Monte Carlo analysis. Detailed data are available from background documents at FOEN (Carbotech 2023).

The uncertainty of the resulting total emissions from source category 2F Product uses as substitutes for ODS is about 20 %. Higher values result for the contributions of sub-categories and for single applications evaluated under 2F1. The calculated refrigerant amount for commercial and industrial refrigeration depends on the consumption of further refrigerant applications. Higher consumption for those applications lead to lower consumption in commercial and industrial applications and vice versa.

Relevant parameters for the building of stock in foam are the PU foam import and export rate of past years and the PU spray first year emission factor. The data base for PU sprays has been significantly improved with effect from the 2007 submission (FOEN 2007). This is attributed to improved models which have been elaborated by the main producer and its blowing agent import firm. However, the following three factors lead to a small amount remaining in the stock with a relative high uncertainty: high import and export rate of PU spray, lacking information on import of PU spray and on propellant used in import products and high uncertainty regarding the emission factor of the first year.

Table 4-52 Summary of results for model parameter “emissions” from Monte Carlo analysis for 2021 data on selected emission sources.

Application	Model para- meter	Value 2021 kt CO <sub>2</sub> eq.	Average kt CO <sub>2</sub> eq.	Median kt CO <sub>2</sub> eq.	min. kt CO <sub>2</sub> eq.	max. kt CO <sub>2</sub> eq.	Uncer- tainty %
2F1 Refrigeration and air conditioning	Emissions in kt CO <sub>2</sub> eq.	1'197	1'296	1'293	929	1'752	21
2F2 Foam blowing agents		23	41	36	6	243	285
2F4 Aerosols		6	6	6	2	11	43
Total 2F Product use as substitutes for ODS		1'225	1'344	1'335	938	2'006	21

Consistency: Time series for 2F are all considered consistent.

#### 4.7.4. Category-specific QA/QC and verification

The entire time series are compared between the latest and the previous submissions. Recalculations were identified and correspond to applied changes and improvements in model calculations.

The assumptions of decreasing emission factors for the different equipment types under source category 2F1 Refrigeration and air conditioning have been cross-checked with the inventories of Austria and Germany and have been found to be in line with the assumptions made for these inventories.

The FOEN supports a monitoring campaign at the high-altitude research station Jungfrauoch, where various greenhouse gases are measured continuously. The location of the research station normally provides analyses of tropospheric background concentrations. However, under special meteorological conditions, an estimate of Swiss emissions can be derived from the measurements. For five HFCs (HFC-134a, HFC-125, HFC-152a, HFC-143a, HFC-32) and for SF<sub>6</sub> a comparison of the inventory data with the inferred emissions is presented in Annex A6.1. Estimated emissions based on measurements at Jungfrauoch agree fairly well with the emission estimates of HFC-134a, HFC-125, HFC-143a, HFC-32 and of SF<sub>6</sub> of the Swiss greenhouse gas inventory. Larger differences result for less relevant contributions of HFC-152a. The allocations of first year emissions of foam blowing agents to the country of production might be the reason for the observed differences.

#### 4.7.5. Category-specific recalculations

Recalculations reported in submission 2023:

- 2F1, HFC-134a: Activity data were recalculated for 1992–2020. The stock in mobile air-conditioning equipment of buses was reduced (quote of refilled loss reduced).
- 2F1, HFC/PFC: Activity data were revised based on information on new installed stationary equipment, vehicle statistics and programs to support the early replacement of refrigerants with high GWP. Deviations in model values for vehicle disposal were corrected.
- 2F1, HFC/PFC: The emission factor applied 2020 in commercial refrigeration was corrected (no further decline).

#### 4.7.6. Category-specific planned improvements

Changes are expected and will be analysed in this area due to the revision of the Chemical Risk Reduction Ordinance and CO<sub>2</sub> compensation programmes (share of products with HFC, recycling of HFC, replacement of HFC).

## 4.8. Source category 2G – Other product manufacture and use

### 4.8.1. Source category description

Table 4-53 Key categories of 2G Other product manufacture and use. Combined KCA results, level for 2021 and trend for 1990–2021, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC category	Gas	Identification criteria
2G3	N <sub>2</sub> O from product uses	N <sub>2</sub> O	T2

Table 4-54 Specification of source category 2G Other product manufacture and use.

2G	Source category	Specification
2G1	Electrical equipment	Emissions of SF <sub>6</sub> from use in electrical equipment
2G2	SF <sub>6</sub> and PFCs from other product use	Emissions of SF <sub>6</sub> and PFC not accounted in other source categories (i.e. for particle accelerators, soundproof windows, leakage detection, medicinal products, research and laboratory use)
2G3	N <sub>2</sub> O from product uses	Emissions of N <sub>2</sub> O from the use of N <sub>2</sub> O in hospitals; Emissions of N <sub>2</sub> O from the use of aerosol cans
2G4	Other	Emissions of NMVOC from domestic solvent use, printing, other solvent and product use as well as emissions of CO <sub>2</sub> resulting from post-combustion of NMVOC in exhaust gases of these sources; Emissions of CO <sub>2</sub> , NO <sub>x</sub> , CO, NMVOC and SO <sub>2</sub> from use of fireworks; Emissions of N <sub>2</sub> O from the production of rock wool; Emissions of NO <sub>x</sub> , CO and NMVOC from use of tobacco; Emissions of HFC not accounted elsewhere

### 4.8.2. Methodological issues

#### 4.8.2.1. Electrical equipment (2G1)

##### Methodology

Under an agreement with FOEN, the industry association Swissmem is reporting actual emissions of SF<sub>6</sub> on the basis of a mass-balance approach (Tier 3a). The mass balance includes mainly data for the production, installation, operation and disposal of electrical equipment, but included in past years also small amounts of SF<sub>6</sub> for other applications (i.e. research, magnesium foundry). Swissmem is collecting data from its members and is cross-checking the reported SF<sub>6</sub> consumption data with data from importers of SF<sub>6</sub>. Installations in operation with electrical equipment containing SF<sub>6</sub> are periodically inspected for leakage, and losses are refilled (topping up). The refilled quantities and any SF<sub>6</sub> charge required during repair are reported as emissions at the time of filling. A product lifetime of 35 years is assumed.

##### Emission factors

Emission factors for source category 2G1 are based on industry information and are calculated values based on the mass-balance data. The discontinuity in emission factor from 2005 to 2006 data is due to the inspection intervals, optimised data collection and technical

optimisation of equipment. The trend for reduced emission factors can be linked to the existing agreement of Swissmem and FOEN on the reduction of SF<sub>6</sub> emissions.

### Activity data

Activity data are based on industry information. The wide annual fluctuation of SF<sub>6</sub> emissions from electrical equipment is related to the annual fluctuation of market volumes for such equipment as well as variations in inspection intervals and equipment break-down requiring topping up of SF<sub>6</sub> charge in the equipment. Import declarations obtained for FOEN import statistics are cross-checked regularly in order to eliminate double counting between Swissmem data and other import declarations.

#### 4.8.2.2. SF<sub>6</sub> and PFCs from other product use (2G2)

### Methodology

The emissions reported under 2G2 are related to the use of SF<sub>6</sub> for industrial particle accelerators (2G2b), the use of SF<sub>6</sub> for soundproof windows (2G2c) and other PFC and SF<sub>6</sub> use (2G2e). 2G2e summarizes medicinal products, research/analytics and further applications that are not specified (including the unallocated difference in SF<sub>6</sub> emissions based on the FOEN import statistics and the Swissmem mass balance).

Under an agreement with FOEN, the industry association Swissmem is reporting actual emissions of SF<sub>6</sub> from industrial particle accelerators on the basis of a mass-balance approach (Tier 3a).

For 2G2c soundproof windows and 2G2e Other a Tier 2 approach is applied for SF<sub>6</sub>. Therefore, the unallocated amount of SF<sub>6</sub> under 2G2e has been modelled assuming applications similar to those in 2G1.

Further evaluations of applications under 2G2e are based on FOEN import statistics and industry data, including applications with direct emissions and applications with banks. No further details are provided due to confidentiality. They are available in the confidential NID for reviewers on request.

### Emission factors

For the unallocated amount of SF<sub>6</sub>, the emission factor is assumed to be 4 % for manufacturing and 1 % per year during the product life. The remaining charge is completely emitted at the time of disposal after a lifetime of 40 years. Because of the long lifetime, the disposal emissions are not yet relevant for the results.

For soundproof windows an emission rate of 1 % per year is assumed, including the portion of broken windows. For the manufacturing an emission factor of 33 % is assumed. However, since 2008, there is no production of windows with SF<sub>6</sub> in Switzerland.

### Activity data

Activity data are based on import statistics and industry information. For the unallocated amount of SF<sub>6</sub> an export rate of 80 % is assumed similar to electrical equipment 2G1. In

2015, the split factors for allocation of imported amounts to different applications was checked through industry interviews and in-depth analysis in order to eliminate double counting between Swissmem data and other import declarations (Carbotech 2023). Interviews with industry were carried out in the past years to identify applications of substances related to research and analytics under source category 2G2e Other. Improvements and recalculations in the present inventory are related to better data from one of the companies. No further details are provided due to confidentiality. They are available in the confidential NID for reviewers on request.

#### 4.8.2.3. N<sub>2</sub>O from product uses (2G3)

##### Methodology

Emissions of N<sub>2</sub>O from the source category 2G3 occur from the anaesthesia use in hospitals (2G3a Medical applications) and from the use of aerosol cans in households and restaurants (2G3b Other). For both categories a Tier 2 method based on country-specific emission factors for the production/consumption of N<sub>2</sub>O is used (IPCC 2006, vol. 3 chp. 8.4).

##### Emission factors

For source category 2G3a Medical applications the emission factor is calculated based on the amount of N<sub>2</sub>O sold for anaesthesia purpose in Switzerland divided by the number of inhabitants. The amount of N<sub>2</sub>O sold is derived from annual sales data from the main suppliers from 2005 onwards (EMIS 2023/2G3a Lachgasanwendung Spitaler).

Source category 2G3b Other includes N<sub>2</sub>O emissions from whipped-cream makers using gas capsules for private households and restaurants. The emission factor is calculated based on sales data and N<sub>2</sub>O content of gas capsules sold in Switzerland divided by the number of inhabitants (EMIS 2023/2G3b Lachgasanwendung Haushalt).

Table 4-55 N<sub>2</sub>O emission factors for the source categories 2G3a Medical applications and 2G3b Other.

2G3a Use of N <sub>2</sub> O for anaesthesia	Unit	1990	1995	2000	2005	2010					
N <sub>2</sub> O	g/inhabitant	43	30	16	13	6.8					
2G3b N <sub>2</sub> O from aerosol cans	Unit	1990	1995	2000	2005	2010					
N <sub>2</sub> O	g/inhabitant	9.0	10	11	11	12					
2G3a Use of N <sub>2</sub> O for anaesthesia	Unit	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
N <sub>2</sub> O	g/inhabitant	5.7	3.5	3.8	3.3	2.5	2.3	2.2	2.1	2.0	2.0
2G3b N <sub>2</sub> O from aerosol cans	Unit	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
N <sub>2</sub> O	g/inhabitant	12	11	11	11	10	10	10	10	10	10

##### Activity data

As the emission factors are expressed in g N<sub>2</sub>O per capita, the corresponding activity data for the source categories 2G3a Medical applications and 2G3b Other are the Swiss population (FSO 2022c).

Table 4-56 Activity data for the source categories 2G3a Use of N<sub>2</sub>O for anaesthesia and 2G3b N<sub>2</sub>O from aerosol cans.

2G3 N <sub>2</sub> O from product uses	Unit	1990	1995	2000	2005	2010
2G3a, 2G3b	inhabitants	6'712'000	7'041'000	7'184'000	7'437'000	7'825'000

2G3 N <sub>2</sub> O from product uses	Unit	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
2G3a, 2G3b	inhabitants	7'997'000	8'089'000	8'189'000	8'282'000	8'373'000	8'452'000	8'514'000	8'575'000	8'638'000	8'705'000

#### 4.8.2.4. Other (2G4)

##### Other solvent use (2G4)

Since the IPCC Guidelines (IPCC 2006, vol. 3, chp. 5.5) refer to the EMEP/EEA guidebook regarding methodologies for estimating NMVOC emissions from solvent use, the respective NFR codes are indicated as reference as well. Within 2G4 Other solvent use, the NMVOC emissions from domestic solvent use (2D3a NFR), printing (2D3h NFR), other solvent use (2D3i NFR) as well as other product use (2G NFR) are reported. Domestic solvent use comprises mainly the use of cleaning agents, detergents, cosmetics and toiletries in private households whereas the other three NFR source categories consist of solvent applications in various production processes and services and the use of solvent-based products in various industrial processes, services and commerce. Domestic solvent use is by far the largest NMVOC emission source of 2G4 Other solvent use. Indirect CO<sub>2</sub> emissions resulting from NMVOC emissions in this source category are included in CRF Table6 as documented in chp. 9.

##### Methodology

For the determination of NMVOC emissions from domestic solvent use (2D3a NFR), printing (2D3h NFR), other solvent use (2D3i NFR) and other product use (2G NFR) a Tier 2 method according to the EMEP/EEA guidebook (EMEP/EEA 2019) is used. For domestic solvent use, the emissions are based on the products consumed and their solvent content and are calculated in proportion to the Swiss population. For package printing and other printing industry the emissions are based on the ink consumption, for other solvent use mainly on the number of employees and for other product use on the number of employees and products applied or manufactured. Switzerland's Informative Inventory Report (FOEN 2023b, chp. 4.5.2.1, 4.5.2.8, 4.5.2.9 and 4.6.2.1) contains a detailed description of the country-specific emission factors and activity data of these four NFR source categories.

##### Post-combustion of NMVOC from other solvent use (2G4)

Due to the obligations of the Ordinance on Air Pollution Control (Swiss Confederation 1985) and Ordinance on the Incentive Tax on Volatile Organic Compounds (Swiss Confederation 1997) several industrial plants use facilities and equipment to reduce NMVOC in exhaust gases and room ventilation output. Often this implies the feeding of air with high NMVOC content into the burning chamber of boilers or other facilities to incinerate NMVOC. These CO<sub>2</sub> emissions from post-combustion of NMVOC are estimated based on industry data and expert estimates (Carbotech 2022a).

### Methodology

The CO<sub>2</sub> emissions from post-combustion of NMVOC are calculated by a Tier 2 method using country-specific emission factors. Emissions are calculated based on the amount of NMVOC (and their carbon content) destroyed in the respective combustion facility of more than 100 industrial plants (Carbotech 2022a).

Post-combustion facilities are applied in source categories 2D3a Solvent use (see chp. 4.5.2.2) and 2G4 Other solvent use comprising printing (2D3h NFR), other solvent use (2D3i NFR) and other product use (2G NFR). In 2018, the source category allocation of all post-combustion plants has been verified. For the ten largest facilities (within 2D3a and 2G4), which are responsible for about 70 % of the emissions, the NMVOC quantities and respective carbon contents based on the composition of the solvents were updated annually whereas all the others every five years. For the previous submission, a complete update of all facilities was carried out by means of a survey of all cantonal air pollution control authorities, in addition, with VOC balances. If no information of the solvent composition was available, mean source category-specific values were applied for the carbon content.

Not all facilities have been in use for the entire period 1990–2021. There was a significant increase in total number of facilities from 32 in the year 1990 to 115 in 2002. Since then, the number fluctuates around 120.

These amounts of NMVOC eliminated by post-combustion are also declared in the respective VOC balances of the industrial plants and are thus not included as NMVOC emissions. When deriving the NMVOC emission factors for these source categories, the amount of NMVOC destroyed in post-combustion facilities is taken into account, i.e. the NMVOC emission factor is reduced accordingly.

### Emission factors

CO<sub>2</sub> emission factors are derived based on the composition of the solvents (carbon content) destroyed in each post-combustion installation. For the ten most important installations (within 2D3a and 2G4), amount and composition of solvents destroyed were updated annually whereas for all others at least every five years. In between the values were kept constant (see Table 4-57). For installations with no information on the solvent composition, mean industry-specific values are applied. The emission factors given in Table 4-57 are (source category specific) implied emission factors that depend both on carbon content and respective amount of the destroyed NMVOC. Thus, the implied emission factors of source categories with large post-combustion facilities may vary significantly over the years, due to changes in solvent compositions and amounts, starting-up or shutting down of facilities, etc.

Table 4-57 CO<sub>2</sub> emission factors for post-combustion of NMVOC in 2G4 Other.

2G4 Other		CO <sub>2</sub>				
Post-combustion of NMVOC	Unit	1990	1995	2000	2005	2010
Printing (2D3h NFR)	t/t NMVOC	2.25	2.20	2.17	2.14	2.14
Other solvent use (2D3i NFR)	t/t NMVOC	1.97	1.96	1.96	1.94	1.95
Other product use (2G NFR)	t/t NMVOC	1.30	1.60	1.64	1.71	1.90

2G4 Other		CO <sub>2</sub>									
Post-combustion of NMVOC	Unit	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Printing (2D3h NFR)	t/t NMVOC	2.14	2.14	2.15	2.09	2.10	2.10	2.09	2.10	2.00	2.00
Other solvent use (2D3i NFR)	t/t NMVOC	1.98	2.00	2.05	2.27	2.27	2.27	2.27	2.27	2.49	2.49
Other product use (2G NFR)	t/t NMVOC	1.76	1.77	1.74	1.67	1.71	1.69	1.75	1.79	1.83	1.83

### Activity data

Activity data are the amounts of NMVOC destroyed in post-combustion installations and are provided by the industry, VOC balances and cantonal air pollution control authorities. For the ten most important installations (within 2D3a and 2G4), they were updated annually whereas for all others at least every five years.

Table 4-58 Activity data of NMVOC post-combustion in 2G4 Other.

2G4 Other	Unit	1990	1995	2000	2005	2010
<b>Post-combustion of NMVOC</b>						
Printing (2D3h NFR)	t NMVOC	2'188	9'357	11'276	13'036	13'414
Other solvent use (2D3i NFR)	t NMVOC	288	474	530	395	554
Other product use (2G NFR)	t NMVOC	412	1'034	1'217	939	688

2G4 Other	Unit	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
<b>Post-combustion of NMVOC</b>											
Printing (2D3h NFR)	t NMVOC	14'091	14'424	13'752	14'112	14'477	15'661	15'292	15'423	14'732	14'732
Other solvent use (2D3i NFR)	t NMVOC	573	583	364	368	360	352	344	336	58	58
Other product use (2G NFR)	t NMVOC	964	996	1'046	1'086	1'097	1'255	1'224	1'237	1'154	1'154

### Other product use (2G4)

In addition to NMVOC emissions from the use of solvent-based products in industrial processes, services and commerce, emissions of CO<sub>2</sub>, NO<sub>x</sub>, CO and SO<sub>2</sub> as well as of NO<sub>x</sub>, CO and NMVOC from the use of fireworks and tobacco, respectively, are reported in source category 2G4 Other product use (2G NFR).

Since the emissions of CO and NMVOC from tobacco use are of biogenic origin, they are not considered for calculation of indirect CO<sub>2</sub> emissions. Thus indirect CO<sub>2</sub> emissions resulting from CO emissions from use of fireworks only are included in CRF Table6 as documented in chp. 9.

### Methodology

The emissions are determined by a Tier 2 method according to the EMEP/EEA guidebook (EMEP/EEA 2019) using country-specific emission factors. For tobacco use a description of the country-specific emission factors and activity data is given in Switzerland's Informative Inventory Report (FOEN 2023b, chp. 4.6.2).

### Emission factors

The emission factors for CO<sub>2</sub>, NO<sub>x</sub>, CO and SO<sub>2</sub> from the use of fireworks are documented in FOEN (2014p) and are displayed in Table 4-59.

Table 4-59 Emission factors for CO<sub>2</sub>, N<sub>2</sub>O, NO<sub>x</sub>, CO, SO<sub>2</sub> for source category 2G4 Use of fireworks and 2G4 Rock wool production in 2021.

2G4 Other	Unit	CO <sub>2</sub>	N <sub>2</sub> O	NO <sub>x</sub>	CO	SO <sub>2</sub>
<b>Other product use (2G NFR)</b>						
Fireworks	kg/t	43	NA	0.26	7.4	4.1
Rock wool production	g/t	NA	C	NA	NA	NA

### Activity data

Activity data for the use of fireworks are annual sales figures based on import statistics (until 2009, EMIS 2023/2G4 Feuerwerke) and the statistics of the Swiss federal office for police (FEDPOL 2022).

Table 4-60 Activity data for source category 2G4 Use of Fireworks and Rock wool production.

2G4 Other	Unit	1990	1995	2000	2005	2010
<b>Other product use (2G NFR)</b>						
Fireworks	kt	0.8	1.0	1.5	1.4	1.7
Rock wool production	kt	C	C	C	C	C

2G4 Other		2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
<b>Other product use (2G NFR)</b>											
Fireworks	kt	1.9	2.3	1.8	1.6	1.2	1.7	1.8	1.0	1.0	1.0
Rock wool production	kt	C	C	C	C	C	C	C	C	C	C

### Rock wool production (2G4)

In connection with the updating of allocations under the 3rd commitment period of the Swiss Emissions Trading Scheme (ETS), it became apparent that nitrous oxide is also emitted during rock wool production. It seems that nitrous oxide is produced in the curing process due to the high temperatures. The binder used in the production process is assumed to be the source of the nitrogen. Small amounts of nitrous oxide are apparently also released from the cupola furnace process. These process emissions are now reported in the annual monitoring report of the Swiss Emission Trading System.

### Methodology

The N<sub>2</sub>O emissions from rock wool production are determined by an approach analogous to a Tier 2 method using a country-specific emission factor.

### Emission factor

The N<sub>2</sub>O emission factor is based on analyses and estimates of nitrous oxide emissions in various European rock wool plants. It is assumed that the emission factor is constant over the entire period. The data (Table 4-59) are confidential but available to reviewers.

### Activity data

Activity data on annual production of rock wool are provided annually by the Swiss production plant for the entire time period. Since 2013, activity data is taken from annual ETS monitoring reports. The data (Table 4-60) are confidential but available to reviewers (see EMIS 2023/2G4 Steinwolle-Imprägnierung).

### HFC not accounted in other source categories (2G4)

Emissions of HFC not accounted for in any other source categories are reported under 2G4 Other. For confidentiality reasons, no further details are provided here. Information is documented in the confidential NID.

### *Methodology*

A Tier 2 approach is applied for HFCs with prompt emissive applications based on import statistics.

### *Emission factors*

Prompt emissions of HFC are calculated following the IPCC Guidelines assuming a total loss of product within two years (50 % loss in the first and 50 % in the second year) (IPCC 2006).

### *Activity data*

HFC activity data under 2G4 are based on FOEN import statistic and company data.

## **4.8.3. Uncertainties and time-series consistency**

The uncertainty of total CO<sub>2</sub> emissions from the entire source category 2G4 is obtained assuming 10 % uncertainty for the activity data (expert estimate) and 20 % uncertainty for the emission factor (expert estimate).

The uncertainty of N<sub>2</sub>O emissions from source category 2G3 is estimated at 80 % (expert estimate, see Table 1-8).

For N<sub>2</sub>O in source category 2G4 Rock wool production, the uncertainty of the activity data is estimated to be 1 % and the uncertainty of the emission factor 40 % (expert estimate).

The uncertainty of SF<sub>6</sub>, HFC and PFC emissions in source category 2G is estimated based on a Monte Carlo analysis and reported in Table A-2 of Annex A2.1. Further details are available from background documents, confidential/internal excel calculations and the respective report (Carbotech 2023).

Time series is consistent, with exception of the source category 2G2 Electrical equipment where from 2000 onwards the data are based on a Tier 3a approach instead of model calculations according to Tier 2 as applied for data before 2000. Due to lack of basic information it is not possible to provide a consistent time series for category 2G2 Electrical equipment retroactively.

## **4.8.4. Category-specific QA/QC and verification**

The general QA/QC measures are described in chp. 1.5.

For SF<sub>6</sub>, measurements at Jungfrauoch are used to estimate Swiss emissions for verification purposes (see chp. 4.7.4 and Annex 6). Estimated emissions based on measurements at Jungfrauoch agree within uncertainties with the emissions from the inventory.

## **4.8.5. Category-specific recalculations**

The following recalculations were implemented in submission 2023. Major recalculations which contribute significantly to the total differences emissions of sector 2 IPPU between the latest and the previous submissions are presented also in chp. 10.1.2.2.

- 2G2: The calculation model for activity data and emission factors of SF<sub>6</sub> were revised based on company-specific data for the years 2003–2020 (for further details see confidential NID).
- 2G2, activity data: The PFC amount declared for consumption was revised for the year 2020 (for further details see confidential NID).
- 2G4: Due to new information in the monitoring report of the Swiss emissions trading system, the N<sub>2</sub>O emissions from the curing process of source category 2G4 Rock wool production are now also reported for the entire time series. The N<sub>2</sub>O emission factor is based on analyses and estimates in 16 similar European plants of the company group.

#### **4.8.6. Category-specific planned improvements**

No category-specific improvements are planned.

## 4.9. Source category 2H – Other

### 4.9.1. Source category description

Table 4-61 Key categories of 2H Other. Combined KCA results, level for 2021 and trend for 1990–2021, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Source category 2H Other is not a key category.
---

Table 4-62 Specification of source category 2H Other in Switzerland.

2H	Source category	Specification
2H1	Pulp and paper	Emissions from NMVOC from pulp and paper including chipboard, fibreboard and cellulose production (ceased in 2008)
2H2	Food and beverages industry	Emissions of CO and NMVOC from production of food and drink
2H3	Other	Emissions of CO <sub>2</sub> , NO <sub>x</sub> , CO, NMVOC and SO <sub>2</sub> from blasting and shooting

### 4.9.2. Methodological Issues

#### 4.9.2.1. Pulp and paper (2H1)

##### Methodology

In 2021, the production of chipboard and fibreboard are the relevant industrial processes in the source category 2H1 Pulp and paper. In Switzerland, chipboard and fibreboard were produced in one and two plants, respectively, until 2019. Since 2020 only one plant is left. The cellulose production was closed down in 2008 and is not occurring anymore in Switzerland. The NMVOC emissions are calculated by a Tier 2 method according to the EMEP/EEA guidebook (EMEP/EEA 2019) using country-specific emission factors.

Indirect CO<sub>2</sub> emissions resulting from NMVOC emissions in this source category are included in CRF Table6 as documented in chp. 9.

##### Emission factors

The emission factor for NMVOC emissions from pulp and paper production in Switzerland is country-specific and based on measurements and data from industry and expert estimates documented in EMIS 2023/2H1. The implied emission factor given in Table 4-63 is production-weighted and related to chipboard and fibreboard production. It is confidential but available to reviewers on request.

Table 4-63 Emission factors for CO and NMVOC in pulp and paper production and food and beverages industry, CO<sub>2</sub>, NO<sub>x</sub>, CO, NMVOC and SO<sub>2</sub> from blasting and shooting for 2021.

2H Other	Unit	CO <sub>2</sub>	NO <sub>x</sub>	CO	NMVOC	SO <sub>2</sub>
2H1 Pulp and paper	g/t	NA	NA	NE	C	NE
2H2 Food and beverage industry (exc. beer, wine, spirits)	g/t	NA	NA	250	2'250	NA
2H2 Food and beverage industry (beer, wine, spirits)	g/m <sup>3</sup>	NA	NA	NA	350	NA
2H3 Blasting and shooting	kg/t	400	35	310	60	0.5

### Activity data

The annual amount of pulp and paper produced in Switzerland is based on data from industry and expert estimates documented in EMIS 2023/2H1. Due to the production structure in Switzerland, i.e. one production site for cellulose (ceased in 2008), one for chipboard and two for fibreboard (one ceased in 2019), only the sum of the production volume of 2H1 Pulp and paper industry is provided, and since 2020 activity data are confidential. Detailed data can be accessed by reviewers on request.

Table 4-64 Pulp and paper production, food and beverages production and amount of explosives used.

2H Other	Unit	1990	1995	2000	2005	2010
2H1 Pulp and paper	kt	604	593	641	693	602
2H2 Food and beverage industry (exc. beer, wine, spirits)	kt	2'249	2'114	2'300	2'134	2'397
2H2 Food and beverage industry (beer, wine, spirits)	m3	560'972	516'519	492'208	452'877	467'699
2H3 Blasting and shooting; blasting agent and powder	kt	2.6	1.3	1.9	0.79	2.4

2H Other	Unit	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
2H1 Pulp and paper	kt	533	510	516	519	503	507	502	460	C	C
2H2 Food and beverage industry (exc. beer, wine, spirits)	kt	2'491	2'413	2'533	2'473	2'471	2'492	2'455	2'479	2'393	2'482
2H2 Food and beverage industry (beer, wine, spirits)	m3	454'903	449'070	446'567	447'709	439'556	435'426	457'265	464'866	437'731	430'891
2H3 Blasting and shooting; blasting agent and powder	kt	2.3	2.2	2.1	2.1	0.67	0.73	0.81	0.67	0.63	0.61

### 4.9.2.2. Food and beverages industry (2H2)

#### Methodology

Production of beverages comprises wine, beer and spirits and food industry comprises production of bread, sugar, smoked meat, roasting of coffee and the milling industry. The CO and NMVOC emissions from food and beverages industry are calculated by a Tier 2 method according to the EMEP/EEA guidebook (EMEP/EEA 2019) using country-specific emission factors. Since these CO and NMVOC emissions are of biogenic origin, they are not considered for calculation of indirect CO<sub>2</sub> emissions.

#### Emission factors

The emission factors for CO and NMVOC emissions from food and beverages industry are country-specific and based on measurements and data from industry and expert estimates as documented in the EMIS database (EMIS 2023/2H2). The implied emission factors are production-weighted (Table 4-63).

### **Activity data**

The annual amount of food and beverages produced is based on data from industry and the farmers' association (SBV) and expert estimates as documented in EMIS 2023/2H2 (Table 4-64).

#### **4.9.2.3. Other (2H3)**

##### **Methodology**

For determination of emissions of CO<sub>2</sub>, NO<sub>x</sub>, CO, NMVOC and SO<sub>2</sub> from blasting and shooting, an analogous Tier 2 method with country-specific emission factors is used as documented in the EMIS database (EMIS 2023/2H3 Sprengen und Schiessen).

Indirect CO<sub>2</sub> emissions resulting from CO and NMVOC emissions in this source category are included in CRF Table6 as documented in chp. 9.

##### **Emission factors**

The emission factors for CO<sub>2</sub>, NO<sub>x</sub>, CO, NMVOC and SO<sub>2</sub> from blasting and shooting activities are country-specific and based on measurements and data from industry and expert estimates (see Table 4-63).

### **Activity data**

The annual amount of used explosives is based on the Federal statistics on explosives (FEDPOL 2022) (Table 4-64).

#### **4.9.3. Uncertainties and time-series consistency**

The uncertainty for CO<sub>2</sub> emissions from 2H3 Other is estimated to be 8 % (expert judgement) since activity data are taken from customs statistics.

Consistency: Time series for 2H Other are all considered consistent.

#### **4.9.4. Category-specific QA/QC and verification**

The general QA/QC measures are described in chp. 1.5.

#### **4.9.5. Category-specific recalculations**

There were no recalculations implemented in submission 2023.

#### **4.9.6. Category-specific planned improvements**

No category-specific improvements are planned.

## 5. Agriculture

Responsibilities for sector Agriculture	
Overall responsibility, author	Daniel Bretscher (Agroscope)
Sector experts (including QC)	Christoph Ammann (Agroscope), Thomas Kupper (HAFL), Chloé Wüst (Agroscope; QC)
EMIS database operation	Sabine Schenker (FOEN)
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Annual updates (NID text, tables, figures)	Daniel Bretscher (Agroscope)
Internal review	Michael Bock (FOEN)

### 5.1. Overview

This chapter provides information on the estimation of the greenhouse gas emissions from the sector Agriculture. The following categories are reported:

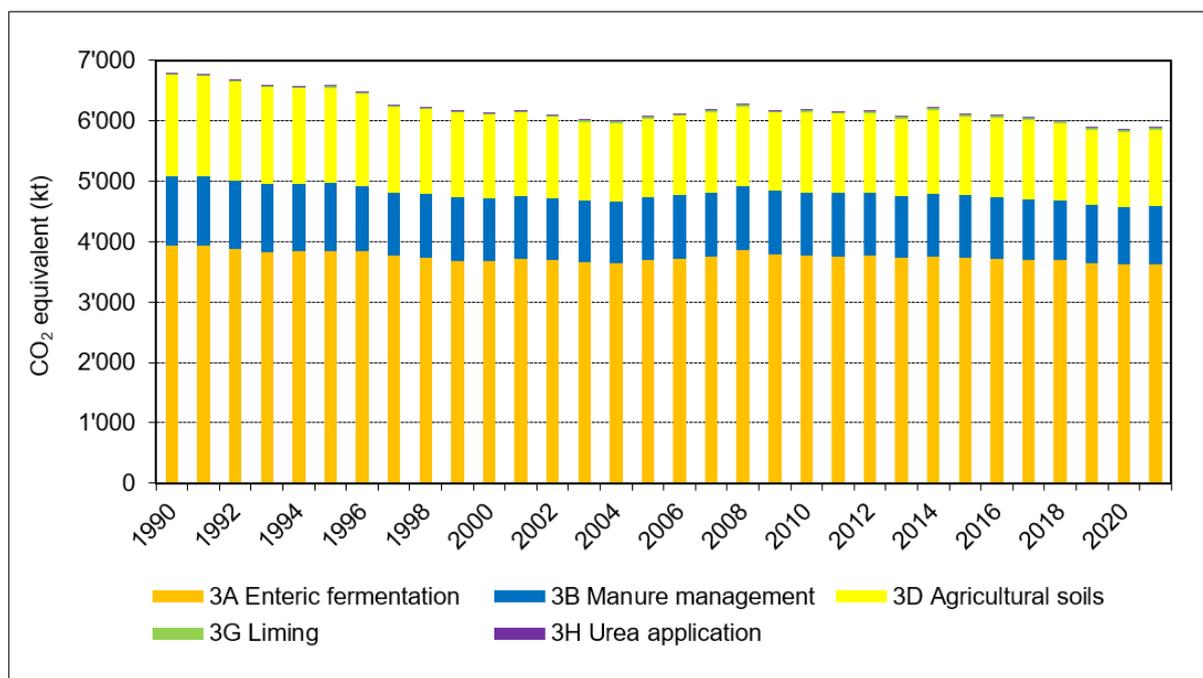
- 3A Enteric fermentation, CH<sub>4</sub> emissions from domestic livestock.
- 3B Manure management, emissions of CH<sub>4</sub>, N<sub>2</sub>O and NO<sub>x</sub>
- 3D Agricultural soils, emissions of N<sub>2</sub>O, NO<sub>x</sub> and NMVOC
- 3G Liming, emissions of CO<sub>2</sub>
- 3H Urea application; emissions of CO<sub>2</sub>

No emissions are reported for 3C Rice cultivation as in Switzerland only a small area is cultivated with upland rice. The categories 3E Prescribed burning of savannahs and 3F Field burning of agricultural residues do not occur in Switzerland and are therefore not reported.

CO<sub>2</sub> emissions from soils are reported under 4 Land use, land-use change and forestry (LULUCF). CO<sub>2</sub> emissions from energy use in agriculture are reported under 1A4c Agriculture/forestry/fishing.

Because CH<sub>4</sub> and NMVOC emissions from the Agriculture sector are of biogenic origin (CO emissions do not occur), from this sector no indirect CO<sub>2</sub> emissions are included in CRF Table 6 as documented in chp. 9.

Total greenhouse gas emissions from the Agriculture sector in 2021 were 5'898 kt CO<sub>2</sub> equivalent which is a contribution of 13.0 % to the total of Swiss greenhouse gas emissions (excluding indirect CO<sub>2</sub>, excluding LULUCF, Table 2-5, Table 5-1). Main agricultural sources of greenhouse gases were 3A Enteric fermentation, emitting 62 % of all agricultural greenhouse gases, followed by 3D Agricultural soils with 21 % and 3B Manure management with 16 % (Figure 5-1). EG Liming and 3H Urea application contributed 0.6 % and 0.2 % respectively.

Figure 5-1 Greenhouse gas emissions of the agricultural sector in CO<sub>2</sub> equivalent (kt).Table 5-1 Greenhouse gas emissions of the agricultural sector in CO<sub>2</sub> equivalent (kt).

Gas	1990	1995	2000	2005	2010
	kt CO <sub>2</sub> equivalent				
CO <sub>2</sub>	49	42	39	42	44
CH <sub>4</sub>	4'706	4'607	4'362	4'375	4'449
N <sub>2</sub> O	2'046	1'934	1'736	1'658	1'689
Sum	6'801	6'583	6'137	6'076	6'183

Gas	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
	kt CO <sub>2</sub> equivalent									
CO <sub>2</sub>	42	42	46	45	47	48	46	45	45	46
CH <sub>4</sub>	4'452	4'404	4'434	4'420	4'388	4'346	4'335	4'266	4'232	4'249
N <sub>2</sub> O	1'664	1'633	1'734	1'648	1'662	1'666	1'618	1'584	1'581	1'603
Sum	6'158	6'079	6'214	6'113	6'098	6'060	6'000	5'895	5'859	5'898

CH<sub>4</sub> and N<sub>2</sub>O emissions generally declined from 1990 until 2004 (Figure 5-2). Subsequently CH<sub>4</sub> emissions increased slightly until 2008 and decreased again afterwards. N<sub>2</sub>O emissions remained more or less on a constant level since 2004 with a decreasing trend in the last years. This general development can be explained by the development of the cattle population and the input of mineral fertilisers. Use of mineral fertiliser declined due to the introduction of the “Proof of Ecological Performance (PEP)” in the early 1990s (Agroscope 2019a, Leifeld and Fuhrer 2005), while the cattle population was influenced by the market situation, the milk quotation system (suspended in 2009) and the general agricultural policy- and subsidy-system (OECD 2022). Most emission factors did not change significantly over the inventory years. CO<sub>2</sub> emissions display high year to year variability due to variability of urea application, which depends among others on the relative price levels of different industrial fertilisers.

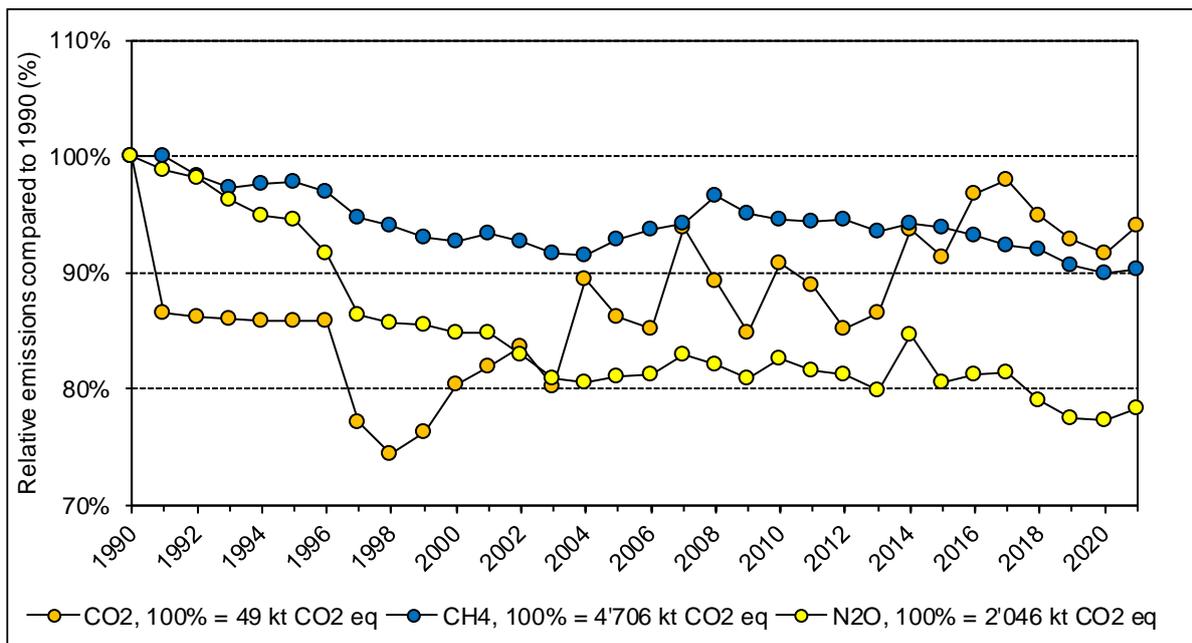


Figure 5-2 Relative trends of the greenhouse gas emissions of sector 3 Agriculture. The base year 1990 represents 100 %.

Among the key categories of the Swiss inventory, six are from the agricultural sector (Figure 5-3).

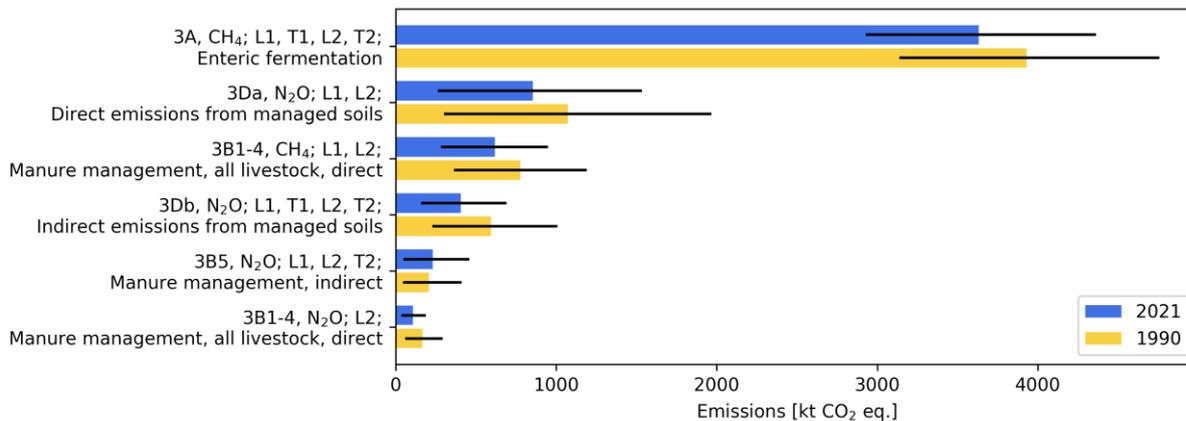


Figure 5-3. Key categories in the Swiss GHG inventory from sector 3 Agriculture determined by the key category analyses, approaches 1 and 2. Categories are set out in order of decreasing emissions in 2021. L1: key category according to approach 1 level in 2021; L2: same for approach 2; T1: key category according to approach 1 trend 1990–2021; T2: same for approach 2. Black uncertainty bars represent the narrowest 95 % confidence interval obtained by Monte Carlo simulations (see chp. 1.6 for details).

## 5.2. Source category 3A – Enteric fermentation

### 5.2.1. Source category description

Table 5-2 Key categories of 3A Enteric fermentation. Combined KCA results, level for 2021 and trend for 1990–2021, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC category	Gas	Identification criteria
3A	Enteric fermentation	CH <sub>4</sub>	L1, T1, L2, T2

This emission source comprises the domestic livestock population broken down into 3 cattle categories (mature dairy cattle, other mature cattle, growing cattle), sheep, swine, buffalo, camels, deer, goats, horses, mules and asses, poultry, rabbits and livestock not covered by the agricultural census (livestock NCAC) (Table 5-3).

Emissions from 3A Enteric fermentation declined from 1990 until 2004, mainly due to a reduction in the number of cattle. However, between 2004 and 2008 cattle livestock numbers and subsequently CH<sub>4</sub> emissions increased, whereas since 2008 they were decreasing again.

Cattle contribute over 90 % to the overall emissions from 3A Enteric fermentation and the contribution of mature dairy cattle is almost 60 %.

Emissions from fur-bearing animals are not occurring in Switzerland as provisions for the husbandry of wild animals are very strict according to the Swiss Animal Welfare Act (Swiss Confederation 2003). This is true for the whole inventory time period as the first version of the law dates back to 1978. Consequently, fur farming is not economically viable in Switzerland. In addition, fur animals (other than rabbits) are not included in national livestock data.

Table 5-3 Specification of source category 3A Enteric fermentation.

3A	Source	Specification
3A1	Cattle	Mature Dairy Cattle
		Other Mature Cattle
		Growing Cattle (Fattening Calves <sup>1</sup> , Pre-Weaned Calves, Breeding Cattle 1st year (Breeding Calves + Breeding Cattle 4-12 months), Breeding Cattle > 1 year, Fattening Cattle (Fattening Calves 0-4 months <sup>2</sup> , Fattening Cattle 4-12 months))
3A2	Sheep	Lambs < 1 year Mature Sheep
3A3	Swine	
3A4a	Buffalo	Bisons < 3 years <sup>3</sup>
3A4b	Camels	Bisons > 3 years <sup>3</sup>
		Llamas < 2 years Llamas > 2 years Alpacas < 2 years Alpacas > 2 years
3A4c	Deer	Fallow Deer Red Deer
3A4d	Goats	
3A4e	Horses	Horses < 3 years Horses > 3 years
3A4f	Mules and Asses	Mules
		Asses
3A4g	Poultry	
3A4h i	Rabbits	
3A4h ii	Livestock NCAC	Sheep
		Goats
		Horses < 3 years
		Horses > 3 years
		Mules Asses

<sup>1</sup> Fattening for veal with a milk based diet (slaughtered at ap. 100 days). See chp. 5.2.2.3.

<sup>2</sup> Fattening for beef meat (slaughtered at ap. 400 days). See chp. 5.2.2.3.

<sup>3</sup> Bisons (*Bos bison* and/or *Bos bonasus*). Water buffalos (*Bubalus bubalis*) are included under cattle. See chp. 5.2.2.3.

## 5.2.2. Methodological issues

### 5.2.2.1. Methodology

For mature dairy cattle a detailed Tier 3 model approach is applied, predicting gross energy intake by the means of a feeding model that takes into account animal performance and diet bio-chemical composition. A country-specific methane conversion rate ( $Y_m$ ) was derived from a series of studies representing Swiss specific feeding conditions.

Emission estimation for all other cattle categories follows a Tier 2 approach. This means that detailed country-specific data on nutrient requirements and feed intake were used.  $CH_4$  conversion rates were taken from the 2019 Refinement to the 2006 IPCC Guidelines (IPCC 2019).

Methods for all other animal categories are based on a Tier 2 approach, estimating country-specific energy intake rates. Methane conversion rates were taken from the 2019 Refinement (IPCC 2019), the 2006 IPCC Guidelines (IPCC 2006) or from published peer reviewed literature.

The calculation of  $CH_4$  emissions is done by Agroscope, the Swiss centre of excellence for agricultural research (Agroscope 2023).

### 5.2.2.2. Emission factors

All emission factors for 3A Enteric fermentation are country-specific, based on IPCC equation 10.21 (IPCC 2019):

$$EF = \frac{GE * (Y_m \div 100) * 365 \text{ days / y}}{55.65 \text{ MJ / kg CH}_4}$$

EF = annual CH<sub>4</sub> emission factor (kg/head/year)

GE = gross energy intake (MJ/head/day)

Y<sub>m</sub> = methane conversion rate, which is the fraction of gross energy in feed converted to methane (%)

55.65 MJ/kg = energy content of methane.

#### 5.2.2.2.1. Gross energy intake (GE)

For calculating the gross energy intake (GE), country-specific methods based on available data on requirements of net energy, digestible energy and metabolizable energy were used. The different energy levels used for energy conversion from energy required for maintenance and production to GE intake are illustrated in Figure 5-4. The respective conversion factors are given in Table 5-4.

For the **cattle categories** detailed estimations for energy requirements are necessary. As the Swiss Farmers Union (SBV) does not provide these estimates on a detailed cattle sub-category level, requirements for each cattle category were calculated individually following the feeding recommendations for Switzerland provided in RAP (1999) and Morel et al. (2017). These RAP recommendations are also used by the Swiss farmers as the basis for their cattle feeding regimes and for filling in application forms for direct payments; they are therefore highly appropriate.

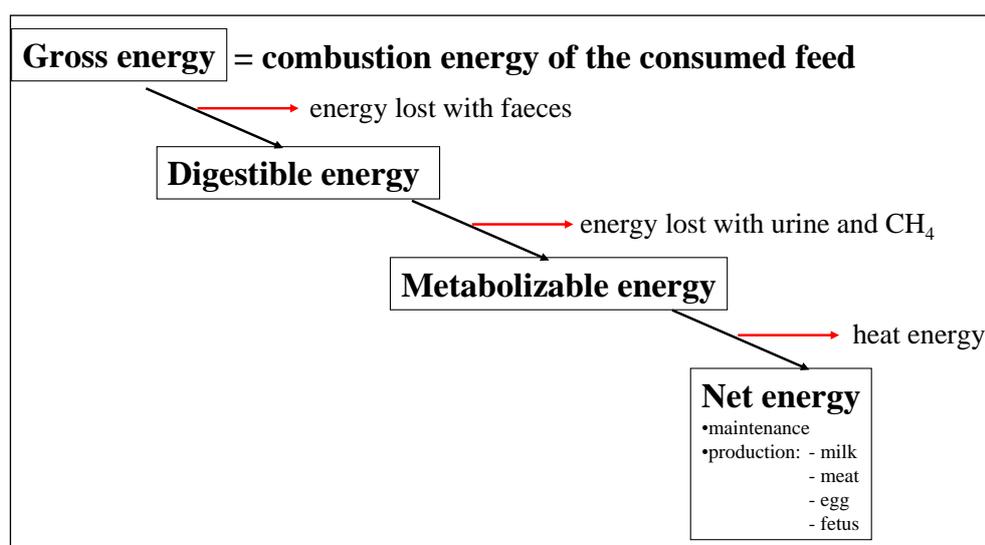


Figure 5-4 Levels of feed energy conversion (Soliva 2006).

Table 5-4 Conversion factors used for calculation of energy requirements of individual livestock categories (Soliva 2006). GE: Gross energy; DE: Digestible energy; ME: Metabolisable energy; NEL: Net energy for lactation; NEV: Net energy for growth. Blue: annually changing parameters, value for 2021.

Livestock Category		Conversion Factors	
Mature Dairy Cattle		NEL to GE	0.342
Other Mature Cattle		NEL to GE	0.265
Growing Cattle	<i>Fattening Calves</i>	<i>ME to GE</i>	0.939
	<i>Pre-Weaned Calves</i>	<i>NEL to GE</i>	0.299
	<i>Breeding Calves</i>	<i>NEL to GE</i>	0.358
	<i>Breeding Cattle (4-12 months)</i>	<i>NEL to GE</i>	0.319
	<i>Breeding Cattle (&gt; 1 year)</i>	<i>NEL to GE</i>	0.313
	<i>Fattening Calves (0-4 months)</i>	<i>NEV to GE</i>	0.355
	<i>Fattening Cattle (4-12 months)</i>	<i>NEV to GE</i>	0.397
Sheep	<i>Fattening Sheep</i>	<i>NEV to GE</i>	0.350
	<i>Milksheep</i>	<i>NEL to GE</i>	0.287
Swine		DE to GE	0.682
Buffalo		NA	NA
Camels and Llamas		NA	NA
Deer		NA	NA
Goats		NEL to GE	0.283
Horses		DE to GE	0.700
Mules and Asses		DE to GE	0.700
Poultry		ME to GE	0.700
Rabbits		NA	NA
Livestock NCAC		NA	NA

For **mature dairy cattle** a detailed feeding model from the Agroscope department for Livestock Sciences was used to predict gross energy intake (Agroscope 2014c).

Energy and protein requirements were estimated based on animal performance (body weight, milk production, pregnancy) following the standard feeding recommendations for Switzerland (RAP 1999). Live weight was estimated based on statistics of carcass weight according to Burren et al. (2021). Live weight increased more or less linearly from 637 kg in 1990 to 685 kg in 2021. Statistics of annual milk production are provided by the Swiss Farmers Union (SBV 2022, Table 5-5). Milk production includes marketed milk, milk consumed by calves on farms and milk sold outside the commercial industry (MISTA 2022). It should be noted that daily milk yield refers to milk production during the whole year (365 days) and not during lactation only (305 days). During the dry months additional energy requirements for pregnancy were accounted for.

To cover total animal energy and protein requirements, typical Swiss specific basic feed rations were defined as model inputs. The average basic feed ration in summer consisted of 92 % fresh grass and 8 % maize cubes. In winter the feed ration consisted of 10 % maize silage, 13 % grass silage, 72 % hay and 5 % fodder beet. Concentrates are automatically supplemented in the model according to additional energy and protein requirements not covered by the basic feed ration. Concentrates consisted of a varying mixture of barley grains, wheat grains, maize grains, maize gluten, soybean meal and rapeseed meal according to specific animal requirements.

As suggested by Menzi et al. (2016) all calculations of feed intake and excretions rates for mature dairy cattle are based on the average between the model results of one first lactation

(primiparous) and two subsequent lactations. The feed requirements for the additional weight gain during the first lactation is included in the equations to estimate feed intake as these equations are directly derived from feeding experiments.

Average bio-chemical composition and properties of the total feed ration (e.g. energy content, protein content, digestibility) were derived accounting for one first and two subsequent lactations as mentioned above, and weighing the respective values of the individual feed ingredients given in the Swiss Feed Database (Agroscope 2014b). Finally, gross energy intake was estimated based on the total feed intake and the gross energy content of the total ration that was 18.26 MJ/kg on average for the years 1990–2021.

In the year 2003 yearly milk yield surpassed 6000 kg per head. To achieve yearly milk yields higher than 6000 kg, cows have to be fed with an increasing share of feed concentrates that have a substantially higher net energy (NE) density than the basic feed ration. The model reproduces this behaviour. Due to the increasing ratio of net energy to gross energy the increase of gross energy intake is slower after the year 2003 although milk yield increases more or less at the same rate (Table 5-6).

A more exhaustive model description is contained in Agroscope (2019a).

Table 5-5 Average daily milk production in Switzerland (yearly milk production divided by 365).

Milk Production Cattle		1990	1995	2000	2005	2010
Population Size Mature Dairy Cattle	head	783'100	739'641	669'410	620'708	589'024
Lactation Period	day	305	305	305	305	305
Milk Yield Mature Dairy Cattle	kg/head/day	13.21	14.13	15.57	17.15	18.76
Milk Yield Other Mature Cattle	kg/head/day	6.85	6.85	6.85	6.85	6.85

Milk Production Cattle		2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Population Size Mature Dairy Cattle	head	591'212	586'609	587'385	583'277	575'766	569'185	564'190	554'588	546'479	545'533
Lactation Period	day	305	305	305	305	305	305	305	305	305	305
Milk Yield Mature Dairy Cattle	kg/head/day	19.03	18.68	19.13	19.32	19.30	19.11	19.53	19.30	19.43	19.77
Milk Yield Other Mature Cattle	kg/head/day	6.85	6.85	6.85	6.85	6.85	6.85	6.85	6.85	6.85	6.85

For **other mature cattle** and **growing cattle**, data on energy intake were based on the feeding requirements according to RAP (1999) and Morel et al. (2017). In the calculation of the NE data, the animal's weight, daily growth rate, daily feed intake (dry matter), daily feed energy intake, and energy required for milk production and pregnancy for the respective sub-categories were considered (for more detailed data see Annex A5.3). The method is described in detail in Soliva (2006) but has been revised slightly here. A distinction is made between NE for lactation (NEL) and NE for growth (NEV) (Table 5-4). For some of the growing cattle categories NEL is used instead of NEV, even if NEV would seem appropriate. However, cattle-raising is often coupled with dairy cattle activities and therefore the same energy unit (NEL) is used in these cases. Exceptions are the fattening calves (milk-fed calves), whose requirement for energy is expressed as metabolizable energy (ME).

Table 5-6 Gross energy intake per head of different livestock groups. Sub-categories not contained in the reporting tables (CRF) are displayed in italic. The entire time series at a livestock sub-category level is provided in a separate spreadsheet (Agroscope 2023b).

Gross Energy Intake	1990-2010				
	1990	1995	2000	2005	2010
	MJ/head/day				
Cattle					
Mature Dairy Cattle	255.2	265.0	279.2	294.1	302.4
Other Mature Cattle	250.6	250.6	250.6	250.6	250.6
Growing Cattle (weighted average)	103.3	103.9	103.6	101.0	99.8
<i>Fattening Calves</i>	47.1	47.1	47.1	47.1	47.1
<i>Pre-Weaned Calves</i>	60.1	60.1	60.1	60.1	60.1
<i>Breeding Calves</i>	44.0	44.0	44.0	44.0	44.0
<i>Breeding Cattle (4-12 months)</i>	90.1	90.1	90.1	90.1	90.1
<i>Breeding Cattle (&gt; 1 year)</i>	143.6	143.6	143.6	143.6	143.6
<i>Fattening Calves (0-4 months)</i>	56.9	56.9	56.9	56.9	56.9
<i>Fattening Cattle (4-12 months)</i>	126.3	126.3	126.3	126.3	126.3
Sheep	21.2	24.0	22.4	22.8	22.6
Swine	25.7	26.5	25.1	24.5	24.7
Buffalo (weighted average)	NA	136.6	146.9	140.6	136.9
Camels (weighted average)	NA	NA	34.8	31.7	31.0
Deer (weighted average) <sup>1)</sup>	50.5	55.3	56.4	55.4	56.5
Goats	25.0	27.9	25.7	25.4	25.1
Horses (weighted average)	107.3	106.9	107.4	107.7	107.9
Mules and Asses (weighted average)	39.2	39.7	39.5	39.4	40.2
Poultry <sup>2)</sup>	1.2	1.2	1.3	1.1	1.0
Rabbits	1.2	1.2	1.2	1.2	1.2
Livestock NCAC (weighted average)	90.2	72.0	32.9	34.3	37.8

Gross Energy Intake	2012-2021									
	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
	MJ/head/day									
Cattle										
Mature Dairy Cattle	304.4	302.1	304.2	305.7	306.3	305.7	308.6	308.1	309.6	311.5
Other Mature Cattle	250.6	250.6	250.6	250.6	250.6	250.6	250.6	250.6	250.6	250.6
Growing Cattle (weighted average)	100.2	100.1	99.9	99.7	99.2	99.0	98.6	98.4	98.0	97.9
<i>Fattening Calves</i>	47.1	47.1	47.1	47.1	47.1	47.1	47.1	47.1	47.1	47.1
<i>Pre-Weaned Calves</i>	60.1	60.1	60.1	60.1	60.1	60.1	60.1	60.1	60.1	60.1
<i>Breeding Calves</i>	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0
<i>Breeding Cattle (4-12 months)</i>	90.1	90.1	90.1	90.1	90.1	90.1	90.1	90.1	90.1	90.1
<i>Breeding Cattle (&gt; 1 year)</i>	143.6	143.6	143.6	143.6	143.6	143.6	143.6	143.6	143.6	143.6
<i>Fattening Calves (0-4 months)</i>	56.9	56.9	56.9	56.9	56.9	56.9	56.9	56.9	56.9	56.9
<i>Fattening Cattle (4-12 months)</i>	126.3	126.3	126.3	126.3	126.3	126.3	126.3	126.3	126.3	126.3
Sheep	22.5	22.4	22.6	22.5	22.9	23.0	23.3	23.4	23.2	23.2
Swine	24.4	25.1	25.1	25.4	25.8	25.5	25.2	26.3	25.6	25.6
Buffalo (weighted average)	135.9	136.0	134.6	134.5	134.4	133.1	162.8	159.8	159.1	158.4
Camels (weighted average)	31.6	31.9	31.8	31.6	31.2	31.2	31.0	31.2	31.4	31.3
Deer (weighted average) <sup>1)</sup>	57.0	58.1	58.0	58.0	58.5	58.8	59.3	59.6	59.6	59.7
Goats	25.6	25.6	25.0	25.5	25.1	25.2	25.1	25.3	24.9	24.9
Horses (weighted average)	107.9	108.0	108.1	108.3	108.4	108.4	108.5	108.5	108.5	108.5
Mules and Asses (weighted average)	39.9	39.6	39.6	39.6	39.6	39.5	38.4	38.4	38.4	38.5
Poultry <sup>2)</sup>	1.0	1.0	1.0	1.1	1.0	1.1	1.1	1.0	1.1	1.1
Rabbits	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Livestock NCAC (weighted average)	37.8	39.0	38.7	39.3	40.3	40.4	36.9	37.6	37.6	37.7

<sup>1)</sup> Deer: Gross energy intake per animal place (mother with offspring)

<sup>2)</sup> Poultry data is not gross energy intake (GE) but metabolizable energy intake (ME)

The gross energy intake for other mature cattle is significantly higher than would be suggested by the IPCC (IPCC 2019), since the category “other mature cattle” in Switzerland only includes mature cows that produce offspring for meat (so-called “suckler cows” or “mother cows”). Milk production of other mature cattle is 2'500 kg per head and year (305 days of lactation) and has not changed over the inventory time period (Morel et al. 2017).

The gross energy intake of growing cattle was calculated separately for all sub-categories displayed in Table 5-6 (in italics) and subsequently averaged (weighted average). No methane is generated from milk. Nevertheless, energy intake from milk or milk products is considered when estimating methane emission factors from enteric fermentation of calves. However, the methane conversion rate is adjusted accordingly as explained under chp.

5.2.2.2.2. The energy intake values for all 7 sub-categories are constant over time. Since the composition of the growing cattle category changed over time (e.g. more pre-weaned calves, fewer fattening calves, see Table 5-8), the average gross energy intake for growing cattle also changes slightly. To calculate an annual emission factor, the categories breeding calves and breeding cattle 4-12 months were combined in the category breeding cattle 1st year (not shown in Table 5-6 and Table 5-8). Accordingly, the respective animals have two separate gross energy intake values, i.e. 44.0 MJ/head/day for the first 4 months and 90.1 MJ/head/day for the last 8 months. The same procedure is applied for fattening calves 0–4 months (56.9 MJ/head/day) and fattening cattle 4–12 months (126.3 MJ/head/day) summing up to the category fattening cattle.

Energy requirements and gross energy intake of **sheep, swine, goats and poultry** were obtained from the respective estimates of the Swiss Farmers Union (SBV 2022, Giuliani 2022). These estimates are not officially published anymore in the statistical yearbooks (e.g. SBV 2022) but are still available from background data and are based on the same method as used for energy requirement statistics in earlier years (e.g. SBV 2007).

Gross energy intake for **horses, mules and asses** were estimated by Stricker (2012), mainly based on Meyer and Coenen (2002).

Table 5-7 Dry matter and gross energy requirements for buffalo, camels and deer according to Richner and Sinaj (2017).

		DM Intake	GE Intake
		kg DM/head/day	MJ/head/day
Buffalo	Bisons < 3 years	4.93	90.99
	Bisons > 3 years	10.68	197.14
Camels	Llamas < 2 years	1.34	24.77
	Llamas > 2 years	2.33	42.97
	Alpacas < 2 years	0.82	15.16
	Alpacas > 2 years	1.51	27.80
Deer <sup>1)</sup>	Fallow Deer	2.74	50.55
	Red Deer	5.48	101.10

<sup>1)</sup> Requirements for deer are assessed per animal place i.e. mother with offspring.

For **buffalo, camels and deer**, energy intake was derived from data on dry matter intake provided in Richner and Sinaj (2017) (Table 5-7). According to the IPCC Guidelines an energy density of 18.45 MJ\*kg<sup>-1</sup> was used to convert dry matter to gross energy (IPCC 2019).

Energy intake of **rabbits** was estimated by Menzi (2014) based on Schlegel and Menzi (2013).

Finally for **livestock NCAC** the same energy intakes as the respective animal categories in the official census were used.

Final compilation of livestock gross energy intake was conducted in Agroscope (2023). Resulting estimates are provided in Table 5-6 (main categories) and in a separate spreadsheet (Agroscope 2023b, all years and all sub-categories).

#### 5.2.2.2. Methane conversion rate ( $Y_m$ )

For the methane conversion rate ( $Y_m$ ), few country-specific data exist. Accordingly, for most animal categories default or literature values were used. Due to its great importance a country-specific  $Y_m$  was used for **mature dairy cattle**. A value of 6.9 % was derived from a series of measurements conducted under Swiss specific feeding and husbandry conditions at the Federal Institute of Technology in Zurich (based on data compiled in Zeitz et al. (2012) and additional measurements described in Estermann et al. (2001), Külling et al. (2002) and Staerfl et al. (2012)).

For all **other cattle categories, goats and buffalo** default values recommended by the IPCC for developed countries in Western Europe were used (IPCC 2019: Tables 10.12, 10.13). For all juvenile cattle consuming milk or milk products (i.e. calves) the methane conversion rate is weighted, assuming a  $Y_m$  of zero for milk energy and a  $Y_m$  of 6.3 % for all other energy.

For mature sheep an  $Y_m$  of 6.5 % was used as suggested for sheep with a dry matter intake higher than  $0.8 \text{ kg} \cdot \text{day}^{-1}$  (IPCC 2019). For lambs <1 year the  $Y_m$  values of 4.5 % from the 2006 IPCC Guidelines was adopted (IPCC 2006). Overall  $Y_m$  for **sheep** was subsequently weighted according to the population structure. For **camels and deers** the same methane conversion rate as for sheep was applied, assuming the same relationship between adult and juvenile animals.

For **swine** a methane conversion rate of 0.6 % was used. This value was suggested by Crutzen et al. (1986) and was confirmed by the compilation of references in Minonzio et al. (1998). For **Horses, mules and asses** an  $Y_m$  of 2.45 % was used, which corresponds to a methane energy loss of 3.5 % of digestible energy (Vermorel et al. 1997, Minonzio et al. 1998) and a feed digestibility of 70 % (Stricker 2012). For **poultry** a country-specific value (0.16 % of metabolizable energy) was used. This value was evaluated in an in vivo trial with broilers (Hadorn and Wenk 1996). For **rabbits** an  $Y_m$  of 0.6 % was applied as suggested in the national GHG inventory of Italy (ISPRA 2020). Finally, as for gross energy intake, the same methane conversion rates as for the respective animals in the official census were used for **livestock NCAC**.

#### 5.2.2.3. Activity data

Livestock population data were obtained from statistics published by the Swiss Farmers Union (SBV 2022) and the Federal Statistical Office (FSO 2022a) (Table 5-8). In 2011 activity data for the time series 1990–2010 were revised and harmonised during a joint effort of the Agroscope Reckenholz-Tänikon Research Station (ART) and the Swiss College of Agriculture (SHL) (ART/SHL 2012).

The category other mature cattle only includes mature cows used to produce offspring for meat.

Emission estimation for growing cattle was conducted at a more disaggregated level than the one displayed in the reporting tables (CRF). The livestock category growing cattle in the reporting tables includes the sub-categories fattening calves, pre-weaned calves, breeding calves, breeding cattle 4–12 months, breeding cattle >1 year, fattening calves 0–4 months and fattening cattle 4–12 months. The two sub-categories of fattening calves are distinguished by their weight at slaughter and their feeding regime. The first sub-category (“fattening calves”) refers to animals raised for veal with a milk-based diet (slaughtered at

approximately 100 days) whereas the second sub-category ("fattening calves 0-4 months") refers to animals fattened for beef meat (slaughtered at app. 400 days). Although not growing cattle in the proper sense, bulls are contained in the categories breeding cattle (>1 year) and fattening cattle (4–12 months) according to their purposes. This disaggregation of the category growing cattle enhances the accuracy of the emission estimation procedure from livestock activities (also refer to chp. 5.3.2.1).

Emission estimation for buffalo, camels, horses, mules and asses and deers was also conducted on a more disaggregated level than displayed in the reporting tables (CRF). Additional data on a livestock sub-category level are contained in a separate spreadsheet (Agroscope 2023b). The livestock category "buffalo" in the Swiss GHG Inventory contains only bisons (*Bos bison* and/or *Bos bonasus*). Water buffalos (*bubalus bubalis*) are included under cattle. The category "camels" contains only llamas and alpacas.

For the categories "Fattening Pigs over 25 kg" (subcategory of swine) and "Broilers" (subcategory of poultry) adjustments were made in order to correctly consider animal turnover rates (Kupper et al. 2022, FSO 2022b). The values for these subcategories are thus higher here than in the official statistics.

Additional corrections of livestock population statistics implied to ensure time series consistency are described under chp. 5.2.3.

Additionally to official statistical data, population data of livestock not covered by the agricultural census of the Federal Statistical Office were assessed. The respective category "Livestock NCAC" (livestock not covered by agricultural census) consists of sheep, goats, horses and mules and asses held for non-agricultural purposes (e.g. horses for sports and leisure) and/or livestock held by private persons or enterprises that do not fulfil the criteria of an agricultural enterprise. Data for the respective horses, mules and asses were derived from background data of the gross nutrient balance of the Federal Statistical Office (FSO 2022b). For sheep and goats, data from individual cantons having full livestock census were used to estimate the relative share for the whole of Switzerland. The respective estimates were conducted in the course of the elaboration of the gross nutrient balance of the Federal Statistical Office (FSO 2022b).

Table 5-8 Activity data for calculating methane emissions from 3A Enteric fermentation (ART/SHL 2012, SBV 2022, FSO 2022a, FSO 2022b). The complete time series on a livestock sub-category level are provided in a separate spreadsheet (Agroscope 2023b).

Population Size	1990-2010				
	1990	1995	2000	2005	2010
	1'000 head				
Cattle	1'855	1'748	1'588	1'555	1'591
Mature Dairy Cattle	783	740	669	621	589
Other Mature Cattle	12	23	45	78	111
Growing Cattle	1'060	986	874	856	891
<i>Fattening Calves</i>	112	102	103	106	114
<i>Pre-Weaned Calves</i>	10	18	36	62	86
<i>Breeding Cattle 1st Year</i>	346	295	236	222	222
<i>Breeding Calves</i>	214	166	76	75	75
<i>Breeding Cattle (4-12 months)</i>	132	129	161	147	146
<i>Breeding Cattle (&gt; 1 year)</i>	404	378	352	318	326
<i>Breeding Cattle 2nd Year</i>	253	239	222	205	215
<i>Breeding Cattle 3rd Year</i>	151	139	130	113	111
<i>Fattening Cattle</i>	188	193	147	147	144
<i>Fattening Calves (0-4 months)</i>	88	82	43	35	34
<i>Fattening Cattle (4-12 months)</i>	100	110	105	112	110
Sheep	395	387	421	446	434
Swine	1'965	1'739	1'670	1'744	1'750
Buffalo	0	0	0	0	1
Camels	0	0	1	3	6
Deer <sup>1)</sup>	0	1	3	4	6
Goats	68	53	62	74	83
Horses	28	41	50	55	62
Mules and Asses	6	8	12	16	20
Poultry	7'310	6'656	7'160	8'911	10'629
Rabbits	61	41	28	25	35
Livestock NCAC	16	19	88	89	95

Population Size	2012-2021									
	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
	1'000 head									
Cattle	1'565	1'557	1'563	1'554	1'555	1'545	1'543	1'525	1'515	1'514
Mature Dairy Cattle	591	587	587	583	576	569	564	555	546	546
Other Mature Cattle	114	117	118	118	121	123	125	128	131	135
Growing Cattle	859	854	857	853	859	852	854	842	837	833
<i>Fattening Calves</i>	103	102	102	103	107	108	111	110	110	110
<i>Pre-Weaned Calves</i>	88	90	91	91	93	96	97	99	102	105
<i>Breeding Cattle 1st Year</i>	210	208	210	210	211	209	208	201	199	199
<i>Breeding Calves</i>	72	71	71	71	72	71	71	68	68	68
<i>Breeding Cattle (4-12 months)</i>	139	137	138	139	139	138	137	133	131	131
<i>Breeding Cattle (&gt; 1 year)</i>	317	313	312	308	306	305	302	295	290	290
<i>Breeding Cattle 2nd Year</i>	211	210	210	209	209	208	207	204	203	203
<i>Breeding Cattle 3rd Year</i>	106	103	101	99	97	98	94	91	87	88
<i>Fattening Cattle</i>	140	141	143	142	141	134	136	136	136	130
<i>Fattening Calves (0-4 months)</i>	33	34	34	34	33	32	32	32	32	31
<i>Fattening Cattle (4-12 months)</i>	107	108	109	108	107	102	104	104	104	99
Sheep	417	409	403	395	397	398	403	400	398	398
Swine	1'678	1'615	1'631	1'605	1'553	1'546	1'501	1'447	1'449	1'470
Buffalo	1	0	1	1	1	1	1	0	0	0
Camels	6	6	6	6	6	7	7	7	6	6
Deer <sup>1)</sup>	6	6	6	6	6	6	6	7	7	7
Goats	85	85	85	84	85	88	91	92	90	91
Horses	58	57	57	55	56	56	46	47	47	47
Mules and Asses	20	20	20	20	20	21	34	34	33	33
Poultry	11'409	11'844	12'446	12'541	13'180	13'207	13'984	14'417	15'213	15'622
Rabbits	28	28	27	25	25	22	22	21	19	17
Livestock NCAC	114	111	109	120	113	110	108	103	102	103

<sup>1)</sup> Deer: numbers correspond to animal places i.e. mother with offspring.

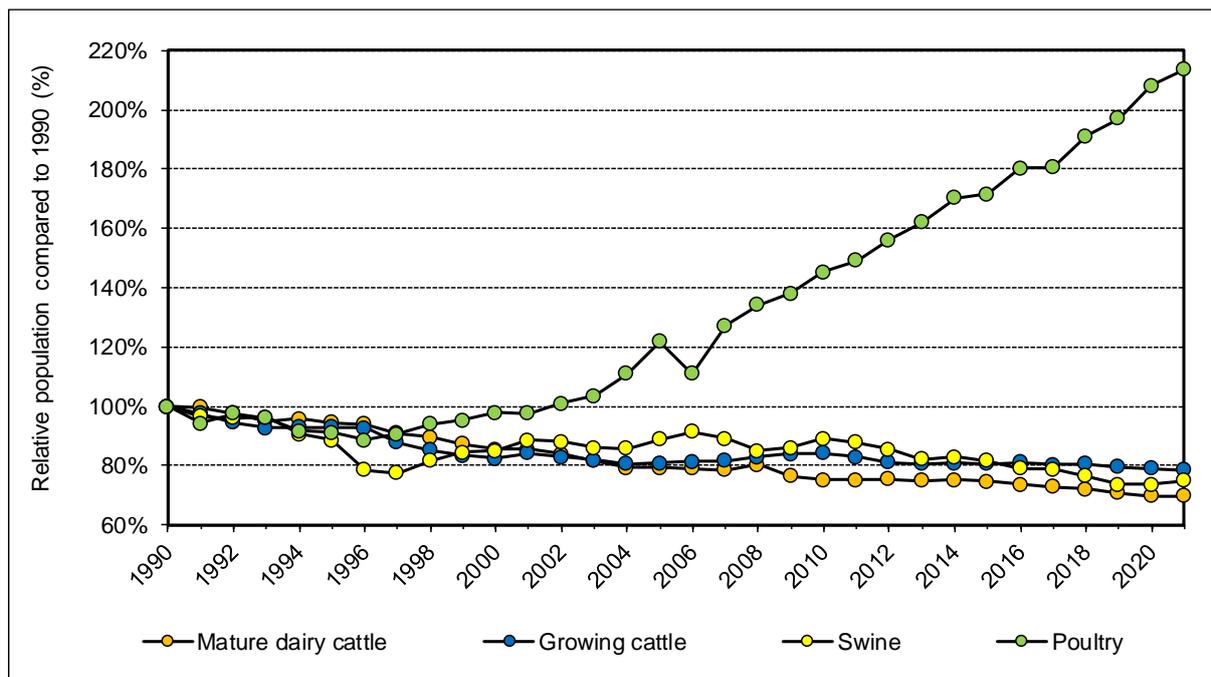


Figure 5-5 Relative development of the populations of main animal categories. The category with the strongest increase, i.e. other mature cattle, is not displayed, as it increases to over 1000 % of the 1990 value by 2021.

Livestock populations in Switzerland are primarily influenced by the general agricultural policy, i.e. the subsidy system, the milk quotation system and the development of the economic framework conditions. Relative development of the populations of main animal categories are shown in Figure 5-5. The number of cattle declined slightly until the year 2004. However, cattle livestock numbers increased between 2004 and 2008, mainly due to an increase of the number of growing cattle. Since 2008 the cattle population was slowly decreasing again, possibly due to the suspension of the milk quotation system in 2009.

After a decrease until 1996, the number of swine increased until 2006 – a process that has been observed in many other European countries (SBV 2004: p.69). Since then, the number of swine is generally showing a slight decreasing trend with some short-term fluctuations. The number of poultry shows a rapid increase between 1990 and 2021 with a distinct dip only between 2005 and 2006, a consequence of changed human consumption patterns as a result of the avian flu in 2006.

The number of sheep was more or less constant while the number of goats increased following a decline between 1990 and 1995.

### 5.2.3. Uncertainties and time-series consistency

For the uncertainty analysis the input data from ART (2008a) were used and were updated with the latest activity and emission data as well as with default uncertainties of the 2019 Refinement (IPCC 2019). The detailed input uncertainty values for category 3A are reported in Annex A2.1. The resulting, combined uncertainty for emissions is [-19 %; +21 %] according to approach 1 (uncertainty propagation, Annex A2.2) and [-19 %; +20 %] according to approach 2 (Monte Carlo simulations, Annex A2.3).

For further results and discussion of the uncertainties see chp. 1.6 and Annex 2.

The time series 1990–2021 are all considered consistent, although the following issues should be considered:

- Between 1998 and 1999 the questionnaire for the collection of livestock data was modified. In some animal categories this led to minor ruptures in the time series. Consequences for overall emissions are, however, of minor importance. An analysis conducted in 2012 revealed, that while the average annual change for the years 1990–2011 over all animal categories (excluding other mature cattle) was 3.3 % points, the annual change for the years 1998–1999 was 3.8 % points (ART/SHL 2012).
- Since 2009 the population statistics of growing cattle are derived from the animal traffic database (ATD 2022). Aggregation was adapted to the format necessary for the AGRAMMON-model and the GHG inventory by the School of Agricultural, Forest and Food Science (HAFL, Kupper et al. 2022). Data in the animal traffic database are considered more complete than the data from the survey of the FSO because the animal traffic database includes also animals held outside agricultural enterprises.
- Since 2015 the census date for sheep and goats is the 1<sup>st</sup> of January instead of May as before. This is especially relevant for juveniles as they are usually only born in spring. Accordingly, a rupture in the official time series can be observed. This has been corrected in the GHG Inventory based on background data of the gross nutrient balance of the Federal Statistical Office (FSO 2022b).
- Since 2018 the population statistics of bisons is assessed in the animal traffic database. The age limit between young and adult bisons changed from 3 years (1095 days) to 900 days. This causes a rupture in the time series. This has been corrected in the GHG Inventory based on background data of the gross nutrient balance of the Federal Statistical Office (FSO 2022b).
- Since 2018 the population statistics of horses, mules and asses are assessed in the animal traffic database (ATD 2022). The age limit between young and adult animals changed from 3 years (1095 days) to 900 days. Furthermore, allocation of different breeds to the categories horses, mules and asses changed. Additionally the animal traffic database comprises now all animals, i.e. equids covered by the official agricultural census of the Federal Statistical Office and equids held by private persons or enterprises that do not fulfil the criteria of an agricultural enterprise. To assure time series consistency population statistics of equids were reconditioned by the Federal Statistical Office (FSO 2022b). Nevertheless, small ruptures may still occur particularly due to the assessment of equids not covered by agricultural census. However, influence on the overall emissions is small.
- Gross energy intake and implied emission factors of some of the aggregated animal categories reveal some fluctuations during the inventory period due to varying shares of the sub-categories.
- Gross energy intake as well as the implied emission factor for mature dairy cattle increase, mainly as a result of higher milk production and live weight (Table 5-5).

#### **5.2.4. Category-specific QA/QC and verification**

General QA/QC measures are described in NID chp. 1.5.

All further category-specific QA/QC activities are described in a separate document (Agroscope 2019a). General information on agricultural structures and policies is provided and eventual differences between national and standard values (IPCC 2006, 2019) are being analysed and discussed. Furthermore, comparisons with data from other countries were conducted and discussed where possible. Agroscope (2019a) is periodically updated with the most recent inventory data.

A mutual peer review was conducted with the German GHG inventory group (Fuß et al. 2021). The respective recommendations were implemented as far as possible during the submission 2022 and 2023.

Livestock data were compared with the livestock data provided by the FAO and checked for plausibility. In all cases the new recalculated data according to ART/SHL (2012) are considered more reliable than the FAO data. Small inconsistencies (usually in the order of  $\pm 2\%$ ) are due to updates of provisional data that are not considered by the FAO. For horses, mules and asses disagreements might be due to the different accounting of agricultural and non-agricultural horses. The Swiss inventory system accounts for all animals and differentiates between animals captured by the official agricultural census and livestock not covered by agricultural census. Moreover, the numbers of mules and asses is higher in the Swiss GHG inventory because unlike the FAO, Switzerland accounts also for ponies and lesser horses. For the categories "Fattening Pigs over 25 kg" (subcategory of swine) and "Broilers" (subcategory of poultry) adjustments were made in the GHG inventory in order to correctly consider animal turnover rates (Kupper et al. 2022; FSO 2022b). The values for these subcategories are thus higher than in the official statistics. The total numbers of poultry in the GHG inventory and the FAO data also show minor discrepancies due to different accounting of turkeys, geese, ducks and quails.

Seasonal fluctuation of the cattle population was analysed for the years 2005–2007 based on detailed information from the Swiss Farmers Union (SBV 2007a). Seasonal fluctuations are usually in the order of  $\pm 3\%$  with census data (April) always slightly above the annual mean. Data from the animal traffic database (i.e. cattle populations for the years 2009–2019) refer to annual mean population.

IPCC tables with data for estimating emission factors for cattle (such as weight, weight gain, milk production) were filled in, checked for consistency and confidence and compared with IPCC (2006, 2019) default values (refer to Annex A5.3).

Country-specific energy-intake rates for all cattle categories were compared to intake rates estimated with the IPCC (2006) Tier 2 default methodology (see Agroscope (2019a) for details). Both approaches are comparable in the assessment of net energy requirements. However, the IPCC approach resulted in higher estimates of GE-intake. Further analyses suggest that the IPCC conversion rates of net energy into gross energy are unrealistic for conditions in Switzerland. Given the experimentally verified high feed quality standards in Switzerland, the results of the country-specific inventory method are thus much more plausible than the estimates using the unaltered IPCC (2006) default method. Moreover, a discrepancy of approximately 5.9 % was found when comparing the overall GE-intake of the cattle population with the respective estimate of the Swiss Farmers Union (Giuliani 2019). As found for the comparison with the IPCC approach, different assumptions on net energy densities of the feed might explain the divergence.

For mature dairy cattle the implied methane emission factor was confirmed by a long-term field study, where methane emissions from a herd of twenty dairy cows were measured over a full grazing season with the eddy covariance method (Felber et al. 2015).

During the past years a couple of studies were conducted to verify methane emissions at the regional scale, comparing bottom-up estimates with atmospheric measurements. While virtually all these measurements are subject to great uncertainties, the overall picture support the bottom-up approach in the Swiss GHG inventory or at least does not indicate the omission of a significant methane source. Hiller et al. (2014a) found that methane emissions

might be underestimated by the inventory method when they measured atmospheric CH<sub>4</sub> concentrations over the Reuss-valley with an airplane. However, the methodological approach applied by Hiller et al. (2014a) still relies on a number of rather uncertain basic assumptions and is therefore not beyond doubts. Additionally, it should be noted, that methane emission estimates from the Agriculture sector in the Swiss GHG inventory were revised since, and currently lie approximately 10 % above the estimates used by Hiller et al. (2014a) in their study. Stieger (2013) and Stieger et al. (2015) reported a very good agreement of bottom-up estimates and flux measurements with a tethered balloon system. Bamberger et al. (2014) conducted regional CH<sub>4</sub> measurements with a measurement device mounted on a car. Measurement precision and duration was not sufficient to validate bottom-up inventory estimates. Nonetheless, they concluded that a locally relevant emission source considered negligible in the emission inventory would have been identified. Finally Henne et al. (2015, 2016, 2017) found a very good agreement between inventory estimates of CH<sub>4</sub> emissions and independent atmospheric measurements over Switzerland (see A6.2).

### 5.2.5. Category-specific recalculations

General information on recalculations is provided in chp. 10.

Recalculations with an overall impact of >0.5 kt CO<sub>2</sub> equivalent are assessed quantitatively. All other recalculations are only described qualitatively.

- Emissions from swine were recalculated for the years 1990–1998. Animal populations statistics (AD) were adjusted due to an error correction in the accounting of suckling piglets. The impact on overall emissions ranges from +5.2 to +7.0 kt CO<sub>2</sub> eq.
- Emissions from livestock were recalculated for the year 2020. Provisional animal populations statistics from background data of the FSO were updated (FSO 2022b). The impact on overall emissions is negligible (<0.1 kt CO<sub>2</sub> eq).
- CH<sub>4</sub> emissions of mature dairy cattle were recalculated for the years 2010–2020. New data on mature life weight provided directly by Identitas AG were used to estimate the emission factors for enteric fermentation and manure management (excretion of volatile solids). The impact on overall emissions ranged from -2.3 to 5.3 kt CO<sub>2</sub> eq on average.
- Reported milk yield of mature dairy cattle was recalculated for the whole time series. Yearly milk yield is now divided by 365 days instead of 305 days (lactation period) as before. This recalculation had no impact on emissions since only the reported values were revised.
- CH<sub>4</sub> emissions from enteric fermentation of sheep, goats, swine and poultry were recalculated for the years 2019 and 2020. Emission factors were revised due to updated data on net energy requirements from the Swiss Farmers Union (Giualiani et al. 2022). Overall emissions decreased by <-0.5 and -5.5 kt CO<sub>2</sub> equivalents for the years 2019 and 2020.
- CH<sub>4</sub> emissions from enteric fermentation of growing cattle were recalculated for the whole time series. New methane conversion rates (Y<sub>m</sub>) were adopted from the 2019 Refinement (IPCC 2019). Overall emissions declined by -30.6 kt CO<sub>2</sub> eq on average.
- CH<sub>4</sub> emissions from enteric fermentation of buffalo and goats were recalculated for the whole time series. New methane conversion rates (Y<sub>m</sub>) were adopted from the 2019 Refinement (IPCC 2019). Overall emissions declined by -1.9 kt CO<sub>2</sub> eq on average.

## 5.2.6. Category-specific planned improvements

No category-specific improvements are planned.

## 5.3. Source category 3B – Manure management

### 5.3.1. Source category description

Table 5-9 Key categories of 3B Manure management. Combined KCA results, level for 2021 and trend for 1990–2021, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC category	Gas	Identification criteria
3B1-4	Manure management, all livestock, direct	CH <sub>4</sub>	L1, L2
3B1-4	Manure management, all livestock, direct	N <sub>2</sub> O	L2
3B5	Manure management, indirect	N <sub>2</sub> O	L1, L2, T2

The emission source is the domestic livestock population broken down into 3 cattle categories (mature dairy cattle, other mature cattle, growing cattle), sheep, swine, buffalo, camels, deer, goats, horses, mules and asses, poultry, rabbits and livestock not covered by agricultural census (Livestock NCAC) (Table 5-10). Six (CH<sub>4</sub>) respectively five (N<sub>2</sub>O) different manure management systems are considered as well as indirect N<sub>2</sub>O emissions from 3B Manure management (Table 5-11). Additionally, NO<sub>x</sub> and NMVOC emissions from manure management are estimated. In the reporting tables all NO<sub>x</sub> emissions are reported under 3D Agricultural soils.

The total emissions from 3B Manure management closely follow the development of the cattle population. Emissions declined from 1990 until 2004, increased until 2008 and subsequently declined slowly until 2015 and somewhat faster until 2020.

Significant contributors to CH<sub>4</sub> emissions from 3B Manure management are cattle with approximately 65 % and swine with approximately 31 % on average over the period 1990–2021. Cattle and swine contribute significantly to N<sub>2</sub>O emissions with 69 % and 19 %, respectively, on average over the period 1990–2021.

Leaching of NO<sub>3</sub><sup>-</sup> from manure management systems is not occurring in Switzerland and is thus not included in the estimates. This assessment is principally based on expert judgement from Thomas Kupper from the “School for Agricultural, Forest and Food Sciences (HAFL)” (Kupper 2014) and based on his personal expertise and on the following literature: Sagoo et al. (2007), Petersen et al. (1998), Webb (2001), Monteny et al. (2006), Oenema et al. (2007) and Chadwick (2005).

Emissions from fur-bearing animals are not occurring in Switzerland as provisions for the husbandry of wild animals are very strict according to the Swiss Animal Welfare Act (Swiss Confederation 2003). See also chp. 5.2.1.

Table 5-10 Specification of source category 3B Manure management by livestock categories.

3B	Source	Specification
3B1	Cattle	Mature Dairy Cattle
		Other Mature Cattle
		Growing Cattle (Fattening Calves <sup>1</sup> , Pre-Weaned Calves, Breeding Cattle 1 <sup>st</sup> year (Breeding Calves + Breeding Cattle 4-12 months), Breeding Cattle > 1 year (Breeding Cattle 2 <sup>nd</sup> year + Breeding Cattle 3 <sup>rd</sup> year), Fattening Cattle (Fattening Calves 0-4 months <sup>2</sup> + Fattening Cattle 4-12 months))
3B2	Sheep	Lambs < 1 year Mature Sheep Fattening Sheep Milk Sheep
3B3	Swine	Piglets Fattening Pig over 25 kg Dry Sows Nursing Sows Boars
3B4a	Buffalo	Bisons < 3 years <sup>3</sup>
3B4b	Camels	Bisons > 3 years <sup>3</sup> Llamas < 2 years Llamas > 2 years Alpacas < 2 years Alpacas > 2 years
3B4c	Deer	Fallow Deer Red Deer
3B4d	Goats	Goat Places
3B4e	Horses	Horses < 3 years Horses > 3 years
3B4f	Mules and Asses	Mules Asses
3B4g	Poultry	Growers Layers Broilers Turkey Other Poultry
3B4h i	Rabbits	
3B4h ii	Livestock NCAC	Sheep Goats Horses < 3 years Horses > 3 years Mules Asses

<sup>1</sup>) Fattening for veal with a milk based diet (slaughtered at ap. 100 days). See chp. 5.2.2.3.

<sup>2</sup>) Fattening for beef meat (slaughtered at ap. 400 days). See chp. 5.2.2.3.

<sup>3</sup>) Bisons (Bos bison and/or Bos bonasus). Water buffalos (Bubalus bubalis) are included under cattle. See chp. 5.2.2.3.

Table 5-11 Specification of source category 3B Manure management by manure management systems.

3B	Source	Specification CH <sub>4</sub>	Specification N <sub>2</sub> O	
3B6a	Direct Emissions	Liquid systems	Liquid systems --> Pit storage below animal confinement	
3B6b		Solid storage and dry lot	Solid storage and dry lot	
3B6c / 3D		Pasture, range and paddock	NA <sup>1</sup>	
3B6d		Digesters (anaerobic digestion)	Digesters (anaerobic digestion)	
3B6e		Other	Deep litter	Other
			Poultry system	Deep litter Poultry system
3B5a	Indirect Emissions	NA	Atmospherical deposition	
3B5b		NA	Leaching and run-off	

<sup>1</sup>) Reported under 3D Agricultural Soils

## 5.3.2. Methodological issues

### 5.3.2.1. Methodology

The calculation is based on methods described in the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (CH<sub>4</sub>: IPCC 2019 equation 10.23; N<sub>2</sub>O: IPCC 2019 equation 10.25).

CH<sub>4</sub> emissions from 3B Manure management were generally estimated using a Tier 2 methodology. For cattle a more detailed Tier 3 method was applied, estimating volatile solids (VS) excretion based on gross energy intake estimates as used for enteric fermentation. VS excretion from sheep, goats, buffalo, camels, horses, mules and asses and deer was equally estimated based on gross energy intake. For swine, poultry and rabbits default parameters were used. Methane conversion factors (MCF) are from IPCC (2019; solid storage, pasture range and paddock, poultry manure), country-specific (deep litter) or were modelled according to Mangino et al. (2001) (liquid systems, anaerobic digesters).

N<sub>2</sub>O emissions from 3B Manure management were estimated using a country-specific Tier 3 methodology. Activity data were adjusted to the particular situation of Switzerland in coordination with the Swiss ammonia model AGRAMMON (Kupper et al. 2022). Detailed country-specific data on nitrogen excretion rates, manure management system distribution and nitrogen volatilisation were applied. Emission factors for direct N<sub>2</sub>O emissions (EF<sub>3</sub>) are based on IPCC (2019) and Kupper 2017 whereas the emission factor for indirect emissions from atmospheric deposition is country-specific (Bühlmann et al. 2015, Bühlmann 2014).

The N<sub>2</sub>O emissions from pasture, range and paddock are reported under 3D Agricultural soils, source category 3Da3 Urine and dung deposited by grazing animals.

For calculation of CH<sub>4</sub> and N<sub>2</sub>O emissions, slightly different livestock sub-categories were used (Table 5-12). The livestock categories reported in the reporting tables (CRF) are the same, but the respective sub-categories as a basis for the calculation are different. The categorisation for the estimation of CH<sub>4</sub> emissions had to be adapted to data availability for energy requirements, while the categorisation for the estimation of N<sub>2</sub>O emissions is determined by the respective categorisation of the Swiss ammonia inventory (AGRAMMON, Kupper et al. 2022, Richner and Sinaj 2017). Nevertheless, there is no inconsistency in the total number of animals as they are the same both for CH<sub>4</sub> and N<sub>2</sub>O emissions. Note that although not growing cattle in the proper sense, bulls are contained in the categories breeding cattle >1 year, breeding cattle 3<sup>rd</sup> year and/or fattening cattle according to their purposes.

The calculation of CH<sub>4</sub> and N<sub>2</sub>O emissions is done by Agroscope, the Swiss centre of excellence for agricultural research (Agroscope 2023).

Table 5-12 Livestock categories for estimating CH<sub>4</sub> and N<sub>2</sub>O emissions from 3B Manure management.

3B	CH <sub>4</sub>	N <sub>2</sub> O
Cattle	Mature Dairy Cattle	Mature Dairy Cattle
	Other Mature Cattle	Other Mature Cattle
	Growing Cattle Fattening Calves <sup>1</sup> Pre-Weaned Calves Breeding Cattle 1 <sup>st</sup> year (Breeding Calves + Breeding Cattle 4-12 months) Breeding Cattle > 1 year  Fattening Cattle (Fattening Calves 0-4 months <sup>2</sup> + Fattening Cattle 4-12 months)	Growing Cattle Fattening Calves <sup>1</sup> Pre-Weaned Calves Breeding Cattle 1 <sup>st</sup> year  Breeding Cattle 2 <sup>nd</sup> year Breeding Cattle 3 <sup>rd</sup> year Fattening Cattle
Sheep	Lambs < 1 year Mature Sheep	Fattening Sheep Milk Sheep
Swine	Swine	Piglets Fattening Pig over 25 kg Dry Sows Nursing Sows Boars
Buffalo	Bisons < 3 years <sup>3</sup> Bisons > 3 years <sup>3</sup>	Bisons < 3 years <sup>3</sup> Bisons > 3 years <sup>3</sup>
Camels	Llamas < 2 years Llamas > 2 years Alpacas < 2 years Alpacas > 2 years	Llamas < 2 years Llamas > 2 years Alpacas < 2 years Alpacas > 2 years
Deer	Fallow Deer Red Deer	Fallow Deer Red Deer
Goats	Goats	Goat places
Horses	Horses < 3 years Horses > 3 years	Horses < 3 years Horses > 3 years
Mules and Asses	Mules Asses	Mules Asses
Poultry	Poultry	Growers Layers Broilers Turkey Other Poultry
Rabbits	Rabbits	Rabbits
Livestock NCAC	Sheep Goats Horses < 3 years Horses > 3 years Mules Asses	Sheep Goats Horses < 3 years Horses > 3 years Mules Asses

<sup>1</sup>) Fattening for veal with a milk based diet (slaughtered at ap. 100 days). See chp. 5.2.2.3.

<sup>2</sup>) Fattening for beef meat (slaughtered at ap. 400 days). See chp. 5.2.2.3.

<sup>3</sup>) Bisons (Bos bison and/or Bos bonasus). Water buffalos (Bubalus bubalis) are included under cattle. See chp. 5.2.2.3.

### 5.3.2.2. Emission factors CH<sub>4</sub>

Calculation of CH<sub>4</sub> emissions from 3B Manure management is based on methods described in the 2019 Refinement (IPCC 2019, equation 10.23):

$$EF_T = VS_T \cdot 365 \text{ days / year} \cdot B_{0T} \cdot 0.67 \text{ kg / m}^3 \cdot \sum_S MCF_S \cdot MS_{TS}$$

EF<sub>T</sub> = annual CH<sub>4</sub> emission factor for livestock category T (kg/head/year)

$VS_T$  = daily volatile solids (VS) excreted for livestock category  $T$  (kg/head/day)

$B_{0T}$  = maximum  $CH_4$  producing capacity for manure produced by livestock category  $T$  ( $m^3/kg$ )

$0.67 \text{ kg}/m^3$  = conversion factor of  $m^3 \text{ } CH_4$  to kilograms  $CH_4$

$MCF_S$  =  $CH_4$  conversion factors for each manure management system  $S$  (%)

$MS_{TS}$  = fraction of livestock category  $T$ 's manure handled using manure management system  $S$  (dimensionless)

### 5.3.2.2.1. Volatile solids excretion (VS)

The daily excretions of volatile solids (VS) for **all cattle sub-categories** were estimated based on equation 10.24 in the 2019 Refinement (IPCC 2019):

$$VS = \left[ GE * \left( 1 - \frac{DE\%}{100} \right) \right] * \left[ \frac{1 - ASH}{EDF} \right]$$

VS = volatile solids excretion per day on a dry-organic matter basis (kg/day)

GE = gross energy intake (MJ/head/day)

DE = digestibility of the feed (%)

ASH = ash content of manure calculated as a fraction of the dry matter feed intake

EDF = energy density of feed, conversion factor for dietary GE per kg of dry matter (MJ/kg)

IPCC equation 10.24 originally contains an additional term to take account for the urinary energy (IPCC 2019). However, Dämmgen et al. (2011) highlight that the organic matter in urine does not account for any  $CH_4$  formation and the term was hence omitted.

Gross energy intake was calculated according to the method described in chp. 5.2.2.2.1. In the case of **mature dairy cattle** the same model was used as for the estimation of  $CH_4$  emissions from 3A Enteric fermentation. Content of net energy, gross energy and ash in feed dry matter as well as feed digestibility were also estimated using the Agroscope feeding model (Agroscope 2014c). The digestibility of feed is of crucial importance for the calculation of volatile solids. The modelled values for dairy cattle are in the range of the values provided in table 10.2 of the 2019 Refinement (IPCC 2019) and were compared to measurements from feeding trials in Switzerland. The comparison revealed that modelled values are on average slightly higher than measurements. Accordingly, an adjustment was made in order to take account of digestibility depression at high feeding levels that are usually above maintenance (Ramin and Huhtanen 2012). High feeding levels may lead to an increase in rumen passage rate and subsequently to lower feed digestibility (Nousiainen et al. 2009). The correction decreased the feed digestibility on average by 2.6 percent points. Resulting feed digestibility was 72.2 % on average, gross energy content (EDF) was 18.26 MJ/kg and ash content was 9.0 % each with very small fluctuations along the time series.

For **calves and other growing cattle** IPCC default values were taken for the feed digestibility (IPCC 2019, table 10A.2). For the energy density of the feed (EDF) the IPCC (2019) default value, i.e. 18.45 MJ/kg was adopted. Furthermore, an ash content of 8.0 % was used for all these categories.

For **sheep, goats, buffalo, camels, horses, mules and asses** and **deer** VS excretion was estimated based on equation 10.24 in IPCC 2019 with default values for feed digestibility of 65 % (sheep, goats, buffalo, camels and deer, IPCC 2019) and 70 % (horses, mules and asses, Stricker 2012). The energy density of the feed (EDF) was 18.45 MJ/kg. The ash content of manure was 8.0 % for sheep, goats, buffalo, camels and deer and 4.0 % for horses and mules and asses (IPCC 2006).

For VS excretion of the livestock categories **swine** and **poultry**, default values from IPCC were taken (IPCC 2006: Tables 10A-7, 10A-8, 10A-9). For **rabbits** the default value of IPCC 2019 was adopted.

Finally for **livestock NCAC** the same VS excretion rates as for the respective animal categories in the official census were used.

#### **5.3.2.2.2. Maximum CH<sub>4</sub> producing capacity (B<sub>0</sub>)**

For the methane producing capacity (B<sub>0</sub>) default values were used (IPCC 2019). For deer and rabbits no default values were available. Consequently, the same value as for sheep was applied for deer and the value of IPCC 2006 was applied for rabbits. For all grazing animals a B<sub>0</sub> of 0.19 was adopted as suggested in table 10.16 of the 2019 Refinement (IPCC 2019).

#### **5.3.2.2.3. Methane conversion factor (MCF)**

For estimating CH<sub>4</sub> emissions from manure management, six different manure management systems are distinguished. Switzerland has an average annual temperature below 15°C (MeteoSwiss 2022) and was therefore allocated to the cool climate region without differentiation.

In the case of **solid manure** and **pasture range and paddock** the default MCF values from table 10.17 of the 2019 Refinement (IPCC 2019) was used (Table 5-13).

**Liquid/slurry systems** are responsible for the major part of methane emissions from Manure management (87 % on average). Accordingly a more detailed model was used to determine the respective MCF. For this purpose the model developed by Mangino et al. (2001), that is also the basis of the model used in the IPCC Guidelines, was adapted to the specific conditions of Switzerland. On a monthly time step, loading of a virtual liquid/slurry manure system was simulated according to the VS excretion of the total livestock herd and the manure management system distribution (MS) in the respective inventory year. Thereby it was assumed that excretion on pasture, range and paddock takes only place during summer months, i.e. from April to September. Subsequently, monthly manure degradation was forecast using the temperature-dependent van't Hoff-Arrhenius equation with the parametrization as suggested by Mangino et al. (2001). Monthly mean air temperatures for the Swiss central plateau during the 1991–2020 time period were obtained from the Federal Office of Meteorology and Climatology (MeteoSwiss 2022). Minimum temperature in the liquid/slurry system was allowed to drop to 1°C instead of 5°C as proposed in the original model (see e.g. Vergé et al. 2007, Van der Zaag et al. 2013). Any carry-over effect of undergraded manure from one month to the next was neglected (see e.g. Park et al. 2006, Van der Zaag et al. 2013). Finally, an annual methane conversion factor was calculated by dividing the total VS degraded by the total load of VS.

Several authors have found that the simulated MCF-values according to the model described above are unrealistically high (Park et al. 2006, Van der Zaag et al. 2013). Consequently they propose to use a management and design practice factor (MDP factor) to bring the modelled factors into accordance with measurements. Accordingly, a MDP factor of 0.8 was applied here as suggested by Mangino et al. (2001). The resulting MCF-values for liquid/slurry systems range from 13.7 % to 14.8 %. The variation of the MCF along the time series is due to varying shares of manure dropped on pasture, range and paddock. The higher the share of manure dropped on pasture, range and paddock, the lower is the overall MCF for liquid/slurry systems (as livestock is only grazing during summer, the relative share of low methane conversion factors during the cold winter month increases when summer grazing time increases).

**Anaerobic digestion** of animal manure is increasing in Switzerland since the 1990s but is still not widespread (7.8 % of all volatile solids in 2021). Emissions from the digestion plant itself are reported under source category 5B2 (Anaerobic digestion at biogas facilities) and described in chp. 7.3.2.2. However, emissions from manure storage before alimentation into the digester are reported in source category 3B Manure management. The amount of manure digested anaerobically was estimated based on total energy production (SFOE 2022a) and eight monitoring protocols of agricultural biogas plants (Genossenschaft Ökostrom Schweiz 2014, GES Biogas GmbH 2014). According to the data in the monitoring protocols the total amount of manure entering the plant originated mainly from cattle manure stored as liquid/slurry (57 %) and solid storage (23 %) and from swine manure stored as liquid/slurry (20 %). It is assumed that 22.5 % of the liquid/slurry manure is coming from the farm where the biogas plant is located and is hence directly fed into the digester on a daily basis without being stored (Koehli 2014). The respective MCF was thus set to zero. As solid manure usually has a low MCF and is stored for only a short period before being fed into the digester, the respective MCF was also set to zero. The MCF for the remaining liquid/slurry manure that is delivered from neighbouring farms to the biogas plant was estimated with the methodology described in the “Standard method for compensating projects of the type “agricultural biogas plants”” (FOEN 2014n). This method is based on the “Approved small scale baseline and monitoring methodology AMS-III.D./Version 19.0. Methane recovery in animal manure management systems” and relies thus on a generally accepted foundation (UNFCCC 2013c).

According to this methodology the MCF value for conventional liquid/slurry systems given in Table 5-13 is reduced according to the duration of pre-storage before the manure is delivered to the digester:

$$MCF_{PSAD} = MCF_{LS} * \left( \frac{14.49 * (e^{-k * AI_j} - 1)}{AI_j} + 1 \right)$$

$MCF_{PSAD}$  = CH<sub>4</sub> conversion factor for pre-storage of liquid manure before delivery to biogas plants (%)

$MCF_{LS}$  = CH<sub>4</sub> conversion factor for liquid/slurry systems (%)

k = degradation rate constant (0.069)

$AI_j$  = average pre-storage time period (day)

The average pre-storage time was estimated to be 12 days (Koehli 2014). The resulting weighted average MCF-value for anaerobic digestion varies between 2.6 % and 2.8 %. Variation is due to the variation of the underlying MCF of liquid/slurry systems.

Fattening calves, sheep, camels, deer and goats are kept in **deep litter systems**. A MCF of 10 % was adopted, which is the mean value between the IPCC default values for cattle and swine deep bedding <1 month and >1 month at 10°C in IPCC (2006). The choice of a MCF of 10 % for deep litter is supported by the specific feeding and manure management regime in Switzerland (especially cold winter temperatures) and confirmed by a number of studies representative for the country-specific management conditions (Amon et al. 2001, Külling et al. 2002, Külling et al. 2003, Moller et al. 2004, Hindrichsen et al. 2006, Park et al. 2006 and Sommer et al. 2007, Zeitz et al. 2012). For further details see FOEN 2011 (chp. 16.5 attachment E).

For all poultry categories a MCF value of 1.5 % was used according to the default value for **poultry manure systems** in the 2019 Refinement (IPCC 2019).

Table 5-13 Manure management systems and methane conversion factors (MCFs). Blue: annually changing parameters, value for 2021.

Manure management system		Description	MCF (%)
Pasture		Manure is allowed to lie as it is, and is not managed (distributed, etc.).	0.5
Solid storage		Dung and urine are excreted in a barn. The solids (with and without litter) are collected and stored in bulk for a long time (months) before disposal.	2.0
Liquid/slurry systems		Combined storage of dung and urine under animal confinements for longer than 1 month.	13.8
Digesters		Storage before alimentation into anaerobic digester. Storage system can be liquid/slurry or solid storage.	2.6
Other	Deep litter	Dung and urine is excreted in a barn with lots of litter and is not removed for a long time (months).	10.0
	Poultry system	Manure is excreted on the floor with or without bedding.	1.5

#### **5.3.2.2.4. Manure management system distribution (MS)**

The fraction of animal manure handled using different manure management systems (MS) as well as the percentages of urine and dung deposited on pasture, range and paddock was separately assessed for each livestock category (Table 5-14). The fractions are determined by the livestock husbandry system (e.g. tie stall or loose housing system) as defined in Richner and Sinaj (2017). Estimation is conducted within the Swiss ammonium model AGRAMMON based on expert judgement and values from the literature (1990, 1995) and on extensive farm surveys (2002, 2007, 2010, 2015 and 2019) (Kupper et al. 2022). The data clearly reproduce the shift towards an increased use of pasture, range and paddocks and a decrease in solid storage. The changes of the manure management system distribution reflect the shift to a more animal-friendly livestock husbandry in the course of the agricultural policy reforms during the 1990s and the early 20<sup>th</sup> century. One of the most important voluntary programmes in this context is called "RAUS" and implies at least 156 days of pasture per year (Swiss Confederation, 2008). Accordingly, the share of mature dairy cattle (and other animals) going to pastures increased substantially and so did the length of stay on the pasture. In the year 2007 78 % of the dairy cattle were held on farms participating in the RAUS programme. The average number of pasture days (including all farms) in that year was 178, and it was 173 in 2010. It can thus be assumed, that already in the early years of the new millennium most farms accomplished the transition to RAUS and that a new management standard was reached at this point of time, which did not change significantly afterwards.

Data for manure management system distribution for cattle are different for VS and nitrogen. This is because cattle stables often have simultaneously both liquid and solid manure storage systems. As volatile solids are excreted mainly in dung and nitrogen mainly in urine, the proportion of VS stored as solid manure is higher compared to the proportion of N. For cattle categories the MS-distribution for nitrogen as provided by Kupper et al. (2022) was thus adjusted using data on stable systems and manure accumulation from Richner and Sinaj (2017) as well as data on frequency of stable systems on farms from (Kupper et al. 2022) (for a more detailed description of the approach see chp. A5.3.4). More or less the same result could be gained by adjusting the distribution of nitrogen by the VS/N-ratio. Data provided in Table 5-14 refer to the distribution of nitrogen while data provided in CRF Table3.B(a)s2 refer to the distribution of VS.

The amount of manure digested anaerobically was estimated based on total energy production (SFOE 2022a) and eight monitoring protocols of agricultural biogas plants (Genossenschaft Ökostrom Schweiz 2014, GES Biogas GmbH 2014) as described under 5.3.2.2.3.

#### **5.3.2.3. Activity data CH<sub>4</sub>**

Activity data of all livestock categories covered by the official census were obtained from SBV (2022) and the FSO (2022a). In 2011 the respective data for the time series 1990–2010 were revised and harmonised during a joint effort of the Agroscope Reckenholz Tänikon Research Station (ART) and the Swiss College of Agriculture (SHL) (ART/SHL 2012). Additionally to official statistical data, population data of livestock not covered by the agricultural census of the Federal Statistical Office were assessed based on background data of the gross nutrient balance of the Federal Statistical Office (FSO 2022b). For further details and additional data on a livestock sub-category level refer to chp. 5.2.2.3, Table 5-8 as well as Agroscope (2023b).

Table 5-14 Manure management system distribution for nitrogen (MS) according to the AGRAMMON model. Detailed data on livestock sub-category levels for the distribution of nitrogen and volatile solids are provided in a separate spreadsheet (Agroscope 2023b).

MS Distribution	1990					1995					2002					2007				
	%					%					%					%				
	Liquid / Slurry	Solid storage	Pasture range and paddock	Digesters	Other (Deep litter, Poultry manure)	Liquid / Slurry	Solid storage	Pasture range and paddock	Digesters	Other (Deep litter, Poultry manure)	Liquid / Slurry	Solid storage	Pasture range and paddock	Digesters	Other (Deep litter, Poultry manure)	Liquid / Slurry	Solid storage	Pasture range and paddock	Digesters	Other (Deep litter, Poultry manure)
Mature Dairy Cattle	65.7	25.6	8.3	0.5	0.0	67.5	22.5	9.6	0.4	0.0	65.4	17.1	16.9	0.6	0.0	68.1	13.1	17.3	1.5	0.0
Other Mature Cattle	41.1	28.8	29.6	0.5	0.0	38.6	31.4	29.6	0.4	0.0	43.3	19.5	36.7	0.6	0.0	53.7	17.0	27.8	1.5	0.0
Growing Cattle (weighted average)	49.5	29.9	15.8	0.5	4.4	50.0	29.2	15.9	0.4	4.4	45.2	22.3	27.1	0.6	4.8	48.6	20.3	25.2	1.5	4.4
Fattening Calves	15.9	0.0	0.0	0.5	83.6	15.6	0.0	0.0	0.4	83.9	14.9	0.0	0.7	0.6	83.9	25.1	0.0	0.4	1.5	73.0
Pre-Weaned Calves	41.1	28.8	29.6	0.5	0.0	38.6	31.4	29.6	0.4	0.0	40.2	23.8	35.5	0.6	0.0	52.7	16.7	29.2	1.5	0.0
Breeding Cattle 1st Year	39.1	46.3	14.1	0.5	0.0	40.1	45.3	14.2	0.4	0.0	37.3	34.7	27.4	0.6	0.0	44.8	28.9	24.8	1.5	0.0
Breeding Cattle 2nd Year	47.1	27.0	25.4	0.5	0.0	48.7	25.2	25.7	0.4	0.0	41.3	21.0	37.1	0.6	0.0	44.5	18.7	35.3	1.5	0.0
Breeding Cattle 3rd Year	52.3	27.1	20.0	0.5	0.0	52.9	26.3	20.4	0.4	0.0	45.6	19.6	34.2	0.6	0.0	48.8	17.1	32.6	1.5	0.0
Fattening Cattle	72.1	22.3	0.0	0.5	5.1	68.0	26.3	0.0	0.4	5.3	72.5	20.5	4.0	0.6	2.4	64.8	24.2	6.8	1.5	2.6
Sheep (weighted average)	0.0	0.0	30.1	0.0	69.9	0.0	0.0	30.3	0.0	69.7	0.0	0.0	48.7	0.0	51.3	0.0	0.0	45.4	0.0	54.6
Swine (weighted average)	98.9	0.0	0.0	1.1	0.0	99.0	0.0	0.0	1.0	0.0	97.4	1.0	0.3	1.3	0.0	95.3	0.2	0.9	3.7	0.0
Buffalo (weighted average)	NA	NA	NA	NA	NA	0.0	70.8	29.2	0.0	0.0	0.0	64.2	35.8	0.0	0.0	63.8	36.2	0.0	0.0	0.0
Camels (weighted average)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.0	0.0	47.2	0.0	52.8	0.0	0.0	45.4	0.0	54.6
Deer (weighted average)	0.0	0.0	35.7	0.0	64.3	0.0	0.0	35.7	0.0	64.3	0.0	0.0	47.2	0.0	52.8	0.0	0.0	45.4	0.0	54.6
Goats	0.0	0.0	13.6	0.0	86.4	0.0	0.0	13.6	0.0	86.4	0.0	0.0	28.5	0.0	71.5	0.0	0.0	27.3	0.0	72.7
Horses (weighted average)	0.0	87.2	12.8	0.0	0.0	0.0	87.2	12.8	0.0	0.0	0.0	84.0	16.0	0.0	0.0	76.7	23.3	0.0	0.0	0.0
Mules and Asses (weighted average)	0.0	87.2	12.8	0.0	0.0	0.0	87.2	12.8	0.0	0.0	0.0	84.0	16.0	0.0	0.0	76.7	23.3	0.0	0.0	0.0
Poultry (weighted average)	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.5	0.0	99.5	0.0	0.0	2.7	0.0	97.3	0.0	0.0	3.2	0.0	96.8
Rabbits	0.0	100.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0
Livestock NCAC (weighted average)	0.0	87.2	12.8	0.0	0.0	0.0	75.9	12.9	0.0	11.2	0.0	32.4	36.1	0.0	31.6	0.0	35.8	33.8	0.0	30.3

MS Distribution	2010					2015					2019				
	%					%					%				
	Liquid / Slurry	Solid storage	Pasture range and paddock	Digesters	Other (Deep litter, Poultry manure)	Liquid / Slurry	Solid storage	Pasture range and paddock	Digesters	Other (Deep litter, Poultry manure)	Liquid / Slurry	Solid storage	Pasture range and paddock	Digesters	Other (Deep litter, Poultry manure)
Mature Dairy Cattle	68.6	12.0	17.2	2.2	0.0	69.5	9.9	16.5	4.1	0.0	67.9	8.9	16.7	6.4	0.0
Other Mature Cattle	53.7	14.7	29.3	2.2	0.0	54.4	12.3	29.2	4.1	0.0	49.5	13.1	31.0	6.4	0.0
Growing Cattle (weighted average)	48.5	19.5	24.8	2.2	5.1	50.7	16.6	24.1	4.1	4.5	49.3	15.6	24.3	6.4	4.4
Fattening Calves	25.4	0.0	1.0	2.2	71.5	33.3	0.0	1.2	4.1	61.3	37.2	0.0	1.7	6.4	54.7
Pre-Weaned Calves	44.5	20.8	32.5	2.2	0.0	43.2	20.3	32.4	4.1	0.0	40.0	20.8	32.7	6.4	0.0
Breeding Cattle 1st Year	47.9	25.8	24.2	2.2	0.0	48.4	24.1	23.4	4.1	0.0	49.2	21.1	23.3	6.4	0.0
Breeding Cattle 2nd Year	46.2	16.8	34.8	2.2	0.0	45.5	15.4	35.0	4.1	0.0	47.1	12.7	33.8	6.4	0.0
Breeding Cattle 3rd Year	50.7	15.3	31.8	2.2	0.0	52.5	13.2	30.2	4.1	0.0	50.2	12.7	30.7	6.4	0.0
Fattening Cattle	60.2	28.3	5.9	2.2	3.3	68.2	19.0	6.3	4.1	2.4	60.4	21.3	9.2	6.4	2.7
Sheep (weighted average)	0.0	0.0	38.8	0.0	61.2	0.0	0.0	45.3	0.0	54.7	0.0	0.0	42.9	0.0	57.1
Swine (weighted average)	94.2	0.2	0.3	5.3	0.0	89.2	0.1	0.1	10.7	0.0	81.6	0.0	0.1	18.3	0.0
Buffalo (weighted average)	0.0	65.0	35.0	0.0	0.0	64.4	35.6	0.0	0.0	0.0	65.6	34.4	0.0	0.0	0.0
Camels (weighted average)	0.0	0.0	38.4	0.0	61.6	0.0	0.0	45.4	0.0	54.6	0.0	0.0	43.7	0.0	56.3
Deer (weighted average)	0.0	0.0	38.4	0.0	61.6	0.0	0.0	45.4	0.0	54.6	0.0	0.0	43.7	0.0	56.3
Goats	0.0	0.0	28.1	0.0	71.9	0.0	0.0	28.3	0.0	71.7	0.0	0.0	33.7	0.0	66.3
Horses (weighted average)	0.0	76.1	23.9	0.0	0.0	0.0	78.4	21.6	0.0	0.0	0.0	76.6	23.4	0.0	0.0
Mules and Asses (weighted average)	0.0	76.9	23.1	0.0	0.0	0.0	77.9	22.1	0.0	0.0	0.0	80.4	19.6	0.0	0.0
Poultry (weighted average)	0.0	0.0	2.8	0.0	97.2	0.0	0.0	3.0	0.0	97.0	0.0	0.0	3.4	0.0	96.6
Rabbits	0.0	100.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0
Livestock NCAC (weighted average)	0.0	39.1	30.3	0.0	30.6	0.0	42.6	31.2	0.0	26.2	0.0	40.4	31.6	0.0	27.9

### 5.3.2.4. Emission factors N<sub>2</sub>O

Estimation of direct N<sub>2</sub>O emissions from manure management relies basically on the same animal waste management systems as the estimation of CH<sub>4</sub> emissions (compare chp. 5.3.2.2). For liquid/slurry storage systems an emission factor of 0.002 kg N<sub>2</sub>O-N/kg N as suggested for “Pit storage below animal confinements” was considered appropriate (IPCC 2019, Kupper 2017). The emission factors poultry manure is based on default values given in table 10.21 of IPCC 2019 whereas emissions factors for solid storage and anaerobic digesters are from the respective table in the 2006 IPCC Guidelines (see also Kupper 2017) (Table 5-15).

Table 5-15 Emission factors for calculating N<sub>2</sub>O emissions from manure management. Blue: annually changing parameters, value for 2021.

Animal waste management system	Emission factor
	kg N <sub>2</sub> O-N / kg N
Liquid/Slurry: Pit storage below animal confinement	0.002
Solid storage	0.005
Anaerobic digester	0.000
Cattle and swine deep bedding: no mixing	0.010
Poultry manure	0.001
Indirect emissions due to volatilisation	0.026

The emission factor for indirect N<sub>2</sub>O emissions after volatilisation of NH<sub>3</sub> and NO<sub>x</sub> from manure management systems was reassessed during a literature review by Bühlmann et al. 2015 and Bühlmann 2014. Due to the fragmented land use in Switzerland, where agricultural land use alternates with natural and semi-natural ecosystems over short distances, the share of volatilised nitrogen that is re-deposited in (semi-)natural habitats is on average higher than 55 %. Thus, the assumption made in the 2006 IPCC Guidelines that “a substantial fraction of the indirect emissions will in fact originate from managed land”, cannot be applied to Switzerland. Accordingly, the overall emission factor for indirect emissions was estimated by calculating an area-weighted mean of the indirect emission factor for managed land (i.e. 0.01 based on IPCC 2019) and the indirect emission factor for (semi-)natural land (as provided in Bühlmann 2014 chp. 5.2.1) (Table 5-16). Due to slightly changing land use over the inventory time period, the resulting emission factor shows some small temporal variation around a mean value of 2.57 % (see also chp. 9.2.2). Note that the emission factor in cell R37 of CRF Table3.B(b) refers to kg N<sub>2</sub>O/kg N instead of kg N<sub>2</sub>O-N/kg N.

Table 5-16 Data for estimating emission factors for indirect N<sub>2</sub>O emissions from atmospheric deposition according to Bühlmann (2014).

EF <sub>a</sub> atmospheric deposition	Unit	1990-2010				
		1990	1995	2000	2005	2010
Share of deposition on agricultural land	%	0.573	0.574	0.575	0.569	0.543
Share of deposition in semi-natural ecosystems	%	0.427	0.426	0.425	0.431	0.457
EF <sub>a</sub> for agricultural land	kg N <sub>2</sub> O-N / total kg N-deposited	0.010	0.010	0.010	0.010	0.010
EF <sub>a</sub> for semi-natural ecosystems	kg N <sub>2</sub> O / kg N-deposited	0.030	0.030	0.030	0.031	0.033
EF <sub>a</sub> weighted	kg N <sub>2</sub> O-N / kg N-deposited	0.0248	0.0248	0.0248	0.0257	0.0264

EF <sub>a</sub> atmospheric deposition	Unit	2012-2021									
		2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Share of deposition on agricultural land	%	0.543	0.543	0.543	0.543	0.543	0.543	0.543	0.543	0.543	0.543
Share of deposition in semi-natural ecosystems	%	0.457	0.457	0.457	0.457	0.457	0.457	0.457	0.457	0.457	0.457
EF <sub>a</sub> for agricultural land	kg N <sub>2</sub> O-N / total kg N-deposited	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.01
EF <sub>a</sub> for semi-natural ecosystems	kg N <sub>2</sub> O / kg N-deposited	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033
EF <sub>a</sub> weighted	kg N <sub>2</sub> O-N / kg N-deposited	0.0264	0.0264	0.0264	0.0264	0.0264	0.0264	0.0264	0.0264	0.0264	0.0264

### 5.3.2.5. Activity data N<sub>2</sub>O

Activity data for N<sub>2</sub>O emissions from 3B Manure management were estimated according to equation 10.25 of the IPCC 2019:

$$N_2O_{D(mm)} = \left[ \sum_S \left[ \sum_T (N_{(T)} \cdot Nex_{(T)} \cdot MS_{(T,S)}) \right] \cdot EF_{3(S)} \right] \cdot \frac{44}{28}$$

N<sub>2</sub>O<sub>D(mm)</sub> = direct N<sub>2</sub>O emissions from manure management (kg N<sub>2</sub>O/year)

$N_{(T)}$  = number of head of livestock species/category  $T$  (head)

$N_{ex(T)}$  = annual average N excretion per head of species/category  $T$  (kg N/head/year)

$MS_{(T,S)}$  = fraction of total annual nitrogen excretion for each livestock species/category  $T$  that is managed in manure management system  $S$

$EF_{3(S)}$  = emission factor for direct  $N_2O$  emissions from manure management system  $S$  (kg  $N_2O-N/kg$  N)

44/28 = conversion of  $(N_2O-N)_{(mm)}$  emissions to  $N_2O_{(mm)}$  emissions

#### 5.3.2.5.1. *Livestock population*

Activity data of all livestock categories covered by the official census were obtained from SBV (2022) and the FSO (2022a). In 2011 the respective dataset for the time series 1990–2010 was revised and harmonised during a joint effort of the Agroscope Reckenholz Tänikon Research Station (ART) and the Swiss College of Agriculture (SHL) in 2011 (ART/SHL 2012). Additionally to official statistical data, population data of livestock not covered by the agricultural census of the Federal Statistical Office were assessed based on background data of the gross nutrient balance of the Federal Statistical Office (FSO 2022b) and based on data of the Swiss animal traffic database (ATD 2022). For further details and additional data on a livestock sub-category level refer to chp. 5.2.2.3, Table 5-8 as well as Agroscope (2023b).

#### 5.3.2.5.2. *Nitrogen excretion ( $N_{ex}$ )*

Data on nitrogen excretion per animal category (kg N/head/year) are country-specific and were obtained from Kupper et al. (2022) (Table 5-17). These values are based on the “Principles of Fertilisation in Arable and Forage Crop Production” (Richner and Sinaj 2017). As compared to the methods in IPCC 2019, the age structure of the animals and the different use of the animals (e.g. fattening and breeding) are considered in more detail. Generally, nitrogen excretion rates were determined by estimating nitrogen intake and then subtracting nitrogen retention in body tissue and products (milk, offspring). Most calculations are based on feeding requirements that were assessed in feeding trials at the Agroscope research station in Posieux as published e.g. in RAP (1999, ruminants) and Agroscope (2016c, swine). Additional data on feed ration composition and properties and nitrogen retention and excretion is available from the background literature listed for the specific animal categories below. Standard nitrogen excretion rates are modified within the AGRAMMON model in order to account for changing agricultural structures and production techniques over the years (e.g. milk yield, use of feed concentrates, protein reduced animal feed etc.; Kupper et al. (2022)). This more disaggregated approach leads to considerably lower calculated nitrogen excretion rates compared to IPCC (2019) mainly because lower  $N_{ex}$ -rates of young animals are considered explicitly.

The nitrogen excretion rates are given on an annual basis, considering replacement of animals (growing cattle, swine, poultry, rabbits) and including excretions from corresponding offspring and other associated animals (sheep, deer, goats, swine, rabbits) (ART/SHL 2012).

Nitrogen excretion rates of **mature dairy cattle** were adopted from the most recent version of the AGRAMMON model (Kupper et al. 2022). Regional data of animal performance and

feed ration composition were used to adjust standard nitrogen excretion rates from Richner and Sinaj (2017). The calculations are based on the same feeding model as used for the estimation of gross energy intake and the excretion of volatile solids (Agroscope 2014c; chp. 5.2.2.2.1, 5.3.2.2.1) and are further described in Menzi et al. (2016). Nitrogen excretion is calculated as the nitrogen intake minus the nitrogen excretion in the milk minus the nitrogen in the calve assuming no change in body weight of the cow. Accordingly, nitrogen excretion of mature dairy cattle is dependent on feed composition (use of feed concentrates, corn silage, corn cubes, and hay in summer and winter rations), feed properties (N-content and digestibility of the individual feed components) and milk production. Estimated values of crude protein contents of animal feeds in the Swiss Feed Database are based on an extensive measurement program particularly also for roughages (Agroscope 2014b). Nitrogen content of the feed is estimated as crude protein content divided by 6.25. Protein content in the milk was set to  $0.033 \text{ g} \cdot \text{kg milk}^{-1}$ . Nitrogen content in the milk is estimated as protein content divided by 6.38. After the year 2006 the yearly increase of nitrogen excretion slowed down due to an increased use of energy dense feedstuff (concentrates) and a slower increase of the milk yield compared to earlier years.

For the category **other mature cattle** as well as all **growing cattle** categories the nitrogen excretion rates of the AGRAMMON model (Kupper et al. 2022) were adopted which are again based on the standard values of Richner and Sinaj (2017). The assessment of these standard values is based on the Swiss feeding recommendations (RAP et al. 1999, Morel et al. 2017, Schlegel et al. 2020, Rediger et al. 2019) which are elaborated based on a great number of feeding trials at the Agroscope research station in Posieux. Nitrogen excretion rates of some sub-categories are fluctuating along the time series due to changes in feeding and management practices.

**Sheep** in Switzerland are fed mainly on roughage from extensive pasture and meadows (Richner and Sinaj 2017) and are estimated to excrete approximately 8.1 kg N per head and year. This is somewhat lower than IPCC default (IPCC 2006, 2019). However, nitrogen excretion is averaged over the whole population, of which roughly 40 % are lambs and other immature animals. **Swine** show a significant decrease in nitrogen excretion rates until 2007, which can be explained by the increasing use of protein-reduced fodder (Kupper et al. 2022, Bracher and Spring 2011, Sollberger et al. 2013). Changing production techniques and increasing use of protein-reduced fodder are also drivers of nitrogen excretion rates for **poultry**.

Table 5-17 Nitrogen excretion rates of Swiss livestock. The complete time series on a livestock sub-category level are provided in a separate spreadsheet (Agroscope 2023b).

Nitrogen Excretion	1990-2010					
	1990	1995	2000	2005	2010	
	kg N/head/year					
Mature Dairy Cattle	100.4	101.5	104.1	107.4	110.1	
Other Mature Cattle	85.0	85.0	85.0	85.0	85.0	
Growing Cattle (weighted average)	33.0	33.1	33.1	32.6	32.7	
Fattening Calves	13.0	13.0	13.0	14.2	16.0	
	Pre-Weaned Calves	22.0	22.0	22.0	22.0	22.0
	Breeding Cattle 1st Year	25.0	25.0	25.0	25.0	25.0
	Breeding Cattle 2nd Year	40.0	40.0	40.0	40.0	40.0
	Breeding Cattle 3rd Year	55.0	55.0	55.0	55.0	55.0
	Fattening Cattle	33.0	33.0	33.0	34.2	36.0
Sheep (weighted average)	7.5	7.6	8.0	8.1	8.5	
Swine (weighted average)	14.3	14.0	11.0	9.6	9.2	
Buffalo (weighted average)	NA	37.2	41.1	38.7	37.3	
Camels (weighted average)	NA	NA	14.1	12.8	12.6	
Deer (weighted average) <sup>1)</sup>	20.0	21.9	22.3	21.9	22.4	
Goats	11.2	11.1	11.3	11.1	11.2	
Horses (weighted average)	43.6	43.5	43.6	43.7	43.7	
Mules and Asses (weighted average)	16.0	16.0	16.0	16.0	16.0	
Poultry (weighted average)	0.5	0.5	0.5	0.5	0.5	
Rabbits	1.0	1.0	1.0	1.0	1.0	
Livestock NCAC (weighted average)	36.5	29.4	12.5	13.0	14.7	

Nitrogen Excretion	2012-2021									
	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
	kg N/head/year									
Mature Dairy Cattle	110.5	110.7	110.9	111.1	111.1	111.2	111.3	111.4	111.4	111.4
Other Mature Cattle	85.0	85.0	85.0	85.0	85.0	85.0	85.0	85.0	85.0	85.0
Growing Cattle (weighted average)	33.0	33.1	33.1	33.1	33.0	32.9	32.8	32.7	32.6	32.5
Fattening Calves	16.8	17.2	17.6	18.0	18.0	18.0	18.0	18.0	18.0	18.0
	Pre-Weaned Calves	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0
	Breeding Cattle 1st Year	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
	Breeding Cattle 2nd Year	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
	Breeding Cattle 3rd Year	55.0	55.0	55.0	55.0	55.0	55.0	55.0	55.0	55.0
	Fattening Cattle	36.8	37.2	37.6	38.0	38.0	38.0	38.0	38.0	38.0
Sheep (weighted average)	8.5	8.6	8.5	8.4	8.4	8.5	8.5	8.5	8.5	8.5
Swine (weighted average)	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1
Buffalo (weighted average)	36.9	36.9	36.4	36.4	36.4	35.9	47.1	45.9	45.7	45.4
Camels (weighted average)	12.8	12.9	12.8	12.7	12.6	12.6	12.5	12.6	12.6	12.6
Deer (weighted average) <sup>1)</sup>	22.5	23.0	23.0	23.0	23.1	23.3	23.4	23.6	23.6	23.6
Goats	11.5	11.6	11.6	11.4	11.4	11.4	11.4	11.4	11.4	11.4
Horses (weighted average)	43.7	43.8	43.8	43.8	43.8	43.9	43.9	43.9	43.9	43.9
Mules and Asses (weighted average)	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0
Poultry (weighted average)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Rabbits	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Livestock NCAC (weighted average)	15.4	15.9	15.7	15.8	16.1	16.1	14.7	14.9	15.0	15.0

<sup>1)</sup> Deer: Excretion per animal place

### 5.3.2.5.3. Manure management system distribution (MS)

The split of nitrogen flows into the different animal waste management systems and its temporal dynamics are based on the respective analysis in the AGRAMMON model (Kupper et al. 2022) and on data provided in Richner and Sinaj (2017). For cattle, the distribution of animal excreta to the various manure management systems is different with regard to estimating CH<sub>4</sub> emissions from 3B Manure management compared to estimating N<sub>2</sub>O emissions from 3B Manure management (for further information refer to chp. 5.3.2.2.4 and chp. A5.3.4). This is because cattle stables often have simultaneously both liquid and solid manure storage systems. As volatile solids are excreted mainly in dung and nitrogen mainly in urine, the proportion of VS stored as solid manure is higher compared to the proportion of N. Data provided in Table 5-14 refer to the distribution of nitrogen while data provided in CRF

Table 3.B(a)s2 refer to the distribution of VS. A detailed table of the distribution of VS is provided in a separate spreadsheet (Agroscope 2023b).

#### **5.3.2.5.4. Volatilisation of $\text{NH}_3$ , $\text{NO}_x$ and $\text{N}_2$ from manure management systems**

For indirect  $\text{N}_2\text{O}$  emissions from manure management the deposition of volatilised  $\text{NH}_3$  and  $\text{NO}_x$  is considered. Losses of ammonia from stables and manure storage systems to the atmosphere are calculated according to the Swiss ammonia model AGRAMMON (Kupper et al. 2022). Specific loss-rates for all major livestock categories are estimated based on agricultural structures and techniques (e.g. stable type, manure management system, measures to reduce  $\text{NH}_3$  emissions). Accordingly, the overall fraction of reactive nitrogen ( $\text{NH}_3$ ,  $\text{NO}_x$ ) volatilised underlies certain temporal dynamics that can be explained by changes in agricultural management practices (e.g. the transition to more animal friendly housing systems). It ranges from 14.5 to 20.4 %.

For the volatilisation of  $\text{NO}_x$  values from van Bruggen et al. (2014) were used. Accordingly, it is estimated that 0.2 %, 0.5 %, 1.0 % and 0.1 % of the total nitrogen in liquid/slurry, solid storage, deep litter and poultry manure systems are lost to the atmosphere, respectively. In this context the management systems “anaerobic digestion” is treated as liquid/slurry system.

For the estimation of the amount of animal manure applied to soils, the volatilisation of dinitrogen ( $\text{N}_2$ ) during manure management is also considered. It is estimated that 0.020 %, 0.025 %, 0.050 % and 0.025 % of the total nitrogen in liquid/slurry, solid storage, deep litter and poultry manure systems are lost to the atmosphere, respectively (van Bruggen et al. 2014).

Note that volatilisation from pasture, range and paddock manure is included under 3Db (Indirect  $\text{N}_2\text{O}$  emissions from managed soils). A graphical overview of the nitrogen flow system is given in Figure 5-6 and respective numbers are provided in Table 5-21.

#### **5.3.2.6. NMVOC emissions from manure management**

The NMVOC emissions from animal husbandry are calculated by a Tier 1 approach according to the EMEP/EEA guidebook using country-specific and default emission factors (EMEP/EEA 2019, chp. 3B Manure management, Table 3.4) for cattle and all other livestock categories, respectively. A comprehensive literature study by Bühler and Kupper (2018) has shown that the data base of NMVOC emissions from animal husbandry is very scarce and that the derived emission factors differ widely. The studies on which the emission factors in EMEP/EEA (2016) (unchanged in EMEP/EEA 2019) are based show several inconsistencies that could affect significantly the emission factors. It remains also unknown, how the emissions from the studies performed in the United States were adapted to European agricultural feeding conditions and how the corresponding emission factors were derived. Therefore, a study was conducted between 2018 and 2021 in order to measure NMVOC emissions from dairy cattle with and without silage feeding in an experimental housing system during summer, winter and the transitional season and to derive emission factors that are representative for cattle husbandry in Switzerland (Schrade et al. 2023). Switzerland's Informative Inventory Report (FOEN 2022b, chp. 5.2.2.) contains a detailed description of these country-specific emission factors for cattle.

### 5.3.3. Uncertainties and time-series consistency

For the uncertainty analysis the input data from ART (2008a) were used and were updated with current activity and emission data as well as with default uncertainties from the 2019 Refinement (IPCC 2019). The detailed input uncertainty values for category 3B are reported in Annex A2.1. The resulting, combined uncertainty for emissions according to approach 1 (uncertainty propagation) are reported in Annex A2.2 and in Annex A2.3 for results obtained by approach 2 (Monte Carlo simulations). The 95 % confidence intervals obtained by Monte Carlo simulations are slightly narrower and, for non-symmetric distributions, slightly shifted towards the lower edge.

Table 5-18 Uncertainties for 3B Manure management. Approach 1: intervals are exactly from 2.5 % to 97.5 % of the distribution; Approach 2: the narrowest interval representing 95 % of the distribution is given.

Source category	Gas	Activity data uncertainty 2021		Emission factor uncertainty 2021		Emission combined uncertainty 2021	
		(-) %	(+) %	(-) %	(+) %	(-) %	(+) %
Approach 1: uncertainty propagation							
3B1-4 Manure management, all livestock, direct	CH4	6.5	6.5	55	55	55	55
3B1-4 Manure management, all livestock, direct	N2O	24	24	57	81	62	84
3B5 Manure management, indirect	N2O	46	60	62	92	78	110
Approach 2: Monte Carlo simulations							
3B1-4 Manure management, all livestock, direct	CH4	6.4	6.3	54	53	54	54
3B1-4 Manure management, all livestock, direct	N2O	23	24	63	71	66	75
3B5 Manure management, indirect	N2O	50	54	69	79	79	99

The time series 1990–2021 are all considered consistent, although the following issues should be considered:

- For time series consistency of livestock population data and gross energy intake see chp. 5.2.3.
- The MCF for liquid/slurry systems varies according to the development of the grazing management over the years as described under chp. 5.3.2.2.3.
- Input data from the AGRAMMON-model are available for the years 1990 and 1995 (expert judgement and literature) as well as for 2002, 2007, 2010, 2015 and 2019 (extensive surveys on approximately 3000 farms). Values in-between the assessment years were interpolated linearly. For 2020 and 2021 the same value as in 2019 was applied.
- The emission factor for indirect N<sub>2</sub>O emissions after volatilisation of NH<sub>3</sub> and NO<sub>x</sub> from manure management systems varies according to varying land use as described in chp. 5.3.2.4.

### 5.3.4. Category-specific QA/QC and verification

General QA/QC measures are described in NID chp. 1.5.

All further category-specific QA/QC activities are described in a separate document (Agroscope 2019a). General information on agricultural structures and policies is provided and eventual differences between national and standard values (IPCC 2006, 2019) are being analysed and discussed. Furthermore, comparisons with data from other countries were conducted and discussed where possible. Agroscope (2019a) is periodically updated with the most recent inventory data.

A mutual peer review was conducted with the German GHG inventory group (Fuß et al. 2021). The respective recommendations were implemented as far as possible during the submission 2022 and 2023.

For quality assurance of livestock population data and livestock energy intake consult chp. 5.2.4.

#### **5.3.4.1. QA/QC and verification – CH<sub>4</sub>**

IPCC tables with data for estimating emission factors of all livestock categories (such as weight, feed digestibility, maximum CH<sub>4</sub> producing capacity (B<sub>0</sub>) or daily excretion of volatile solids) were filled in, checked for consistency and confidence and compared with IPCC (2006) default values (refer to Annex A5.3).

VS excretion rates of swine and poultry are based on IPCC default values (IPCC 2006). For swine, estimates using equation 10.24 from IPCC (2019) would yield very similar results. As for some of the parameters used in equation 10.24 (e.g. feed digestibility) no reliable country-specific data were available, it was decided to still use the default values.

Factors for methane conversion (MCF) and manure management system distribution (MS) were analysed considering the national agricultural context. The estimated MCF-values for liquid/slurry systems in Switzerland are somewhat lower than IPCC (2019) default. However, a relatively low MCF is supported by the fact that more than 80 % of all liquid/slurry storage tanks are covered and approximately one third of the remaining tanks have a surface crust (Kupper et al. 2022). Furthermore, a series of laboratory measurements of MCF-values by the group of animal nutrition from the Swiss Federal Institute of Technology in Zurich yielded consistently low MCF-values (Zeitz et al. 2012).

During the past years studies were conducted to verify methane emissions at the regional scale comparing bottom-up estimates with atmospheric measurements (Bamberger et al. 2014, Henne et al. 2015, Henne et al. 2016, Henne et al. 2017, Hiller et al. 2014, Hiller et al. 2014a, Stieger 2013, Stieger et al. 2015). For further information on these studies see chp. 5.2.4. and Annex A6.2.

#### **5.3.4.2. QA/QC and verification – N<sub>2</sub>O**

Estimation of N<sub>2</sub>O emissions is mainly based on the Swiss ammonium emission model AGRAMMON that is documented in Kupper et al. (2022).

All relevant data needed for the calculation of N<sub>2</sub>O emissions such as nitrogen excretion rates, manure management system distribution and N<sub>2</sub>O emission factors were checked for consistency and were compared to the corresponding values of other countries and to the IPCC (2006, 2019) default value if available (Agroscope 2019a).

As one of the most important parameters, nitrogen excretion rates were analysed in more detail. In order to validate the total nitrogen excretion of the whole livestock population a cross check was conducted comparing the bottom-up inventory estimates with an independent top-down approach. Thereby, the total amount of nitrogen contained in animal livestock products such as meat, milk or eggs (output) was subtracted from the total amount of nitrogen in animal feedstuff produced in or imported to the country (input). Under the condition that the nitrogen pool in the animal population remains constant, the result should

be equal to the amount of nitrogen excreted in the manure (see e.g. Spiess 2011). There was good agreement (average discrepancy of  $\pm 2\%$ ) for the years 1990–2005. However, for later years the top-down estimates were on average 10 % higher than the bottom-up estimates. Reasons for this observation are not yet clear and this finding will be subject to further analysis.

$N_{\text{ex}}$ -values for the most important animal categories (mature dairy cattle and swine, being responsible for 65 % of total nitrogen excretion) were compared to the values of the alternative gross energy approach suggested in equation 10.32 in IPCC 2019. For swine, the IPCC approach estimated on average 16 % lower  $N_{\text{ex}}$  values for the years 1990–2004. This is probably due to an underestimation of the feed protein content in this model calculation and the inventory estimates are considered more realistic. After the year 2005 inventory estimates were lower than the IPCC approach using equation 10.32, which can be explained by the increased use of nitrogen reduced feed. Further QA/QC checks of the  $N_{\text{ex}}$  values are elaborated in Agroscope (2019a).

Henne et al. (2019) conducted a top-down assessment of Swiss  $N_2O$  emissions using atmospheric measurements and an inverse modelling framework. The inverse modelling methodology described in Henne et al. (2019) was later extended to the period 2017 to 2021. Inversely estimated Swiss  $N_2O$  emissions were slightly smaller than reported  $N_2O$  emission. However, due to the given uncertainties connected to these numbers, the inverse estimates are not significantly different from the NID estimates. The best estimate of annual  $N_2O$  emissions for the investigated period in 2017–2021 was  $10.8 \pm 3.1 \text{ Gg yr}^{-1}$ , which compares to  $11.5 (8.3 \text{ to } 14.9) \text{ Gg yr}^{-1}$  given for the same period in this NID (2- $\sigma$  confidence range). For more information see also Annex A6.2).

### 5.3.5. Category-specific recalculations

General information on recalculations is provided in chp. 10.

Recalculations with an overall impact of  $>0.5 \text{ kt CO}_2$  equivalent are assessed quantitatively. All other recalculations are only described qualitatively.

- Recalculation of livestock population data and gross energy intake (influencing VS-excretion rates) is reported under chp. 5.2.5.
- $\text{CH}_4$  emissions of mature dairy cattle were recalculated for the years 2010–2020. New data on mature life weight provided directly by Identitas AG were used to estimate the emission factors for enteric fermentation and manure management (excretion of volatile solids). The impact on overall emissions ranged from  $-2.3$  to  $5.3 \text{ kt CO}_2 \text{ eq}$  on average.
- $\text{CH}_4$  emissions from manure management of growing cattle and other mature cattle were recalculated for the whole time series. Emission factors were revised in the course of the adoption of the 2019 refinements of the IPCC Guidelines by adjusting the values for feed digestibility when calculating excretion of volatile solids (VS). New values for feed digestibility are higher for all animal categories concerned leading to lower estimates of excretion of VS and a reduction of overall emissions of  $-26.0 \text{ kt CO}_2$  equivalents on average.
- $\text{CH}_4$  emissions from manure management of buffalo, camels and llamas and deer were recalculated for the whole time series. Emission factors were revised in the course of the adoption of the 2019 Refinement (IPCC 2019) by adjusting the values for feed digestibility when calculating excretion of volatile solids (VS). New values for feed digestibility are higher for all animal categories concerned leading to lower estimates of

excretion of VS and a reduction of overall emissions of <0.1 kt CO<sub>2</sub> equivalents on average.

- CH<sub>4</sub> emissions from manure management of sheep, goats, horses and mules and asses were recalculated for the whole time series. Emission Factors were revised by directly using equation 10.24 of the IPCC Guidelines (IPCC 2019) to estimate excretion of volatile solids (VS) instead of default values. The impact on overall emissions ranges from -0.6 to +1.3 kt CO<sub>2</sub> equivalents.
- CH<sub>4</sub> emissions from manure management of horses were recalculated for the whole time series. Emission factors were revised due to new default values for the maximum methane producing capacity (B<sub>0</sub>) from IPCC 2019. The impact on overall emissions is below 0.5 kt CO<sub>2</sub> equivalents.
- CH<sub>4</sub> emissions from manure management of all animals grazing on pastures were recalculated for the whole time series. Emission factors were revised due to a new default value for the maximum methane producing capacity (B<sub>0</sub>) for grazing animals from IPCC 2019 (Table 10.17). The impact on overall emissions ranges from -1.5 to -0.6 kt CO<sub>2</sub> equivalents.
- CH<sub>4</sub> emissions from manure management of all animals grazing on pastures were recalculated for the whole time series. Emission factors were revised due to a new default value for the methane conversion factor (MCF) for pasture from the IPCC 2019. The impact on overall emissions ranges from -7.6 to -4.1 kt CO<sub>2</sub> equivalents.
- CH<sub>4</sub> emissions from liquid manure management and anaerobic digestion were recalculated for the whole time series. Emission factors were revised due to new monthly norm temperature values from MeteoSwiss (2022) for estimating the methane conversion factor (MCF) for liquid systems. The impact on overall emissions ranges from +15.7 to +21.2 kt CO<sub>2</sub> equivalents.

### 5.3.6. Category-specific planned improvements

No category-specific improvements are planned.

## 5.4. Source category 3C – Rice cultivation

Rice cultivation is of minor importance in Switzerland. The agricultural land used for rice cultivation and the annual harvest of rice are not estimated by the Swiss Farmers Union (SBV 2022). Only one farm in the south of Switzerland is cultivating upland rice since 1997. CH<sub>4</sub> emissions are assumed to be zero. The area of upland rice is reported from 1997 onward in CRF Table 3.C (EMIS 2023/4C “Reisanbau”).

## 5.5. Source category 3D – Agricultural soils

### 5.5.1. Source category description

Table 5-19 Key categories of 3D Agricultural soils. Combined KCA results, level for 2021 and trend for 1990–2021, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC category	Gas	Identification criteria
3Da	Direct emissions from managed soils	N <sub>2</sub> O	L1, L2
3Db	Indirect emissions from managed soils	N <sub>2</sub> O	L1, T1, L2, T2

The source category 3D includes direct and indirect N<sub>2</sub>O emissions from managed soils (Table 5-20). Direct emissions are further subdivided in emissions from 1. Inorganic N fertilisers, 2. Organic N fertilisers, 3. Urine and dung deposited by grazing animals, 4. Crop residues, 5. Mineralisation/immobilisation associated with loss/gain of soil organic matter, 6. Cultivation of organic soils (i.e. histosols) and 7. Other (i.e. Domestic use of synthetic fertilisers). Indirect N<sub>2</sub>O emissions are further subdivided in 1. Atmospheric deposition and 2. Nitrogen leaching and run-off. All indirect N<sub>2</sub>O emissions after deposition of NO<sub>x</sub> and NH<sub>3</sub> or after leaching of NO<sub>3</sub><sup>-</sup> are reported under source category 3Db Indirect N<sub>2</sub>O Emissions from managed soils. This includes indirect N<sub>2</sub>O emissions after NO<sub>3</sub><sup>-</sup> leaching from N mineralisation in Cropland remaining cropland and Grassland remaining grassland. To avoid double counting the respective emissions are not reported under source category 4(IV) Indirect N<sub>2</sub>O emissions from managed soils and not included in CRF Table6 (see also chp. 9).

Table 5-20 Specification of source category 3D Agricultural soils.

3D	Source	Specification
3Da	Direct N <sub>2</sub> O emissions from managed soils	<ol style="list-style-type: none"> <li>1. Inorganic N fertilisers</li> <li>2. Organic N fertilisers (animal manure applied to soils, sewage sludge applied to soils, other organic fertilisers applied to soils)</li> <li>3. Urine and dung deposited by grazing animals</li> <li>4. Crop residues (incl. residues from meadows and pasture)</li> <li>5. Mineralisation/immobilisation associated with loss/gain of soil organic matter</li> <li>6. Cultivation of organic soils (i.e. histosols)</li> <li>7. Other (domestic use of synthetic fertilisers)</li> </ol>
3Db	Indirect N <sub>2</sub> O emissions from managed soils	<ol style="list-style-type: none"> <li>1. Atmospheric deposition</li> <li>2. Nitrogen leaching and run-off</li> </ol>

Furthermore, NO<sub>x</sub> emissions from managed soils as well as NMVOC emissions are estimated.

Direct and indirect N<sub>2</sub>O emissions from managed soils have decreased since 1990 in almost all major sub-categories. Only N<sub>2</sub>O emissions from 3Da3 (Urine and dung deposited by

grazing animals) increased due to a higher share of manure excreted on pasture, range and paddock. NO<sub>x</sub> emissions have declined by 24 % since 1990. The general trends can be explained by a reduction in the number of cattle and a reduced input of mineral fertilisers due to the introduction of the “Proof of Ecological Performance (PEP)” requiring a balanced fertiliser management (Agroscope 2019a, Leifeld and Fuhrer 2005). Major changes occurred mainly in the 1990s while most emissions were more or less stable after the year 2000.

The most significant N<sub>2</sub>O emission sources are animal manure applied to soils (27 %, mean 1990–2021), nitrogen input from atmospheric deposition (20 %, mean 1990–2021), inorganic nitrogen fertilisers (16 %, mean 1990–2021) and nitrogen from fertilizers and other agricultural inputs that is lost through leaching and run-off (14 %, mean 1990–2021).

## 5.5.2. Methodological issues

### 5.5.2.1. Methodology

For the calculation of most N<sub>2</sub>O emissions from 3D Agricultural soils a Tier 1 method was applied that is based on the IULIA model from Schmid et al. (2000). IULIA is an IPCC-derived method for the calculation of N<sub>2</sub>O emissions from agriculture that basically uses the default emission factors (IPCC 2019), but adjusts the activity data to the particular situation of Switzerland. For the estimation of N<sub>2</sub>O emissions from animal manure applied to soils as well as for the estimation of indirect N<sub>2</sub>O emissions a more detailed Tier 3 approach was used. IULIA is continuously updated. New values for nitrogen excretion rates, manure management system distribution and ammonium emission factors from the Swiss ammonium model AGRAMMON were adopted (Kupper et al. 2022). Furthermore, the updated version of the "Principles of Fertilisation in Arable and Forage Crop Production" (GRUD; Richner and Sinaj 2017) was used instead of obsolete data from Flisch et al. (2009), FAL/RAC (2001) and Walther et al. (1994). More recently, the N-flow model was extended to include all gaseous N-species (including N<sub>2</sub>) and new NO<sub>x</sub> emission factors were implemented (Kupper 2017). Emission factors for N<sub>2</sub>O are all based on IPCC (2019) default with the exception of the emission factor for indirect N<sub>2</sub>O emissions from atmospheric deposition of N volatilised from managed soils (EF<sub>4</sub>) which is country-specific.

The modelling of the N<sub>2</sub>O emissions is done by Agroscope, the Swiss centre of excellence for agricultural research (Agroscope 2023) and is consistent with source category 3B N<sub>2</sub>O emissions from manure management. The model structure is displayed in Figure 5-6 and the corresponding amounts of nitrogen are given in Table 5-21.

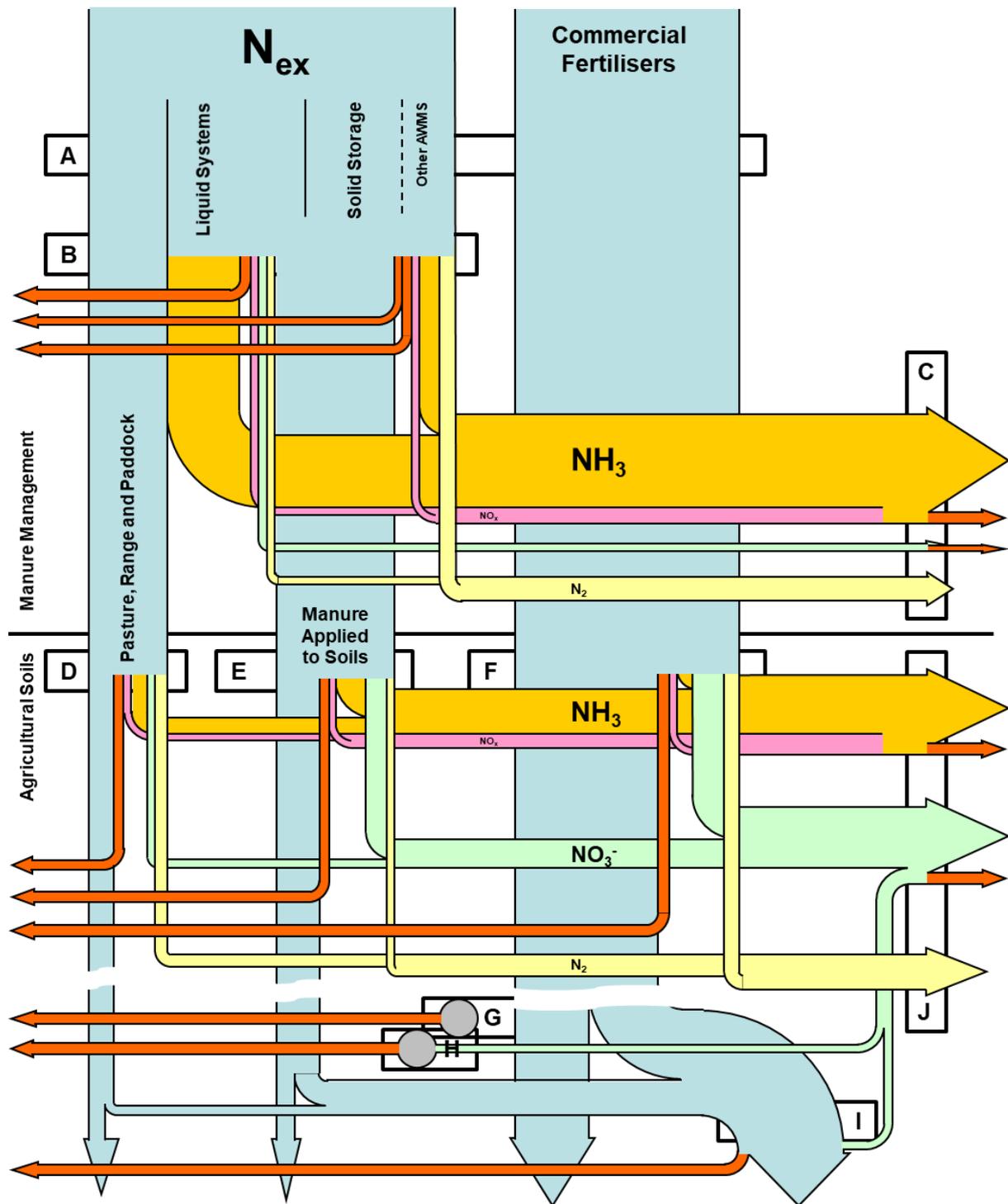
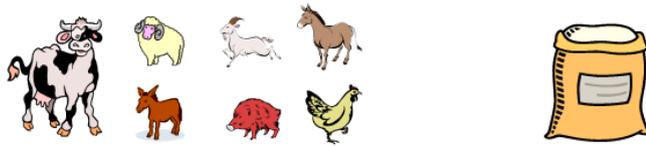


Figure 5-6 Diagram depicting the methodology of the approach to calculate the N<sub>2</sub>O emissions in agriculture (red arrows). Black frames and the respective letters refer to the nitrogen flows in Table 5-21. Note that the figure shows explicitly the methodology of the approach and not necessarily the physical nitrogen flows. Commercial fertilisers refer to the sum of urea, other mineral fertilisers, sewage sludge, other organic fertilisers and domestic use of fertilisers. Blue: nitrogen; orange: ammonia (NH<sub>3</sub>); pink: nitrogen oxides (NO<sub>x</sub>); green: nitrate (NO<sub>3</sub><sup>-</sup>); yellow: dinitrogen (N<sub>2</sub>).

Table 5-21 Nitrogen flows of the N-flow-model for Swiss agriculture. Letters refer to the letters in Figure 5-6. Processes refer to the nitrogen flows in the black frames in Figure 5-6 from left to right or from top to bottom.

	Process	Amount of N			CRF table
		1990	2021		
		tN			
A	1 Pasture, range and paddock	13'546	23'554	= B	3.Da3
	2 Liquid/slurry systems	97'247	69'990		3.B(b)
	3 Solid storage	32'566	13'534		3.B(b)
	4 Other AWMS	9'081	21'852		3.B(b)
	5 Commercial fertiliser	75'084	53'733	= F	3.Da1,2bc,7
B	1 Pasture, range and paddock	13'546	23'554	= A1 + A2 + A3 + A4	3.Da3
	2 NH <sub>3</sub> volatilisation housing	11'623	13'969		3.B(b)5
	3 N <sub>2</sub> O emission liquid/slurry	194	140		3.B(b)
	4 NO <sub>x</sub> volatilisation liquid/slurry and digester	196	161		3.B(b)5
	5 Leaching manure management	0	0		3.B(b)5
	6 N <sub>2</sub> volatilisation liquid/slurry and digester	1'963	1'608		
	7 Manure applied to soils	115'222	81'675		3.Da2a
	8 N <sub>2</sub> O emission solid storage	163	68		3.B(b)
	9 N <sub>2</sub> O emission other AWMS	46	50		3.B(b)
	10 NO <sub>x</sub> volatilisation solid storage and deep litter	209	118		3.B(b)5
	11 NH <sub>3</sub> volatilisation storage	8'154	6'855		3.B(b)5
	12 N <sub>2</sub> volatilisation solid storage and deep litter	1'125	733		
C	1 NH <sub>3</sub> deposition manure management	19'776	20'824	= B2+B11	3.B(b)5
	2 NO <sub>x</sub> deposition manure management	406	279	= B4+B10	
	3 Leaching manure management	0	0	= B5	
D	1 Plant available N PR&P and N <sub>2</sub> volatilisation	9'972	17'904	= B1	
	2 N <sub>2</sub> O emission PR&P	78	132		3.Da3
	3 NO <sub>x</sub> volatilisation PR&P	75	130		
	4 NH <sub>3</sub> volatilisation PR&P	630	1'186		
	5 Leaching and run-off PR&P	2'791	4'202		
E	1 Plant available N animal manure and N <sub>2</sub> vol.	61'204	48'996	= B7	
	2 N <sub>2</sub> O emission application animal manure	1'152	817		3.Da2a
	3 NO <sub>x</sub> volatilisation application animal manure	634	449		
	4 NH <sub>3</sub> volatilisation application animal manure	28'487	16'843		
	5 Leaching and run-off application animal manure	23'745	14'570		
F	1 Plant available N com. fertiliser and N <sub>2</sub> vol.	53'803	40'407	= A5	
	2 N <sub>2</sub> O emission application com. fertiliser	751	522		3.Da1,2bc,7
	3 NO <sub>x</sub> volatilisation application com. fertiliser	413	296		
	4 NH <sub>3</sub> volatilisation application com. fertiliser	4'644	3'081		
	5 Leaching and run-off application com. fertiliser	15'474	9'427		
G	1 Cultivation of organic soils (ha)	18'039	17'247		3.Da6
H	1 Mineralisation/immobilisation soil organic matter	6'867	10'525		3.Da5
I	1 N in crop residues pasture, range and paddock	26'440	24'547		3.Da4
	2 N in crop residues arable crops	11'953	9'492		
J	1 NH <sub>3</sub> deposition fertiliser appl. and PR&P	33'761	21'110	= D4+E4+F4	3.Db1
	2 NO <sub>x</sub> deposition fertiliser appl. and PR&P	1'121	874	= D3+E3+F3	
	4 Leaching and run-off fertiliser appl. and PR&P	42'010	28'199	= D5+E5+F5	3.Db2
	5 Leaching and run-off mineralisation SOM	1'415	1'878		
	6 Leaching and run-off crop residues	7'912	6'072		

### 5.5.2.2. Direct N<sub>2</sub>O emissions from managed soils (3Da)

Calculation of Direct N<sub>2</sub>O emissions from managed soils is based on IPCC 2006 equation 11.1 including six terms for activity data and three different emission factors:

$$N_2O_{Direct-N} = (F_{SN} + F_{ON} + F_{CR} + F_{SOM}) \cdot EF_1 + F_{OS} \cdot EF_2 + F_{PRP} \cdot EF_3$$

N<sub>2</sub>O<sub>Direct-N</sub> = annual direct N<sub>2</sub>O–N emissions produced from managed soils (kg N<sub>2</sub>O–N/year)

F<sub>SN</sub> = annual amount of synthetic fertiliser N applied to soils (kg N/year)

F<sub>ON</sub> = annual amount of animal manure, compost, sewage sludge and other organic N additions applied to soils (kg N/year)

F<sub>CR</sub> = annual amount of N in crop residues, including N-fixing crops, returned to soils (kg N/year)

F<sub>SOM</sub> = annual amount of N in mineral soils that is mineralised, in association with loss of soil C from soil organic matter as a result of changes of land use or management (kg N/year)

F<sub>OS</sub> = annual area of managed/drained organic soils (ha)

F<sub>PRP</sub> = annual amount of urine and dung N deposited by grazing animals on pasture, range and paddock (kg N/year)

EF<sub>1</sub> = emission factor for N<sub>2</sub>O emissions from N inputs (kg N<sub>2</sub>O–N/kg N input)

EF<sub>2</sub> = emission factor for N<sub>2</sub>O emissions from drained/managed organic soils (kg N<sub>2</sub>O–N/ha)

EF<sub>3</sub> = emission factor for N<sub>2</sub>O emissions from urine and dung N deposited on pasture, range and paddock by grazing animals (kg N<sub>2</sub>O–N/kg N input)

#### 5.5.2.2.1. Emission factors

Emission factors for calculating 3Da Direct N<sub>2</sub>O emissions from managed soils are based on default values as provided in the 2019 Refinement (Table 5-22). For EF<sub>1</sub> the aggregated default value of 1 % is used (IPCC 2019). A rationale for the appropriateness is provided in chp. 5.5.4. Since the year 2007 mineral fertilisers with nitrification inhibitors are used in Switzerland. The use of nitrification inhibitors reduces direct N<sub>2</sub>O emissions from these fertilisers by 65 %. This reduction factor is ultimately based on Pfab et al. (2012) but also supported by studies of Weiske et al. (2001) and a meta-analysis by Akiyama et al. (2009) as described in First Climate (2017). The applied amounts are still small and the weighted emission factor (EF<sub>1</sub>) reported is thus only slightly below 1.0 %. The amount of fertilisers with nitrification inhibitors is classified as confidential (C). An additional table is available to reviewers on request, including all confidential data and information (Table 5-23). Due to the lack of data no other source specific emission factors were applied for EF<sub>1</sub>. The emission factor for urine and dung deposited by grazing animals was calculated as the weighted mean between the emission factor for cattle, poultry and pigs in wet climates (EF<sub>3PRP,CPP</sub> = 0.006 kg N<sub>2</sub>O–N/kg N) and the emission factor for sheep and “other animals” (EF<sub>3PRP,SO</sub> = 0.003 kg N<sub>2</sub>O–N/kg N) according to the shares of nitrogen excreted by the respective animals (IPCC 2019).

Table 5-22 Emission factors for calculating direct N<sub>2</sub>O emissions from managed soils (based on IPCC 2019). Blue: annually changing parameters, value for 2021.

Emission source	Emission factor
EF <sub>1</sub> Inorganic N fertilisers (kg N <sub>2</sub> O-N/kg)	0.0097
EF <sub>1</sub> Organic N fertilisers (kg N <sub>2</sub> O-N/kg)	0.01
EF <sub>1</sub> Crop residue (kg N <sub>2</sub> O-N/kg)	0.01
EF <sub>1</sub> Mineralisation/immobilisation soil organic matter (kg N <sub>2</sub> O-N/kg)	0.01
EF <sub>1</sub> Other (domestic synthetic fertilisers) (kg N <sub>2</sub> O-N/kg)	0.01
EF <sub>2</sub> Cultivation of organic soils (kg N <sub>2</sub> O-N/ha)	8
EF <sub>3</sub> Urine and dung deposited by grazing animals (kg N <sub>2</sub> O-N/kg)	0.0056

Table 5-23 In the confidential NID, the amount of mineral fertilisers with and without nitrification inhibitors and corresponding emission factors are separately reported and available to reviewers.

#### 5.5.2.2.2. Activity data

Activity data for calculation of 3Da Direct soil emissions include 1. Inorganic N fertilisers, 2. Organic N fertilisers, 3. Urine and dung deposited by grazing animals, 4. Crop residues, 5. Nitrogen from mineralisation/immobilisation associated with loss/gain of soil organic matter 6. Area of organic soils (i.e. histosols) and 7. Other (i.e. Domestic use of inorganic fertilisers).

Emissions from **inorganic nitrogen fertilisers** include urea and other mineral fertilisers (mainly ammonium-nitrate). The amount of nitrogen input due to these fertilisers is obtained from Agricura (2021). Fertiliser statistics are based on sales statistics of the compulsory stockpiling of fertilisers (“Pflichtlagerhalter”) and small importers. Agricura conducts plausibility checks with import-data received by the Federal Office for Customs and Border Security (FOCBS). The estimates contain fertilisers used in Liechtenstein which are subtracted for the Swiss GHG inventory. Furthermore, it is estimated that 4 % of the mineral fertilisers are used for non-agricultural purposes (i.e. domestic use of inorganic fertilisers; Kupper et al. 2022). These fertilisers are used in public green areas, sports grounds and home gardens. In the reporting tables (CRF) they are reported under 3Da7 **Other (Domestic inorganic fertilisers)** while emission calculation is conducted together with 3Da1. In some occasions, as for instance for the estimation of indirect N<sub>2</sub>O emissions from managed soils, the sum of urea, other mineral fertilisers, sewage sludge, other organic fertilisers and domestic use of fertilisers is referred to as “commercial fertilisers” (see also Figure 5-6 and Table 5-21).

**Organic nitrogen fertilisers** include animal manure, sewage sludge and other organic fertilisers. The amount of nitrogen in **animal manure applied to soils** is calculated according to the methods described in chp. 5.3.2.5. As suggested in chp. 10.5.4. and equation 10.34 of IPCC 2019, all nitrogen excreted on pasture, range and paddock as well as all nitrogen volatilised prior to final application to managed soils is subtracted from the total excreted manure (for the estimation of the respective N–volatilisation during manure management see chp. 5.3.2.5, compare also Figure 5-6). Fra<sub>CGASM</sub> in CRF Table3.D represents the amount of nitrogen volatilised as NH<sub>3</sub>, NO<sub>x</sub>, N<sub>2</sub>O and N<sub>2</sub> from housing and manure storage divided by the manure excreted in the stable (liquid/slurry, solid storage, digesters, deep litter and poultry manure). The nitrogen input from manure applied to soils under 3Da2a in CRF Table3.D can thus be calculated with the numbers given in CRF Table3.B(b) and 3.D. Nitrogen from bedding material was not accounted for under animal

manure applied to soils. The respective nitrogen is included in the nitrogen returned to soils as crop residues.

The amount of **sewage sludge** applied to agricultural soils was estimated according to Kupper et al. (2022). Since 2003 it is forbidden in Switzerland to use sewage sludge as a fertiliser. As of 2006, this prohibition has been made effective for all agricultural areas with a transition period to 2008 (UVEK 2003). **Other organic fertilisers** include compost as well as liquid and solid digestates from biogas plants and are also estimated according to Kupper et al. (2022). Additionally nitrogen input through co-substrates in agricultural biogas plants is accounted for under this sub-category.

Calculation of emissions from **urine and dung deposited by grazing animals** is based on equation 11.5 of IPCC 2019. Estimation of total livestock nitrogen excretion was described under chp. 5.3.2.5. The share of manure nitrogen excreted on pasture, range and paddock was estimated according to the AGRAMMON-model (Kupper et al. 2022; Table 5-14). For each livestock category the share of animals that have access to grazing, the number of days per year they are actually grazing as well as the number of hours per day grazing takes place was assessed. Estimates are based on values from the literature and expert judgement (1990, 1995) and on surveys on approximately 3000 Swiss farms (2000, 2007, 2010, 2015, 2019).

N<sub>2</sub>O emissions from **crop residues** are based on the amount of nitrogen in crop residues returned to soil. For **arable crops**, data on total annual crop harvests were adopted from the statistical yearbooks of the Swiss Farmers Union (SBV 2021, note that this data refers to total harvest and not to yields per ha). Harvest data is based on surveys at the primary recipients (e.g. mills, sugar processing industry), yield assessment at approximately 1000 producers, as well as on data from central accounting evaluations of roughly 3000 farms (Agroscope, 2019a). To estimate the amount of nitrogen in crop residues, the harvested amount in tonnes is multiplied with the term NR<sub>T</sub>/SY<sub>T</sub> which corresponds to the amount of nitrogen in crop residues per amount of fresh matter crop yield. Standard values for NR<sub>T</sub> and SY<sub>T</sub> are published in Richner and Sinaj (2017, chapter 8 table 9; SY<sub>T</sub>="Referenzertrag / Körner, Hauptprodukt", NR<sub>T</sub>="Nährstoffentzug basierend auf dem Referenzertrag (N) / Körner, Hauptprodukt") and FAL/RAC (2001, table 2) and are based on long-term field trials by Agroscope.

$$F_{CR,AC} = \sum_T \left( Y_T \cdot \frac{NR_T}{SY_T} \right)$$

F<sub>CR,AC</sub> = amount of nitrogen in crop residues from arable crops returned to soils (t N)

Y<sub>T</sub> = amount of fresh matter crop harvest for crop T (t)

NR<sub>T</sub> = standard amount of nitrogen in crop residues for crop T (dt/ha)

SY<sub>T</sub> = standard amount of fresh matter crop yield for crop T (dt/ha)

For sugar beet and fodder beet it is assumed that 10 % of the crop residues are removed from the fields for animal fodder. The use of crop residues for fuel or the (open) burning of crop residues are not common practice in Switzerland and are subject to strong regulations. These activities are therefore not considered to reduce the amount of N returned to soils. Straw used as bedding material is later applied to soils together with animal manure. In order

to prevent double counting, the respective amount of nitrogen is not subtracted here as it is not added to animal manure nitrogen under manure management (see chp. 5.3.2.5).

Crop residues from **meadows and pastures** were also assessed as suggested in the 2019 Refinement (IPCC 2019, other forages including perennial grasses and grass/clover pastures). Two thirds of the agricultural land consists of grassland which underscores the importance of this source for Switzerland. Field losses during harvest, from feed not eaten by the animals and feed losses due to trampling effects are included.

With the elaboration of the “Model-based carbon inventory for national greenhouse gas reporting of mineral agricultural soils” (Wüst-Galley et al. 2019) the estimation of nitrogen inputs from crop residues from meadows and pastures was revised in order to assure consistent reporting of C- and N-fluxes in agricultural soils. For the assessment of total crop dry matter produced a mixed approach based on reported annual harvest data (overall harvest in tonnes, e.g. SBV 2022), standard yields (dt/ha, Richner and Sinaj 2017; attribution to the different grassland types) and surface data of detailed grassland types (in ha, background data of the Federal Statistical Office, unpublished) was applied. The former is affected primarily by meteorological conditions. The latter two data sets allowed fluctuations in the management intensity of the grassland surface to be accounted for. For each year the different yields of the grassland types are weighted according to the respective areas (compare also chp. 6.6.2.1.1). Nitrogen contents of dry matter were adopted from Richner and Sinaj (2017, chapter 9 table 3b) and yield losses in percent were adopted from Agridea (2016).

Estimated values of total crop production, nitrogen incorporated with crop residues  $F_{(CR)}$ , residue/crop ratio, dry matter fraction of residues and nitrogen content of residues are provided in Annex A5.3.

Assessment of nitrogen **mineralisation/immobilisation associated with loss/gain of soil organic matter** was conducted based on data from the LULUCF sector. For reasons of consistency, losses and gains of soil organic matter on cropland and grasslands were accounted for. The same methodology as described under chp. A5.4.1 was applied. Nitrogen mineralisation was estimated by dividing the carbon loss on Cropland remaining cropland and Grassland remaining grassland with a C/N-ratio of 9.8 according to Leifeld et al. (2007). It should be noted that for grassland the carbon losses were assessed based on land-use changes on a sub-category level. Only land-use changes that led to a net carbon stock loss were considered, excluding land-use changes that led to a net carbon stock increase. Consequently, the carbon losses used for calculating  $N_2O$  emissions from nitrogen mineralisation are not identical with the net carbon stock changes reported in the reporting table (Table 4.C).  $N_2O$  emissions from nitrogen mineralisation of land converted to cropland or land converted to grassland are reported under category 4(III) “Direct nitrous oxide ( $N_2O$ ) emissions from nitrogen (N) mineralisation/immobilisation associated with loss/gain of soil organic matter resulting from change of land use or management of mineral soils”.

Estimates of  $N_2O$  emissions from **cultivated organic soils** are based on the area of cultivated organic soils and the IPCC default emission factor for  $N_2O$  emissions from cultivated organic soils (IPCC 2006). The area of cultivated organic soils corresponds to the total area of organic soils under cropland and grassland as reported in CRF Table 4.B and 4.C (see also chp. 6.2.2.1).

The relevant activity data for calculating N<sub>2</sub>O emissions from soils are displayed in Table 5-24. Additional information is given in a separate spreadsheet (Agroscope 2023b).

Table 5-24 Activity data for calculating 3Da Direct N<sub>2</sub>O emissions from managed soils.

Activity Data		1990-2010				
		1990	1995	2000	2005	2010
		t N/yr				
1. Inorganic N fertilisers	Urea	16'284	10'707	7'631	6'605	7'101
	Other mineral fertilisers	50'390	47'652	43'042	43'478	45'985
2. Organic N fertilisers	a. Animal manure	115'222	106'497	87'265	82'437	85'964
	b. Sewage sludge	4'815	4'942	3'356	1'054	0
	c. Other organic fertilisers	817	1'286	1'829	2'169	3'281
3. Urine and dung deposited by grazing animals		13'546	14'279	21'269	23'955	24'234
4. Crop residues	Arable crops	11'953	11'350	12'345	11'750	10'740
	Residues M&P	26'440	25'251	26'301	26'158	24'701
5. Min./imm. associated with loss/gain of SOM		6'867	12'837	12'497	5'244	7'049
6. Cultivation of organic soils (ha)		18'039	17'912	17'751	17'584	17'457
7. Other (domestic inorganic fertilisers)		2'778	2'432	2'111	2'087	2'212

Activity Data		2012-2021									
		2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
		t N/yr									
1. Inorganic N fertilisers	Urea	5'377	5'793	7'942	7'223	8'872	9'250	8'324	7'752	7'397	8'101
	Other mineral fertilisers	39'771	37'924	41'393	36'521	37'531	40'113	37'432	32'400	33'694	37'269
2. Organic N fertilisers	a. Animal manure	85'360	84'755	85'072	84'572	84'078	83'392	82'824	81'715	81'443	81'675
	b. Sewage sludge	0	0	0	0	0	0	0	0	0	0
	c. Other organic fertilisers	4'345	4'670	4'709	4'908	5'435	5'542	5'668	6'211	6'357	6'472
3. Urine and dung deposited by grazing animals		24'094	23'922	23'867	23'672	23'718	23'767	23'736	23'615	23'464	23'554
4. Crop residues	Arable crops	11'429	10'330	12'504	10'925	10'144	11'850	11'168	11'470	11'988	9'492
	Residues M&P	26'729	22'797	28'051	21'184	26'641	24'318	21'060	25'161	24'547	24'547
5. Min./imm. associated with loss/gain of SOM		9'809	11'898	17'608	16'500	12'417	11'910	12'041	9'875	9'105	10'525
6. Cultivation of organic soils (ha)		17'413	17'392	17'373	17'354	17'334	17'317	17'300	17'282	17'265	17'247
7. Other (domestic inorganic fertilisers)		1'881	1'822	2'056	1'823	1'933	2'057	1'907	1'673	1'712	1'890

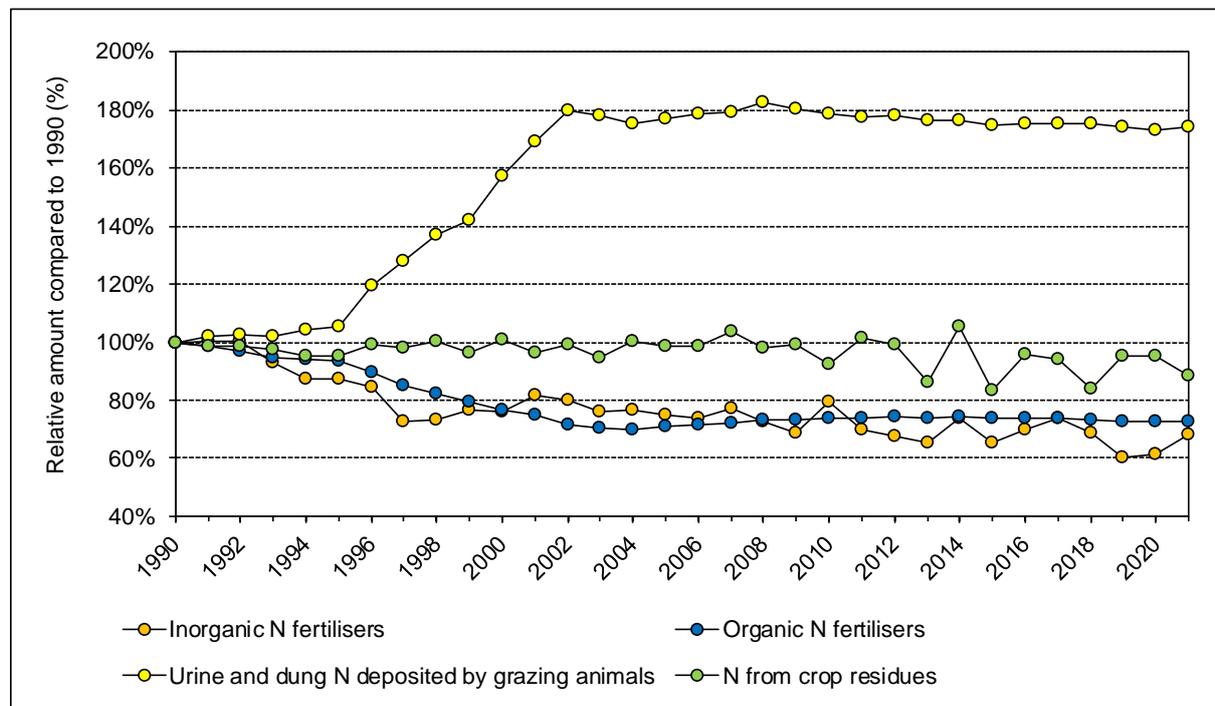


Figure 5-7 Relative development of the most important activity data for 3Da Direct N<sub>2</sub>O emissions from managed soils.

Figure 5-7 represents the development of the most important activity data for 3Da Direct N<sub>2</sub>O emissions from managed soils. The use of inorganic N-fertiliser declined mainly during the 1990s due to the agricultural policy reforms and the introduction of the “Proof of Ecological Performance (PEP)” that requires a balanced fertiliser management. Simultaneously, nitrogen input from animal manure declined due to declining livestock populations (mainly cattle). Urine and dung deposited by grazing animals increased substantially due to the shift to more animal-friendly livestock husbandry in the course of the agricultural policy reforms during the 1990s and the early 21<sup>st</sup> century (see also chp. 5.3.2.2.4). N inputs from crop residues remained more or less constant during the inventory time period due to more or less stable crop production.

### 5.5.2.3. Indirect N<sub>2</sub>O emissions from atmospheric deposition of N volatilised from managed soils (3Db1)

N<sub>2</sub>O emissions from atmospheric deposition of N volatilised from managed soils were estimated based on equations 11.9 and 11.11 of IPCC 2019 Guidelines. However, the method was adapted to the far more detailed approach of Switzerland:

$$N_2O_{(ATD)} - N = \left\{ \left[ \sum_i (F_{CN_i} * Frac_{GASF_i}) + \sum_T (F_{AM_T} * Frac_{GASM_T}) + \sum_T (F_{PRP_T} * Frac_{GASP_T}) \right] + [(F_{CN} + F_{AM}) * Frac_{NOXA} + F_{PRP} * Frac_{NOXP}] \right\} * EF_4$$

N<sub>2</sub>O<sub>(ATD)</sub>-N = annual amount of N<sub>2</sub>O–N produced from atmospheric deposition of N volatilised from managed soils (kg N<sub>2</sub>O–N/year)

F<sub>CNi</sub> = annual amount of commercial fertiliser N of type *i* applied to soils (kg N/year)

Frac<sub>GASFi</sub> = fraction of commercial fertiliser N of type *i* that volatilises as NH<sub>3</sub> (kg N/kg N)

F<sub>AMT</sub> = annual amount of managed animal manure N of livestock category *T* applied to soils (kg N/year)

Frac<sub>GASMT</sub> = fraction of applied animal manure N of livestock category *T* that volatilises as NH<sub>3</sub> (kg N/kg N)

F<sub>PRPT</sub> = annual amount of urine and dung N deposited on pasture, range and paddock by grazing animals of livestock category *T* (kg N/year)

Frac<sub>GASPT</sub> = fraction of urine and dung N deposited on pasture, range and paddock by grazing animals of livestock category *T* that volatilises as NH<sub>3</sub> (kg N/kg of N)

F<sub>CN</sub> = total amount of commercial fertiliser N applied to soils (kg N/year)

F<sub>AM</sub> = total amount of managed animal manure N applied to soils (kg N/year)

Frac<sub>NOXA</sub> = fraction of applied N (commercial fertilisers and animal manure) that volatilises as NO<sub>x</sub> (kg N/kg N)

F<sub>PRP</sub> = total amount of urine and dung N deposited on pasture, range and paddock by grazing animals (kg N/year)

$Frac_{NOXP}$  = fraction of urine and dung N deposited on pasture, range and paddock that volatilises as  $NO_x$  (kg N/kg of N)

$EF_4$  = emission factor for  $N_2O$  emissions from atmospheric deposition of N on soils and water surfaces (kg  $N_2O$ -N/ kg N volatilised).

#### 5.5.2.3.1. Emission factor

The emission factor for indirect  $N_2O$  emissions from atmospheric deposition of N volatilised from managed soils is the same as used for the assessment of indirect  $N_2O$  emissions after volatilisation of  $NH_3$  and  $NO_x$  from manure management systems. The emission factor was reassessed by a literature review by Bühlmann et al. (2015) and Bühlmann (2014). Due to slightly changing land use, the resulting emission factor shows some small variations around a mean value of 2.56 %. For further information see chp. 5.3.2.4.

#### 5.5.2.3.2. Activity data

The estimation of volatilisation of ammonia and  $NO_x$  was harmonised with the Swiss ammonia model AGRAMMON using the same emission factors and basic parameters (Table 5-25). Losses of commercial fertiliser nitrogen, animal manure N applied to soils, as well as urine and dung N deposited on pasture, range and paddock by grazing animals were considered. For the calculation of  $NH_3$  emissions, changes of agricultural structures (changes to more animal friendly housing systems) and techniques (manure management, measures to reduce  $NH_3$  emissions) are considered and explain temporal dynamics.

Ammonia volatilisation from **commercial fertiliser N** was estimated separately for synthetic fertilisers (based on EMEP/EEA 2016), sewage sludge, and other organic fertilisers (compost, liquid and solid digestates from biogas plants). Ammonia volatilisation of nitrogen in synthetic fertilisers was assessed separately for individual fertiliser types based on the EMEP/EEA guidebook (EMEP/EEA 2016). The weighted mean value for synthetic fertilisers excluding urea is 2.8 % (mean 1990–2021). Furthermore 13.1 % of urea-nitrogen is lost as ammonia. Ammonia emission factors for sewage sludge range from 20 % to 26 % depending on the composition of the sludge (Kupper et al. 2022). Other organic fertilisers include compost as well as liquid and solid digestates. Ammonia emission factors are 3.4 % for compost, 21 % to 30 % for liquid digestate and 4.0 % for solid digestate. The ammonia loss rate for liquid digestates decreased from 2001 until 2010 due to the increasing use of trailing hoses during field application.

Total  $Frac_{GASF}$  (including  $NO_x$  emissions) as reported in CRF Table3.D declined considerably from 6.7 % in 1990 to 5.0 % in 2006 and then increased again to 6.3 % in 2021 due to a change in the shares of the different commercial fertilisers.

Different ammonia loss factors were used for **animal manure N applied to soils** from different livestock categories according to the detailed approach of the AGRAMMON model (Kupper et al. 2022). Overall weighted  $Frac_{GASMT}$  for animal manure applied to soils slightly declined from 25.3 % in the early 1990s to 21.2 % in 2021 (Table 5-25).

Ammonia volatilisation from **urine and dung N deposited on pasture, range and paddock by grazing animals** was also assessed individually for each livestock category. Weighted mean loss rates ( $Frac_{GASPT}$ ) range from 5.2 % to 5.6 %.

**NO<sub>x</sub> emissions** were estimated separately for applied fertiliser N (commercial fertilisers, animal manure) and for urine and dung N deposited on pasture, range and paddock by grazing animals. NO<sub>x</sub> emission factors (Frac<sub>NO<sub>x</sub>A</sub> and Frac<sub>NO<sub>x</sub>P</sub>) for applied fertilisers and for urine and dung N deposited on pasture, range and paddock are 0.55 % each, based on Stehfest and Bouwman (2006).

Nitrogen pools and flows for calculating 3Db Indirect N<sub>2</sub>O emissions from managed soils are displayed in Table 5-26. Additional information is given in a separate spreadsheet (Agroscope 2023b).

Table 5-25 Overview of NH<sub>3</sub> and NO<sub>x</sub> emission factors used for the assessment of 3Db Indirect N<sub>2</sub>O emissions from atmospheric deposition. Complete time series on a livestock sub-category level are provided in a separate spreadsheet (Agroscope 2023b).

Emission factors volatilisation		1990-2010				
		1990	1995	2000	2005	2010
		%				
NH <sub>3</sub> from commercial fertiliser N (Frac <sub>GASFI</sub> )		6.19	6.05	5.42	4.66	4.69
	Urea	13.11	13.11	13.11	13.11	13.11
	Other Mineral Fertilisers	2.72	2.72	2.51	2.76	3.07
	Recycling Fertilisers (weighted average)	17.60	19.97	18.80	13.40	9.37
	Sewage Sludge	20.00	23.94	26.07	26.07	26.07
	Compost	3.43	3.43	3.43	3.43	3.43
	Digestate Liquid	30.00	30.00	30.00	26.06	21.00
	Digestate Solid	4.00	4.00	4.00	4.00	4.00
NH <sub>3</sub> from application of animal manure N (Frac <sub>GASMT</sub> )		24.72	24.54	23.47	23.32	21.95
	Mature Dairy Cattle	26.85	26.78	26.04	26.21	24.94
	Other Mature Cattle	22.86	22.06	22.38	22.72	22.47
	Growing Cattle (weighted average)	23.68	23.51	23.14	23.48	22.71
	Sheep (weighted average)	4.89	4.89	4.75	5.33	5.45
	Swine (weighted average)	24.20	23.95	21.93	21.28	19.09
	Other Livestock (weighted average)	10.12	10.09	9.09	9.54	9.98
NH <sub>3</sub> from urine and dung N deposited on PR&P (Frac <sub>GASPT</sub> )		4.65	4.69	4.80	4.89	4.89
	Mature Dairy Cattle	4.67	4.65	4.63	4.61	4.60
	Other Mature Cattle	4.56	4.57	4.56	4.56	4.56
	Growing Cattle (weighted average)	4.56	4.56	4.57	4.57	4.57
	Sheep (weighted average)	5.00	5.00	5.00	5.00	5.00
	Swine (weighted average)	NA	NA	14.00	14.00	14.00
	Other Livestock (weighted average)	5.00	6.47	7.58	8.48	8.51
NO <sub>x</sub> from applied fertilisers (Frac <sub>NO<sub>x</sub>A</sub> )		0.55	0.55	0.55	0.55	0.55
NO <sub>x</sub> from urine and dung N deposited on PR&P (Frac <sub>NO<sub>x</sub>P</sub> )		0.55	0.55	0.55	0.55	0.55

Emission factors volatilisation		2012-2021									
		2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
		%									
NH <sub>3</sub> from commercial fertiliser N (Frac <sub>GASFI</sub> )		4.81	5.02	5.20	5.57	5.47	5.56	5.65	5.95	5.93	5.73
	Urea	13.11	13.11	13.11	13.11	13.11	13.11	13.11	13.11	13.11	13.11
	Other Mineral Fertilisers	3.10	3.11	3.03	3.29	2.80	2.99	3.05	3.12	3.20	3.01
	Recycling Fertilisers (weighted average)	10.41	10.73	11.24	11.74	11.64	11.83	12.07	12.04	12.30	12.46
	Sewage Sludge	26.07	26.07	26.07	26.07	26.07	26.07	26.07	26.07	26.07	26.07
	Compost	3.43	3.43	3.43	3.43	3.43	3.43	3.43	3.43	3.43	3.43
	Digestate Liquid	21.00	21.00	21.00	21.00	21.00	21.00	21.00	21.00	21.00	21.00
	Digestate Solid	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
NH <sub>3</sub> from application of animal manure N (Frac <sub>GASMT</sub> )		21.46	21.21	20.96	20.70	20.69	20.69	20.71	20.69	20.64	20.62
	Mature Dairy Cattle	24.28	23.96	23.63	23.31	23.32	23.33	23.34	23.36	23.36	23.35
	Other Mature Cattle	22.12	21.94	21.77	21.59	21.53	21.46	21.40	21.34	21.33	21.33
	Growing Cattle (weighted average)	22.13	21.82	21.52	21.22	21.28	21.37	21.42	21.48	21.46	21.47
	Sheep (weighted average)	5.26	5.16	5.05	4.93	4.98	5.03	5.07	5.11	5.12	5.12
	Swine (weighted average)	18.76	18.57	18.40	18.22	18.24	18.27	18.30	18.32	18.34	18.34
	Other Livestock (weighted average)	9.98	10.02	10.08	10.04	10.16	10.16	10.41	10.43	10.57	10.61
NH <sub>3</sub> from urine and dung N deposited on PR&P (Frac <sub>GASPT</sub> )		4.90	4.90	4.90	4.91	4.94	4.96	4.98	5.00	5.03	5.04
	Mature Dairy Cattle	4.60	4.59	4.59	4.59	4.59	4.59	4.59	4.59	4.59	4.59
	Other Mature Cattle	4.56	4.56	4.56	4.56	4.56	4.56	4.56	4.56	4.56	4.56
	Growing Cattle (weighted average)	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57
	Sheep (weighted average)	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
	Swine (weighted average)	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00
	Other Livestock (weighted average)	8.44	8.54	8.67	8.76	9.09	9.24	9.67	9.83	10.27	10.27
NO <sub>x</sub> from applied fertilisers (Frac <sub>NO<sub>x</sub>A</sub> )		0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
NO <sub>x</sub> from urine and dung N deposited on PR&P (Frac <sub>NO<sub>x</sub>P</sub> )		0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55

Table 5-26 Overview of N pools and flows for calculating 3Db Indirect N<sub>2</sub>O emission from managed soils. Complete time series are provided in a separate spreadsheet (Agroscope 2023b).

Nitrogen pools and flows		1990-2010				
		1990	1995	2000	2005	2010
		t N/yr				
	Animals manure N applied to soils	115'222	106'497	87'265	82'437	85'964
	Commercial fertiliser	75'084	67'019	57'969	55'394	58'579
Deposition	Sum volatilised N (NH <sub>3</sub> and NO <sub>x</sub> )	34'882	31'897	25'558	23'870	23'729
	NH <sub>3</sub> emissions from commercial fertilisers	4'644	4'058	3'142	2'582	2'747
	NH <sub>3</sub> emissions from applied animal manure	28'487	26'136	20'479	19'228	18'868
	NH <sub>3</sub> emissions from pasture, range and paddock	630	670	1'021	1'172	1'185
	NO <sub>x</sub> emissions from commercial fertilisers	413	369	319	305	322
	NO <sub>x</sub> emissions from applied animal manure	634	586	480	453	473
	NO <sub>x</sub> emissions from PR&P	75	79	117	132	133
Leaching and run-off	Sum leaching and run-off	51'337	48'889	42'844	38'451	37'667
	Leaching and run-off from commercial fertilisers	15'474	13'811	11'411	10'393	10'429
	Leaching and run-off from applied animal manure	23'745	21'947	17'178	15'467	15'335
	Leaching and run-off from pasture, range and paddock	2'791	2'943	4'187	4'495	4'323
	Leaching and run-off from crop residues	7'912	7'543	7'608	7'113	6'322
	Leaching and run-off from mineralisation of SOM	1'415	2'645	2'460	984	1'258

Nitrogen pools and flows		2012-2021									
		2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
		t N/yr									
	Animals manure N applied to soils	85'360	84'755	85'072	84'572	84'078	83'392	82'824	81'715	81'443	81'675
	Commercial fertiliser	51'374	50'208	56'100	50'475	53'771	56'962	53'331	48'036	49'160	53'733
Deposition	Sum volatilised N (NH <sub>3</sub> and NO <sub>x</sub> )	22'853	22'540	22'828	22'358	22'394	22'499	22'222	21'787	21'754	21'984
	NH <sub>3</sub> emissions from commercial fertilisers	2'471	2'521	2'919	2'812	2'940	3'167	3'011	2'859	2'916	3'081
	NH <sub>3</sub> emissions from applied animal manure	18'318	17'973	17'831	17'509	17'394	17'252	17'150	16'905	16'809	16'843
	NH <sub>3</sub> emissions from pasture, range and paddock	1'179	1'172	1'170	1'163	1'172	1'178	1'182	1'180	1'181	1'186
	NO <sub>x</sub> emissions from commercial fertilisers	283	276	309	278	296	313	293	264	270	296
	NO <sub>x</sub> emissions from applied animal manure	469	466	468	465	462	459	456	449	448	449
	NO <sub>x</sub> emissions from PR&P	133	132	131	130	130	131	131	130	129	130
Leaching and run-off	Sum leaching and run-off	37'220	36'348	39'793	36'958	37'565	37'770	36'308	35'497	35'470	36'149
	Leaching and run-off from commercial fertilisers	9'137	8'929	9'983	8'977	9'558	10'077	9'401	8'410	8'614	9'427
	Leaching and run-off from applied animal manure	15'228	15'120	15'176	15'087	14'999	14'876	14'775	14'577	14'529	14'570
	Leaching and run-off from pasture, range and paddock	4'298	4'268	4'258	4'223	4'231	4'240	4'234	4'213	4'186	4'202
	Leaching and run-off from crop residues	6'807	5'909	7'235	5'728	6'562	6'452	5'749	6'535	6'518	6'072
	Leaching and run-off from mineralisation of SOM	1'750	2'122	3'141	2'944	2'215	2'125	2'148	1'762	1'624	1'878

Figure 5-8 shows the development of the most important activity data for 3Db Indirect N<sub>2</sub>O emissions from managed soils. Ammonia emissions from application of commercial fertilisers declined mainly due to reduced fertiliser use and partly also due to the decreasing share of fertilisers with high ammonia emission rates (i.e. urea and sewage sludge). Ammonia emissions from applied animal manure declined mainly due to declining livestock populations and hence due to the reductions of available manure N. The fraction of applied animal manure N that volatilises as NH<sub>3</sub> (Frac<sub>GASMT</sub>) declined slightly and also contributed to the decreasing trend.

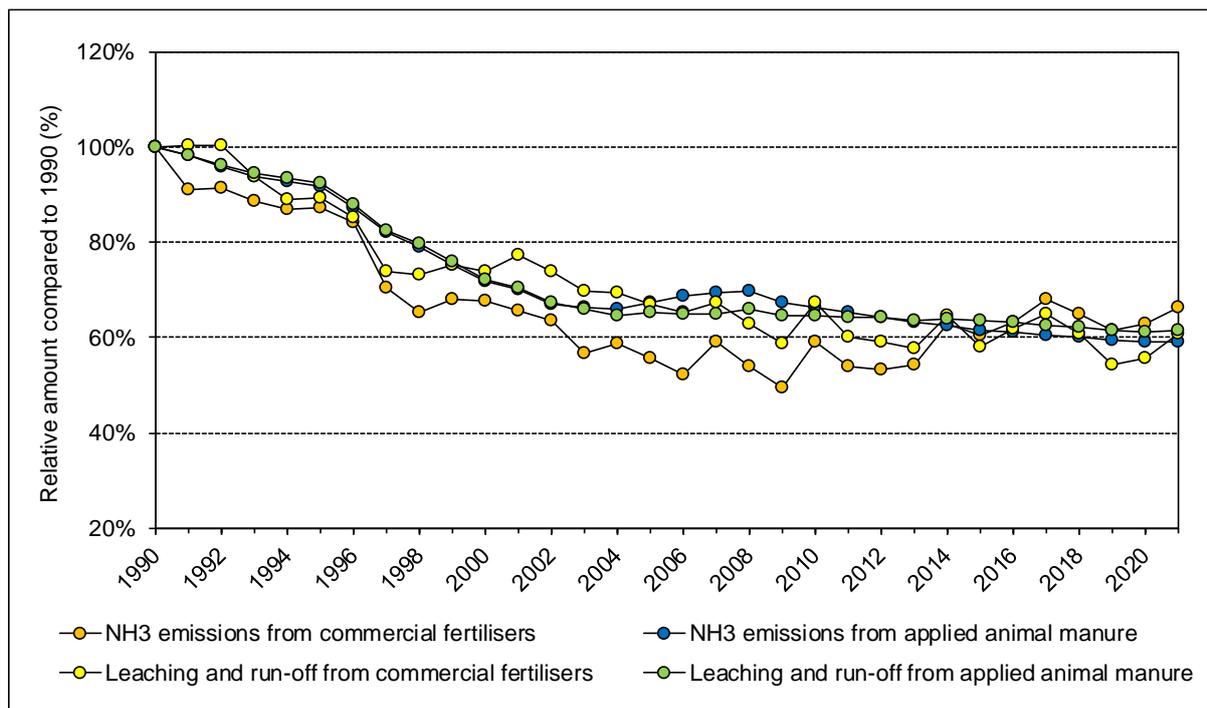


Figure 5-8 Relative development of the most important activity data for 3Db Indirect N<sub>2</sub>O emissions from managed soils.

#### 5.5.2.4. Indirect N<sub>2</sub>O emissions from leaching and run-off from managed soils (3Db2)

N<sub>2</sub>O emissions from leaching and run-off from managed soils are estimated based on equation 11.10 of IPCC 2019:

$$N_2O_{(L)} - N = (F_{CN} + F_{AM} + F_{PRP} + F_{CR} + F_{SOM}) \cdot \text{Frac}_{LEACH-(H)} \cdot EF_5$$

$N_2O_{(L)} - N$  = annual amount of N<sub>2</sub>O–N produced from leaching and run-off of N additions to managed soils (kg N<sub>2</sub>O–N/year)

$F_{CN}$  = annual amount of commercial fertiliser N applied to soils (kg N/year)

$F_{AM}$  = annual amount of managed animal manure N applied to soils (kg N/year)

$F_{PRP}$  = annual amount of urine and dung N deposited by grazing animals (kg N/year)

$F_{CR}$  = annual amount of N in crop residues, including N-fixing crops, returned to soils (kg N/year)

$F_{SOM}$  = annual amount of N in mineral soils that is mineralised, in association with loss of soil C from soil organic matter as a result of changes of land use or management (kg N/year)

$\text{Frac}_{LEACH-(H)}$  = fraction of all N added to/mineralised in managed soils that is lost through leaching and runoff (kg N/kg of N additions)

$EF_5$  = emission factor for N<sub>2</sub>O emissions from N leaching and run-off (kg N<sub>2</sub>O–N/kg N leached and run-off)

### 5.5.2.4.1. Emission factor

The emission factor for indirect N<sub>2</sub>O emissions from leaching and run-off from managed soils is 0.011 kg N<sub>2</sub>O–N/kg N according to IPCC (2019).

### 5.5.2.4.2. Activity data

For the calculation of N<sub>2</sub>O emissions from leaching and run-off from managed soils, N-leaching from commercial fertilisers (including synthetic fertilisers, sewage sludge, compost, and liquid and solid digestates from biogas plants) ( $F_{CN}$ ), managed animal manure N applied to soils ( $F_{AM}$ ), urine and dung N deposited by grazing animals ( $F_{PRP}$ ), N in crop residues returned to soils ( $F_{CR}$ ) and N mineralised in mineral soils ( $F_{SOM}$ ) were accounted for. The method for the assessment of the respective amounts of nitrogen is described in chp. 5.5.2.2 and activity data are contained in Table 5-24.

Frac<sub>LEACH-H</sub> was estimated for the years 1990 and 2010 by dividing the available amount of nitrogen by the amount of nitrogen that is lost due to leaching and run-off in Switzerland according to model estimates of Prasuhn (2016). The respective loss rates are 20.6 % for 1990 and 17.8 % for 2010 (Table 5-27). Spiess and Prasuhn (2006) confirm that the loss rates were somewhat higher in the early 1990s and then declined due to the agricultural policy reforms. Accordingly, the reduction in the nitrate loss rate was implemented between 1995 and 2010 with constant loss rates after 2010. The same loss rates were applied to all nitrogen pools independent of their origin and composition. An additional reduction of the nitrate loss rate originates from the application of fertilisers with nitrification inhibitors. The nitrogen loss rate is reduced by 23 % for fertilisers with nitrification inhibitors (Weiske et al. 2001). Due to the limited application of nitrification inhibitors the respective effect is still small (see also chp. 5.5.2.2.1). The overall amount of nitrogen that is lost through leaching and run-off is given in Table 5-26.

Table 5-27 Fractions of mineralised N lost by leaching or run-off (Frac<sub>LEACH-(H)</sub>).

	<b>Unit</b>	<b>1990</b>	<b>1991</b>	<b>1992</b>	<b>1993</b>	<b>1994</b>	<b>1995</b>	<b>1996</b>	<b>1997</b>	<b>1998</b>	<b>1999</b>
Frac <sub>LEACH-(H)</sub>	--	0.206	0.206	0.206	0.206	0.206	0.206	0.204	0.202	0.201	0.199
	<b>Unit</b>	<b>2000</b>	<b>2001</b>	<b>2002</b>	<b>2003</b>	<b>2004</b>	<b>2005</b>	<b>2006</b>	<b>2007</b>	<b>2008</b>	<b>2009</b>
Frac <sub>LEACH-(H)</sub>	--	0.197	0.195	0.193	0.191	0.189	0.188	0.186	0.184	0.182	0.180
	<b>Unit</b>	<b>2010</b>	<b>2011</b>	<b>2012</b>	<b>2013</b>	<b>2014</b>	<b>2015</b>	<b>2016</b>	<b>2017</b>	<b>2018</b>	<b>2019</b>
Frac <sub>LEACH-(H)</sub>	--	0.178	0.178	0.178	0.178	0.178	0.178	0.178	0.178	0.178	0.178
	<b>Unit</b>	<b>2020</b>	<b>2021</b>								
Frac <sub>LEACH-(H)</sub>	--	0.178	0.178								

Figure 5-8 illustrates the development of the most important activity data for 3Bb Indirect N<sub>2</sub>O emissions from managed soils. Both leaching and run-off from commercial fertiliser and animal manure N declined during the inventory time period due to the reduced nitrogen inputs and the decreasing nitrate loss rates (Frac<sub>LEACH-H</sub>).

### 5.5.2.5. NMVOC emissions from agricultural soils

The NMVOC emissions from crop production and agricultural soils are calculated based on the Tier 2 approach of the EMEP/EEA guidebook (EMEP/EEA 2019). Three types of agricultural areas are differentiated, i.e. cropland, grassland and summer pastures. The NMVOC emission factors for cropland and grassland are based on the values for wheat and grass (15°C), respectively, of Table 3.3 of the EMEP/EEA guidebook (EMEP/EEA 2019) taking into account country-specific values for the mean dry matter yield (Richner and Sinaj 2017). For summer pastures, the same NMVOC emission value as for grass (15°C) and a fraction of the growing period of 0.3 (Bühler and Kupper 2018) are assumed using a country-specific value for the mean dry matter yield (Richner and Sinaj 2017). The resulting NMVOC emission factors are constant for the entire time series.

### 5.5.3. Uncertainties and time-series consistency

For the uncertainty analysis the input data from ART (2008a) were used and were updated with current activity and emission data as well as with new default uncertainties of the 2019 Refinement (IPCC 2019), causing a significant uncertainty reduction for this source category, compared to the previous submission. The detailed input uncertainty values for category 3D are reported in Annex A2.1. The resulting, combined uncertainty for emissions according to approach 1 (uncertainty propagation) are reported in Annex A2.2 and in Annex A2.3 for results obtained by approach 2 (Monte Carlo simulations). The 95 % confidence intervals obtained by Monte Carlo simulations are slightly narrower and, for non-symmetric distributions, slightly shifted towards the lower edge.

Table 5-28 Uncertainties for 3D Agricultural soils. Approach 1: intervals are exactly from 2.5 % to 97.5 % of the distribution; Approach 2: the narrowest interval representing 95 % of the distribution is given.

Source category	Gas	Activity data uncertainty 2021		Emission factor uncertainty 2021		Emission combined uncertainty 2021	
		(-) %	(+) %	(-) %	(+) %	(-) %	(+) %
Approach 1: uncertainty propagation							
3Da Direct emissions from managed soils	N2O	13	13	62	90	63	91
3Db Indirect emissions from managed soils	N2O	27	32	52	70	58	77
Approach 2: Monte Carlo simulations							
3Da Direct emissions from managed soils	N2O	13	13	69	78	69	79
3Db Indirect emissions from managed soils	N2O	29	30	57	62	61	70

The time series 1990–2021 are all considered consistent, although the following issues should be considered:

- For time series consistency of livestock population data see chp. 5.2.3.
- Input data from the AGRAMMON model are available for the years 1990 and 1995 (expert judgement and literature) as well as for 2002, 2007, 2010, 2015 and 2019 (extensive surveys on approximately 3000 farms). Values in-between the assessment years were interpolated linearly. For 2020 and 2021 the same values as in 2019 were used.
- $Fra_{CGASF}$ ,  $Fra_{CGASM}$  and  $Fra_{CGASP}$  are fluctuating along the time series due to fluctuating shares of different fertiliser types and animal populations with different ammonia emission factors.

- The emission factor for indirect N<sub>2</sub>O emissions following volatilisation of NH<sub>3</sub> and NO<sub>x</sub> from applied fertilisers and urine and dung excreted on pasture, range and paddock varies according to varying land use as described in chp. 5.3.2.4.

For more details on time-series consistency see also chp. 5.2.3 and 5.3.3.

#### 5.5.4. Category-specific QA/QC and verification

General QA/QC measures are described in NID chp. 1.5.

All further category-specific QA/QC activities are described in a separate document (Agroscope 2019a). General information on agricultural structures and policies is provided and eventual differences between national and (IPCC 2006, 2019) standard values are being analysed and discussed.

The Swiss ammonium emission model AGRAMMON is documented in Kupper et al. (2022) and Agrammon (2021). Generally the reporting of N<sub>2</sub>O emissions in the national GHG inventory is consistent with the reporting of other nitrogen compounds (NH<sub>3</sub>, NO<sub>x</sub>) under the CLRTAP.

All relevant parameters needed for the calculation of direct and indirect nitrogen inputs to agricultural soils (e.g. F<sub>CN</sub>, MS-distribution, Fra<sub>C</sub>GAS<sub>F</sub>, N<sub>ex</sub>, Fra<sub>C</sub>GAS<sub>MT</sub>, F<sub>ON</sub>, F<sub>CR</sub>, Fra<sub>C</sub>LEACH-H) were checked for consistency and confidence and were compared (where possible) to IPCC default values (IPCC 2006, 2019), values of other countries as well as values in the literature. Nitrogen excretion, being one of the most important parameters, was analysed in more detail as described in chp. 5.3.4.2.

For quality assurance of livestock population data consult chp. 5.2.4.

N<sub>2</sub>O emission factors were compared to values in the literature to ensure plausibility. Implied emission factors are similar to measured values from the literature representative for Swiss conditions (Agroscope 2019a). In 2018 a focus study in the context of the national research programme 68 (Nationales Forschungsprogramm 68: Ressource Boden) made an independent assessment of the N<sub>2</sub>O emission factors under Swiss conditions based on a literature review (Krause et al. 2018). The authors found that the N<sub>2</sub>O emission factors of mineral soils were 2.06±2.66 % for arable soils and 1.45±1.07 % for grassland soils. Based on the limited data availability and on the great variability between the different measurements they concluded, that these emission factors are not significantly different to the IPCC (2019) values. Still, the numerical difference indicated that further efforts should be made to development country-specific emission factors (see chp. 5.5.6). In 2020, Ammann et al. (2020) investigated the effect of management and weather variations on N<sub>2</sub>O emissions and the greenhouse gas budget of two grasslands in the central plateau of Switzerland during a 10-year experiment. N<sub>2</sub>O emissions were measured quasi-continuously with the eddy-covariance method. The total N<sub>2</sub>O-flux was partitioned to the different categories using the IPCC emission factor approach and confirmed the validity of the respective default values. More recently dos Reis Martins et al. (2022) modelled N<sub>2</sub>O emissions of complex cropland management in Western Europe using DayCent and compared results with measurements and the IPCC default emission factor approaches. They also found that the IPCC default emission factors tend to underestimate emissions although modelled mean values were still well within the great range of the measurements. Within this same project a process-oriented model-framework will be developed to improve estimation of N<sub>2</sub>O emissions from agricultural soils in Switzerland (see chp. 5.5.6).

For the time being Switzerland is still using the aggregated default emission factor for direct soil emissions ( $EF_1$ ) from the 2019 Refinement (IPCC 2019) instead of using disaggregated emission factors for synthetic fertiliser and other nitrogen inputs in wet climates. Reasons for this are:

- Measurements conducted in Switzerland and neighbouring countries have not yet been fully evaluated in this respect. An extensive study in Germany did not indicate higher emission factors of synthetic fertilisers as compared to organic nitrogen inputs (Mathivanan 2021).
- Animal manure is mainly applied to grasslands whereas synthetic fertilisers are mainly applied on croplands. The effect of fertiliser type is thus interacting with land use, management and seasonal weather conditions potentially confounding systematic differences between organic and synthetic fertilisers.
- Emission factors may also differ between different types of synthetic fertilisers (e.g. Cowan et al. 2020, Harty et al. 2016) and different types of organic fertilisers (e.g. Charles et al. 2017) pointing out that the question of fertiliser type should be addressed in a broader way.

The question of the effect of fertiliser type on  $N_2O$  emission factors will be further explored within ongoing field experiments and the current work on a process-oriented model-framework for the estimation of  $N_2O$  emissions from agricultural soils in Switzerland (see chp. 5.5.6).

The  $N_2O$  emission factor for cultivated organic soils was validated by a study from Leifeld (2018) that used a large dataset of C/N ratios in Swiss organic soils to predict  $N_2O$  emissions. The study concluded that the current national GHG inventory neither systematically over- nor underestimates total emissions.

A study by Agroscope (2019b) analysed the greenhouse gas flux measurements of a grazed pasture system for dairy cows in western Switzerland over five years. The fertiliser-related  $N_2O$  emission factor was on average close to the corresponding IPCC default value of 1%. The excreta-related factor was considerably lower than the 2 % proposed in IPCC (2006) albeit higher than the default emission factor of 0.6 % for cattle in wet climate of IPCC (2019). It could also be shown that there is a clear difference in the individual emission factors for urine and dung patches on the pasture. Further experimental measurements at other sites as well as process-based modelling are being conducted in order to consolidate these first results (see chp. 5.5.6).

The estimate for the area of cultivated histosols in the agricultural sector is consistent with the estimates reported under cropland and grassland in the LULUCF sector. A literature study conducted by Leifeld et al. (2003) estimates  $17'000 \pm 5'000$  ha which is close to the numbers reported in the LULUCF sector ( $17'700$  ha on average).

The country-specific value of  $Frac_{LEACH-H}$  is based on a very detailed model for the assessment of leaching and run-off in Switzerland (Hürdler et al. 2015, Prasuhn 2016) that takes into account regional parameters such as topography, different crop species as well as fertiliser application levels.

Henne et al. (2019) conducted a top-down assessment of Swiss  $N_2O$  emissions using atmospheric measurements and an inverse modelling framework. An update is presented in Annex A6.2. The best estimate of annual  $N_2O$  emissions for the investigated period in 2017–2021 was  $10.8 \pm 3.1$  Gg yr<sup>-1</sup>, which compares to 11.5 (8.3 to 14.9) Gg yr<sup>-1</sup> given for the same period in this NID (2- $\sigma$  confidence range). Due to the large uncertainties connected to both numbers, these estimates are not significantly different (see also Annex A6.2).

### 5.5.5. Category-specific recalculations

General information on recalculations is provided in chp. 10.

Recalculations with an overall impact of >0.5 kt CO<sub>2</sub> equivalent are assessed quantitatively. All other recalculations are only described qualitatively.

- For recalculations of livestock population data and emissions from manure management (affecting the amount of animal manure applied to soils) refer to chp. 5.2.5 and chp.5.3.5.
- N<sub>2</sub>O emissions from inorganic fertilizers were recalculated for the whole time series. Activity data was revised due to updated values for inorganic fertilizers used in Liechtenstein that were subtracted from amounts applied in Switzerland. The impact on overall emissions is negligible (<0.2 kt CO<sub>2</sub> equivalents).
- N<sub>2</sub>O emissions from other organic fertilizers were recalculated for the year 2020. Activity data was revised due to updated values for the amount of compost applied to agricultural soils. The impact on overall emissions is negligible (<0.4 kt CO<sub>2</sub> equivalents).
- N<sub>2</sub>O emissions from Urine and dung deposited by grazing animals were recalculated for the whole time series. New emission factors for pasture, range and paddocks (EF<sub>3</sub>'s) from the 2019 IPCC Refinements were adopted. The impact on overall emissions ranges from -135.4 to -75.4 kt CO<sub>2</sub> equivalents.
- N<sub>2</sub>O emissions from nitrogen in crop residues returned to soils were recalculated for the years 2018, 2019 and 2020. Activity data was revised due to updated values for arable crop yields from the Swiss Farmers Union (SFU/SBV). The impact on overall emissions is negligible (<0.1 kt CO<sub>2</sub> equivalents).
- N<sub>2</sub>O emissions from nitrogen in crop residues returned to soils were recalculated for the whole time series. Activity data was revised due to updated values for grassland yields in the LULUCF sector. The impact on overall emissions ranges from -25.2 to +7.9 kt CO<sub>2</sub> equivalents.
- N<sub>2</sub>O emissions from mineralization/immobilization associated with loss/gain of soil organic matter were recalculated for the whole time series. Activity data was revised due to new values for the amount of nitrogen mineralized in the LULUCF sector. The impact on overall emissions ranges from -15.4 to +23.9 kt CO<sub>2</sub> equivalents.
- N<sub>2</sub>O emissions from cultivation of organic soils were recalculated for the years 2013 to 2020. Activity data was revised due to new values for the area of drained organic soils under cropland and grassland in the LULUCF sector. The impact on overall emissions is negligible (<0.05 kt CO<sub>2</sub> equivalents).
- N<sub>2</sub>O emissions from nitrogen leaching and run-off were recalculated for the whole time series. The respective emission factor (EF<sub>5</sub>) from the 2019 IPCC Refinements was adopted. The impact on overall emissions ranges from +51.7 to +74.8 kt CO<sub>2</sub> equivalents.

### 5.5.6. Category-specific planned improvements

FOEN funds the development and evaluation of a process-oriented model for N<sub>2</sub>O emissions (LACHSIM) in agricultural soils subject to common Swiss management practices. Additional N<sub>2</sub>O-measurements (LACHMESS) with automated static chambers on cropland support the calibration and validation of the simulation model. The projects started in 2019 and will continue until the end of 2023 (dos Reis Martins et al. 2022).

A number of measurement projects at Agroscope, partially financed by FOEN, contribute to the establishment of a country specific emission factor for direct N<sub>2</sub>O emissions from urine and dung deposited by grazing animals (EF<sub>3PRP, CPP</sub>). Accordingly, it is foreseen that the

respective estimates for direct N<sub>2</sub>O emissions will be revised during the submission 2024 at the latest.

The methodology for the calculation of emission from nitrogen in crop residues returned to soils is planned for the submission 2024 in order to improve consistency with the methodologies for grassland and cropland in the LULUCF sector.

An update of the area of organic soils is planned as described in chp. 6.3.1.6.

## 5.6. Source category 3E – Prescribed burning of savannahs

Burning of savannahs does not occur (NO) in Switzerland.

## 5.7. Source category 3F – Field burning of agricultural residues

Field burning of agricultural residues does not occur (NO) in Switzerland.

Open burning of natural forest, field and garden waste is regulated in the Ordinance on Air Pollution Control OAPC, (Swiss Confederation 1985: Art. 26b). In Switzerland, cantonal authorities are responsible for the enforcement of the OAPC regulations. The 26 cantons have thus probably slightly different interpretations and implementations of the federal ordinance. An inquiry of some cantonal authorities was performed in order to assess the activity data for these processes (INFRAS 2014).

Emissions from open burning of branches in agriculture and forestry were reported here in the past. However, the respective emissions were moved to the sectors 4 LULUCF and 5 Waste based on recommendations from the UNFCCC expert review teams (e.g. FCCC/ARR/2016/CHE W12 and W13). Respective information can be found under category 4V “Biomass Burning” (see chp. 6.4.2.6.4) and source category 5C “Incineration and open burning of waste” (see chp. 7.4).

## 5.8. Source category 3G – Liming

### 5.8.1. Source category description

Table 5-29 Key categories of 3G Liming. Combined KCA results, level for 2021 and trend for 1990–2021, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

CO<sub>2</sub> emission from 3G Liming is not a key category.

Emissions from the application of lime (Ca(CO<sub>3</sub>)) and dolomite (CaMg(CO<sub>3</sub>)<sub>2</sub>) to agricultural soils are reported.

The emissions due to liming of agricultural soils range from 22.2 to 32.9 kt CO<sub>2</sub> per year.

## 5.8.2. Methodological issues

A simple Tier 1 approach was adopted using estimated amounts of lime and dolomite applied and IPCC (2006) default emission factors.

### 5.8.2.1. Emission factor

The availability of country-specific emission factors for agricultural lime and dolomite application was investigated, but no domestic measurement data could be found.

Consequently, the IPCC default carbon conversion factors for carbonate containing lime (0.12 t C per t  $\text{Ca}(\text{CO}_3)$ ) and for dolomite (0.13 t C per t  $\text{CaMg}(\text{CO}_3)_2$ ) were used (IPCC 2006).

### 5.8.2.2. Activity data

The total annual amount of lime and dolomite applied to agricultural soils is between 50'300 Mg (1990) and 74'050 Mg (2008–2021). It was estimated by Agroscope in 2009 for the period 1990–2008. Major retailers / providers of lime in Switzerland were directly contacted and interviewed. For 2009–2021 the same value as for 2008 was used: An inquiry in 2013 including the most important production and trading companies of lime products suggests that the consumption of limestone remains constant (Agroscope 2014a). This assumption is further supported by the fact that agricultural structures and management did not change fundamentally in recent years. Furthermore, the import of calcium carbonate mixed with ammonium nitrate (contributing 20 % to lime use in Switzerland) is assessed yearly via the import statistics. These statistics do not show a significant trend along the past 20 years (FOCBS 2022a).

The split of lime into calcium carbonate and dolomite is based on the following assumptions and data:

- $\text{Ca}(\text{CO}_3)$  contained in mixed compound fertilisers as reported by Agricura (2021)
- All material originating from nuclear power plants and from the sugar beet industry is  $\text{Ca}(\text{CO}_3)$
- The remaining lime not covered under the points above was divided equally into  $\text{Ca}(\text{CO}_3)$  and  $\text{CaMg}(\text{CO}_3)_2$ .

## 5.8.3. Uncertainties and time-series consistency

The amount of total lime applied in agriculture is mainly based on expert judgement; the resulting number is uncertain. A normal distribution with a relative uncertainty of  $\pm 40$  % for a 95 % coverage interval was used as an approximation (Agroscope 2014a). For the emission factor of lime a lower uncertainty of  $\pm 5$  % was chosen, because it is a simple chemical process. The detailed input uncertainty values for category 3G are reported in Annex A2.1. The resulting, combined uncertainty for emissions according to approach 1 (uncertainty propagation) is thus  $\pm 40$  % (see Annex A2.2), in general concordance with results from approach 2 (Monte Carlo simulations, Annex A2.3).

Consistency: Time series for 3G Liming are all considered consistent.

#### 5.8.4. Category-specific QA/QC and verification

General QA/QC measures are described in NID chp. 1.5.

No further category-specific quality assurance activities were conducted.

#### 5.8.5. Category-specific recalculations

General information on recalculations is provided in chp. 10.

There were no recalculations implemented in submission 2023.

#### 5.8.6. Category-specific planned improvements

No category-specific improvements are planned.

### 5.9. Source category 3H – Urea application

#### 5.9.1. Source category description

Table 5-30 Key categories of 3H Urea application. Combined KCA results, level for 2021 and trend for 1990–2021, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

CO <sub>2</sub> emission from 3H Urea application is not a key category.
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Adding urea to soils during fertilisation leads to a loss of CO<sub>2</sub> that was fixed during the industrial production process of the fertiliser. Emissions in Switzerland range from 8.7 to 26.7 kt CO<sub>2</sub> per year with a general decreasing trend during the 1990s and values near 12 kt CO<sub>2</sub> per year for the later part of the time series.

#### 5.9.2. Methodological issues

A simple Tier 1 approach was adopted using estimated amounts of urea applied and IPCC (2006) default emission factors.

##### 5.9.2.1. Emission factor

No country-specific emission factors are available. Consequently, the IPCC (2006) default emission factor of 0.20 t of C per t of urea was applied.

##### 5.9.2.2. Activity data

The amount of urea applied to agricultural soils was obtained from Agricura (2021). Two positions of the customs tariff list were considered, namely “urea” (tariff number 3102.1000.011) and “urea-ammonia-nitrate” (tariff number 3102.8000.011). Fertiliser statistics are based on sales statistics by the compulsory stockpiler of fertilisers

(Pflichtlagerhalter) and small importers. Agricura conducts plausibility checks with import-data received by the Federal Office for Customs and Border Security (FOCBS).

### **5.9.3. Uncertainties and time-series consistency**

An uncertainty of  $\pm 5\%$  for the activity data was estimated according to ART (2008a). An uncertainty of  $\pm 5\%$  was assumed for the emission factor since it is a simple chemical process (see input uncertainty values in Annex A2.1). The resulting, combined uncertainty for emissions according to approach 1 (uncertainty propagation) is reported in Annex A2.2 and in Annex A2.3 for approach 2 (Monte Carlo simulations). The combined approach 1 uncertainty is  $\pm 7\%$ , in concordance with approach 2.

Consistency: Time series for 3H Urea application are all considered consistent.

### **5.9.4. Category-specific QA/QC and verification**

General QA/QC measures are described in NID chp. 1.5.

No further category-specific quality assurance activities were conducted.

### **5.9.5. Category-specific recalculations**

General information on recalculations is provided in chp. 10.

There were no recalculations implemented in submission 2023.

### **5.9.6. Category-specific planned improvements**

No category-specific improvements are planned.

## 6. Land use, land-use change and forestry (LULUCF)

Responsibilities for sector Land use, land-use change and forestry (LULUCF)	
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### 6.1. Overview of LULUCF

#### 6.1.1. Methodology

Chapter 6 presents estimates of GHG emissions by sources and removals by sinks from land use, land-use change and forestry (LULUCF). The sector LULUCF includes emissions and removals from the carbon pool in Harvested wood products (HWP). Data acquisition and calculations are based on the 2006 IPCC Guidelines for National Greenhouse Gas Inventories and their 2019 Refinement (IPCC 2006, 2019, Volume 4 "Agriculture, Forestry and Other Land Use" (AFOLU)).

In 1979, the Swiss Land Use Statistics AREA was launched. Aerial photos from the periods 1979/85, 1990/98, 2004/09, 2012/19 and 2020 were evaluated by the Federal Statistical Office. AREA produces geographically explicit land use data with a resolution of one hectare (following approach 3 for representing land areas; IPCC 2006). In 2022, first results of the fifth survey were available. The repeated assessment of land use allows for a harmonised tracking of land use and land-use change across the entire national territory over the inventory period.

The six main land-use categories required by IPCC (2006) are: A. Forest land, B. Cropland, C. Grassland, D. Wetlands, E. Settlements and F. Other land. These were subdivided into 17 land-use categories, which form the basis for LULUCF reporting. The land-use categories are usually referred to in this document together with their combination category (CC) code. Following the guidelines, lands in each land-use category were stratified by mineral and organic soil. Due to the topography of Switzerland, Forest land, Cropland and permanent grassland were further stratified by three elevation zones. For Forest land, an additional

stratification based on the five production regions of the National Forest Inventory (NFI) was used.

For Forest land, country-specific carbon stocks and carbon stock change factors were derived from four National Forest Inventories (NFI1, NFI2, NFI3, NFI4, finalized in 1985, 1995, 2006 and 2017, respectively) and two annual tranches of the continuous NFI5 (2018, 2019). The inventories comprised ca. 1'350 (NFI5), 6'000 (NFI2, NFI3, NFI4) and 11'000 (NFI1) terrestrial plots, where biomass stock, growth, cut and mortality were measured. The carbon dynamics in dead wood, litter and mineral soil were simulated with the model Yasso07. For Cropland and permanent grassland, a modelling approach with RothC forms the basis for reporting carbon fluxes in living biomass and mineral soil.

For the remaining land-use categories and carbon pools, carbon stocks and carbon stock change factors were derived from domestic surveys, particular research activities, measurements and expert estimates. Partially, mainly for non-CO<sub>2</sub> emission factors, IPCC (2006, 2019) default values were used (see CRF Summary3s2).

## 6.1.2. Emissions and removals

### 6.1.2.1. CO<sub>2</sub> emissions and removals

Over the inventory period, total net emissions and removals of CO<sub>2</sub> varied between -5'521 kt (1996) and 5'205 kt (2000). Table 6-1 and Figure 6-1 show a breakdown of Switzerland's CO<sub>2</sub> balance in the LULUCF sector. Five components were differentiated:

- Carbon gains in living biomass on all land uses and due to land-use changes; this component acts as the largest sink of carbon.
- Carbon losses in living biomass on all land uses and due to land-use changes; this component acts as the largest source of carbon. The highest losses were observed in the year 2000 after a heavy storm with windfall in December 1999.
- Net carbon stock changes in dead organic matter (DOM; consisting of dead wood and litter) on Forest land remaining forest land as well as land converted to or from Forest land. This component acts as a sink of carbon in most years.
- Net carbon stock changes in mineral and organic soils due to land use and land-use changes. In all years soils are net emitters of CO<sub>2</sub>.
- Net carbon stock changes in Harvested wood products. With the exception of the years 2013, 2017 and 2019 this component acted as a sink of carbon, i.e. the overall carbon stock stored in wood products was increasing.

The largest part of carbon gains and carbon losses in living biomass occurred in forests, where growth of biomass (carbon gains) exceeded cut and mortality (carbon losses), except for the year 2000 (see also chp. 2.2.2.3). Overall, the LULUCF sector acted as a net sink of on average -2'262 kt CO<sub>2</sub> yr<sup>-1</sup> over the inventory period (see Table 6-1).

Table 6-1 CO<sub>2</sub> emissions and removals in the LULUCF sector broken down by (1) CO<sub>2</sub> removals due to carbon gains in living biomass, (2) CO<sub>2</sub> emissions due to carbon losses in living biomass, (3) net CO<sub>2</sub> changes in dead organic matter, (4) net CO<sub>2</sub> changes in mineral and organic soils, and (5) net CO<sub>2</sub> changes in Harvested wood products. Positive values refer to emissions; negative values refer to removals.

LULUCF	Unit	1990	1995	2000	2005	2010
Gains in living biomass	kt CO <sub>2</sub>	-12'794	-12'849	-12'718	-12'899	-13'171
Losses in living biomass	kt CO <sub>2</sub>	12'092	9'361	18'447	11'494	11'828
Net change in dead organic matter	kt CO <sub>2</sub>	-343	-559	-542	-1'153	-1'492
Net change in organic and mineral soils	kt CO <sub>2</sub>	325	626	719	294	392
LULUCF (excluding HWP)	kt CO <sub>2</sub>	-720	-3421	5906	-2263	-2443
Net change in Harvested wood products (HWP)	kt CO <sub>2</sub>	-1'127	-442	-701	-687	-424
Total LULUCF	kt CO <sub>2</sub>	-1848	-3863	5205	-2950	-2867

LULUCF	Unit	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	Mean
Gains in living biomass	kt CO <sub>2</sub>	-13'406	-13'194	-13'232	-13'270	-13'263	-13'249	-13'599	-13'383	-13'309	-13'601	-13'034
Losses in living biomass	kt CO <sub>2</sub>	10'827	11'399	11'776	10'842	10'649	11'310	11'978	10'999	11'237	11'607	11'201
Net change in dead organic matter	kt CO <sub>2</sub>	-524	-807	402	-393	-124	-481	-99	-71	168	-522	-632
Net change in organic and mineral soils	kt CO <sub>2</sub>	633	721	922	876	720	664	646	549	445	617	523
LULUCF (excluding HWP)	kt CO <sub>2</sub>	-2470	-1881	-133	-1945	-2018	-1756	-1074	-1905	-1459	-1898	-1942
Net change in Harvested wood products (HWP)	kt CO <sub>2</sub>	-107	77	-90	-71	-28	8	-75	78	-29	-39	-320
Total LULUCF	kt CO <sub>2</sub>	-2'577	-1804	-222	-2016	-2046	-1749	-1149	-1828	-1488	-1937	-2262

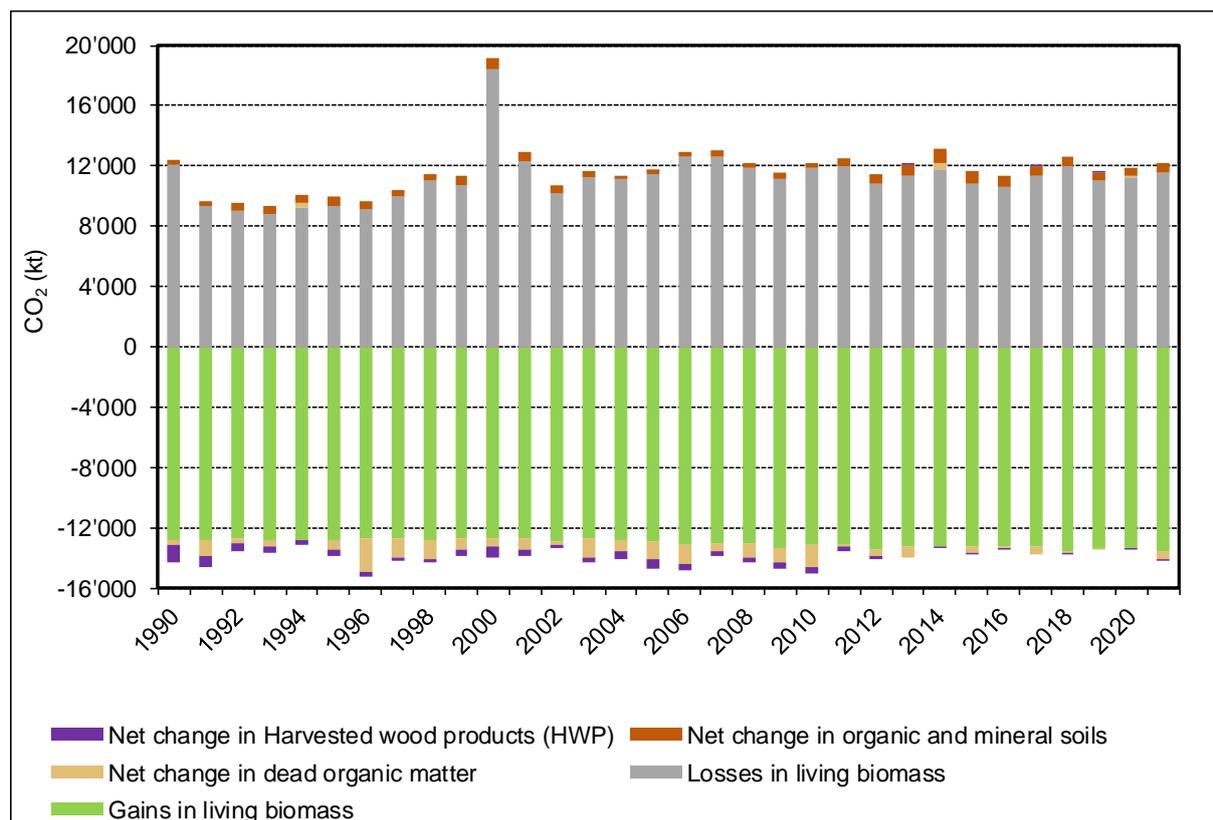


Figure 6-1 CO<sub>2</sub> emissions and removals in the LULUCF sector (in kt CO<sub>2</sub>) broken down by (1) carbon gains in living biomass, (2) carbon losses in living biomass, (3) net changes in dead organic matter, (4) net changes in organic and mineral soils, and (5) net changes in Harvested wood products. Positive values refer to net emissions, negative values refer to net removals.

### 6.1.2.2. Non-CO<sub>2</sub> emissions

The non-CO<sub>2</sub> emissions associated with land use, land-use change and forestry were small. Maximum annual CH<sub>4</sub> emissions were 1.24 kt yr<sup>-1</sup> (35 kt CO<sub>2</sub> eq; 1997), and maximum annual N<sub>2</sub>O emissions were 0.20 kt yr<sup>-1</sup> (54 kt CO<sub>2</sub> eq; 1997) (Figure 6-2). The emissions arose from (1) drained organic soil (N<sub>2</sub>O; CRF Table4(II)), (2) flooded lands/reservoirs (CH<sub>4</sub>; CRF Table4(II)), (3) nitrogen mineralisation associated with loss of soil organic matter resulting from land use on non-agricultural soils and land-use change (direct N<sub>2</sub>O emissions; CRF Table4(III)), (4) nitrogen leaching and run-off on non-agricultural soils and land-use change (indirect N<sub>2</sub>O emissions; CRF Table4(IV)), (5) wildfires on Forest land and Grassland (CH<sub>4</sub> and N<sub>2</sub>O; CRF Table4(V)), and (6) controlled burning of residues from forestry (CH<sub>4</sub> and N<sub>2</sub>O; CRF Table4(V)).

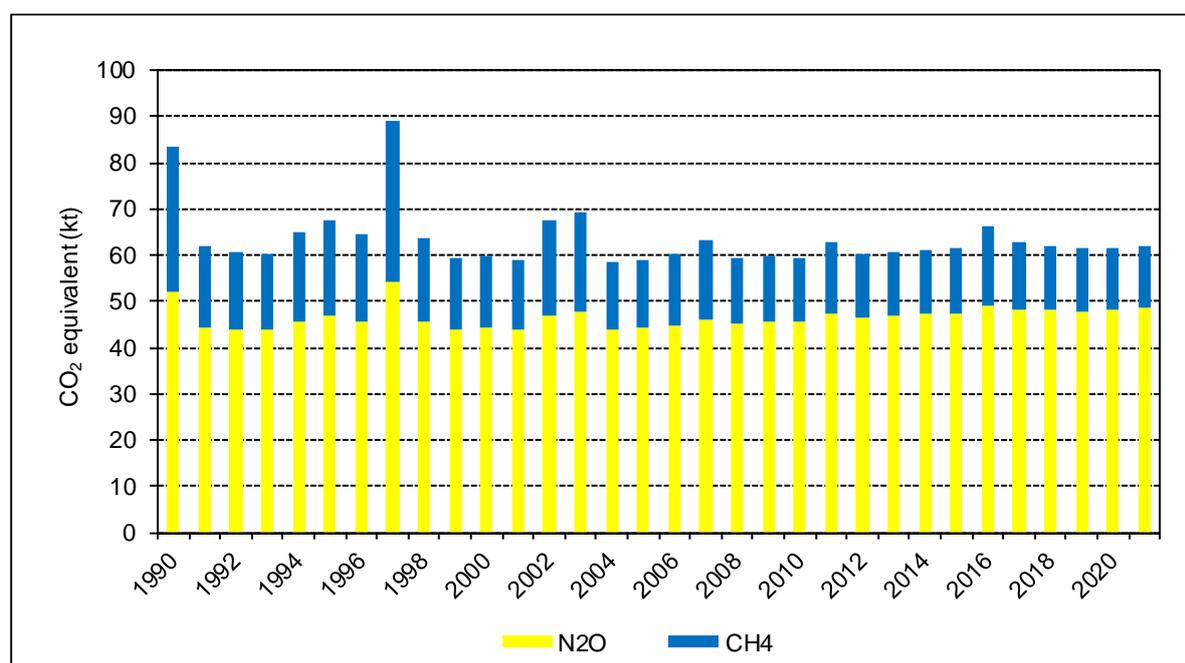


Figure 6-2 N<sub>2</sub>O and CH<sub>4</sub> emissions in the LULUCF sector (in kt CO<sub>2</sub> eq).

### 6.1.2.3. GHG emissions and removals

Figure 6-3 shows the resulting net GHG (CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O) emissions and removals in the LULUCF sector over the inventory period broken down by categories 4A–4G. GHG fluxes were dominated by biomass dynamics in forests (4A). Further explanatory notes on LULUCF trends can be found in chp. 2.2.2.3 “Emission and removal trends in sector 4 LULUCF”.

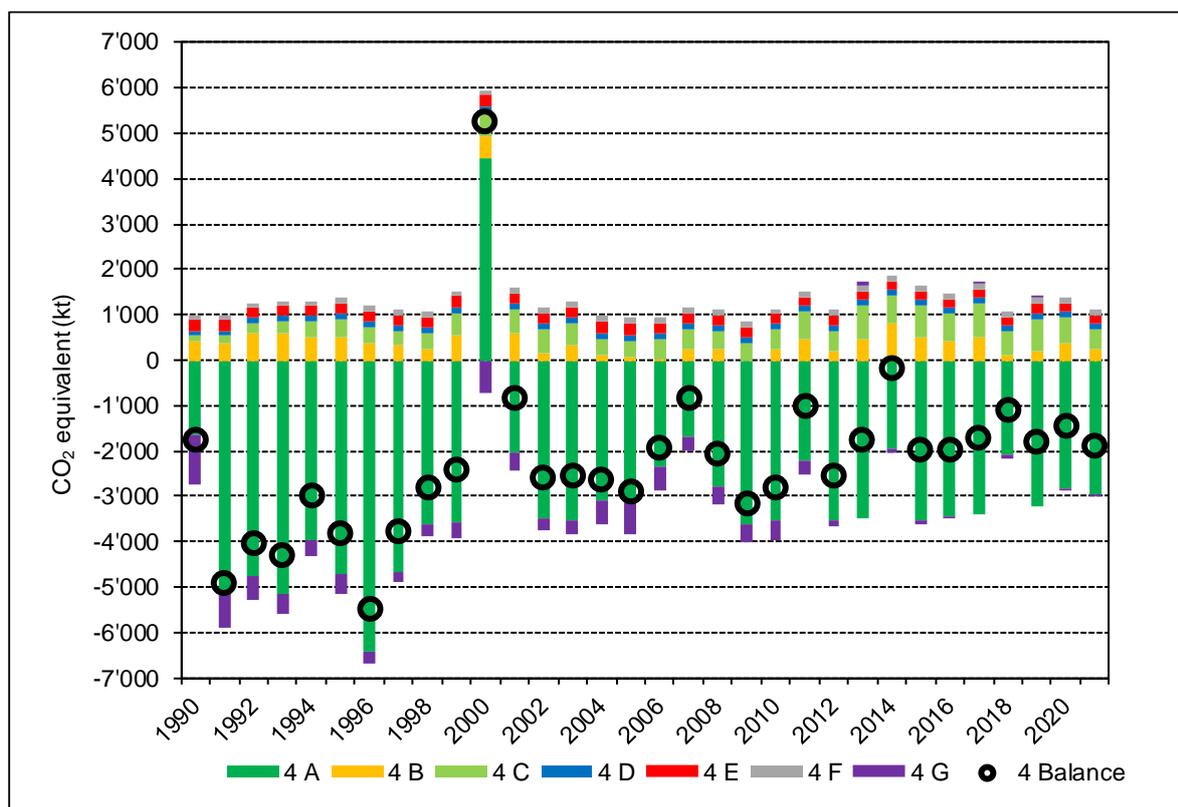


Figure 6-3 Stacked net GHG (CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O) emissions and removals in the LULUCF sector (in kt CO<sub>2</sub> eq) broken down by categories 4A–4G. Balance indicates the annual net total. Positive values refer to net emissions, negative values refer to net removals. Figure 2-8 shows a simplified and Figure 2-9 an unstacked representation of the data set.

### 6.1.3. Approach for calculating carbon emissions and removals

#### 6.1.3.1. Work steps

The selected procedure for calculating carbon emissions and removals in the LULUCF sector corresponds to a Tier 2 approach as described in IPCC 2006 (Volume 4, chp. 3). It can be summarised as follows:

- Define managed and unmanaged land: In Switzerland, all land besides Other land is considered to be managed. Other land (see Table 6-2) is unmanaged. It is defined as the residual country's land area without relevant human activity.
- Define land-use categories with respect to available land use data (see Table 6-2). Land-use categories were introduced as combination categories (CC), defined on the basis of the AREA land-use and land-cover categories (see chp. 6.2.1 and Table 6-6; SFSO 2006a; FSO 2022i).
- Define criteria and collect data for the spatial stratification of the land-use categories.
- For Forest land: Derive carbon stocks in living biomass (stockC<sub>l</sub>), dead wood (stockC<sub>d</sub>), litter (stockC<sub>h</sub>), and soil (stockC<sub>s</sub>) for each spatial stratum of the land-use categories. For non-Forest land: Derive carbon stocks in living biomass (stockC<sub>l</sub>), dead organic matter (stockC<sub>dom</sub>), and soil (stockC<sub>s</sub>) for each spatial stratum of the land-use categories.
- For Forest land: Derive carbon gains in living biomass (gainC<sub>l</sub>), carbon losses in living biomass (lossC<sub>l</sub>), net carbon stock change in dead wood (changeC<sub>d</sub>), litter (changeC<sub>h</sub>), and soil (changeC<sub>s</sub>) for each spatial stratum of the land-use categories. For non-Forest land: Derive carbon gains in living biomass (gainC<sub>l</sub>), carbon losses in

living biomass ( $\text{lossC}_i$ ), net carbon stock change in dead organic matter ( $\text{changeC}_{\text{dom}}$ ) and soil ( $\text{changeC}_s$ ) for each spatial stratum of the land-use categories.

- Calculate land use and land-use change matrices for each spatial stratum over the inventory period.
- For Forest land: Calculate net carbon stock changes in living biomass ( $\text{deltaC}_i$ ), dead wood ( $\text{deltaC}_d$ ), litter ( $\text{deltaC}_h$ ), and soil ( $\text{deltaC}_s$ ) for all cells of the land-use change matrix for each year under consideration.  
For non-Forest land: Calculate net carbon stock changes in living biomass ( $\text{deltaC}_i$ ), dead organic matter ( $\text{deltaC}_{\text{dom}}$ ), and soil ( $\text{deltaC}_s$ ) for all cells of the land-use change matrix for each year under consideration.
- Finally, aggregate the results by summarising the carbon stock changes over land-use categories and spatial strata according to the level of disaggregation displayed in the reporting tables.
- Calculate  $\text{CO}_2$  emissions and removals of the carbon pool in Harvested wood products (HWP).

Table 6-2 Six main land-use categories (according to IPCC 2006) and 17 land-use categories used for LULUCF reporting. Additionally, descriptive remarks, abbreviations used in the reporting tables, and combination categories codes are given (CC code; see chp. 6.2.1 and Table 6-6).

Main category	Land-use category	Remarks	Terminology in CRF tables	CC code
A. Forest land	productive forest	dense and open forest meeting the criteria of forest land	4A1: CC12 4A2: productive	12
	unproductive forest	brush forest and forest on unproductive areas meeting the criteria of forest land	4A1: CC13 4A2: unproductive	13
B. Cropland	cropland	arable and tillage land (annual crops and leys in arable rotations)	CC21	21
C. Grassland	permanent grassland	meadows, pastures (low-land and alpine)	4C1: CC31 4C2: permanent	31
	shrub vegetation	agricultural and unproductive areas predominantly covered by shrubs	4C1: CC32 4C2: woody	32
	vineyard, low-stem orchard, tree nursery	perennial agricultural plants with woody biomass and grass understorey	4C1: CC33 4C2: woody	33
	copse	agricultural and unproductive areas covered by perennial woody biomass including trees, with grass understorey	4C1: CC34 4C2: woody	34
	orchard	permanent grassland with fruit trees and grass understorey	4C1: CC35 4C2: woody	35
	stony grassland	grass, herbs and shrubs on stony surfaces	4C1: CC36 4C2: unproductive	36
	unproductive grassland	unproductive grass vegetation	4C1: CC37 4C2: unproductive	37
D. Wetlands	surface water	lakes and rivers	surface water	41
	unproductive wetland	reed, extensively managed wetland	unprod wetland	42
E. Settlements	buildings and constructions	areas without vegetation such as houses, roads, construction sites, dumps	building	51
	herbaceous biomass in settlements	areas with low vegetation, e.g. lawns	herb	52
	shrubs in settlements	areas with perennial woody biomass (no trees)	shrub	53
	trees in settlements	areas with perennial woody biomass including trees	tree	54
F. Other land	other land	unmanaged areas without soil and vegetation: rocks, sand, scree, glaciers		61

### 6.1.3.2. Calculating carbon stock changes

For calculating carbon stock changes, the following input parameters (mean values per hectare) were quantified for all land-use categories (coded as CC) and spatial strata (i):

stockC <sub>l,i,CC</sub>	carbon stock in living biomass (t C ha <sup>-1</sup> )
stockC <sub>d,i,CC</sub>	carbon stock in dead wood (t C ha <sup>-1</sup> )
stockC <sub>h,i,CC</sub>	carbon stock litter (organic soil horizons) (t C ha <sup>-1</sup> )
stockC <sub>s,i,CC</sub>	carbon stock in soil (t C ha <sup>-1</sup> )
gainC <sub>l,i,CC</sub>	annual carbon gain in living biomass (t C ha <sup>-1</sup> yr <sup>-1</sup> )
lossC <sub>l,i,CC</sub>	annual carbon loss in living biomass (t C ha <sup>-1</sup> yr <sup>-1</sup> )
changeC <sub>d,i,CC</sub>	annual net carbon stock change in dead wood (t C ha <sup>-1</sup> yr <sup>-1</sup> )
changeC <sub>h,i,CC</sub>	annual net carbon stock change in litter (t C ha <sup>-1</sup> yr <sup>-1</sup> )
changeC <sub>s,i,CC</sub>	annual net carbon stock change in soil (t C ha <sup>-1</sup> yr <sup>-1</sup> )

In the reporting tables on non-Forest land under the UNFCCC (Table4.B to Table4.F), the carbon stocks and carbon stock changes of litter and dead wood are merged into "dead organic matter" (DOM):

$$\text{stockC}_{\text{dom},i,CC} = \text{stockC}_{d,i,CC} + \text{stockC}_{h,i,CC}$$

$$\text{changeC}_{\text{dom},i,CC} = \text{changeC}_{d,i,CC} + \text{changeC}_{h,i,CC}$$

On this basis, the total changes in carbon stocks (t C yr<sup>-1</sup>) in living biomass (deltaC<sub>l</sub>), dead wood (deltaC<sub>d</sub>), litter (deltaC<sub>h</sub>), or dead organic matter (deltaC<sub>dom</sub>), respectively, and soils (deltaC<sub>s</sub>) were calculated for all cells of the land-use change matrix for each year under consideration. Each cell is characterized by a land-use category before the conversion (b), a land-use category after the conversion (a), and the area of converted land within the spatial stratum (i). This approach includes cases without any land-use change (a = b).

Equations 6.1–6.8 show, according to the IPCC Guidelines (IPCC 2006, Volume 4), two approaches and their application for calculating carbon gains and losses: (1) the gain-loss approach (Equation 2.4; IPCC 2006, Volume 4) and (2) the stock-difference approach (Equation 2.5; IPCC 2006, Volume 4).

The gain-loss approach for calculating (net) carbon stock changes is defined as:

$$\text{deltaC}_{l,i,ba} = (\text{gainC}_{l,i,a} - \text{lossC}_{l,i,a}) * A_{i,ba} \quad (6.1)$$

$$\text{deltaC}_{d,i,ba} = \text{changeC}_{d,i,a} * A_{i,ba} \quad (6.2)$$

$$\text{deltaC}_{h,i,ba} = \text{changeC}_{h,i,a} * A_{i,ba} \quad (6.3)$$

$$\text{deltaC}_{s,i,ba} = \text{changeC}_{s,i,a} * A_{i,ba} \quad (6.4)$$

The stock-difference approach for calculating carbon stock changes is defined as:

$$\text{deltaC}_{l,i,ba} = [ ( \text{stockC}_{l,i,a} - \text{stockC}_{l,i,b} ) / \text{CT} ] * A_{i,ba} \quad (6.5)$$

$$\text{deltaC}_{d,i,ba} = [ ( \text{stockC}_{d,i,a} - \text{stockC}_{d,i,b} ) / \text{CT} ] * A_{i,ba} \quad (6.6)$$

$$\text{deltaC}_{h,i,ba} = [ ( \text{stockC}_{h,i,a} - \text{stockC}_{h,i,b} ) / \text{CT} ] * A_{i,ba} \quad (6.7)$$

$$\text{deltaC}_{s,i,ba} = [ ( \text{stockC}_{s,i,a} - \text{stockC}_{s,i,b} ) / \text{CT} ] * A_{i,ba} \quad (6.8)$$

The change in dead organic matter (DOM) is the sum of the changes in dead wood and litter:

$$\text{deltaC}_{\text{dom},i,ba} = \text{deltaC}_{d,i,ba} + \text{deltaC}_{h,i,ba} \quad (6.9)$$

where:

a	land-use category after conversion (CC = a)
b	land-use category before conversion (CC = b)
ba	land-use conversion from b to a
i	spatial stratum
$A_{i,ba}$	area of land (ha) converted from b to a in the spatial stratum i (area converted in the inventory year if CT=1 year, or the sum of the areas converted within the last 20 years if CT=20 years)
CT	conversion time (yr), see chp. 6.1.3.3.

Table 6-3 defines the calculation approaches. The gain-loss approach was used in cases of no change in land use and generally for continuous transitions, e.g. the growth of living biomass on land converted to forest land. The stock-difference approach was used for abrupt changes following discrete events (e.g. loss of biomass by deforestation, CT = 1 year) as well as for slow processes such as the change in soil carbon content (CT = 20 years, see chp. 6.1.3.3).

For conversions between the two forest land-use categories the approach was chosen in such a way that potential carbon losses of living biomass cannot be underestimated: e.g. for CC12 to CC13 stock-difference is used, and for CC13 to CC12 gain-loss is used, respectively (see Table 6-3).

In case of a land-use change to "Buildings and constructions" (CC51) a loss of 20 % of the initial soil carbon stock was reported (for a detailed documentation see chp. 6.8.2.2.3). In case of land-use changes from CC51 to other categories the regular stock-difference approach according to equation 6.8 and Table 6-3, respectively, were applied.

Table 6-3 Calculation approaches (gain-loss or stock-difference with conversion time in years) applied for different land-use changes and carbon pools. Combination category codes CC12–CC61 were introduced in Table 6-2.

Change in land-use category	Living biomass	Dead wood, litter (dead organic matter)	Mineral soil	Organic soil	Remarks
no change in category	gain-loss	gain-loss	gain-loss	gain-loss	
4A1: CC13 to CC12	gain-loss	stock-diff., 20	stock-diff., 20	gain-loss	forest land internal changes
4A1: CC12 to CC13	stock-diff., 20	stock-diff., 20	stock-diff., 20	gain-loss	forest land internal changes
4A2: non-forest category to CC12/CC13	gain-loss	stock-diff., 20	stock-diff., 20	gain-loss	change to forest land
4B2: change to CC21	stock-diff., 1	stock-diff., 1	stock-diff., 20	gain-loss	change to cropland
4C1: change among CC31-37	stock-diff., 1	stock-diff., 1	stock-diff., 1	gain-loss	grassland internal changes
4C2: change to CC31, CC36, CC37	stock-diff., 1	stock-diff., 1	stock-diff., 20	gain-loss	change to permanent and unproductive grassland categories
4C2: change to CC32-35	stock-diff., 20	stock-diff., 1	stock-diff., 20	gain-loss	change to woody grassland categories
4D1: change among CC41-42	stock-diff., 1	stock-diff., 1	stock-diff., 1	gain-loss	wetlands internal changes
4D2: change to CC41	stock-diff., 1	stock-diff., 1	stock-diff., 1	gain-loss	change to surface water
4D2: change to CC42	stock-diff., 1	stock-diff., 1	stock-diff., 20	gain-loss	change to unproductive wetland
4E1: change among CC51-54	stock-diff., 1	stock-diff., 1	stock-diff., 1	gain-loss	settlements internal changes
4E2: change to CC51	stock-diff., 1	stock-diff., 1	stock-diff., 20 (20%)	stock-diff., 20 (20%)	change to sealed settlement areas; soil carbon stock reduced by 20%
4E2: change to CC52-54	stock-diff., 1	stock-diff., 1	stock-diff., 20	gain-loss	change to unsealed settlement areas
4F2: change to CC61	stock-diff., 1	stock-diff., 1	stock-diff., 20	stock-diff., 20	change to other land

### 6.1.3.3. Conversion time in the stock-difference approach

Table 6-3 shows the conversion times applied in the stock-difference approach to carbon stock changes in living biomass, dead organic matter (dead wood, litter), and soil for different land-use changes.

Changes in the soil carbon stock, and this is also true for the increase of woody biomass, as a result of land-use changes are slow processes that might take decades. Therefore, IPCC (2006, Volume 4, chp. 2) suggests implementing a conversion time (CT). Following the IPCC default value (CT = 20 years), carbon emissions or removals due to a soil carbon stock difference ( $\text{stock}C_{s,i,a} - \text{stock}C_{s,i,b}$ ) do not occur in one year but are distributed evenly over the 20 years following the land-use change.

A conversion time of 20 years was applied to all mineral soil carbon stock changes except for land converted to surface water and for internal changes in Grassland, Wetlands and Settlements. Accordingly, the area of mineral soil of each category 2 in reporting tables Table4.A to Table4.F contains the cumulative area remaining in the respective category in the reporting year.

There are no consistent data sources on land-use changes before 1990, but it is well known, that the main trends of the Swiss land-use dynamics, e.g. increase of forest area (FOEN 2023f: chp. 1) and settlements (ARE/FOEN 2007) arose before 1972. Therefore, it was assumed that between 1971 and 1989 the annual rate of all land-use changes was the same as in 1990. Based on this assumption it was possible to produce the land-use data required for the consideration of the conversion time in that period.

#### 6.1.3.4. Displaying results in the Common Reporting Format

In the reporting tables Table4.A to Table4.F, a part of the land-use categories and associated spatial strata are shown at an aggregated level. The values of  $\Delta C$  are accordingly summarised. Positive values of  $\Delta C_{l,i,ba}$  were inserted in the column "Gains" and negative values in the column "Losses", respectively. The values of  $\Delta C_{d,i,ba}$ ,  $\Delta C_{h,i,ba}$  were inserted into columns "Net carbon stock change in dead wood" and "Net carbon stock change in litter" in CRF Table4.A, and the values of  $\Delta C_{dom,i,ba}$  were inserted into columns "Net carbon stock change in dead organic matter" in the reporting tables Table4.B to Table4.F. The values of  $\Delta C_{s,i,ba}$  were inserted into columns "Net carbon stock change in soils" in the reporting tables Table4.A to Table4.F.

The reporting tables Table4.A to Table4.F are subdivided in two parts: (1) X land remaining X land and (2) Land converted to X land. Changes of areas from one land use to another within the same main land-use category are reported in part (1) of the reporting tables. For example, the area of "shrub vegetation" (CC32) converted to "permanent grassland" (CC31) would be reported in CRF Table4.C under 4C1 in the subdivision "permanent". As CC31 and CC32 do have different carbon stocks in biomass and soils, carbon stock changes would be calculated according to the equations presented in chp. 6.1.3.2.

The CRF reporter generated errors or inconsistent content in several reporting tables related to the LULUCF sector (see Annex 7).

#### 6.1.4. Overview: Carbon stocks and carbon stock changes in the land-use categories

Table 6-4 presents carbon stocks, carbon gains, carbon losses and net changes in carbon stocks for the pools living biomass, dead wood, litter, and mineral and organic soil stratified by land-use category and spatial strata for the year 1990. These data were used to calculate the net CO<sub>2</sub> emissions and removals presented in the reporting tables according to the methods in chp. 6.1.3.

The values shown in Table 6-4 remain constant during the inventory period with the following exceptions (highlighted cells):

- Productive forest (CC12): (1) Carbon stocks in living biomass, carbon gains and carbon losses in living biomass, (2) carbon stocks and net carbon stock changes in dead wood, (3) carbon stocks and net carbon stock changes in litter, and (4) net carbon stock changes in mineral soil. Derivation of data and annual values are described in chp. 6.4.2.2 and chp. 6.4.2.3.
- Cropland (CC21): (1) Carbon stocks in living biomass, carbon gains and carbon losses in living biomass, (2) carbon stocks and net carbon stock changes in mineral soil. Derivation of data and annual values are described in chp. 6.5.2.

- Permanent grassland (CC31): (1) Carbon stocks in living biomass, carbon gains and carbon losses in living biomass, (2) carbon stocks and net carbon stock changes in mineral soil. Derivation of data and annual values are described in chp. 6.6.2.

The derivation of the individual carbon stocks, carbon gains, carbon losses, and net carbon stock changes is explained in detail in chapters 6.4 to 6.9.

With regard to the columns "Carbon stock in" in Table 6-4, the entry "0" indicates the absence of biomass or soil organic carbon in the corresponding carbon pool.

With regard to the columns "Carbon gains in living biomass", "Carbon losses in living biomass", and "Net change in", the following applies:

- Positive values refer to gains, negative values refer to losses in the respective carbon pool.
- The notation key "NA" indicates a Tier 1 approach, where the carbon pool is assumed to be in equilibrium (in accordance with the conclusions and recommendations from the 16<sup>th</sup> meeting of the GHG inventory Lead Reviewers, Bonn, March 2019). In the calculation with the formulas from chapter 6.1.3.2, this entry is transferred into the numerical value 0.
- The notation key "NO" indicates that the process did not exist in 1990. In the calculation with the formulas from chapter 6.1.3.2, this entry is transferred into the numerical value 0.
- For Forest land, the net change of carbon stocks in drained organic soil is  $-2.6 \text{ t C ha}^{-1} \text{ yr}^{-1}$ . 3 % of the area of organic soil is estimated to be drained (see chp. 6.4.2.3.8), which leads to a correspondingly smaller implied carbon stock change factor of  $-0.08 \text{ t C ha}^{-1} \text{ yr}^{-1}$  in CRF Table 4.A. In contrast, organic soil on non-Forest land is assumed to have 100 % drainage with the land-use category surface waters (CC41) as the only exception (see chp. 6.7.2.2.2).

Table 6-4 Carbon stocks and carbon stock changes in living biomass, dead wood, litter, mineral and organic soil for land-use categories, stratified by elevation zone, NFI production region, and soil type. Data on carbon stock changes apply where the gain-loss calculation approach is used (see Table 6-3). The values are valid for the whole inventory period with the exception of the values in the highlighted cells, which change annually (numbers given here are for the year 1990); see main text.

CC code, land-use category	NFI region	Elevation zone	Carbon stock in living biomass (stockC <sub>l,i</sub> )	Carbon stock in dead wood (stockC <sub>d,i</sub> )	Carbon stock in litter (stockC <sub>h,i</sub> )	Carbon stock in mineral soil (stockC <sub>s,i</sub> )	Carbon stock in organic soil (stockC <sub>s,i</sub> )	Carbon gains in living biomass (gainC <sub>l,i</sub> )		Carbon losses in living biomass (lossC <sub>l,i</sub> )		Net change in dead wood (changeC <sub>d,i</sub> )	Net change in litter (changeC <sub>h,i</sub> )	Net change in mineral soil (changeC <sub>s,i</sub> )	Net change in (drained) organic soil (changeC <sub>s,i</sub> )
								[t C ha <sup>-1</sup> ]	[t C ha <sup>-1</sup> yr <sup>-1</sup> ]	[t C ha <sup>-1</sup> yr <sup>-1</sup> ]	[t C ha <sup>-1</sup> yr <sup>-1</sup> ]				
12 Productive forest	1	1	128.65	4.89	11.97	56.54	145.6	3.60	-2.38	0.03	-0.12	0.00	-2.6		
		2	125.27	5.26	12.16	101.16	145.6	3.21	-2.28	0.03	-0.06	0.00	-2.6		
		3	84.74	4.65	10.35	129.46	145.6	1.95	-1.36	-0.03	-0.16	0.00	-2.6		
	2	1	134.51	8.10	12.35	50.30	145.6	4.63	-4.77	0.03	-0.13	0.00	-2.6		
		2	147.20	7.86	13.23	64.13	145.6	4.63	-4.61	0.03	-0.09	0.00	-2.6		
		3	102.11	7.86	13.23	128.23	145.6	1.60	-1.05	0.03	-0.09	0.00	-2.6		
	3	1	135.07	7.54	14.09	63.42	145.6	4.56	-3.35	0.09	-0.01	0.00	-2.6		
		2	147.49	7.54	14.09	80.18	145.6	4.15	-3.78	0.09	-0.01	0.00	-2.6		
		3	118.79	6.03	13.63	103.28	145.6	2.48	-2.75	0.02	-0.04	0.00	-2.6		
	4	1	92.97	5.39	11.14	69.96	145.6	3.24	-3.19	0.09	0.01	0.00	-2.6		
		2	103.37	5.39	11.14	77.51	145.6	2.49	-2.59	0.09	0.01	0.00	-2.6		
		3	94.98	4.98	14.06	73.68	145.6	1.81	-2.47	0.11	0.10	0.00	-2.6		
	5	1	72.68	2.15	8.14	119.86	145.6	2.74	-0.92	0.05	0.01	0.00	-2.6		
		2	76.85	2.09	9.62	112.91	145.6	2.20	-0.61	0.07	0.12	0.00	-2.6		
		3	76.43	1.77	11.17	97.05	145.6	1.61	-0.30	0.02	0.16	0.00	-2.6		
	13 Unproductive forest	1	1	38.53	0	12.10	57.08	145.6	NA	NA	NA	NA	NA	-2.6	
			2	51.10	0	12.92	106.91	145.6	NA	NA	NA	NA	NA	-2.6	
			3	51.34	0	10.57	123.61	145.6	NA	NA	NA	NA	NA	-2.6	
2		1	20.45	0	12.07	52.49	145.6	NA	NA	NA	NA	NA	-2.6		
		2	35.83	0	13.01	65.35	145.6	NA	NA	NA	NA	NA	-2.6		
		3	51.33	0	13.01	125.59	145.6	NA	NA	NA	NA	NA	-2.6		
3		1	20.45	0	14.62	61.82	145.6	NA	NA	NA	NA	NA	-2.6		
		2	47.53	0	14.62	80.81	145.6	NA	NA	NA	NA	NA	-2.6		
		3	42.36	0	13.55	103.24	145.6	NA	NA	NA	NA	NA	-2.6		
4		1	21.60	0	12.02	70.90	145.6	NA	NA	NA	NA	NA	-2.6		
		2	31.48	0	12.02	77.52	145.6	NA	NA	NA	NA	NA	-2.6		
		3	29.88	0	14.86	82.29	145.6	NA	NA	NA	NA	NA	-2.6		
5		1	20.83	0	8.74	100.90	145.6	NA	NA	NA	NA	NA	-2.6		
		2	23.82	0	11.45	99.71	145.6	NA	NA	NA	NA	NA	-2.6		
		3	24.35	0	12.53	102.48	145.6	NA	NA	NA	NA	NA	-2.6		

Legend				
Elevation zones:		NFI regions:		
1	< 601 m	1	Jura	n.s. = no stratification
2	601 - 1200 m	2	Central Plateau	Annual data
3	> 1200 m	3	Pre-Alps	
		4	Alps	
		5	Southern Alps	

(Table 6-4 continued)

CC code, land-use category	NFI region	Elevation zone	Carbon stock in living biomass (stockC <sub>l,i</sub> )	Carbon stock in dead organic matter (DOM) (stockC <sub>d,i</sub> + stockC <sub>h,i</sub> )	Carbon stock in mineral soil (stockC <sub>s,i</sub> )	Carbon stock in organic soil (stockC <sub>s,i</sub> )	Carbon gains in living biomass (gainC <sub>l,i</sub> )	Carbon losses in living biomass (lossC <sub>l,i</sub> )	Net change in dead organic matter (DOM) (changeC <sub>d,i</sub> + changeC <sub>h,i</sub> )	Net change in mineral soil (changeC <sub>s,i</sub> )	Net change in (drained) organic soil (changeC <sub>s,i</sub> )
	Strata		[t C ha <sup>-1</sup> ]				[t C ha <sup>-1</sup> yr <sup>-1</sup> ]				
21 Cropland	n.s.	1	6.39	0	50.10	240	0.05	NO	NA	-0.05	-9.52
	n.s.	2	6.40	0	50.02	240	0.04	NO	NA	-0.04	-9.52
	n.s.	3	6.07	0	41.47	240	0.08	NO	NA	0.06	-9.52
31 Permanent Grassland	n.s.	1	5.78	0	60.62	240	NO	-0.05	NA	-0.09	-9.52
	n.s.	2	5.30	0	65.69	240	NO	-0.04	NA	-0.09	-9.52
	n.s.	3	3.34	0	63.24	240	NO	0.00	NA	0.19	-9.52
32 Shrub Vegetation	n.s.	1	20.45	0	58.3	240	NA	NA	NA	NA	-5.30
	n.s.	2	20.45	0	63.8	240	NA	NA	NA	NA	-5.30
	n.s.	3	20.45	0	64.5	240	NA	NA	NA	NA	-5.30
33 Vineyards et al.	n.s.	n.s.	5.5	0	49.9	240	NA	NA	NA	NA	-9.52
34 Copse	n.s.	1	20.45	0	58.3	240	NA	NA	NA	NA	-5.30
	n.s.	2	20.45	0	63.8	240	NA	NA	NA	NA	-5.30
	n.s.	3	20.45	0	64.5	240	NA	NA	NA	NA	-5.30
35 Orchards	n.s.	n.s.	23.1	0	59.4	240	NA	NA	NA	NA	-9.52
36 Stony Grassland	n.s.	n.s.	7.2	0	22.6	240	NA	NA	NA	NA	-5.30
37 Unproductive Grassland	n.s.	n.s.	3.5	0	64.2	240	NA	NA	NA	NA	-5.30
41 Surface Waters	n.s.	n.s.	0	0	0	240	NA	NA	NA	NA	0
42 Unproductive Wetland	n.s.	n.s.	6.5	0	63.1	240	NA	NA	NA	NA	-5.30
51 Buildings, Constructions	n.s.	n.s.	0	0	0	0	NA	NA	NA	NA	NA
52 Herbaceous Biomass in S.	n.s.	n.s.	9.54	0	49.7	240	NA	NA	NA	NA	-9.52
53 Shrubs in Settlements	n.s.	n.s.	15.43	0	49.7	240	NA	NA	NA	NA	-5.30
54 Trees in Settlements	n.s.	n.s.	20.72	0	49.7	240	NA	NA	NA	NA	-5.30
61 Other Land	n.s.	n.s.	0	0	0	0	NA	NA	NA	NA	NA

Legend	
<i>Elevation zones:</i>	<i>NFI regions:</i>
1 < 601 m	1 Jura
2 601 - 1200 m	2 Central Plateau
3 > 1200 m	3 Pre-Alps
	4 Alps
	5 Southern Alps
	n.s. = no stratification
	Annual data

### 6.1.5. Uncertainty estimates

Table 6-5 gives an overview of uncertainty estimates of activity data, carbon stock change factors (CO<sub>2</sub> emissions and removals in 4A–4G), and emission factors (CH<sub>4</sub> and N<sub>2</sub>O emissions in 4(II)–4(V)).

For categories 4A–4F, the uncertainties of activity data mainly depend on the uncertainty of the AREA survey data (cells highlighted in orange in Table 6-5; see chp. 6.3.1.3 and Table 6-10). For categories 4D1, 4(II)–4(V), and 4G other data sources are relevant, e.g. for 4D1 the uncertainty of the area of organic soil. They are presented in detail in the respective chapters (6.X.3), along with the uncertainty estimates for carbon stock change factors and emission factors.

For categories 4B, 4C and 4D2, the uncertainties are given separately for the carbon pools living biomass, dead organic matter, mineral soil and organic soil. The overall uncertainty is calculated as described in chp. 1.6.2.

In general, the uncertainty of activity data is lower than the uncertainty of carbon stock change factors and emission factors, because activity data are mostly based on a systematic

survey with high spatial resolution (such as AREA), while carbon stock change factors and emission factors include parameters that are difficult to measure or to model such as carbon stocks in biomass, growth rates and biogeochemical processes.

Very large relative uncertainties for carbon stock change factors in categories 4B and 4C are due to the calculation approach, in which absolute uncertainties (in  $\text{t C ha}^{-1} \text{ yr}^{-1}$ ) of the carbon stock changes in categories 4B1, 4B2, 4C1 and 4C2 were divided by the associated net carbon stock changes (chp. 6.5.3.1 and chp. 6.6.3.1).

For the emission factors of  $\text{N}_2\text{O}$  in categories 4(III) and 4(IV2), the uncertainty is modelled by an (asymmetrical) gamma distribution.

The detailed input parameters used for uncertainty computation, approaches 1 and 2, are documented in Annex A2.1.

Table 6-5 Uncertainty estimates expressed as half of the 95 % confidence intervals. Highlighted activity data (AD) uncertainties depend mainly on the uncertainty of the AREA survey. CSCF/EF = carbon stock change factor and emission factor, respectively.

IPCC category	Gas	AD uncertainty	CSCF/EF uncertainty 1990	CSCF/EF uncertainty 2021
		%	%	%
4A1	Forest land remaining forest land	CO <sub>2</sub>	1.1	46.7
4A2	Land converted to forest land	CO <sub>2</sub>	1.5	46.7
4B1	Cropland remaining cropland			
	Carbon gains in living biomass	CO <sub>2</sub>	4.9	13.0
	Carbon losses in living biomass	CO <sub>2</sub>	4.9	13.0
	Net change in mineral soil	CO <sub>2</sub>	4.9	794.3
	Net change in organic soil	CO <sub>2</sub>	37.3	23.0
	Net change in dead organic matter	CO <sub>2</sub>	4.9	6.0
4B2	Land converted to cropland			
	Carbon gains in living biomass	CO <sub>2</sub>	5.1	13.0
	Carbon losses in living biomass	CO <sub>2</sub>	5.1	13.0
	Net change in mineral soil	CO <sub>2</sub>	5.1	153.2
	Net change in organic soil	CO <sub>2</sub>	37.3	23.0
	Net change in dead organic matter	CO <sub>2</sub>	5.1	6.0
4C1	Grassland remaining grassland			
	Carbon gains in living biomass	CO <sub>2</sub>	5.2	13.0
	Carbon losses in living biomass	CO <sub>2</sub>	5.2	13.0
	Net change in mineral soil	CO <sub>2</sub>	5.2	603.0
	Net change in organic soil	CO <sub>2</sub>	68.6	23.0
	Net change in dead organic matter	CO <sub>2</sub>	5.2	6.0
4C2	Land converted to grassland			
	Carbon gains in living biomass	CO <sub>2</sub>	5.3	13.0
	Carbon losses in living biomass	CO <sub>2</sub>	5.3	13.0
	Net change in mineral soil	CO <sub>2</sub>	5.3	49.4
	Net change in organic soil	CO <sub>2</sub>	68.6	23.0
	Net change in dead organic matter	CO <sub>2</sub>	5.3	6.0
4D1	Wetlands remaining wetlands	CO <sub>2</sub>	90.8	72.2
4D2	Land converted to wetlands			
	Carbon gains in living biomass	CO <sub>2</sub>	3.8	13.0
	Carbon losses in living biomass	CO <sub>2</sub>	3.8	13.0
	Net change in mineral soil	CO <sub>2</sub>	3.8	50.0
	Net change in organic soil	CO <sub>2</sub>	90.8	72.2
	Net change in dead organic matter	CO <sub>2</sub>	3.8	6.0
4E1	Settlements remaining settlements	CO <sub>2</sub>	4.4	50.0
4E2	Land converted to settlements	CO <sub>2</sub>	4.6	50.0
4F1	Other land remaining other land	CO <sub>2</sub>	NA	NA
4F2	Land converted to other land	CO <sub>2</sub>	3.2	50.0
4(II)	Drained organic soils	N <sub>2</sub> O	48.8	66.9
4(II)D2	Flooded land	CH <sub>4</sub>	10.0	70.0
4(III)	N mineralization	N <sub>2</sub> O	83.5	-91.4, +200.8
4(IV)2	N leaching and runoff	N <sub>2</sub> O	85.8	-95.1, +233.7
4(V)	Biomass burning	CH <sub>4</sub>	30.0	70.0
4(V)	Biomass burning	CO <sub>2</sub>	NA	NA
4(V)	Biomass burning	N <sub>2</sub> O	30.0	70.0
4G	Harvested wood products	CO <sub>2</sub>	11.2	54.8

## 6.2. Land-use definitions and classification systems

### 6.2.1. Combination Categories (CC) as derived from AREA Land Use Statistics

The standard nomenclature version 2004 (NOAS04; SFSO 2006a; FSO 2022i) of the Swiss Land Use Statistics (AREA) processed by the Federal Statistical Office is the basis for the selection of the land-use categories used for land area representation. In the course of an AREA survey (see chp. 6.3.1.1), every sample point on a hectare-mesh in Switzerland is assigned to a land-use category (NOLU04) and to a land-cover category (NOLC04). The interpretation is backed by a large set of geodata (e.g. forest boundary layer from the NFI; for just a public subset of geodata available to the FSO interpreters see <https://map.geo.admin.ch>; English version available) that can be superimposed if required. These geodata also include data sets indicating the legal status of land use (e.g. residential zones, crop rotation areas, nature reserves). Ambiguous sample points are visited by the AREA staff to verify the on-screen classification of land use (ground control).

The AREA survey is an advanced and well-established land use statistic (see the links to visualization examples in chp. 6.3.1.4.3. It allows for the identification of country-specific categories that are more detailed than those defined in IPCC (2006) (see Table 6-2). The 46 NOLU04 categories and 27 NOLC04 categories were aggregated to 17 combination categories (CC), following the assignment shown in Table 6-6, and adopted as land-use categories for LULUCF reporting. The first digit of the CC code represents the IPCC (2006) main land-use category, whereas the second digit stands for the respective land-use category. The approach enables more accurate estimates for carbon stocks and carbon stock changes than on the basis of the IPCC (2006) main categories alone because each land-use category can be fed with individual carbon data and distinctive carbon dynamics can be assumed (see below).

The combination categories were defined in 2006 in an evaluation process involving experts from the FOEN, the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL), the Federal Statistical Office and Agroscope as well as private consultants. The evaluation process resulted in the elaboration of Table 6-6.

With regard to carbon stock in living biomass, there is a strong relation to the vegetation type (i.e. to land cover in most cases). This is exemplarily reflected by the mainly horizontal arrangement of the individual combination categories in Table 6-6. With regard to carbon stock changes in living biomass, dead organic matter, and soil the definition was driven by the consideration that frequently individual vegetation units – like e.g. orchards – are subject to a similar management all over Switzerland leading to comparable carbon fluxes in living biomass, dead organic matter, and soil.

For individual combination categories (especially for Forest land: CC12 and CC13) further spatial stratifications were introduced (see chp. 6.2.2) with the intent to approximate the real differences in carbon stock, carbon stock changes and soil conditions as closely as possible.

The underlying criteria to include land-use categories such as shrub vegetation, vineyards, low-stem orchards, tree nurseries, copse and orchards under Grassland with woody biomass are: (1) They do not fulfil the criteria for forests; (2) There is an agricultural management in general; (3) They all have woody biomass (i.e. perennial vegetation) with grass understory. Under Cropland, in contrast, there are no perennial crops, but annual crops and leys in arable rotations. All perennial crops are included in the Grassland land-use categories.



All land-use categories of Forest land, Grassland and Wetlands are defined as managed and reported under managed land in CRF Table 4.1. Cropland and Settlements are regarded to be managed by default. Other land is regarded to be unmanaged by default. In a nutshell, the entire land area of Switzerland – except for 4F Other land – is reported to be managed.

## 6.2.2. Spatial stratification

### 6.2.2.1. Soil type

Most soils in Switzerland are mineral soil types. A digital map showing estimates of the surface of organic soils in Switzerland was elaborated by Wüst-Galley et al. (2015). As there is no single data set from which the location of organic soils across the country could be adequately deduced, the authors evaluated numerous spatial and non-spatial data sets providing information on geology, soils, forest habitats and vegetation. According to Wüst-Galley et al. (2015) the total area of organic soils is 28 kha (0.8 % of the total area covered by soils) (see Figure 6-4).

The definition of organic soil in the GHG inventory is as follows:

Intact or degraded peaty soils are considered organic soils. Where information on soil organic carbon (SOC) is known, the definition of organic soil from the IPCC (IPCC 2006, Volume 4, chp. 3, Annex 3A.5) was used to classify soils as mineral / organic (see Wüst-Galley et al. 2015: 11). Thus, this definition was used for the ground-truthing of forest habitat maps and fen inventories. This definition also formed the basis of the classification of soil types from the soils maps, as organic or mineral. Here however, two soil types (“anmoorig” and “antorfig” soils) could not be classified; the SOC values and peat depths used to delimit these soil types are in part less than the SOC values and peat depths used to define organic soil (IPCC 2006), meaning they cannot be classified as either mineral or organic soils. Due to lack of information regarding their distribution, they were not explicitly considered in the estimate of organic soil (see Wüst-Galley et al. 2015: 14–15 and 61); including these additional soil types would lead to inconsistency of the definition of organic soil across the country, because their distribution is only known for a small area in Switzerland.

For the other data sets used in the construction of the organic soils map (geology maps, hydrogeology maps and other habitat maps), no information on SOC is available, and the presence of peat was used as evidence of organic soil. The carbon content of peat meets the IPCC (2006) definition of organic soil.

Consistency: A single map of organic soil is applied to all years (1990 to present), meaning the classifications used are consistent through time. The same definition of organic soil was used across the whole country.

### 6.2.2.2. Elevation

For Forest land (CC12, CC13), Cropland (CC21) and permanent grassland (CC31) three elevation zones were differentiated: <601 m a.s.l. (meters above sea level), 601–1200 m a.s.l., and >1200 m a.s.l. (Figure 6-4). Elevation data from the Federal Office of Topography (swisstopo.ch) on a 25x25 m raster (product DHM25) were used to map the three zones. The elevation zones are coded Z1, Z2 and Z3 in the reporting tables (with increasing elevation).

### 6.2.2.3. Forest production region

Forest land was differentiated into the five production regions of the National Forest Inventory (Brändli and Hägeli 2019: chp. 1.5.2; Figure 6-4, see also <https://s.geo.admin.ch/8d972b5708>). These are (in brackets the coding in the reporting tables):

Jura (L1), Central Plateau (L2), Pre-Alps (L3), Alps (L4) and Southern Alps (L5).

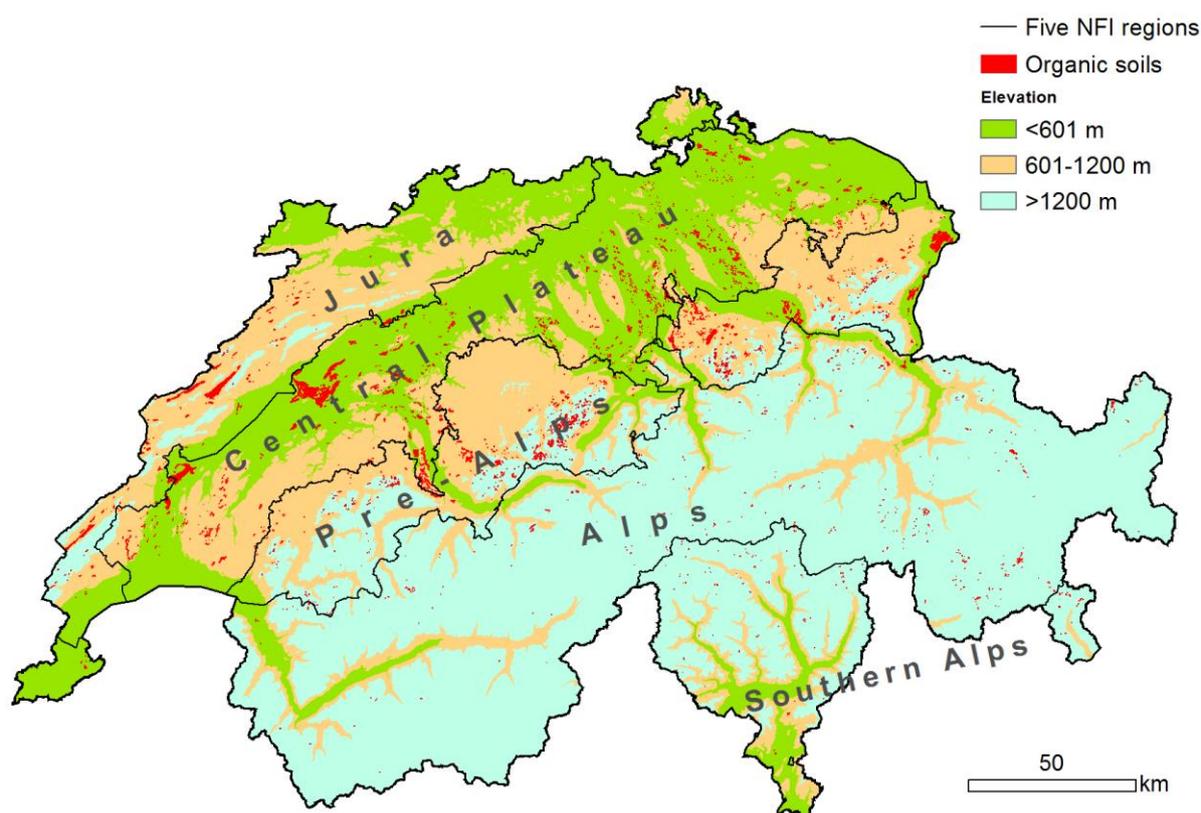


Figure 6-4 Map showing the spatial stratification according to NFI production region, elevation zone, and soil type.

### 6.2.2.4. Strata

Applying all spatial stratifications, 30 different strata (referred to as subscript *i* in chp. 6.1.3.2) would be theoretically possible. Not all of them, but altogether 29 have been actually realised and applied for the calculation of CO<sub>2</sub> eq emissions and removals.

### 6.2.3. Land-use tables and change matrices

In Table 6-7 the land-use statistics resulting from spatial stratification (chp. 6.2.2) and interpolation in time (chp. 6.3.1.2) are exemplarily shown for the year 1990. The table gives also the area size of the individual spatial strata (column "Sum").

Table 6-7 Land use projection by the end of 1990 for land-use categories (shown by their CC codes), stratified separately for elevation (3 zones), soil type (mineral or organic) and NFI production region (1-5), in kha, rounded values. The country's total area is 4'129'073 ha (FSO 2022).

CC	12	13	21	31	32	33	34	35	36	37	41	42	51	52	53	54	61	Sum
<b>Elevation</b>																		
Z1	225.9	6.2	299.8	153.8	2.6	22.5	32.4	1.2	0.5	2.9	138.6	5.2	116.7	47.5	2.8	18.6	2.0	1079.1
Z2	505.7	18.1	131.7	358.2	8.7	3.9	29.9	0.3	2.5	1.5	9.7	5.7	46.4	17.0	0.9	5.3	8.1	1153.9
Z3	379.2	79.9	0.4	425.4	144.4	0.0	27.1	0.0	148.7	61.9	13.3	14.3	11.4	3.7	0.2	1.0	585.2	1896.1
	1110.8	104.2	432.0	937.4	155.7	26.5	89.3	1.6	151.6	66.3	161.6	25.1	174.6	68.2	3.9	24.9	595.3	4129.1
<b>Soil</b>																		
mineral	1107.2	104.1	420.3	931.8	155.6	26.4	89.0	1.6	151.6	66.1	161.3	21.4	173.4	67.7	3.9	24.8	595.3	4101.3
organic	3.6	0.2	11.7	5.6	0.1	0.0	0.4	0.0	0.0	0.2	0.3	3.7	1.2	0.5	0.0	0.1	0.025	27.7
	1110.8	104.2	432.0	937.4	155.7	26.5	89.3	1.6	151.6	66.3	161.6	25.1	174.6	68.2	3.9	24.9	595.3	4129.1
<b>NFI region</b>																		
L1	197.9	8.3	78.0	122.6	0.9	4.7	11.9	0.3	0.2	0.6	23.6	1.2	26.8	10.9	0.5	4.7	0.5	493.5
L2	227.9	4.1	307.0	152.4	0.9	9.9	27.4	1.0	0.2	1.6	70.4	4.1	84.9	34.7	1.6	12.6	0.7	941.5
L3	215.3	13.0	30.2	261.3	10.4	0.8	17.8	0.1	8.5	6.8	30.6	12.0	26.8	9.2	0.5	2.9	15.0	661.2
L4	332.8	56.1	13.8	365.4	110.2	9.5	24.5	0.2	118.1	49.2	26.2	7.2	26.9	9.8	0.8	3.0	524.8	1678.2
L5	136.9	22.6	3.0	35.7	33.3	1.5	7.8	0.0	24.6	8.1	10.7	0.7	9.2	3.7	0.6	1.9	54.3	354.6
	1110.8	104.2	432.0	937.4	155.7	26.5	89.3	1.6	151.6	66.3	161.6	25.1	174.6	68.2	3.9	24.9	595.3	4129.1

Table 6-8 shows the overall trends of land-use changes over the inventory period. For example, the area of cropland (CC21) decreased by 12 % during this period, while the area of productive forests (CC12) increased by 5 %.

Table 6-8 Statistics of land use for land-use categories (shown by their CC codes; in kha, rounded values) and relative change (in %, rounded values; see bottom line) between 1990 and 2021. The country's total area is 4'129'073 ha (FSO 2022).

CC	12	13	21	31	32	33	34	35	36	37	41	42	51	52	53	54	61	Sum
<b>Year</b>																		
1990	1'110.8	104.2	432.0	937.4	155.7	26.5	89.3	1.6	151.6	66.3	161.6	25.1	174.6	68.2	3.9	24.9	595.3	4'129.1
1991	1'112.9	104.4	431.2	935.6	155.2	26.5	88.3	1.5	151.4	66.2	161.6	25.1	176.2	68.7	4.0	25.3	595.0	4'129.1
1992	1'115.0	104.7	430.4	933.8	154.7	26.6	87.3	1.4	151.1	66.0	161.6	25.1	177.9	69.3	4.0	25.6	594.6	4'129.1
1993	1'116.9	104.9	429.4	932.3	154.2	26.5	86.2	1.4	150.9	65.8	161.6	25.1	179.5	69.9	4.1	25.9	594.2	4'129.1
1994	1'118.7	105.1	428.0	931.7	153.7	26.5	85.2	1.3	150.8	65.7	161.6	25.1	181.1	70.4	4.2	26.2	593.8	4'129.1
1995	1'120.3	105.3	426.1	931.6	153.2	26.5	84.3	1.3	150.6	65.5	161.6	25.2	182.7	71.2	4.2	26.2	593.4	4'129.1
1996	1'121.7	105.4	424.2	931.8	152.7	26.4	83.3	1.3	150.5	65.3	161.6	25.2	184.2	71.9	4.2	26.2	592.9	4'129.1
1997	1'123.0	105.6	422.1	932.3	152.3	26.3	82.4	1.2	150.4	65.2	161.7	25.2	185.8	72.7	4.2	26.2	592.5	4'129.1
1998	1'124.1	105.6	420.0	932.7	152.1	26.3	81.5	1.2	150.5	65.0	161.7	25.2	187.3	73.6	4.2	26.1	592.0	4'129.1
1999	1'125.2	105.7	418.0	933.2	151.9	26.2	80.5	1.2	150.5	64.8	161.8	25.3	188.8	74.4	4.2	26.0	591.5	4'129.1
2000	1'126.4	105.7	415.9	933.6	151.7	26.1	79.6	1.2	150.6	64.6	161.8	25.3	190.3	75.2	4.2	25.9	591.0	4'129.1
2001	1'127.5	105.8	413.8	934.0	151.5	26.0	78.6	1.1	150.7	64.3	161.9	25.4	191.9	76.1	4.2	25.8	590.6	4'129.1
2002	1'128.6	105.8	411.8	934.5	151.3	25.9	77.7	1.1	150.7	64.1	161.9	25.4	193.4	76.9	4.2	25.7	590.1	4'129.1
2003	1'129.7	105.9	409.7	934.9	151.1	25.8	76.7	1.1	150.8	63.9	162.0	25.4	194.9	77.7	4.2	25.6	589.6	4'129.1
2004	1'130.8	106.0	407.6	935.4	150.9	25.7	75.8	1.1	150.8	63.7	162.0	25.5	196.4	78.6	4.2	25.5	589.1	4'129.1
2005	1'132.0	105.9	406.0	935.1	150.7	25.6	74.9	1.1	150.9	63.5	162.1	25.5	198.1	79.4	4.2	25.4	588.7	4'129.1
2006	1'133.3	106.0	404.1	934.9	150.6	25.5	74.1	1.0	151.1	63.3	162.1	25.5	199.7	80.0	4.2	25.4	588.2	4'129.1
2007	1'134.9	105.8	402.3	934.3	150.7	25.5	73.5	1.0	151.2	63.0	162.2	25.6	201.4	80.5	4.2	25.5	587.5	4'129.1
2008	1'136.8	105.6	400.6	933.2	151.1	25.4	73.2	1.0	151.6	62.7	162.3	25.6	203.0	80.6	4.1	25.8	586.4	4'129.1
2009	1'138.8	105.4	398.9	931.9	151.4	25.3	73.1	1.1	152.0	62.5	162.3	25.6	204.6	80.7	4.1	26.2	585.3	4'129.1
2010	1'140.9	105.3	397.2	930.4	151.6	25.3	73.1	1.1	152.4	62.2	162.3	25.6	206.2	80.7	4.1	26.7	584.1	4'129.1
2011	1'143.0	105.1	395.5	929.0	151.8	25.3	73.1	1.1	152.8	61.9	162.4	25.6	207.8	80.7	4.0	27.1	582.8	4'129.1
2012	1'145.0	105.0	393.9	927.6	152.0	25.2	73.1	1.2	153.2	61.6	162.4	25.6	209.5	80.7	4.0	27.5	581.5	4'129.1
2013	1'147.1	104.8	392.2	926.2	152.2	25.2	73.1	1.2	153.6	61.3	162.5	25.6	211.1	80.7	4.0	28.0	580.3	4'129.1
2014	1'149.1	104.8	390.4	925.0	152.5	25.1	73.2	1.3	154.0	61.1	162.5	25.7	212.6	80.5	3.9	28.4	579.0	4'129.1
2015	1'151.1	104.7	388.7	923.8	152.8	25.0	73.2	1.3	154.4	60.8	162.5	25.7	214.1	80.4	3.9	28.9	577.8	4'129.1
2016	1'153.0	104.7	386.8	922.5	153.1	25.0	73.2	1.4	154.8	60.6	162.6	25.7	215.6	80.3	3.8	29.3	576.5	4'129.1
2017	1'155.0	104.7	385.3	921.2	153.1	25.0	73.2	1.4	155.2	60.3	162.6	25.7	217.1	80.4	3.8	29.7	575.3	4'129.1
2018	1'156.9	104.7	383.8	919.7	153.2	25.0	73.3	1.5	155.6	60.1	162.6	25.7	218.7	80.4	3.8	30.0	574.0	4'129.1
2019	1'158.9	104.7	382.3	918.2	153.2	24.9	73.3	1.5	156.1	59.9	162.7	25.7	220.2	80.4	3.8	30.4	572.7	4'129.1
2020	1'161.0	104.7	380.8	916.7	153.3	24.9	73.3	1.5	156.5	59.6	162.7	25.8	221.7	80.5	3.8	30.7	571.5	4'129.1
2021	1'163.1	104.6	379.3	915.2	153.5	24.8	73.4	1.6	156.9	59.4	162.7	25.8	223.3	80.6	3.8	31.1	570.3	4'129.1
<b>Change:</b>	5	0	-12	-2	-1	-6	-18	0	3	-10	1	3	28	18	-4	25	-4	0

The annual land-use changes across the entire territory of Switzerland (change matrices, see examples for 1990 and 2021 in Table 6-9) were obtained by adding up the annual changes on a hectare basis per land-use category. For calculating the carbon stock changes, fully stratified (see chp. 6.2.2) land-use change tables were used for each year (Meteotest 2023).

More aggregated land transition matrices are reported in CRF Table4.1 for each year of the inventory period.

In general, the numbers given in the change matrices (Table 6-9) cannot be directly compared with the activity data in categories 2 in CRF Table4.A, Table4.B, Table4.C, Table4.D, Table4.E and Table4.F (Land converted to X), where the cumulative area remaining in the respective category in the reporting year is recorded (see the description of conversion time of 20 years in chp. 6.1.3.3). In contrast, the change matrices below present the land-use changes occurring in the specified year only.

Table 6-9 Annual land-use changes in 1990 and in 2021 (change matrices). Units: ha/year, rounded values. Empty cells indicate that no change occurred.

1990		change to CC																			
		12	13	21	31	32	33	34	35	36	37	41	42	51	52	53	54	61	decrease		
change from CC	12		159	5	126	86	6	59		12	19	11	7	118	27	11	17	50	712		
	13	678		8	354	48	5	89	0	3	3	1	3	41	20	3	15	10	1280		
	21	9	5		663	6	181	35	1	4	4	4	4	632	317	21	18	22	1926		
	31	302	480	717		1007	123	311	4	46	43	9	11	870	490	27	44	67	4554		
	32	1046	715	2	126		9	309		14	15	6	0	24	8	5	3	30	2313		
	33	3	4	126	65	4		28	2	0	1	0		50	26	4	3	5	323		
	34	556	63	143	866	49	35		11	9	23	4	3	171	94	6	41	14	2087		
	35	0	0	8	13	0	4	46						4	2	0	1	0	80		
	36	30	26	2	162	243	1	41			89	4	0	8	1	0		45	652		
	37	33	6	1	8	234	1	68		10		3	0	6	2		0	13	384		
	41	5	1	2	2	6	0	4		4	1		17	11	2	1	0	99	156		
	42	32	6	1	3	2	0	2		0	0	6		4	1	0	0	1	59		
	51	56	4	86	158	11	5	7		3	5	6	4		271	58	46	5	726		
	52	11	1	16	32	3	1	1		0	1	1	2	349		68	387	0	874		
	53	13	0	6	7	2	0	2				0	2	45	28		46	0	150		
	54	8	0	1	2	0	0	3			0	0	1	78	152	8		0	253		
	61	45	17	16	67	93	8	31		287	33	96	2	13	1	0	1		709		
increase		2828	1489	1140	2653	1794	381	1036	18	394	236	152	55	2425	1443	211	621	361	17238		

2021		change to CC																			
		12	13	21	31	32	33	34	35	36	37	41	42	51	52	53	54	61	decrease		
change from CC	12		428	1	295	130	4	107	6	38	18	25	20	96	29	10	17	72	1297		
	13	1225		2	419	184	2	108	0	14	4	1	3	25	15	2	14	22	2041		
	21	2	3		2585	6	163	48	9	4	7	4	6	469	193	7	5	13	3523		
	31	184	607	1758		1514	90	465	13	139	78	12	23	814	432	17	20	83	6248		
	32	913	762	1	226		2	686		37	21	8	1	10	3	2	1	45	2719		
	33	6	2	107	96	5		36	4	0	1	0	0	37	27	2	2	2	325		
	34	778	90	32	533	54	8		27	12	26	9	1	76	49	2	31	18	1746		
	35	0		1	11		1	17						1					31		
	36	51	40	2	226	453	0	102			139	7	1	7	1				92		
	37	29	4		21	370		82		56		6	1	4	1				18		
	41	7	1	0	2	10		4		7	6		16	7	2	0	0	143	206		
	42	40	8	1	2	1		4		1	0	10		3	2	0	1	1	73		
	51	36	3	63	154	8	2	6		8	8	7	2		418	54	55	11	835		
	52	15	1	16	61	3	1	3		2	3	1	1	615		75	679	1	1477		
	53	23	1	3	7	4		1		0	1	0	0	52	48		64		205		
	54	13	2	0	3	1		5		0	0	1	0	166	319	28		0	538		
	61	57	27	10	79	129	5	75		1189	25	140	2	6	0	0			1746		
increase		3377	1979	1999	4720	2871	278	1749	59	1506	336	232	81	2386	1539	199	888	523	24720		

## 6.3. Country-specific approaches

### 6.3.1. Information on approaches used for representing land areas and on land-use databases used for the inventory preparation

#### 6.3.1.1. Swiss Land Use Statistics (AREA)

Data of the Swiss Land Use Statistics (AREA) processed by the Federal Statistical Office form the basis of activity data. In the course of an AREA survey, every hectare of Switzerland's territory (4'129'073 ha) is assigned to one of 46 land-use categories and to one of 27 land-cover categories by means of stereographic interpretation of aerial photos (SFSO 2006a; FSO 2022i).

For the reconstruction of the land use conditions in Switzerland during the inventory period data from four surveys were available:

- Land Use Statistics "1979/85" (AREA1), status: completed
- Land Use Statistics "1992/97" (AREA2), status: completed
- Land Use Statistics "2004/09" (AREA3), status: completed
- Land Use Statistics "2013/18" (AREA4), status: completed (in 2021, see <https://www.bfs.admin.ch/bfs/en/home.gnpdetail.2021-0316.html>)
- Land Use Statistics "2020/25" (AREA5), status: 0.7 % of national territory processed.

The aerial photos for AREA1, AREA2, AREA3, AREA4 and AREA5 were taken 1979–1985, 1990–1998, 2004–2009, 2012–2019 and in 2020, respectively. All photos were interpreted according to the standard nomenclature NOAS04 (SFSO 2006a; FSO 2022i).

The inter-survey period is not identical throughout the Swiss territory, but varies regionally (see flyover periods shown above). It averages approximately 12 years for AREA1, AREA2 and AREA3. For AREA4 and AREA5 it was shortened to approximately 9 and 7 years, respectively. This methodic characteristic needs to be considered when reconstructing the annual country-wide status of land use or when calculating annual rates of land-use change.

#### 6.3.1.2. Interpolation of the status for each year

The exact dates of aerial photo shootings are known for each hectare. However, the exact occurrence date (year) of a land-use change on a specific hectare is unknown. The actual change can have taken place in any year between two AREA surveys. In this study, it was assumed that the probability of a land-use change between two surveys is uniformly distributed over the respective interim period. Therefore, the land-use change of each hectare has to be equally distributed over its specific interim period.

The land-use status for the years between two data collection dates can be calculated by linear interpolation. Dates of aerial photo shootings (i.e. starting and ending year of the inter-survey period) and the land-use categories of AREA1–AREA5 for every hectare were used for these calculations. An example is shown in Figure 6-5: A hectare had been assigned to the land-use category Cropland in AREA1 (aerial photo in 1980). A land-use change to 'Surrounding of Buildings' was discovered 10 years later (1990) in AREA2.

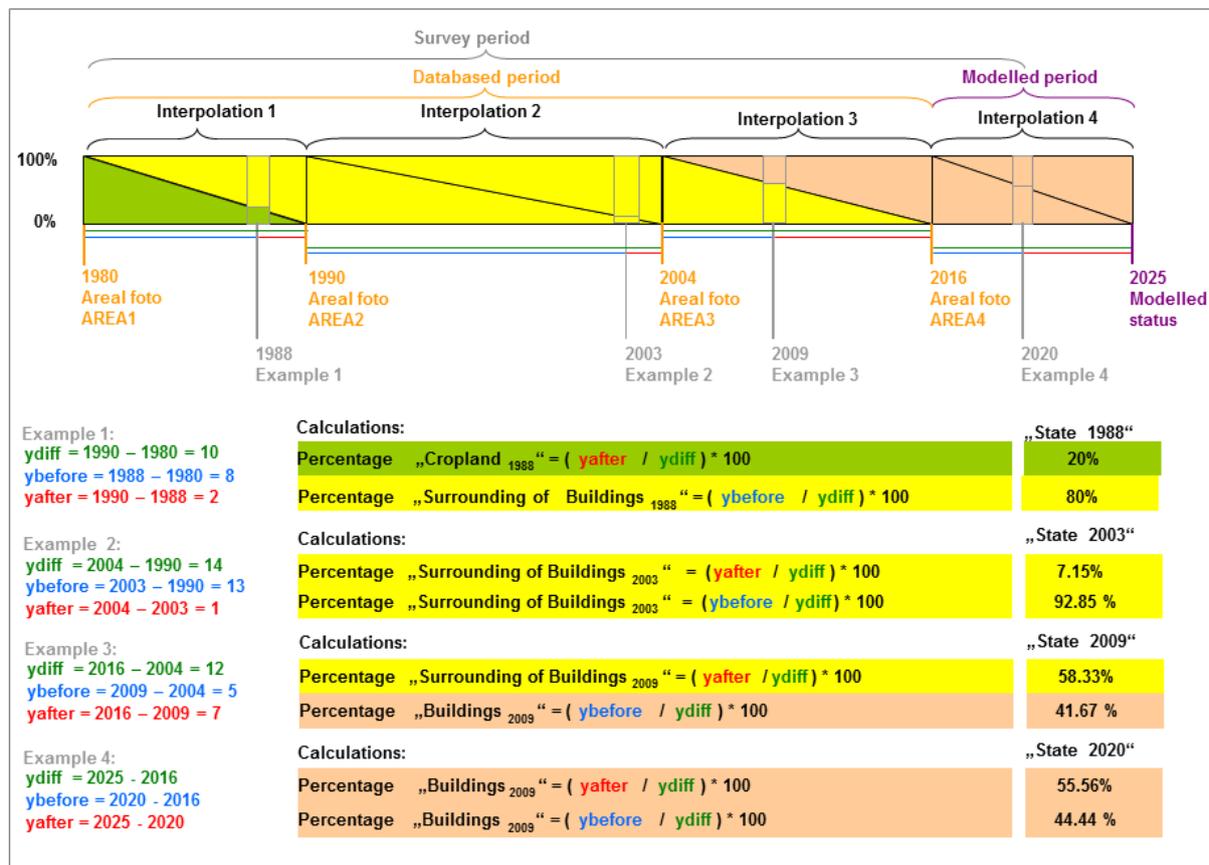


Figure 6-5 Hypothetical development of land use for a supposed survey period 1980–2020. The linear land-use changes between AREA1, AREA2, AREA3 and AREA4 considering as example a hectare changing from “Cropland” to “Surrounding of Buildings” and later from “Surrounding of Buildings” to “Buildings”. For 2020, a linear interpolation was carried out between AREA4 and a virtual fifth survey (AREA5v) that was modelled for the year 2025 (here resulting in no change of land use).

The “state 1988” of that hectare is determined by calculating the fractions of the two land-use categories for the year 1988. A linear development from “Cropland” to “Surrounding of Buildings” during the whole interim period was assumed. Thus, in 1988 the hectare was split up in two fractions: 80 % is “Surrounding of Buildings” and 20 % is “Cropland”. The same procedure can be applied for two survey dates between AREA2 and AREA3 (here exemplarily shown for the period 1990–2004, highlighting “state 2003”) or between AREA3 and AREA4 (here exemplarily shown for the period 2004–2016, highlighting “state 2009”).

To obtain consistent and complete nationwide data for each year, the following analysis is required:

1) For those hectares that currently have no data in AREA5 (99.3 % of national territory), the land-use states after AREA4 were interpolated between AREA4 and a “virtual” 5th survey (AREA5v). AREA5v was modelled for each sample point using a Markov-chain approach, where transition probabilities between AREA4 and AREA5v were assessed based on the transition distribution between AREA3 and AREA4 within each spatial stratum. See example 4 in Figure 6-5.

2) For those hectares that were already covered by AREA5 (0.7 % of national territory), the land-use states after the flight year of AREA5 were interpolated between AREA5 and a “virtual” 6th survey (AREA6v). AREA6v was modelled for each sample point using a Markov-chain approach, where transition probabilities between AREA5 and AREA6v were assessed

based on the transition distribution between AREA4 and AREA5 within each spatial stratum (Sigmoplan 2023). Therefore, the land-use changes occurring after the flight year of AREA5 (i.e. when the hectare was covered) were calculated from the linear development detected between AREA5 and the virtual 6th survey AREA6v for this type of hectare (regarding CC and spatial strata).

The wall-to-wall land-use status within Switzerland for each individual year in the inventory period results from the summation of the fractions of all hectares per land-use category, additionally considering the spatial strata where appropriate.

### 6.3.1.3. Uncertainties and time-series consistency of activity data

An overview of uncertainty estimates of activity data, carbon stock change factors and emission factors is shown in Table 6-5. Details related to uncertainties of AREA data are presented in this chapter, while the remaining uncertainties of other activity data (such as consumption of Harvested wood products) and of carbon stock change factors and emission factors are presented in the respective chapters (6.X.3).

In most cases, the uncertainty of activity data for categories 4A–4F depends on the quality of the AREA survey data. For categories with relevant emissions from drained organic soil, also the uncertainty of the spatial allocation of organic soil (see chp. 6.2.2.1 and below) was considered.

The uncertainty of AREA-based activity data has two main sources (Table 6-10). They were quantified on the basis of the AREA data (FSO 2022) as follows:

1) Interpretation error: In the AREA survey, the first classification of the aerial photos is checked by a second independent interpreter. The portion of sampling points with a mismatch of the first and the second interpretation was used as the uncertainty of the interpretation. This uncertainty of interpretation integrates all errors related to the manual interpretation of land-use and land-cover classes on aerial photographs. While it is clear that this is rather an estimate of the maximum potential interpretation error than of the actual interpretation error, it is reported hereafter unless better information is available.

2) Statistical sampling error: In the AREA survey, the land-use types are interpreted on points situated on a regular 100x100 m grid. Thus, the uncertainty of the measured surface area covered by a certain land-use type or land-use change decreases with increasing numbers of sampling points that are used for the measurement. Assuming a binomial distribution of the errors, this uncertainty was calculated as

$$U_{\text{sampling}} = 100 * 1.96 * (\text{number of points})^{-0.5}$$

The number of sampling points lies between 2'787 (for 4D2) and 1'334'376 (for 4C1) leading to values of  $U_{\text{sampling}}$  between 3.7 % and 0.2 %.

The overall uncertainty was calculated as:

$$U_{\text{overall}} = (U_{\text{interpret}}^2 + U_{\text{sampling}}^2)^{0.5}$$

Table 6-10 Sources of uncertainty of activity data and overall uncertainties in the allocation of land-use categories, expressed as half of the 95 % confidence intervals. Calculations are based only on AREA data from FSO (2022); uncertainties with respect to other data sources (organic soil, wildfires) are not included, see main text.

Category	Description	Interpretation uncertainty	Sampling uncertainty	Overall uncertainty
4A1	Forest land remaining forest land	1.1	0.2	1.1
4A2	Land converted to forest land	1.1	1.1	1.5
4B1	Cropland remaining cropland	4.9	0.3	4.9
4B2	Land converted to cropland	4.9	1.5	5.1
4C1	Grassland remaining grassland	5.2	0.2	5.2
4C2	Land converted to grassland	5.2	0.8	5.3
4D1	Wetlands remaining wetlands	0.9	0.5	1.0
4D2	Land converted to wetlands	0.9	3.7	3.8
4E1	Settlements remaining settlements	4.4	0.4	4.4
4E2	Land converted to settlements	4.4	1.3	4.6
4F1	Other land remaining other land	1.4	0.3	1.4
4F2	Land converted to other land	1.4	2.8	3.2

An update of the uncertainty analysis of the spatial allocation of organic soil published by Wüst-Galley et al. (2015) (Wüst-Galley 2019) resulted in 35.3 % for Forest land, 37.3 % for Cropland, 68.6 % for Grassland and 90.8 % for Wetlands. For Forest land (chp. 6.4.3.1), CO<sub>2</sub> emissions from organic soil were not considered in the calculation of the overall uncertainty (Meteotest 2023). For Settlements (chp. 6.8.3.1), the uncertainty of CO<sub>2</sub> emissions from organic soil was not calculated separately.

Activity data for wildfires were taken from the Swissfire database (see chp. 6.4.2.6.4 and chp. 6.6.2.3.3). The uncertainty for areas affected by wildfires was estimated between 10 % (NFI production region 5) and 30 % (other NFI production regions) for Forest land by expert judgment (Pezzatti 2017). For Grassland the mean uncertainty is probably higher than for Forest land. As a consequence, a value of 30 % was agreed on for both land uses.

Consistency: Time series for activity data are all considered consistent; they were calculated based on consistent methods for interpolation and extrapolation and homogenous databases.

#### 6.3.1.4. QA/QC and verification of activity data

The general QA/QC measures are described in chp. 1.5.

##### 6.3.1.4.1. QA/QC measures

The AREA survey is a well-defined and controlled, long-term process in the responsibility of the Federal Statistical Office (SFSO 2006a; FSO 2022i). The data supplied by FSO (2022) were checked for consistency (Sigmaplan 2023).

The temporal interpolation and extrapolation of the AREA sample is quite a complex procedure, whose internal consistency is checked systematically as described in Sigmoplan (2023). Further checks (interannual comparisons, plausibility) were carried out after producing the land-use change tables presented in chp. 6.2.3.

#### **6.3.1.4.2. Country area**

The total country area remains constant over the inventory period.

#### **6.3.1.4.3. Federal geoportal**

The federal geoportal <https://www.geo.admin.ch/en> provides digital access to the maps, aerial photographs and geographic information of the federal administration covering the entire territory of Switzerland. The map viewer <https://map.geo.admin.ch> allows a visualization of the completed AREA surveys. See the example <https://s.geo.admin.ch/96e44254c8> for the change in direct neighbourhood of a FOEN building in Bern-Ittigen. Legend: yellow crosses represent sample points; circles represent land cover, triangles (they appear when clicking on “Land use statistics standard”) represent land use statistics based on the standard nomenclature. Click circles and triangles for object information. To get a clue on the situation prior to the construction of the FOEN building check the box “Journey through time – Maps” (pre-set 1986, but year is freely selectable) and look out for the former course of the stream nowadays bound to the south of the rail tracks. Please note: The background aerial photograph is of recent age. Examples of characteristic landscape changes in Switzerland across the four survey phases can be found under "Documentation of landscape change".

The free availability and ease of use of the federal geoportal increase the transparency of the (raw) activity data used in the LULUCF reporting and provides an opportunity for public reviewing.

#### **6.3.1.5. Recalculations of activity data**

- 4: Land use areas: The most recent land-use data from the fifth area survey (AREA5) were included (FSO 2022). They are based on aerial photographs from 2020. The interpolation and projection procedures were adapted accordingly (chp. 6.3.1.2; Sigmoplan 2023). The inclusion of first AREA5 data led to small recalculations of areas for all land-use categories from 2013 onwards (Table 6-11). Only the two smallest land-use categories orchards (CC35) and shrubs in settlements (CC53) (see Table 6-8) exceed a relative change of 1 %. There are no changes in the years before 2013, as the AREA1 to AREA4 surveys are were kept unchanged by the Federal Statistical Office.
- 4A: With the retirement of the Kyoto Protocol, the land-use category afforestations (CC11) was abandoned. This category was originally created in analogy to the KP activity Afforestation. Its continued use now no longer produces any added value for the UNFCCC inventory. The integration of afforestations in the land-use category productive forest (CC12) is evident in Table 6-11 over the whole time series 1990–2020.

Table 6-11 Differences of areas per year and land-use category (shown by their CC codes) between the latest and the previous submissions (in kha). The bottom line shows the percentage change between 1990 and 2020. Note: CC11 (afforestations) is no longer used in the latest submission. Green text colour indicates that no change occurred.

CC	11	12	13	21	31	32	33	34	35	36	37	41	42	51	52	53	54	61
Year																		
1990	-3.890	3.890	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1991	-3.783	3.783	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1992	-3.676	3.676	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1993	-3.541	3.541	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1994	-3.364	3.364	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1995	-3.175	3.175	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1996	-2.994	2.994	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1997	-2.807	2.807	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1998	-2.596	2.596	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1999	-2.384	2.384	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2000	-2.172	2.172	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2001	-1.961	1.961	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2002	-1.749	1.749	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2003	-1.538	1.538	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2004	-1.326	1.326	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2005	-1.161	1.161	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2006	-1.016	1.016	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2007	-0.905	0.905	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2008	-0.834	0.834	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2009	-0.783	0.783	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2010	-0.730	0.730	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2011	-0.676	0.676	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2012	-0.623	0.623	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2013	-0.573	0.572	0.001	-0.011	-0.013	-0.001	0.008	0.003	-0.003	0.000	0.002	-0.001	-0.002	0.002	0.019	-0.005	-0.001	0.002
2014	-0.533	0.531	0.000	-0.030	-0.020	0.014	0.008	0.001	-0.008	0.010	-0.001	0.003	0.000	0.004	0.027	-0.008	0.004	-0.001
2015	-0.502	0.504	0.018	-0.041	-0.057	0.024	0.010	-0.009	-0.013	0.017	-0.006	0.009	0.001	0.012	0.032	-0.014	0.014	0.000
2016	-0.467	0.461	0.027	-0.066	-0.062	0.021	0.012	-0.009	-0.014	0.030	-0.013	0.013	0.002	0.021	0.040	-0.024	0.019	0.009
2017	-0.444	0.423	0.045	-0.072	-0.049	0.019	0.016	-0.017	-0.017	0.037	-0.011	0.011	0.003	0.016	0.047	-0.031	0.019	0.004
2018	-0.427	0.398	0.061	-0.091	-0.035	0.019	0.010	-0.020	-0.016	0.056	-0.010	0.010	0.002	0.022	0.050	-0.035	0.017	-0.010
2019	-0.410	0.376	0.078	-0.109	-0.025	0.021	0.003	-0.025	-0.016	0.071	-0.010	0.011	0.001	0.027	0.057	-0.039	0.012	-0.023
2020	-0.404	0.369	0.081	-0.120	-0.008	0.020	-0.003	-0.022	-0.015	0.072	-0.009	0.010	-0.002	0.025	0.068	-0.043	0.005	-0.024
2020%	-100%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	-1.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	-1.1%	0.0%	0.0%

### 6.3.1.6. Planned improvements for activity data

Switzerland's activity data for land areas are currently based on the surveys AREA1 to AREA5. Interpretation and processing of AREA4 were completed in 2021; first results of AREA5 became available in 2022. More results of the fifth survey (AREA5) will be included in future submissions. It will be based on aerial photographs from 2020 to 2025, reducing the interim period between successive surveys in the future to six years.

An update of the study "Locating organic soils for the Swiss Greenhouse Gas Inventory" by Wüst-Galley et al. (2015), incorporating any newly available or updated data sources, will be completed shortly.

The FOEN is evaluating the suitability of newly available satellite data (e.g. Sentinel 2) in the field of environmental reporting. Several feasibility studies were commissioned. Depending on the results (and on the future availability of EU satellite data in Switzerland) it is intended to refine the spatio-temporal pattern of land use dynamics in Switzerland provided by the Land Use Statistics AREA by the use of satellite data in the medium term. In the course of this evaluation the design of the land-use categories used in the GHG inventory (i.e. the combination categories CC) will be scrutinised.

The establishment of a geo-referenced LULUCF reporting system is being pursued.

## 6.3.2. Information on approaches used for natural disturbances

### 6.3.2.1. Forest land

#### 6.3.2.1.1. *Application of the provision of natural disturbances*

Under the Kyoto Protocol, Switzerland indicated to apply the provision of natural disturbances for the elected activity Forest management (FOEN 2016c, FOEN 2016d). Under the Paris Agreement, Switzerland will continue to do so (FOEN 2021n). In cases or events in which emissions from natural disturbances on Forest land are higher than the nationally established threshold value and in which all other requirements defined in 2/CMP.7 and IPCC (2014) are met, Switzerland will evaluate whether the technical effort would be justified to exclude them.

The parameters for natural disturbances (background level and margin) on Forest land were reported in Switzerland's Second Initial Report (FOEN 2016d).

In the reporting year, no natural disturbances causing emissions exceeding the upper confidence interval (background level plus margin) occurred. Thus, no emissions from natural disturbances were excluded.

#### 6.3.2.1.2. *Technical correction of the background level and margin*

The background level and margin were reviewed and reported in the update of Switzerland's Second Initial Report (FOEN 2016d).

There is no technical correction of the background level and margin. Both parameters will be checked and if necessary updated for the submission in 2024.

### 6.3.2.2. Non-Forest land

For non-Forest land, no provisions for natural disturbances will be applied (FOEN 2021n).

## 6.3.3. Information on approaches used for harvested wood products

For reporting harvested wood products (HWP), the approach B (production approach) as described in chp. 12, Volume 4 of IPCC (2019) was applied. The wood products pool contains only products made from wood harvested in Switzerland. It includes products made from domestic harvest that are exported to foreign countries. Details and results are presented in chp. 6.10.

## 6.4. Category 4A – Forest land

### 6.4.1. Description

Table 6-12 Key categories in category 4A. Combined KCA results, level for 2021 and trend for 1990–2021, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC category	Gas	Identification criteria
4A1	Forest land remaining forest land	CO <sub>2</sub>	L1, T1, L2, T2
4A2	Land converted to forest land	CO <sub>2</sub>	L1, L2

Only temperate forests occur in Switzerland. Forest is defined as a minimum area of land of 0.0625 ha with crown cover of at least 20 % and a minimum width of 25 m. The minimum height of the dominant trees must be 3 m or have the potential to reach 3 m at maturity in situ (FOEN 2006h). The following forest areas are not subject to the criteria of minimum stand height and minimum crown cover, but must have the potential to achieve it: afforested, regenerated, as well as burnt, cut or damaged areas. Some land categories were explicitly excluded from the land-use category Forest land, although they may partly fulfil the (quantitative) requirements of the Swiss forest definition (FOEN 2006h; Table 6-6):

- Vineyards, low-stem orchards, tree nurseries, copses and orchards in the land-use category Grassland;
- Cemeteries, public parks, open tree formations in settlements, gardens, sports and parking fields in the land-use category Settlements.

According to the Federal Act on Forest, it is one objective to “conserve the forest in its area and spatial distribution” (Swiss Confederation 1991: Art. 1a). Any deliberate reduction in forest area has to be authorized. Therefore, all forests in Switzerland are considered to be under management.

Forest land is reported using two land-use categories, productive forest (CC12) and unproductive forest (CC13) (chp. 6.1.3 and Table 6-2). Productive forest is covered in chp. 6.4.2.2 and chp. 6.4.2.3, and a description of unproductive forest can be found in chp. 6.4.2.4.

In the inventory period, the total net emissions and removals of category 4A1 Forest land remaining forest land range from 4'951 kt CO<sub>2</sub> in 2000 to -5'761 kt CO<sub>2</sub> in 1996 (average -2'575 kt CO<sub>2</sub>; Figure 6-6 top panel). Particularly the pools living biomass, dead wood and litter introduce temporal variability (Figure 6-6 both panels). The exceptionally high net emissions in 2000 and the small net removals in the following year 2001 originate from winter storm “Lothar” at the end of 1999, which caused large-scale damages in forest stands and increased losses of living biomass due to salvage logging. Harvesting rates in Swiss forests gradually increased between 1991 and 2007. Peak harvesting values in 2006 and 2007 resulted in small removals from Forest land. In 2008 harvesting rates dropped (Table 6-15) due to the international and domestic economic framework conditions and remained relatively constant thereafter with interannual fluctuation of ca. 2 to 8 %. These fluctuations are reflected in the year-to-year variability of the removals from Forest land. The small net removals in 2011, 2014 and 2018 are due to relative high harvesting rates in conjunction with above-average losses in the litter pool (related to climatic circumstances).

Category 4A2 Land converted to forest land was a net sink in all years (average -593 kt CO<sub>2</sub>; Figure 6-6 top panel) with small fluctuations mainly due to slight variations in land use change rates over the inventory period and the associated living biomass on these areas.

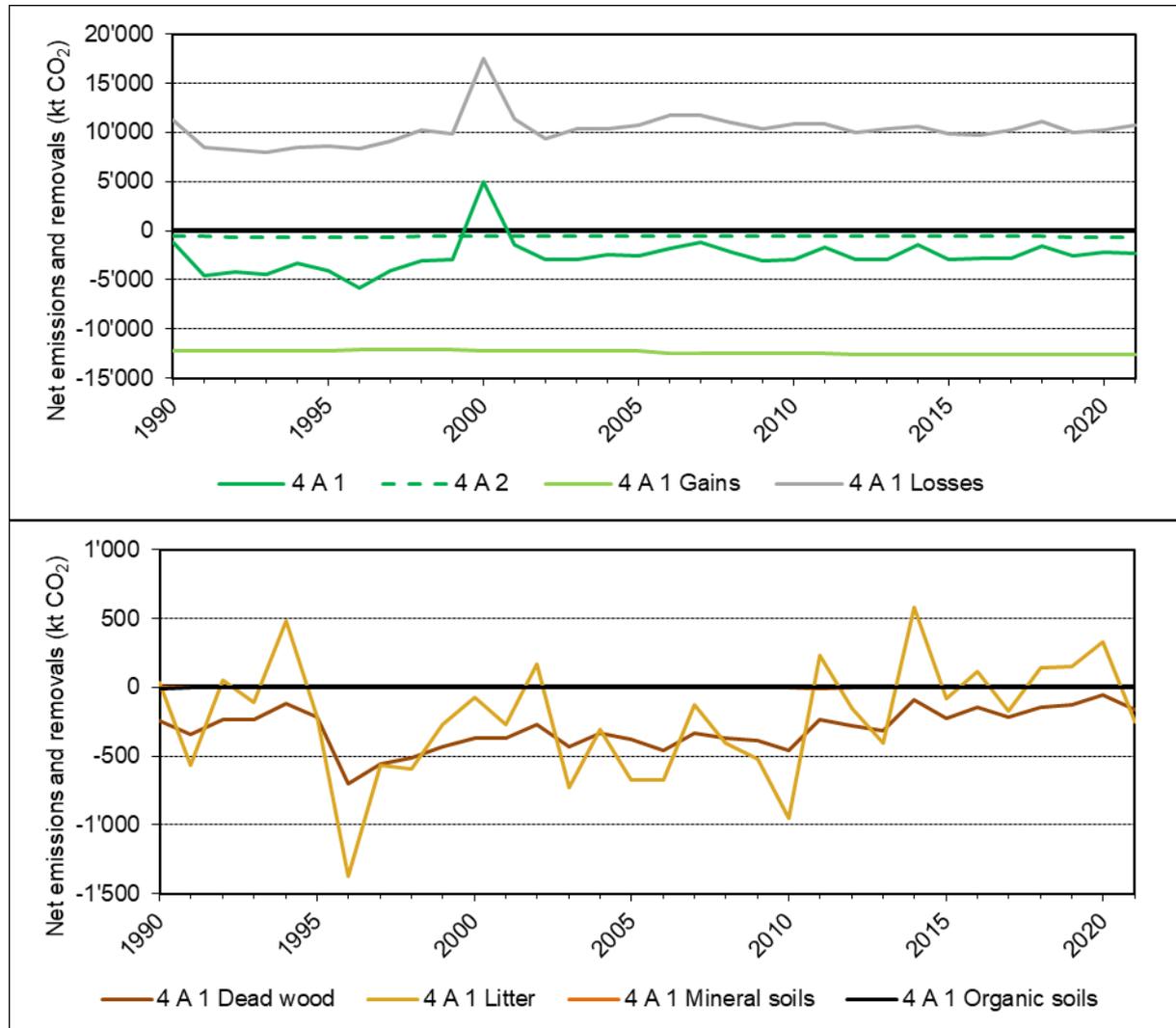


Figure 6-6 Net CO<sub>2</sub> emissions (positive values) and removals (negative values) from categories 4A1 and 4A2. Category 4A1 is broken down by gains and losses in living biomass (top panel), and net carbon stock changes in dead wood, litter, mineral soil and organic soil (bottom panel). Note the different scaling of the y-axis. The changes in mineral and organic soils are too small to be distinguished from the zero line.

Forest land is expanding in Switzerland (see Table 6-8). The land-use change matrices show that expansions are mainly occurring on former grasslands (CC3X to CC12 or to CC13; Table 6-9) and are primarily due to natural forest regeneration in the alpine area and not by plantation (Gehrig-Fasel et al. 2007; Rutherford et al. 2008; SWI 2009; Brändli 2014; Rigling and Schaffer 2015; Brändli et al. 2020). Such newly forested areas typically exhibit a large diversity in diameter at breast height and tree age.

## 6.4.2. Methodological issues

### 6.4.2.1. Choice of methods

#### 6.4.2.1.1. National Forest Inventory

##### 6.4.2.1.1.1. National Forest Inventory data

The National Forest Inventory (NFI) is the primary source for estimating carbon stock change factors for Forest land. Growing stock, cut and mortality are estimated based on tally trees with a diameter at breast height (DBH)  $\geq 12$  cm. For tally trees, allometric relationships were developed to obtain accurate data on whole tree volume and biomass (Lanz et al. 2019). These data are further used to estimate the annual production of dead wood and litter that drive carbon stocks and carbon stock changes in the dead organic matter and soil carbon pools calculated with Yasso07.

The calculation approaches for land-use changes within, from and to Forest land are shown in Table 6-3. Didion et al. (2019) contains a schematic overview and a detailed description of all tree biomass elements which are included in the estimation of reported carbon stocks and carbon stock changes in above- and belowground biomass. The tree elements comprise stemwood including tree top and stump, large and small branches, foliage, and coarse roots. For estimating the carbon stock changes in litter, dead wood and in mineral soil, also fine roots and seeds are considered (Didion and Zell 2019).

Data from four completed National Forest Inventories (NFI1, NFI2, NFI3, NFI4) and from the first two years of the ongoing NFI5 are currently available (Table 6-13). Descriptions of NFI1, NFI2, and NFI3 results can be found in EAFV/BFL (1988), in Brassel and Brändli (1999), and in Brändli (2010), respectively. These inventories were based on full surveys that were repeated in intervals of approximately 10 years. Starting with the NFI4 (Brändli et al. 2020) a continuous survey approach is used where annually a nationally representative subsample of approximately 12 % of the Swiss forests is surveyed and evaluated. Otherwise, the methodology remained consistent with previous inventories. The NFI5 has started in 2018. A detailed description of the current methods to estimate volume, biomass, and carbon for LULUCF reporting can be found in Herold et al. (2019) and Didion et al. (2019).

Table 6-13 Characteristics of the National Forest Inventories NFI1, NFI2, NFI3, NFI4 and NFI5 (2018–2019), accessible forest plots without brush forest.

	NFI1	NFI2	NFI3	NFI4	NFI5
Inventory cycle	1983-1985	1993-1995	2004-2006	2009-2017	2018-2019
Grid size	1 x 1 km	1.4 x 1.4 km	1.4 x 1.4 km	1.4 x 1.4 km	1.4 x 1.4 km
Terrestrial sample plots	10'981	5'679	5'920	6'042	1'358
Tally trees	128'441	67'297	69'960	71'906	16'343

Data for growing stock (carbon stock of total living biomass) were estimated for a particular NFI. Gross growth (carbon gains in living biomass), cut and mortality (carbon losses in living biomass; Didion et al. 2020: chp. 2.3), and dead wood and litter production (Didion 2020a: chp. 2.3.2) were based on the observed changes between two consecutive NFIs (see chp. 6.4.2.2 and chp. 6.4.2.3). Carbon stock changes between two NFIs were obtained based on data from the common plots (Table 6-14). The total number of common plots can differ for inter-survey periods as a result of land-use changes from or to Forest land (Didion et al. 2020: Table 4).

For compiling the results for the latest GHG inventory, NFI5 data for the years 2018–2019 were used in addition to the data from NFI1, NFI2, NFI3 and NFI4, and the respective inventory periods NFI1-2, NFI2-3, and NFI34-5 (2015–2019). Results on growing stock based on data collected in the five years 2015–2017 (NFI4) and 2018–2019 (NFI5) and for growth and cut and mortality based on the inventory period NFI34-5 (2015–2019) were summarised in the data release NFI34-5 (2015–2019; see Table 6-14 and Didion et al. 2020).

Table 6-14 Number of NFI sample plots in each NFI inter-survey period: number of plots which were forest also in the previous NFI inter-survey period and the number of plots newly converted to forest (Didion et al. 2020). Data from the total number of plots is used to calculate carbon stock changes between two inventories. Footnote 1: not applicable in this first NFI period; footnote 2: for the period NFI34-5 only sample plots common to NFI3 and the sample plots in NFI4 visited in the years 2015 to 2017 and common to NFI4 and NFI5 visited in the years 2018 and 2019 were considered.

NFI period	NFI inter-survey-period	Forest in previous period	Converted to forest since previous period	Total for period
		Number of sample plots		
NFI1-2	1985-1995	NA <sup>1</sup>	NA <sup>1</sup>	5456
NFI2-3	1996-2005	5'370	211	5581
NFI34-5 (2015-2019) <sup>2</sup>	2006-2019	3'022	199	3'221

#### 6.4.2.1.1.2. Updating NFI data

In general, new NFI data have an influence on the time series of carbon stock changes (gains and losses in living biomass, dead wood, litter and mineral soil) because they are calculated based on observed changes between two consecutive forest inventories.

The change from periodic sampling (NFIs 1 to 3) to a continuous sampling starting with the NFI4 required a modification of the estimation of carbon stock changes affecting estimates from 2005 onwards. The adapted method requires NFI data from a shifting five-year window to ensure accuracy and consistency of the estimates of carbon stock changes. The method based on a shifting five-year window of NFI data will also be used in future submissions and thus, recalculations will be performed when new NFI data become available (see chp. 1.1 and chp. 2.3 in Didion et al. 2020). The continuous survey approach allows regular updates of data to obtain the most current and accurate estimates for stocks, gains, and losses in living biomass. The differences in the results arising by an update of the five-year period reflect the uncertainty in the data as the sample plots used for the estimate are exchanged, but time series remain consistent as carbon stock change estimates are still based on representative subsamples of the NFI sample plots.

#### 6.4.2.1.1.3. Data available in the NFI for estimating biomass

In the field surveys standing and lying stems are measured on two nested circular sample plots with 200 m<sup>2</sup> and 500 m<sup>2</sup> in area, respectively. On the smaller plot, trees and shrubs with DBH ≥12 cm are measured, whereas all trees with DBH ≥36 cm are measured on the larger plot. In order to assess the regeneration of the forest, young trees and the main shrub species with a minimum height of 10 cm and DBH <12 cm are assessed on a separate set of four circular sample plots with radii between 0.9 and 4 m (Brändli and Hägeli 2019).

For estimating carbon stocks and carbon stock changes in the GHG inventory, currently, (1) trees with DBH <12 cm with branches, foliage, and roots, and (2) non-tree understory vegetation including shrubs, ferns, grasses, sedges, and herbs are not considered because Switzerland's country-specific allometric functions only apply to trees  $\geq 12$  cm DBH.

#### **6.4.2.1.2. Forest land stratification**

Forests in Switzerland reveal a high heterogeneity in terms of elevation, growth conditions, tree species composition, and interannual growth variability. The suitability of a spatial stratification was analysed for Forest land (see Table 2b in Thürig et al. 2005a and Table 3 in Didion et al. 2020). The analyses indicated that tree species type, production region and elevation all significantly explain differences in gross growth. Accordingly, a spatial stratification into five production regions and three elevation zones was applied (see chp. 6.2.2.2 and chp. 6.2.2.3). For the calculation of growing stock, gross growth, harvesting and mortality these strata were then further divided into two tree species types: coniferous and broadleaved species (Didion et al. 2020).

Forest land was further stratified by soil type (mineral or organic; see chp. 6.2.2.1).

The continuous survey approach since the NFI4 and the use of a five-year shifting window to regularly update estimates of carbon stocks, gains and losses result in a reduced number of sample plots that are simultaneously available for estimating the forest carbon balance (Table 6-14; see Table 5 in Didion et al. 2020), and several spatial strata are represented by a low number of plots. Due to the large variability of the forest structure and composition between sample plots a minimum number of sample plots is needed to obtain reliable estimates of means and sampling errors. Smaller strata are thus merged with neighbouring strata and treated as single strata. This applies to:

- NFI production region 2 Central Plateau 601-1200 m and >1200 m:  
new stratum NFI production region 2 Central Plateau >600 m
- NFI production region 3 Pre-Alps  $\leq 600$  m and 601-1200 m:  
new stratum NFI production region 3 Pre-Alps  $\leq 1200$  m
- NFI production region 4 Alps  $\leq 600$  m and 601-1200 m:  
new stratum NFI production region 4 Alps  $\leq 1200$  m

#### **6.4.2.1.3. Carbon content**

A mean carbon content of 50 % was used to convert the biomass of alive trees to carbon stocks. The carbon content estimate represents an approximation which was based on carbon fractions for coniferous and broadleaved trees in temperate forests provided in Table 4.3 in Volume 4 of IPCC (2006), and on the fact that in Switzerland coniferous trees are more abundant than broadleaved trees (see Brändli et al. 2020: Table 056).

#### **6.4.2.1.4. Soil carbon model Yasso07**

Switzerland uses the soil carbon model Yasso07 to estimate temporal changes in carbon stocks in dead wood, organic soil horizons (LFH; litter) and mineral forest soil (0–100 cm depth) for the land-use category productive forest. The implementation of Yasso07 (Tuomi et al. 2009, 2011) for LULUCF reporting is described in detail in Didion (2020a). Didion et al. (2014a) demonstrated the validity of the model for application in Swiss forests. Consistently

with the estimation procedure for living biomass, the model is applied on the common plots between two NFIs (chp. 6.4.2.1.1; Table 6-14). The estimates used for the latest submission are displayed in supplement 2 to Didion (2020a).

Yasso07 is a model of carbon cycling in mineral soil, litter and dead wood. For estimating stocks of organic carbon in mineral soil up to a depth of ca. 100 cm and the temporal dynamics of the carbon stocks, Yasso07 requires information on carbon inputs (see below) and climate (annual monthly temperature and precipitation).

The NFI is the source of carbon inputs and of the state change of each sample tree between two consecutive inventories (i.e. survivor, cut, mortality, ingrowth and nongrowth trees; Didion et al. 2020). The tree state in two consecutive NFIs determines the type and quantity of carbon inputs. Turnover rates reflecting the longevity of leaves and needles, seeds and fruits, fine roots, and small branches are used to estimate carbon inputs that are produced annually. Stemwood, including tree top and stump, large branches, and coarse roots are assumed to accrue only as the result of mortality. Depending on the cause of mortality, i.e. natural or timber harvesting, either the total mass of these tree elements or only the non-merchantable fraction (coarse root, stump, top, and small branches) is considered for carbon inputs.

By default, Yasso07 does not provide separate estimates of carbon pool sizes for dead wood, litter and mineral soil. In order to report estimates for each pool, the model structure of Yasso07 was examined to obtain separate estimates. Dead wood, litter and soil pools could be correlated with modelled data based on the category of carbon input, i.e., non-woody and woody material, and the five carbon compartments in Yasso07, i.e. four chemical partitions (insoluble, soluble in ethanol, soluble in water or in acid) and humus. The approach was validated using independent, measured data (Didion et al. 2012).

#### **6.4.2.2. Productive forest (CC12): carbon stocks and carbon stock changes in living biomass**

The estimates of carbon stocks in living biomass (growing stock) were based on measurements of individual tally trees of two consecutive NFIs, considering all measured living trees on the common sample plots. Estimates of carbon stock changes, i.e. including gains in living biomass (gross growth) and carbon losses in living biomass (cut and mortality) for productive forests were derived from two consecutive NFIs (see Table 6-14). All values derived from the national forest inventories refer to above- and below ground biomass in mass units ( $t\ ha^{-1}$ ) per spatial stratum. The estimates used for the latest submission are presented and discussed in supplement 2 to Didion et al. (2020).

##### **6.4.2.2.1. Carbon stocks in living biomass – growing stock**

Carbon stock in living biomass was defined as the biomass of all tree elements (stemwood over bark including stump, large (coarse) and small branches, needles/leaves, and roots) of trees with DBH  $\geq 12$  cm. It was estimated based on established allometries to tree dimensions and wood densities. Biomass estimates for stemwood over bark including stump and for all branches are derived based on volume models and conversion to biomass. Foliage and coarse root biomass are derived directly from tree DBH. Fine roots are reported under litter (see chp. 6.4.2.3.2). Except for coarse roots, the biomass functions were empirically derived from a large number of single-tree data from Swiss forest sites. A detailed

overview of the applied allometric biomass functions and the corresponding scientific references per tree element is given in Didion et al. (2020: Table 2).

#### **6.4.2.2.2. Carbon stock changes in living biomass**

##### **Carbon gains – gross growth**

Carbon gains in living biomass were derived from two consecutive NFIs and were assumed to remain constant within the intersurvey periods (see Table 6-14).

##### **Carbon losses – cut and mortality**

Carbon losses in living biomass were derived from two consecutive NFIs (see Table 6-14). To obtain annual values of cut and mortality for each individual NFI intersurvey period, i.e. the years 1985 to 1995, 1996 to 2005 and 2006 to 2019, respectively, the average amount of cut and mortality from NFI was weighted by the percentage of the relative harvesting amounts derived from the forest statistics (Table 6-15; FOEN 2023f and previous editions; Federal Statistical Office: Wood harvest in Switzerland 1975–2021, <https://www.pxweb.bfs.admin.ch>). These relative harvesting amounts, used as weighting factors, were calculated for each year per NFI intersurvey period. Losses for the inventory years 2020 and 2021 were calculated using a weighting factor based on the harvest statistics data on harvested volume for these years and the mean of harvested volume in the period 2006–2019 derived from the NFI.

Harvesting rates in Swiss forests increased since the start of the statistics until 2007 (Table 6-15). Harvesting rates were exceptionally high in 1990 after the storm Vivian (February 1990) and in 2000 after the storm Lothar (December 1999), which resulted in higher losses of living biomass compared to other years. Peak values in 2006 and 2007 resulted in high losses of living biomass in Forest land. In 2008 harvesting rates dropped due to the international and domestic economic framework conditions and remained relatively constant thereafter with interannual fluctuation of ca. 2 to 8 %. These fluctuations are reflected in the year-to-year variability of the CO<sub>2</sub> balance from Forest land (see Figure 6-6).

Table 6-15 Annual harvesting amount in m<sup>3</sup> merchantable wood specified for five NFI production region as well as for coniferous and broadleaved tree species (FOEN 2023f and previous editions; <https://www.pxweb.bfs.admin.ch>).

Year	1. Jura		2. Central plateau		3. Pre-Alps		4. Alps		5. Southern Alps		Total [m <sup>3</sup> ]
	Conif. [m <sup>3</sup> ]	Broadl. [m <sup>3</sup> ]									
1990	687'327	358'647	1'769'813	606'718	1'285'639	138'126	1'301'313	70'064	21'575	22'456	6'261'678
1991	476'956	354'002	1'017'232	489'742	877'851	133'155	1'064'650	72'229	24'356	26'736	4'536'909
1992	555'523	372'249	1'199'596	571'610	735'680	128'934	736'230	70'706	47'388	28'637	4'446'553
1993	550'536	373'298	1'206'294	562'232	723'565	132'676	649'938	63'940	42'511	32'785	4'337'775
1994	621'726	392'967	1'270'296	530'906	798'449	136'103	717'840	66'896	40'986	33'746	4'609'915
1995	650'572	407'119	1'388'932	570'552	774'040	154'108	590'859	56'714	51'643	33'869	4'678'408
1996	520'335	381'365	1'066'770	567'769	654'554	151'164	506'107	59'674	48'288	38'889	3'994'915
1997	599'981	394'846	1'176'333	576'415	742'830	153'719	574'152	63'650	61'043	40'189	4'383'158
1998	604'703	422'216	1'330'973	627'633	836'806	164'348	657'409	108'848	50'626	41'485	4'845'047
1999	602'652	398'648	1'342'905	639'150	824'142	173'845	593'844	68'786	44'556	39'181	4'727'709
2000	994'262	387'183	3'916'680	934'372	2'241'486	213'858	436'743	57'105	21'236	35'049	9'237'974
2001	443'612	338'751	2'020'561	594'616	1'477'489	157'710	510'730	60'152	22'237	35'722	5'661'580
2002	442'519	329'480	1'406'758	493'905	1'090'875	134'603	528'144	63'303	31'236	35'794	4'556'617
2003	557'454	315'096	1'669'605	518'273	1'195'090	142'055	588'062	62'739	37'111	35'486	5'120'971
2004	655'757	305'681	1'774'841	515'877	1'119'243	164'745	488'722	70'090	29'995	35'571	5'160'522
2005	653'049	359'808	1'810'839	614'845	1'010'979	180'546	514'905	70'603	35'462	33'614	5'284'650
2006	735'256	405'850	1'779'973	687'428	1'116'868	229'781	569'673	84'656	43'443	48'599	5'701'527
2007	793'459	425'790	1'587'494	699'076	1'144'370	230'284	621'234	82'414	62'799	43'638	5'690'558
2008	705'815	459'994	1'281'782	727'581	1'018'497	224'634	664'086	82'623	53'064	44'123	5'262'199
2009	598'292	461'055	1'149'202	701'188	878'565	224'490	678'212	90'001	56'375	42'316	4'879'696
2010	647'176	494'739	1'090'994	722'644	992'435	248'151	720'659	99'773	60'391	52'037	5'128'999
2011	617'887	513'720	1'061'986	741'587	983'040	253'300	686'797	101'644	61'822	53'305	5'075'088
2012	566'782	488'626	970'748	719'003	825'019	225'988	665'506	94'480	51'475	50'757	4'658'384
2013	576'744	521'122	948'706	739'180	834'166	254'726	670'170	117'841	64'745	50'928	4'778'328
2014	619'002	539'721	945'695	777'852	863'150	259'888	654'300	110'816	95'192	47'603	4'913'219
2015	528'202	505'431	916'020	766'645	753'783	244'149	625'555	96'230	62'233	53'649	4'551'897
2016	549'561	509'699	859'677	737'207	766'647	236'279	570'415	103'416	65'254	60'836	4'458'991
2017	545'998	514'176	993'430	765'711	806'033	242'423	596'105	96'622	72'298	54'746	4'687'542
2018	564'468	492'343	1'421'416	719'879	910'871	216'813	649'759	94'766	61'417	66'470	5'198'202
2019	537'886	478'869	1'181'674	630'237	787'296	214'837	530'476	94'646	92'495	65'622	4'614'038
2020	604'675	457'399	1'360'224	633'451	814'466	205'946	543'583	74'541	45'401	62'539	4'802'225
2021	695'736	473'009	1'195'542	684'866	907'322	236'511	594'717	83'734	54'734	71'712	4'997'883

#### 6.4.2.2.3. Carbon stocks in living biomass – calculation of time series

In order to develop a consistent time series, annual carbon stocks of living biomass (growing stocks) per species type (stockC<sub>i</sub>) were calculated per spatial strata (i) for productive forests (CC12) backward or forward starting from the growing stock in 2005, determined from common plots from NFI2-3 (Brändli 2010; abbreviations are explained in chp. 6.1.3.2):

$$\text{stockC}_{i,i,CC12,iy} = \text{stockC}_{i,i,CC12,2005} - \sum_{n=2005}^{iy} [\text{gainC}_{i,i,CC12,n}] + \sum_{n=2005}^{iy} [\text{lossC}_{i,i,CC12,n}] \text{ for } iy < 2005$$

$$\text{stockC}_{i,i,CC12,iy} = \text{stockC}_{i,i,CC12,2005} \text{ for } iy = 2005$$

$$\text{stockC}_{i,i,CC12,iy} = \text{stockC}_{i,i,CC12,2005} + \sum_{n=2006}^{iy} [\text{gainC}_{i,i,CC12,n}] - \sum_{n=2006}^{iy} [\text{lossC}_{i,i,CC12,n}] \text{ for } iy > 2005$$

where “iy” indicates the inventory year (years between 1985–2021) and “n” indicates the years between 2005/2006 and the inventory year iy.

The backward calculation was used for the time period 1985–2004 ( $iy < 2005$ ), where the annual carbon stock in living biomass equals the carbon stock in living biomass 2005 minus the net change based on the carbon gains in living biomass due gross growth ( $gainC_{l,i,CC12,iy}$ ) and the carbon losses in living biomass due to the annual amounts of cut and mortality ( $lossC_{l,i,CC12,iy}$ ).

The forward calculation was used for the time period after 2005 ( $iy > 2005$ ), where the annual growing stock equals the growing stock 2005 plus the net change based on the carbon gains due to the annual gross growth ( $gainC_{l,i,CC12,iy}$ ) and the carbon losses due the annual amounts of cut and mortality ( $lossC_{l,i,CC12,iy}$ ).

Table 6-16 shows the time series of growing stocks (carbon stocks in living biomass), gross growth (carbon gains in living biomass), and cut and mortality (carbon losses in living biomass) specified for all spatial strata.

Background information on the NFI data delivery as well as a description of all working steps and data required to reproduce the calculation of carbon stock change factors for the land-use category productive forest in the period 1990 until the inventory year are summarised in Didion et al. (2020).

Table 6-16 Carbon stocks in living biomass (stock<sub>Ci</sub>), carbon gains in living biomass (gross growth, gain<sub>Ci</sub>), and carbon losses in living biomass (cut and mortality, loss<sub>Ci</sub>) for the land-use category productive forest (CC12) stratified for NFI production region (NFI) and elevation zone (Elev.). Highlighted data for 1990 are displayed in Table 6-4.

NFI	Elev.	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
		CC12: carbon stock in living biomass (stock <sub>Ci,i</sub> ) [t C ha <sup>-1</sup> ]									
1	1	128.65	130.14	131.45	132.77	133.91	134.96	134.44	133.64	132.63	131.80
1	2	125.27	126.64	127.81	128.99	129.98	130.87	131.58	132.08	132.48	132.96
1	3	84.74	85.71	86.53	87.36	88.06	88.69	89.46	90.11	90.73	91.37
2	1	134.51	135.97	136.89	137.82	138.74	139.34	140.14	140.70	140.83	140.90
2	2	147.20	148.86	149.99	151.13	152.23	153.02	154.09	154.91	155.30	155.63
2	3	102.11	103.09	103.95	104.81	105.64	106.40	106.82	107.17	107.41	107.64
3	1	135.07	136.81	138.76	140.67	142.46	144.02	146.17	148.18	149.97	151.71
3	2	147.49	148.86	150.59	152.32	153.87	155.38	156.92	158.20	159.16	160.12
3	3	118.79	119.37	120.26	121.17	121.92	122.71	123.80	124.70	125.41	126.14
4	1	92.97	93.11	93.52	94.22	94.77	95.74	97.85	99.66	100.68	102.39
4	2	103.37	103.65	104.48	105.50	106.38	107.54	108.53	109.44	109.85	110.69
4	3	94.98	94.76	95.15	95.71	96.14	96.81	97.56	98.15	98.54	99.09
5	1	72.68	74.33	75.88	77.27	78.63	79.97	80.57	81.13	81.63	82.23
5	2	76.85	78.33	79.69	80.96	82.22	83.44	84.94	86.40	87.86	89.37
5	3	76.43	77.69	78.73	79.79	80.87	81.85	83.06	84.13	85.31	86.56

NFI	Elev.	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
		CC12: carbon stock in living biomass (stock <sub>Ci,i</sub> ) [t C ha <sup>-1</sup> ]									
1	1	130.14	130.09	130.12	129.97	129.67	128.99	129.58	129.98	130.47	131.18
1	2	132.57	133.59	134.64	135.47	136.09	136.57	136.90	137.04	137.30	137.84
1	3	91.47	92.38	93.30	94.06	94.70	95.30	95.04	94.60	94.39	94.47
2	1	135.39	134.39	134.81	134.68	134.37	133.68	132.14	130.97	130.35	130.09
2	2	150.00	149.04	149.58	149.52	149.25	148.67	146.45	145.61	145.35	145.47
2	3	106.15	105.96	106.20	106.26	106.25	106.19	146.45	145.61	145.35	145.47
3	1	151.23	152.21	153.91	155.40	156.81	158.25	156.56	155.99	155.83	156.08
3	2	156.83	156.00	156.38	156.43	156.59	156.97	156.56	155.99	155.83	156.08
3	3	123.92	123.30	123.49	123.46	123.58	123.92	124.21	124.44	124.89	125.58
4	1	104.45	106.39	108.26	110.07	111.88	113.65	117.52	118.28	118.97	119.56
4	2	111.91	112.98	113.98	114.88	115.91	116.88	117.52	118.28	118.97	119.56
4	3	99.99	100.73	101.42	101.99	102.77	103.49	104.61	105.65	106.62	107.55
5	1	82.98	83.71	84.43	85.17	85.90	86.70	87.96	89.37	90.77	92.22
5	2	90.98	92.58	94.16	95.74	97.33	98.93	100.03	101.11	102.22	103.34
5	3	88.06	89.54	90.93	92.26	93.67	95.02	96.45	97.70	99.05	100.37

NFI	Elev.	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
		CC12: carbon stock in living biomass (stock <sub>Ci,i</sub> ) [t C ha <sup>-1</sup> ]									
1	1	131.69	132.21	132.91	133.50	133.94	134.67	135.35	136.02	136.71	137.50
1	2	138.16	138.51	139.05	139.48	139.76	140.36	140.89	141.41	141.95	142.59
1	3	94.40	94.39	94.54	94.64	94.62	94.86	95.05	95.24	95.40	95.63
2	1	129.89	129.68	129.74	129.78	129.71	129.74	129.98	129.84	128.96	128.85
2	2	145.64	145.81	146.26	146.69	147.00	147.41	148.04	148.28	147.74	148.02
2	3	145.64	145.81	146.26	146.69	147.00	147.41	148.04	148.28	147.74	148.02
3	1	155.88	155.68	156.09	156.33	156.46	156.99	157.53	157.91	158.11	158.69
3	2	155.88	155.68	156.09	156.33	156.46	156.99	157.53	157.91	158.11	158.69
3	3	126.07	126.57	127.35	128.11	128.81	129.71	130.59	131.39	132.03	132.89
4	1	120.00	120.48	121.06	121.42	121.88	122.52	123.19	123.88	124.48	125.31
4	2	120.00	120.48	121.06	121.42	121.88	122.52	123.19	123.88	124.48	125.31
4	3	108.42	109.33	110.28	111.21	112.17	113.19	114.29	115.36	116.34	117.51
5	1	93.38	94.50	95.70	96.89	98.18	99.29	100.18	101.26	101.98	102.73
5	2	104.32	105.28	106.32	107.29	108.17	109.12	109.97	110.86	111.65	112.31
5	3	101.63	102.86	104.21	105.42	106.35	107.58	108.76	109.89	111.10	112.00

NFI	Elev.	2020	2021
		CC12: carbon stock in living biomass (stock <sub>Ci,i</sub> ) [t C ha <sup>-1</sup> ]	
1	1	138.21	138.68
1	2	143.12	143.37
1	3	95.70	95.51
2	1	128.35	128.04
2	2	147.89	147.96
2	3	147.89	147.96
3	1	159.23	159.34
3	2	159.23	159.34
3	3	133.69	134.33
4	1	126.28	127.09
4	2	126.28	127.09
4	3	118.68	119.76
5	1	103.57	104.13
5	2	113.23	113.99
5	3	113.37	114.63

(Table 6-16 continued)

NFI	Elev.	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
		CC12: carbon gains in living biomass (gainCl,i) [t C ha <sup>-1</sup> yr <sup>-1</sup> ]									
1	1	3.60	3.60	3.60	3.60	3.60	3.60	3.37	3.37	3.37	3.37
1	2	3.21	3.21	3.21	3.21	3.21	3.21	3.04	3.04	3.04	3.04
1	3	1.95	1.95	1.95	1.95	1.95	1.95	1.80	1.80	1.80	1.80
2	1	4.63	4.63	4.63	4.63	4.63	4.63	4.54	4.54	4.54	4.54
2	2	4.63	4.63	4.63	4.63	4.63	4.63	4.56	4.56	4.56	4.56
2	3	1.60	1.60	1.60	1.60	1.60	1.60	1.28	1.28	1.28	1.28
3	1	4.56	4.56	4.56	4.56	4.56	4.56	4.23	4.23	4.23	4.23
3	2	4.15	4.15	4.15	4.15	4.15	4.15	4.15	4.15	4.15	4.15
3	3	2.48	2.48	2.48	2.48	2.48	2.48	2.50	2.50	2.50	2.50
4	1	3.24	3.24	3.24	3.24	3.24	3.24	3.44	3.44	3.44	3.44
4	2	2.49	2.49	2.49	2.49	2.49	2.49	2.50	2.50	2.50	2.50
4	3	1.81	1.81	1.81	1.81	1.81	1.81	1.90	1.90	1.90	1.90
5	1	2.74	2.74	2.74	2.74	2.74	2.74	2.04	2.04	2.04	2.04
5	2	2.20	2.20	2.20	2.20	2.20	2.20	2.18	2.18	2.18	2.18
5	3	1.61	1.61	1.61	1.61	1.61	1.61	1.79	1.79	1.79	1.79

NFI	Elev.	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
		CC12: carbon gains in living biomass (gainCl,i) [t C ha <sup>-1</sup> yr <sup>-1</sup> ]									
1	1	3.37	3.37	3.37	3.37	3.37	3.37	3.31	3.31	3.31	3.31
1	2	3.04	3.04	3.04	3.04	3.04	3.04	3.20	3.20	3.20	3.20
1	3	1.80	1.80	1.80	1.80	1.80	1.80	2.04	2.04	2.04	2.04
2	1	4.54	4.54	4.54	4.54	4.54	4.54	4.29	4.29	4.29	4.29
2	2	4.56	4.56	4.56	4.56	4.56	4.56	4.89	4.89	4.89	4.89
2	3	1.28	1.28	1.28	1.28	1.28	1.28	4.89	4.89	4.89	4.89
3	1	4.23	4.23	4.23	4.23	4.23	4.23	4.00	4.00	4.00	4.00
3	2	4.15	4.15	4.15	4.15	4.15	4.15	4.00	4.00	4.00	4.00
3	3	2.50	2.50	2.50	2.50	2.50	2.50	2.29	2.29	2.29	2.29
4	1	3.44	3.44	3.44	3.44	3.44	3.44	2.62	2.62	2.62	2.62
4	2	2.50	2.50	2.50	2.50	2.50	2.50	2.62	2.62	2.62	2.62
4	3	1.90	1.90	1.90	1.90	1.90	1.90	2.12	2.12	2.12	2.12
5	1	2.04	2.04	2.04	2.04	2.04	2.04	2.73	2.73	2.73	2.73
5	2	2.18	2.18	2.18	2.18	2.18	2.18	1.92	1.92	1.92	1.92
5	3	1.79	1.79	1.79	1.79	1.79	1.79	1.99	1.99	1.99	1.99

NFI	Elev.	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
		CC12: carbon gains in living biomass (gainCl,i) [t C ha <sup>-1</sup> yr <sup>-1</sup> ]									
1	1	3.31	3.31	3.31	3.31	3.31	3.31	3.31	3.31	3.31	3.31
1	2	3.20	3.20	3.20	3.20	3.20	3.20	3.20	3.20	3.20	3.20
1	3	2.04	2.04	2.04	2.04	2.04	2.04	2.04	2.04	2.04	2.04
2	1	4.29	4.29	4.29	4.29	4.29	4.29	4.29	4.29	4.29	4.29
2	2	4.89	4.89	4.89	4.89	4.89	4.89	4.89	4.89	4.89	4.89
2	3	4.89	4.89	4.89	4.89	4.89	4.89	4.89	4.89	4.89	4.89
3	1	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
3	2	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
3	3	2.29	2.29	2.29	2.29	2.29	2.29	2.29	2.29	2.29	2.29
4	1	2.62	2.62	2.62	2.62	2.62	2.62	2.62	2.62	2.62	2.62
4	2	2.62	2.62	2.62	2.62	2.62	2.62	2.62	2.62	2.62	2.62
4	3	2.12	2.12	2.12	2.12	2.12	2.12	2.12	2.12	2.12	2.12
5	1	2.73	2.73	2.73	2.73	2.73	2.73	2.73	2.73	2.73	2.73
5	2	1.92	1.92	1.92	1.92	1.92	1.92	1.92	1.92	1.92	1.92
5	3	1.99	1.99	1.99	1.99	1.99	1.99	1.99	1.99	1.99	1.99

NFI	Elev.	2020	2021	CC12: carbon gains in living biomass (gainCl,i) [t C ha <sup>-1</sup> yr <sup>-1</sup> ]							
		1	1	3.31	3.31						
1	2	3.20	3.20								
1	3	2.04	2.04								
2	1	4.29	4.29								
2	2	4.89	4.89								
2	3	4.89	4.89								
3	1	4.00	4.00								
3	2	4.00	4.00								
3	3	2.29	2.29								
4	1	2.62	2.62								
4	2	2.62	2.62								
4	3	2.12	2.12								
5	1	2.73	2.73								
5	2	1.92	1.92								
5	3	1.99	1.99								

(Table 6-16 continued)

NFI	Elev.	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
		CC12: carbon losses in living biomass (lossCl,i) [t C ha <sup>-1</sup> yr <sup>-1</sup> ]									
1	1	-2.38	-2.12	-2.29	-2.29	-2.46	-2.55	-3.89	-4.17	-4.37	-4.20
1	2	-2.28	-1.83	-2.04	-2.03	-2.23	-2.32	-2.32	-2.54	-2.63	-2.56
1	3	-1.36	-0.99	-1.13	-1.12	-1.26	-1.32	-1.03	-1.15	-1.18	-1.16
2	1	-4.77	-3.17	-3.72	-3.70	-3.71	-4.03	-3.75	-3.97	-4.41	-4.47
2	2	-4.61	-2.98	-3.50	-3.49	-3.53	-3.84	-3.50	-3.74	-4.18	-4.23
2	3	-1.05	-0.62	-0.74	-0.74	-0.77	-0.84	-0.86	-0.93	-1.04	-1.05
3	1	-3.35	-2.82	-2.60	-2.64	-2.77	-2.99	-2.09	-2.22	-2.44	-2.49
3	2	-3.78	-2.78	-2.42	-2.41	-2.60	-2.63	-2.61	-2.87	-3.19	-3.20
3	3	-2.75	-1.90	-1.60	-1.57	-1.73	-1.69	-1.41	-1.59	-1.79	-1.77
4	1	-3.19	-3.10	-2.83	-2.55	-2.69	-2.27	-1.49	-1.62	-2.42	-1.72
4	2	-2.59	-2.21	-1.66	-1.48	-1.61	-1.33	-1.43	-1.59	-2.10	-1.67
4	3	-2.47	-2.03	-1.41	-1.25	-1.38	-1.14	-1.15	-1.30	-1.51	-1.35
5	1	-0.92	-1.09	-1.18	-1.35	-1.38	-1.40	-1.44	-1.49	-1.54	-1.45
5	2	-0.61	-0.72	-0.84	-0.92	-0.94	-0.98	-0.67	-0.72	-0.72	-0.67
5	3	-0.30	-0.35	-0.57	-0.54	-0.53	-0.63	-0.58	-0.71	-0.61	-0.54

NFI	Elev.	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
		CC12: carbon losses in living biomass (lossCl,i) [t C ha <sup>-1</sup> yr <sup>-1</sup> ]									
1	1	-5.03	-3.41	-3.35	-3.51	-3.67	-4.05	-2.73	-2.91	-2.82	-2.60
1	2	-3.43	-2.02	-1.99	-2.21	-2.41	-2.56	-2.87	-3.07	-2.93	-2.67
1	3	-1.70	-0.89	-0.88	-1.03	-1.16	-1.20	-2.30	-2.47	-2.25	-1.96
2	1	-10.04	-5.54	-4.12	-4.67	-4.85	-5.23	-5.82	-5.46	-4.91	-4.55
2	2	-10.20	-5.52	-4.03	-4.62	-4.83	-5.14	-6.10	-5.72	-5.15	-4.77
2	3	-2.77	-1.47	-1.05	-1.22	-1.29	-1.34	-6.10	-5.72	-5.15	-4.77
3	1	-4.72	-3.24	-2.54	-2.74	-2.82	-2.80	-4.49	-4.57	-4.17	-3.75
3	2	-7.44	-4.99	-3.77	-4.10	-4.00	-3.77	-4.49	-4.57	-4.17	-3.75
3	3	-4.72	-3.12	-2.31	-2.53	-2.38	-2.16	-2.01	-2.06	-1.84	-1.60
4	1	-1.37	-1.50	-1.57	-1.62	-1.63	-1.67	-1.78	-1.85	-1.93	-2.02
4	2	-1.28	-1.44	-1.50	-1.61	-1.48	-1.53	-1.78	-1.85	-1.93	-2.02
4	3	-1.00	-1.16	-1.20	-1.33	-1.12	-1.18	-1.00	-1.09	-1.16	-1.19
5	1	-1.29	-1.32	-1.32	-1.31	-1.31	-1.24	-1.47	-1.32	-1.33	-1.28
5	2	-0.56	-0.58	-0.59	-0.60	-0.59	-0.57	-0.81	-0.84	-0.80	-0.80
5	3	-0.29	-0.31	-0.40	-0.46	-0.38	-0.44	-0.56	-0.73	-0.64	-0.67

NFI	Elev.	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
		CC12: carbon losses in living biomass (lossCl,i) [t C ha <sup>-1</sup> yr <sup>-1</sup> ]									
1	1	-2.80	-2.79	-2.61	-2.72	-2.87	-2.58	-2.63	-2.64	-2.61	-2.52
1	2	-2.88	-2.85	-2.66	-2.77	-2.92	-2.61	-2.67	-2.67	-2.66	-2.56
1	3	-2.11	-2.04	-1.89	-1.93	-2.06	-1.79	-1.85	-1.84	-1.88	-1.80
2	1	-4.49	-4.49	-4.23	-4.24	-4.36	-4.26	-4.05	-4.42	-5.17	-4.40
2	2	-4.72	-4.71	-4.44	-4.46	-4.58	-4.48	-4.26	-4.64	-5.43	-4.61
2	3	-4.72	-4.71	-4.44	-4.46	-4.58	-4.48	-4.26	-4.64	-5.43	-4.61
3	1	-4.21	-4.20	-3.59	-3.77	-3.88	-3.47	-3.47	-3.62	-3.81	-3.43
3	2	-4.21	-4.20	-3.59	-3.77	-3.88	-3.47	-3.47	-3.62	-3.81	-3.43
3	3	-1.81	-1.79	-1.51	-1.54	-1.59	-1.40	-1.41	-1.48	-1.65	-1.44
4	1	-2.18	-2.14	-2.04	-2.25	-2.16	-1.98	-1.94	-1.93	-2.01	-1.79
4	2	-2.18	-2.14	-2.04	-2.25	-2.16	-1.98	-1.94	-1.93	-2.01	-1.79
4	3	-1.26	-1.21	-1.17	-1.20	-1.17	-1.11	-1.02	-1.06	-1.14	-0.95
5	1	-1.57	-1.61	-1.53	-1.54	-1.44	-1.62	-1.84	-1.66	-2.01	-1.98
5	2	-0.94	-0.96	-0.88	-0.94	-1.04	-0.97	-1.07	-1.03	-1.12	-1.26
5	3	-0.74	-0.75	-0.64	-0.77	-1.06	-0.76	-0.81	-0.86	-0.79	-1.09

NFI	Elev.	2020	2021
		CC12: carbon losses in living biomass (lossCl,i) [t C ha <sup>-1</sup> yr <sup>-1</sup> ]	
1	1	-2.60	-2.84
1	2	-2.68	-2.94
1	3	-1.97	-2.23
2	1	-4.78	-4.59
2	2	-5.01	-4.82
2	3	-5.01	-4.82
3	1	-3.46	-3.89
3	2	-3.46	-3.89
3	3	-1.48	-1.66
4	1	-1.64	-1.81
4	2	-1.64	-1.81
4	3	-0.95	-1.04
5	1	-1.89	-2.17
5	2	-1.00	-1.16
5	3	-0.62	-0.74

### **6.4.2.3. Productive forest (CC12): carbon stocks and carbon stock changes in dead wood, litter, mineral soil and organic soil**

#### **6.4.2.3.1. Carbon stocks in dead wood**

Carbon stocks in dead wood were simulated and estimated based on the source of carbon inputs, including (1) stemwood of trees  $\geq 12$  cm diameter at breast height (DBH), (2) large branches  $\geq$  ca. 7 cm in diameter, and (3) dead coarse roots  $>$  ca. 5 mm in diameter. These tree elements were estimated according to Table 2 in Didion et al. (2020). Data are given in Table 6-17.

#### **6.4.2.3.2. Carbon stocks in litter**

Carbon stocks in litter were derived from simulations of carbon inputs of the tree elements small branches and twigs  $<$  ca. 7 cm in diameter, bark of the tree bole, foliage (Didion et al. 2020: Table 2), seeds and fruits (based on published allometries, see Didion and Zell 2019), and fine roots  $<$  ca. 5 mm (estimated as fraction of coarse roots; Perruchoud et al. 1999). Data are given in Table 6-17.

#### **6.4.2.3.3. Carbon stocks in mineral soil**

Carbon stocks in mineral soil were not taken from Yasso07 simulations. Due to the incomplete knowledge of the origin of the high carbon stocks in mineral soils, particularly pyrogenic carbon in the mountainous soils of Southern Switzerland (Eckmeier et al. 2010; Nussbaum et al. 2014; Zanelli et al. 2006), they cannot be reproduced by models yet. Hence, soil carbon stocks were taken from Nussbaum and Burgos (2021), a spatial statistical analysis of soil profile data using the machine learning approach "random forest". The sample material was taken from the soil sample archive (pedothek) maintained at the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL) ( $n = 1033$  sites). Additional 1060 sites either sampled by WSL or in the course of cantonal projects were used. The soil samples were collected over the past 50 years, by far the most between 1990 and 2015, and distributed over different forest types throughout Switzerland. Because of the distribution of sampling over a long time span, it is not possible to attribute the carbon stocks estimates in mineral forest soils to one single year. A combination of these carbon stocks and the carbon stock changes derived from the Yasso07 model (see chp. 6.4.2.3.5) would not result in a consistent time series for soil carbon stocks. Thus, it was assumed that the values from Nussbaum and Burgos (2021) are representative of mineral soil in land-use category productive forest for the whole inventory period and were considered constant. Data are given in Table 6-4.

Table 6-17 Carbon stocks in dead wood (stockC<sub>d</sub>) and in litter (stockC<sub>h</sub>) for the land-use category productive forest (CC12) stratified for NFI production region (NFI) and elevation zone (Elev.). Highlighted data for 1990 are displayed in Table 6-4.

NFI	Elev.	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
CC12: carbon stock in dead wood (stockC <sub>d,i</sub> ) [t C ha <sup>-1</sup> ]											
1	1	4.89	4.95	4.98	5.01	5.01	5.03	5.35	5.70	5.99	6.24
1	2	5.26	5.32	5.36	5.39	5.40	5.43	5.46	5.53	5.60	5.66
1	3	4.65	4.65	4.63	4.62	4.59	4.58	4.36	4.26	4.19	4.12
2	1	8.10	8.18	8.23	8.27	8.26	8.29	8.60	8.93	9.20	9.43
2	2	7.86	7.94	7.98	8.02	8.02	8.05	8.38	8.73	9.05	9.31
2	3	7.86	7.94	7.98	8.02	8.02	8.05	8.38	8.73	9.05	9.31
3	1	7.54	7.66	7.75	7.84	7.88	7.96	8.38	8.76	9.11	9.42
3	2	7.54	7.66	7.75	7.84	7.88	7.96	8.38	8.76	9.11	9.42
3	3	6.03	6.08	6.10	6.13	6.13	6.17	5.99	6.04	6.11	6.18
4	1	5.39	5.50	5.57	5.65	5.70	5.78	5.64	5.63	5.63	5.63
4	2	5.39	5.50	5.57	5.65	5.70	5.78	5.64	5.63	5.63	5.63
4	3	4.98	5.10	5.19	5.29	5.36	5.45	5.22	5.20	5.20	5.19
5	1	2.15	2.20	2.24	2.28	2.32	2.36	2.34	2.38	2.42	2.45
5	2	2.09	2.16	2.21	2.26	2.31	2.36	2.16	2.06	1.97	1.89
5	3	1.77	1.80	1.81	1.84	1.85	1.87	1.74	1.72	1.71	1.69

NFI	Elev.	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
CC12: carbon stock in dead wood (stockC <sub>d,i</sub> ) [t C ha <sup>-1</sup> ]											
1	1	6.47	6.68	6.86	7.10	7.27	7.45	7.23	7.17	7.15	7.16
1	2	5.70	5.75	5.78	5.85	5.89	5.95	5.95	6.15	6.35	6.54
1	3	4.05	3.99	3.92	3.87	3.83	3.80	3.90	4.14	4.38	4.59
2	1	9.63	9.81	9.96	10.21	10.37	10.55	10.16	10.17	10.23	10.30
2	2	9.54	9.76	9.95	10.20	10.38	10.59	10.42	10.44	10.50	10.57
2	3	9.54	9.76	9.95	10.20	10.38	10.59	10.42	10.44	10.50	10.57
3	1	9.70	9.96	10.18	10.43	10.65	10.87	11.03	11.13	11.25	11.37
3	2	9.70	9.96	10.18	10.43	10.65	10.87	11.03	11.13	11.25	11.37
3	3	6.23	6.28	6.32	6.36	6.41	6.47	5.93	5.96	6.00	6.04
4	1	5.61	5.61	5.59	5.61	5.62	5.65	5.14	5.35	5.55	5.74
4	2	5.61	5.61	5.59	5.61	5.62	5.65	5.14	5.35	5.55	5.74
4	3	5.17	5.17	5.15	5.16	5.17	5.20	4.65	4.68	4.71	4.75
5	1	2.48	2.51	2.54	2.58	2.60	2.64	3.15	3.23	3.31	3.38
5	2	1.82	1.76	1.70	1.66	1.61	1.58	1.22	1.31	1.39	1.46
5	3	1.68	1.67	1.66	1.65	1.64	1.65	1.32	1.43	1.52	1.61

NFI	Elev.	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
CC12: carbon stock in dead wood (stockC <sub>d,i</sub> ) [t C ha <sup>-1</sup> ]											
1	1	7.18	7.18	7.17	7.18	7.15	7.18	7.16	7.18	7.19	7.19
1	2	6.74	6.87	7.00	7.15	7.23	7.33	7.42	7.52	7.59	7.66
1	3	4.82	4.97	5.14	5.30	5.42	5.53	5.64	5.76	5.84	5.93
2	1	10.40	10.44	10.49	10.55	10.53	10.60	10.60	10.65	10.68	10.69
2	2	10.68	10.72	10.77	10.83	10.81	10.86	10.86	10.90	10.93	10.94
2	3	10.68	10.72	10.77	10.83	10.81	10.86	10.86	10.90	10.93	10.94
3	1	11.53	11.59	11.69	11.81	11.82	11.88	11.92	11.98	12.03	12.07
3	2	11.53	11.59	11.69	11.81	11.82	11.88	11.92	11.98	12.03	12.07
3	3	6.10	6.10	6.13	6.17	6.17	6.17	6.18	6.19	6.19	6.20
4	1	5.93	6.07	6.21	6.35	6.44	6.54	6.63	6.73	6.80	6.87
4	2	5.93	6.07	6.21	6.35	6.44	6.54	6.63	6.73	6.80	6.87
4	3	4.80	4.81	4.83	4.86	4.86	4.87	4.89	4.90	4.91	4.91
5	1	3.46	3.52	3.58	3.64	3.67	3.72	3.76	3.80	3.84	3.86
5	2	1.54	1.59	1.65	1.70	1.74	1.78	1.82	1.86	1.90	1.92
5	3	1.69	1.76	1.83	1.89	1.95	2.00	2.05	2.09	2.14	2.18

NFI	Elev.	2020	2021
CC12: carbon stock in dead wood (stockC <sub>d,i</sub> ) [t C ha <sup>-1</sup> ]			
1	1	7.18	7.17
1	2	7.71	7.78
1	3	5.99	6.08
2	1	10.69	10.70
2	2	10.92	10.94
2	3	10.92	10.94
3	1	12.07	12.14
3	2	12.07	12.14
3	3	6.19	6.21
4	1	6.92	7.01
4	2	6.92	7.01
4	3	4.91	4.94
5	1	3.89	3.93
5	2	1.95	1.98
5	3	2.21	2.25

(Table 6-17 continued)

NFI	Elev.	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
		CC12: carbon stock in litter (stockCh,i) [t C ha <sup>-1</sup> ]									
1	1	11.97	12.10	12.04	12.02	11.85	11.81	11.99	12.16	12.19	12.15
1	2	12.16	12.29	12.26	12.27	12.12	12.13	12.34	12.48	12.60	12.65
1	3	10.35	10.32	10.20	10.15	9.99	9.99	9.76	9.81	9.93	10.01
2	1	12.35	12.48	12.44	12.40	12.21	12.18	12.33	12.47	12.49	12.43
2	2	13.23	13.36	13.33	13.31	13.13	13.14	13.31	13.42	13.49	13.48
2	3	13.23	13.36	13.33	13.31	13.13	13.14	13.31	13.42	13.49	13.48
3	1	14.09	14.25	14.25	14.27	14.12	14.18	14.38	14.46	14.58	14.65
3	2	14.09	14.25	14.25	14.27	14.12	14.18	14.38	14.46	14.58	14.65
3	3	13.63	13.73	13.67	13.70	13.57	13.64	13.34	13.40	13.58	13.71
4	1	11.14	11.26	11.26	11.27	11.18	11.24	11.23	11.37	11.54	11.62
4	2	11.14	11.26	11.26	11.27	11.18	11.24	11.23	11.37	11.54	11.62
4	3	14.06	14.27	14.30	14.41	14.33	14.48	14.20	14.37	14.62	14.71
5	1	8.14	8.17	8.16	8.14	8.10	8.15	8.36	8.50	8.65	8.76
5	2	9.62	9.76	9.80	9.86	9.84	9.96	10.22	10.53	10.82	11.06
5	3	11.17	11.38	11.43	11.55	11.53	11.69	11.48	11.77	12.08	12.35

NFI	Elev.	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
		CC12: carbon stock in litter (stockCh,i) [t C ha <sup>-1</sup> ]									
1	1	12.14	12.12	12.05	12.35	12.35	12.44	12.26	12.09	12.06	12.10
1	2	12.68	12.73	12.68	12.87	12.91	13.05	13.08	13.07	13.16	13.28
1	3	10.02	10.08	10.05	10.10	10.16	10.27	10.08	10.33	10.61	10.83
2	1	12.38	12.33	12.26	12.52	12.51	12.61	12.06	11.84	11.77	11.78
2	2	13.45	13.45	13.39	13.60	13.62	13.74	12.88	12.69	12.65	12.67
2	3	13.45	13.45	13.39	13.60	13.62	13.74	12.88	12.69	12.65	12.67
3	1	14.65	14.72	14.65	14.77	14.83	14.96	14.73	14.67	14.72	14.79
3	2	14.65	14.72	14.65	14.77	14.83	14.96	14.73	14.67	14.72	14.79
3	3	13.75	13.86	13.82	13.86	13.97	14.13	13.31	13.31	13.39	13.45
4	1	11.65	11.73	11.68	11.86	11.95	12.13	11.94	12.05	12.19	12.39
4	2	11.65	11.73	11.68	11.86	11.95	12.13	11.94	12.05	12.19	12.39
4	3	14.73	14.86	14.81	15.00	15.18	15.43	14.14	14.37	14.59	14.86
5	1	8.80	8.90	8.92	9.07	9.09	9.26	8.57	8.66	8.74	8.82
5	2	11.19	11.37	11.42	11.62	11.69	11.93	11.35	11.59	11.82	12.02
5	3	12.50	12.70	12.75	12.94	13.07	13.40	11.86	12.15	12.44	12.68

NFI	Elev.	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
		CC12: carbon stock in litter (stockCh,i) [t C ha <sup>-1</sup> ]									
1	1	12.21	12.16	12.12	12.15	11.97	12.09	12.00	12.07	12.06	12.03
1	2	13.52	13.44	13.47	13.56	13.40	13.44	13.39	13.46	13.41	13.38
1	3	11.16	11.15	11.27	11.43	11.37	11.37	11.38	11.43	11.39	11.39
2	1	11.87	11.81	11.77	11.79	11.59	11.68	11.57	11.62	11.62	11.55
2	2	12.80	12.70	12.69	12.72	12.50	12.55	12.45	12.49	12.47	12.42
2	3	12.80	12.70	12.69	12.72	12.50	12.55	12.45	12.49	12.47	12.42
3	1	14.98	14.84	14.89	15.00	14.77	14.75	14.68	14.70	14.67	14.64
3	2	14.98	14.84	14.89	15.00	14.77	14.75	14.68	14.70	14.67	14.64
3	3	13.66	13.48	13.52	13.61	13.45	13.37	13.33	13.33	13.26	13.22
4	1	12.66	12.64	12.72	12.86	12.72	12.75	12.73	12.78	12.74	12.72
4	2	12.66	12.64	12.72	12.86	12.72	12.75	12.73	12.78	12.74	12.72
4	3	15.24	15.22	15.29	15.46	15.38	15.37	15.43	15.47	15.39	15.36
5	1	8.98	8.99	9.02	9.05	8.96	9.00	9.00	9.04	9.03	8.99
5	2	12.33	12.36	12.43	12.53	12.47	12.51	12.53	12.57	12.58	12.54
5	3	13.04	13.04	13.13	13.27	13.26	13.25	13.30	13.34	13.35	13.32

NFI	Elev.	2020	2021	CC12: carbon stock in litter (stockCh,i) [t C ha <sup>-1</sup> ]							
		1	1	11.96	11.91						
1	2	13.28	13.33								
1	3	11.30	11.39								
2	1	11.46	11.44								
2	2	12.30	12.31								
2	3	12.30	12.31								
3	1	14.51	14.58								
3	2	14.51	14.58								
3	3	13.10	13.19								
4	1	12.65	12.73								
4	2	12.65	12.73								
4	3	15.30	15.42								
5	1	8.97	9.00								
5	2	12.52	12.60								
5	3	13.31	13.40								

#### **6.4.2.3.4. Carbon stocks in organic soil**

The mean soil organic carbon stock (0–30 cm) for organic soil in the land-use category productive forest is  $145.6 \pm 24.1 \text{ t C ha}^{-1}$  (Wüst-Galley et al. 2016) (Table 6-4).

#### **6.4.2.3.5. Carbon stock changes in dead wood**

Annual stratified values of carbon stock changes for dead wood were calculated from the simulated annual stocks (chp. 6.4.2.3.1). Results are given in Table 6-18.

The carbon stock change in the dead wood pool is to a large extent driven by the increase in dead wood volume in Swiss forests since the mid-1990s (Brändli 2010). Dead wood accumulation as a consequence of the two storms Vivian (1990) and, in particular, Lothar (1999), strongly affects the results of the change analysis for dead wood volume in the period NF12 to NF13. Although the majority of the wind thrown trees were removed from the forest, the dead wood stock increased significantly. As particularly the larger-sized felled trees decay slowly (Didion et al. 2014a), the increased dead wood stock acts as a sustained carbon sink (Figure 6-7). The trend of decreasing harvesting rates for several years after NF13 (see Table 6-15) further sustained the carbon sink of dead wood as mature trees, which could be harvested, remain in the forest and potentially contribute to the dead wood pool.

#### **6.4.2.3.6. Carbon stock changes in litter**

Annual stratified values of carbon stock changes for litter were calculated from the simulated annual stocks (chp. 6.4.2.3.2). Results are given in Table 6-18.

Carbon stock changes in litter are higher and more erratic than changes in the dead wood and soil pools (Figure 6-7). This is expected since non-woody material decomposes faster than dead wood (Tuomi et al. 2011) and its decomposition is more sensitive to interannual changes in temperature and precipitation (Liski et al. 2003). Furthermore there is a high interannual variability in the production of foliage (Etzold et al. 2011).

#### **6.4.2.3.7. Carbon stock changes in mineral soil**

Annual stratified values of carbon stock changes for mineral soil were calculated from the simulated annual stocks (chp. 6.4.2.3.3). Results are given in Table 6-18.

Carbon stock changes in the soil pool are very small (Figure 6-7). Despite limitations to reproduce the comparably high carbon stocks in mineral soils in Swiss forests (chp. 6.4.2.3.3), the carbon stock changes derived from simulated stocks can be expected to be accurate because (1) the pyrogenic carbon which is found particularly in the soils of the Southern Alps is very stable (Eckmeier et al. 2010), and (2) the simulated carbon stock changes including standard error are less than the minimum detection limit of repeated soil carbon stock measurements (see chp. 6.4.4.5). Furthermore, carbon stock changes were validated as described in Didion (2020a).

Table 6-18 Net carbon stock change in dead wood (changeC<sub>d</sub>), in litter (changeC<sub>h</sub>) and in mineral soil (changeC<sub>s</sub>) for the land-use category productive forest (CC12) stratified for NFI production region (NFI) and elevation zone (Elev.). Highlighted data for 1990 are displayed in Table 6-4. Positive values refer to gains in carbon stock, negative values refer to losses in carbon stock.

NFI	Elev.	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
		CC12: net change in dead wood (changeC <sub>d,i</sub> ) [t C ha <sup>-1</sup> yr <sup>-1</sup> ]									
1	1	0.03	0.06	0.03	0.03	0.00	0.02	0.40	0.35	0.29	0.25
1	2	0.03	0.06	0.03	0.04	0.01	0.03	0.11	0.07	0.07	0.05
1	3	-0.03	-0.01	-0.02	-0.01	-0.03	-0.01	-0.07	-0.09	-0.07	-0.07
2	1	0.03	0.09	0.04	0.04	-0.01	0.03	0.38	0.33	0.27	0.22
2	2	0.03	0.08	0.04	0.04	0.00	0.03	0.41	0.35	0.31	0.26
2	3	0.03	0.08	0.04	0.04	0.00	0.03	0.41	0.35	0.31	0.26
3	1	0.09	0.12	0.09	0.09	0.04	0.08	0.45	0.37	0.35	0.31
3	2	0.09	0.12	0.09	0.09	0.04	0.08	0.45	0.37	0.35	0.31
3	3	0.02	0.04	0.02	0.03	0.00	0.03	0.10	0.06	0.07	0.07
4	1	0.09	0.10	0.08	0.08	0.05	0.07	0.01	-0.01	0.00	-0.01
4	2	0.09	0.10	0.08	0.08	0.05	0.07	0.01	-0.01	0.00	-0.01
4	3	0.11	0.12	0.09	0.10	0.07	0.09	0.00	-0.02	0.00	-0.01
5	1	0.05	0.05	0.04	0.04	0.03	0.04	0.05	0.04	0.04	0.03
5	2	0.07	0.07	0.06	0.05	0.04	0.05	-0.10	-0.10	-0.09	-0.08
5	3	0.02	0.03	0.02	0.02	0.01	0.02	-0.01	-0.02	-0.01	-0.01

NFI	Elev.	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
		CC12: net change in dead wood (changeC <sub>d,i</sub> ) [t C ha <sup>-1</sup> yr <sup>-1</sup> ]									
1	1	0.23	0.21	0.18	0.25	0.17	0.18	-0.03	-0.05	-0.02	0.00
1	2	0.05	0.05	0.03	0.07	0.04	0.06	0.24	0.20	0.20	0.19
1	3	-0.07	-0.06	-0.07	-0.05	-0.04	-0.03	0.27	0.25	0.23	0.22
2	1	0.20	0.18	0.15	0.25	0.16	0.18	0.07	0.02	0.05	0.07
2	2	0.23	0.22	0.18	0.25	0.19	0.20	0.07	0.02	0.06	0.07
2	3	0.23	0.22	0.18	0.25	0.19	0.20	0.07	0.02	0.06	0.07
3	1	0.27	0.27	0.22	0.25	0.22	0.23	0.14	0.10	0.12	0.12
3	2	0.27	0.27	0.22	0.25	0.22	0.23	0.14	0.10	0.12	0.12
3	3	0.05	0.06	0.03	0.04	0.05	0.06	0.04	0.03	0.04	0.04
4	1	-0.01	0.00	-0.02	0.02	0.01	0.03	0.26	0.21	0.20	0.19
4	2	-0.01	0.00	-0.02	0.02	0.01	0.03	0.26	0.21	0.20	0.19
4	3	-0.02	0.00	-0.02	0.01	0.01	0.02	0.04	0.03	0.03	0.04
5	1	0.03	0.03	0.03	0.04	0.02	0.04	0.10	0.08	0.08	0.07
5	2	-0.07	-0.06	-0.06	-0.05	-0.05	-0.03	0.10	0.09	0.08	0.07
5	3	-0.01	-0.01	-0.01	-0.01	-0.01	0.01	0.11	0.10	0.09	0.09

NFI	Elev.	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
		CC12: net change in dead wood (changeC <sub>d,i</sub> ) [t C ha <sup>-1</sup> yr <sup>-1</sup> ]									
1	1	0.03	-0.01	-0.01	0.01	-0.04	0.03	-0.01	0.02	0.00	0.00
1	2	0.20	0.13	0.14	0.14	0.08	0.11	0.08	0.10	0.07	0.07
1	3	0.22	0.16	0.16	0.17	0.12	0.11	0.11	0.11	0.09	0.09
2	1	0.10	0.05	0.05	0.06	-0.02	0.07	0.01	0.05	0.03	0.01
2	2	0.11	0.04	0.05	0.06	-0.02	0.05	0.00	0.04	0.03	0.01
2	3	0.11	0.04	0.05	0.06	-0.02	0.05	0.00	0.04	0.03	0.01
3	1	0.16	0.06	0.10	0.12	0.01	0.06	0.04	0.06	0.05	0.04
3	2	0.16	0.06	0.10	0.12	0.01	0.06	0.04	0.06	0.05	0.04
3	3	0.06	0.00	0.03	0.04	-0.01	0.00	0.01	0.01	0.00	0.00
4	1	0.19	0.13	0.14	0.14	0.08	0.11	0.09	0.10	0.07	0.07
4	2	0.19	0.13	0.14	0.14	0.08	0.11	0.09	0.10	0.07	0.07
4	3	0.05	0.01	0.02	0.03	0.00	0.01	0.01	0.01	0.00	0.00
5	1	0.08	0.06	0.06	0.05	0.03	0.05	0.04	0.04	0.03	0.03
5	2	0.07	0.06	0.05	0.05	0.04	0.04	0.04	0.04	0.03	0.03
5	3	0.09	0.07	0.07	0.06	0.05	0.05	0.05	0.05	0.04	0.04

NFI	Elev.	2020	2021	CC12: net change in dead wood (changeC <sub>d,i</sub> ) [t C ha <sup>-1</sup> yr <sup>-1</sup> ]							
		1	1	-0.01	-0.01						
1	2	0.05	0.07								
1	3	0.06	0.09								
2	1	-0.01	0.01								
2	2	-0.02	0.02								
2	3	-0.02	0.02								
3	1	0.00	0.06								
3	2	0.00	0.06								
3	3	-0.01	0.02								
4	1	0.05	0.08								
4	2	0.05	0.08								
4	3	0.00	0.02								
5	1	0.03	0.03								
5	2	0.03	0.03								
5	3	0.04	0.04								

(Table 6-18 continued)

NFI	Elev.	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
		CC12: net change in litter (changeCh,i) [t C ha <sup>-1</sup> yr <sup>-1</sup> ]									
1	1	-0.12	0.13	-0.06	-0.01	-0.17	-0.04	0.31	0.17	0.03	-0.04
1	2	-0.06	0.13	-0.03	0.01	-0.14	0.01	0.35	0.14	0.12	0.05
1	3	-0.16	-0.03	-0.12	-0.05	-0.16	-0.01	0.26	0.05	0.12	0.07
2	1	-0.13	0.13	-0.04	-0.04	-0.19	-0.03	0.24	0.13	0.03	-0.06
2	2	-0.09	0.13	-0.03	-0.02	-0.18	0.01	0.27	0.11	0.07	0.00
2	3	-0.09	0.13	-0.03	-0.02	-0.18	0.01	0.27	0.11	0.07	0.00
3	1	-0.01	0.16	0.00	0.02	-0.15	0.06	0.33	0.08	0.12	0.07
3	2	-0.01	0.16	0.00	0.02	-0.15	0.06	0.33	0.08	0.12	0.07
3	3	-0.04	0.10	-0.06	0.03	-0.14	0.07	0.34	0.05	0.18	0.13
4	1	0.01	0.12	-0.01	0.02	-0.09	0.06	0.33	0.14	0.17	0.07
4	2	0.01	0.12	-0.01	0.02	-0.09	0.06	0.33	0.14	0.17	0.07
4	3	0.10	0.21	0.03	0.11	-0.07	0.14	0.39	0.17	0.24	0.10
5	1	0.01	0.04	-0.01	-0.02	-0.04	0.05	0.26	0.14	0.15	0.11
5	2	0.12	0.14	0.04	0.06	-0.01	0.11	0.57	0.31	0.29	0.24
5	3	0.16	0.21	0.05	0.12	-0.03	0.17	0.63	0.30	0.31	0.26

NFI	Elev.	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
		CC12: net change in litter (changeCh,i) [t C ha <sup>-1</sup> yr <sup>-1</sup> ]									
1	1	-0.01	-0.02	-0.07	0.30	0.00	0.09	-0.06	-0.17	-0.03	0.04
1	2	0.03	0.05	-0.05	0.20	0.04	0.13	0.10	-0.01	0.09	0.12
1	3	0.01	0.06	-0.03	0.05	0.06	0.11	0.36	0.25	0.28	0.23
2	1	-0.05	-0.05	-0.07	0.26	-0.01	0.10	-0.10	-0.22	-0.07	0.01
2	2	-0.03	0.00	-0.06	0.21	0.02	0.12	-0.08	-0.18	-0.04	0.02
2	3	-0.03	0.00	-0.06	0.21	0.02	0.12	-0.08	-0.18	-0.04	0.02
3	1	0.00	0.07	-0.06	0.12	0.06	0.12	0.07	-0.06	0.05	0.06
3	2	0.00	0.07	-0.06	0.12	0.06	0.12	0.07	-0.06	0.05	0.06
3	3	0.04	0.11	-0.04	0.03	0.12	0.16	0.02	0.00	0.08	0.05
4	1	0.03	0.08	-0.05	0.18	0.09	0.17	0.32	0.11	0.14	0.20
4	2	0.03	0.08	-0.05	0.18	0.09	0.17	0.32	0.11	0.14	0.20
4	3	0.02	0.12	-0.05	0.20	0.18	0.25	0.40	0.23	0.23	0.27
5	1	0.04	0.10	0.03	0.14	0.02	0.18	0.24	0.09	0.08	0.08
5	2	0.13	0.18	0.05	0.20	0.07	0.25	0.46	0.24	0.23	0.20
5	3	0.15	0.20	0.05	0.19	0.13	0.33	0.46	0.29	0.29	0.24

NFI	Elev.	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
		CC12: net change in litter (changeCh,i) [t C ha <sup>-1</sup> yr <sup>-1</sup> ]									
1	1	0.12	-0.05	-0.04	0.03	-0.18	0.12	-0.09	0.07	-0.01	-0.03
1	2	0.23	-0.08	0.03	0.10	-0.17	0.04	-0.05	0.07	-0.05	-0.03
1	3	0.33	-0.01	0.12	0.16	-0.06	0.00	0.01	0.05	-0.04	-0.01
2	1	0.09	-0.06	-0.04	0.02	-0.19	0.08	-0.10	0.05	-0.01	-0.06
2	2	0.13	-0.09	-0.02	0.03	-0.22	0.04	-0.10	0.04	-0.02	-0.05
2	3	0.13	-0.09	-0.02	0.03	-0.22	0.04	-0.10	0.04	-0.02	-0.05
3	1	0.19	-0.13	0.05	0.10	-0.23	-0.02	-0.07	0.03	-0.03	-0.04
3	2	0.19	-0.13	0.05	0.10	-0.23	-0.02	-0.07	0.03	-0.03	-0.04
3	3	0.22	-0.18	0.03	0.10	-0.16	-0.08	-0.04	0.00	-0.07	-0.04
4	1	0.27	-0.02	0.09	0.14	-0.15	0.04	-0.02	0.05	-0.04	-0.02
4	2	0.27	-0.02	0.09	0.14	-0.15	0.04	-0.02	0.05	-0.04	-0.02
4	3	0.37	-0.02	0.07	0.17	-0.08	-0.01	0.05	0.05	-0.08	-0.04
5	1	0.16	0.01	0.03	0.03	-0.09	0.04	0.00	0.04	-0.01	-0.04
5	2	0.31	0.03	0.07	0.10	-0.06	0.03	0.02	0.04	0.01	-0.04
5	3	0.36	0.00	0.09	0.14	-0.01	-0.01	0.05	0.03	0.01	-0.02

NFI	Elev.	2020	2021
		CC12: net change in litter (changeCh,i) [t C ha <sup>-1</sup> yr <sup>-1</sup> ]	
1	1	-0.07	-0.05
1	2	-0.10	0.04
1	3	-0.08	0.09
2	1	-0.09	-0.03
2	2	-0.12	0.01
2	3	-0.12	0.01
3	1	-0.13	0.07
3	2	-0.13	0.07
3	3	-0.12	0.08
4	1	-0.07	0.08
4	2	-0.07	0.08
4	3	-0.06	0.14
5	1	-0.02	0.04
5	2	-0.02	0.08
5	3	-0.02	0.13

(Table 6-18 continued)

NFI	Elev.	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
		CC12: net change in mineral soil (changeCs,i) [t C ha <sup>-1</sup> yr <sup>-1</sup> ]									
1	1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001
1	2	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
1	3	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.002	-0.002	-0.002	-0.002
2	1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001
2	2	0.000	0.000	0.001	0.001	0.000	0.000	0.000	0.001	0.001	0.001
2	3	0.000	0.000	0.001	0.001	0.000	0.000	0.000	0.001	0.001	0.001
3	1	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.002	0.002
3	2	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.002	0.002
3	3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4	1	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.002	0.002
4	2	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.002	0.002
4	3	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.003
5	1	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002
5	2	0.002	0.002	0.002	0.002	0.002	0.002	0.003	0.003	0.003	0.004
5	3	0.002	0.002	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003

NFI	Elev.	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
		CC12: net change in mineral soil (changeCs,i) [t C ha <sup>-1</sup> yr <sup>-1</sup> ]									
1	1	0.001	0.001	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
1	2	0.001	0.001	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
1	3	-0.002	-0.002	-0.002	-0.002	-0.001	-0.001	-0.002	-0.001	-0.001	0.000
2	1	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.000
2	2	0.001	0.002	0.002	0.002	0.002	0.002	0.001	0.001	0.001	0.001
2	3	0.001	0.002	0.002	0.002	0.002	0.002	0.001	0.001	0.001	0.001
3	1	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003
3	2	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003
3	3	0.001	0.001	0.001	0.001	0.001	0.001	0.000	0.000	0.000	0.000
4	1	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.003	0.003	0.003
4	2	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.003	0.003	0.003
4	3	0.003	0.003	0.003	0.003	0.003	0.003	0.002	0.002	0.002	0.002
5	1	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
5	2	0.004	0.004	0.004	0.004	0.004	0.004	0.003	0.004	0.004	0.005
5	3	0.004	0.004	0.004	0.004	0.004	0.004	0.003	0.003	0.003	0.004

NFI	Elev.	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
		CC12: net change in mineral soil (changeCs,i) [t C ha <sup>-1</sup> yr <sup>-1</sup> ]									
1	1	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
1	2	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003
1	3	0.000	0.000	0.000	0.001	0.001	0.001	0.001	0.001	0.001	0.001
2	1	0.000	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000
2	2	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
2	3	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
3	1	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
3	2	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
3	3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4	1	0.003	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
4	2	0.003	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
4	3	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003
5	1	0.002	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003
5	2	0.005	0.005	0.005	0.005	0.006	0.006	0.006	0.006	0.006	0.006
5	3	0.004	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.005	0.005

NFI	Elev.	2020	2021	CC12: net change in mineral soil (changeCs,i) [t C ha <sup>-1</sup> yr <sup>-1</sup> ]							
		1	1	0.002	0.002						
1	2	0.003	0.003								
1	3	0.001	0.001								
2	1	0.000	0.000								
2	2	0.001	0.001								
2	3	0.001	0.001								
3	1	0.004	0.003								
3	2	0.004	0.003								
3	3	0.000	0.000								
4	1	0.004	0.004								
4	2	0.004	0.004								
4	3	0.003	0.003								
5	1	0.003	0.003								
5	2	0.006	0.006								
5	3	0.005	0.005								

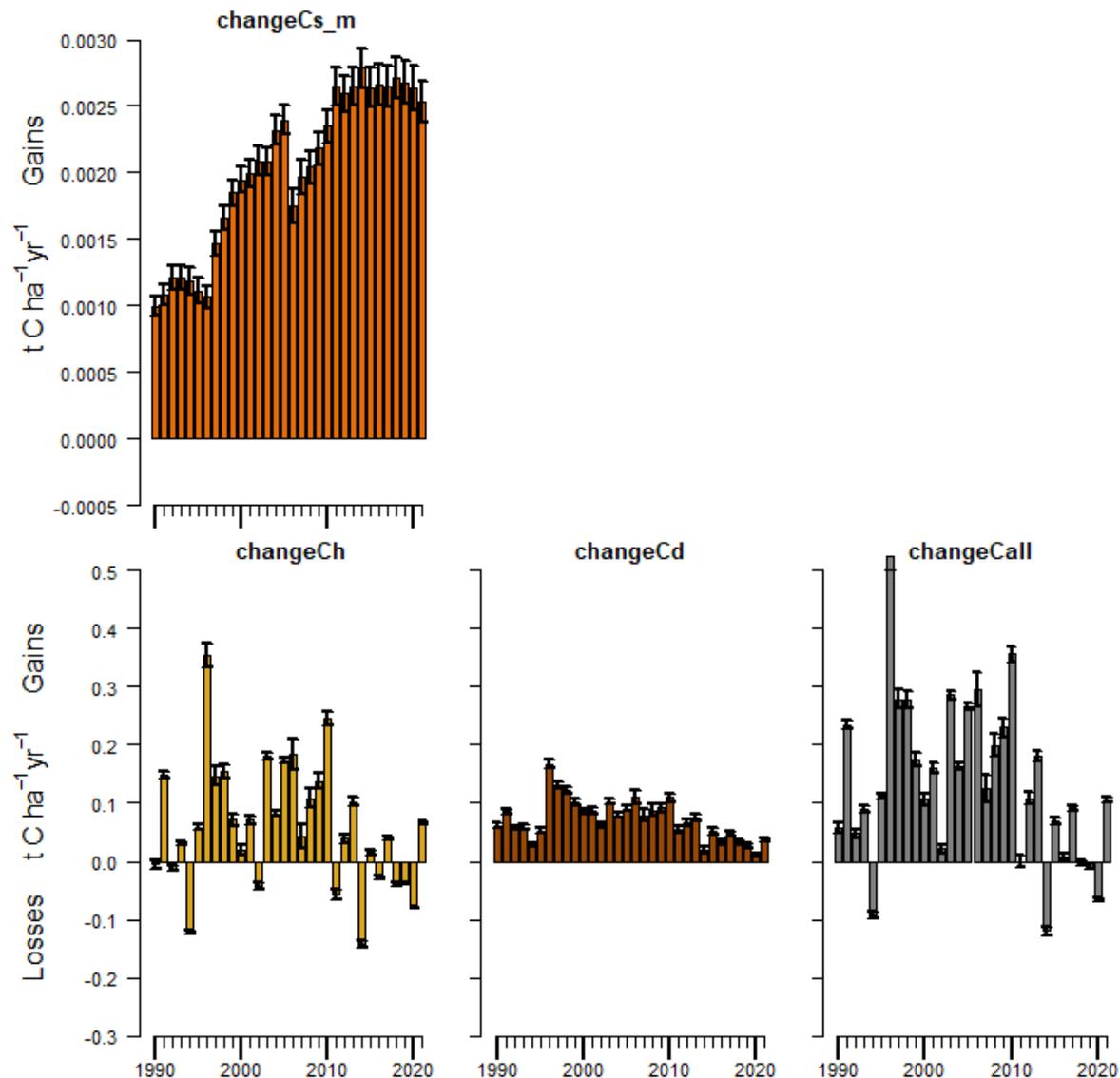


Figure 6-7 Mean carbon stock changes (changeC) over the inventory period for three pools mineral soil (s\_m, 0–100 cm), litter (h), dead wood (d) and their sum (all) in  $\text{t C ha}^{-1} \text{yr}^{-1}$ . Note the difference of the y-axis scale between changeCs\_m and changeCh, changeCd and changeCall, respectively. Negative values indicate losses in carbon stock, positive values gains in carbon stock. The error bars indicate the double standard error.

#### 6.4.2.3.8. Carbon stock changes in organic soil

Drainage of forests is not a permitted practice in Switzerland (Swiss Confederation 1991). However, it is possible that parts of the Swiss forest were drained before 1990 or were established on drained areas. Abegg (2017) estimated the amount of drained organic soil by comparing information on drainage from NFI plots with spatial data of organic soil in Switzerland produced by Wüst-Galley et al. (2015): 3 % of organic soil on Forest land appeared to be subject to drainage.

For the calculation of carbon stock changes in organic soil, the default emission factor of  $2.6 \text{ t C ha}^{-1} \text{yr}^{-1}$  was applied for the land-use category productive forest (CC12; Table 6-4) according to the Wetlands Supplement (IPCC 2014a: Table 2.1).

#### 6.4.2.4. Unproductive forest (CC13): carbon stocks and carbon stock changes

##### 6.4.2.4.1. Description

The land-use category unproductive forest consist of brush forests, inaccessible stands and unproductive forest not covered by the NFI. Unproductive forests exhibit a high variability (see examples of unproductive forests in Switzerland in FOEN 2014f).

For transparency reasons, productive and unproductive forest areas are reported separately. However, there is only scarce information available on unproductive forest. In unproductive forest, wood is not harvested for economic reasons. Only in exceptional cases there can be an intervention (e.g. moving a wood log that is blocking a hiking trail), but no wood is removed from the stand.

The NFI does not include unproductive stands in its regular inventory scheme because (1) the plots are not relevant for timber production or it is not possible to carry out precise measurements (brush forests), (2) the plots are inaccessible or (3) the NFI forest definition is not fulfilled (unproductive forest not covered by the NFI).

- Brush forests: Since brush forests have no direct economic value in terms of wood harvest, an inventory of these stands has not been attributed high priority. During NFI3, some plots in brush forests were visited for the first time, but only a limited number of attributes such as tree species, stem diameter and crown cover were collected.
- Inaccessible stands: Inaccessible stands are forests which cannot be visited because of safety reasons (see description in Brändli 2010: p. 89). They are mainly located in the Alps and often grow on sites of low productivity, including rocky sites and sites at high elevation near the tree line with a short vegetation period and low biological activity.
- Unproductive forest not covered by NFI: After the review of its first Initial Report (FOEN 2006h), Switzerland had to apply a forest definition for reporting activities under the Kyoto Protocol Art. 3.3 and Art. 3.4, which is different from the definition applied by the Swiss NFI and the Land Use Statistics AREA. Because the definition of NFI and AREA was not in line with the specific requirements of the Kyoto Protocol forest definition, Switzerland had to develop an approach to classify certain AREA categories as forest. Those areas are not covered by the regular NFI and are situated in the threshold range between forests and alpine pastures with woody biomass of very low productivity. More specifically, it concerns combinations of “pastures or grasslands with clusters of trees” (NOLC04 47/NOLU04 222, NOLC04 47/NOLU04 223, NOLC04 47/NOLU04 242) and “alpine sheep grazing pastures, in general with open forest” with “clusters of trees”) NOLC04 44/NOLU04 243; see Table 6-6).

##### 6.4.2.4.2. Carbon stocks in living biomass

- Brush forest: Brush forests in Switzerland mainly consist of *Alnus viridis*, horizontal *Pinus mugo var. prostrata* with a percentage cover of 65 % and 16 %, respectively (Düggelin and Abegg 2011: Table 1). Following the NFI definition, brush forests are dominated by more than two thirds by shrubs. In a case study, Düggelin and Abegg (2011) analysed the carbon stock of living biomass of woody shrub species in Swiss brush forests and found an average value of 20.45 t C ha<sup>-1</sup>.
- Inaccessible stands: Inaccessible stands are considered the same as brush forest regarding biomass and carbon stock. Their area is determined based on land cover “tree vegetation” in typically remote and high-elevation land uses such as avalanche chutes (NOLU04 403 and 422; Table 6-6).
- Unproductive forests not covered by NFI: These forests are mainly associated with extensively pastured land where sparse tree vegetation (NOLC04 44 and 47; Table 6-6)

is found. As those forests are assumed to grow preferably on bad site conditions, an average growing stock (>7 cm diameter) of 150 m<sup>3</sup> ha<sup>-1</sup> was assumed. Multiplied by the mean BCEF of 0.69 (i.e. weighted mean based on the quotient of stemwood volume and total tree biomass of coniferous and broadleaved trees as described in Thüring and Herold 2013), an average biomass for these forests of 102.75 t ha<sup>-1</sup> was estimated, which corresponds to 51.38 t C ha<sup>-1</sup> (using a carbon content of 50 %; see chp. 6.4.2.1.3).

The carbon stock of living biomass (C<sub>i</sub>) in unproductive forest (CC13) was calculated as a weighted average of brush forest, inaccessible stands and unproductive forest not covered by NFI per spatial stratum:

$$\text{stockC}_{i,i,CC13} = F_i * \text{stockC}_{i,i,CC13bi} + (1 - F_i) * \text{stockC}_{i,i,CC13u}$$

where  $F_i$  is the fraction of the brush and inaccessible forest per spatial stratum  $i$ ,

$\text{stockC}_{i,i,CC13bi}$  is the carbon stock in brush and inaccessible forest (20.45 t C ha<sup>-1</sup>),

$\text{stockC}_{i,i,CC13u}$  is the carbon stock in unproductive forest not covered by NFI (51.38 t C ha<sup>-1</sup>).

Table 6-19 shows the resulting carbon stocks in living biomass of the land-use category unproductive forest per spatial stratum in t C ha<sup>-1</sup>.

Table 6-19 Area of brush forest, inaccessible forest and unproductive forest not covered by NFI, their areal fractions ( $F_i$ : fraction of brush and inaccessible forest per stratum  $i$ ) and the resulting weighted carbon stocks in living biomass (t C ha<sup>-1</sup>) for the land-use category unproductive forest (CC13) specified for all spatial strata ( $\text{stockC}_{i,i,CC13}$ ).

NFI region	Elevation [m]	Brush forest [ha]	Inaccessessible forest [ha]	Forest not covered by NFI [ha]	Fraction of brush and inaccessible forest ( $F_i$ )	Fraction of forest not covered by NFI ( $1-F_i$ )	Carbon stock in living biomass ( $\text{stockC}_{i,i,CC13}$ ) [t C ha <sup>-1</sup> ]
1	<601	49	0	69	0.42	0.58	38.53
	601-1200	44	0	4'841	0.01	0.99	51.10
	>1200	6	0	4'648	0.00	1.00	51.34
2	<601	188	0	0	1.00	0.00	20.45
	601-1200	94	0	93	0.50	0.50	35.83
	>1200	1	0	633	0.00	1.00	51.33
3	<601	11	0	0	1.00	0.00	20.45
	601-1200	172	0	1'210	0.12	0.88	47.53
	>1200	3'486	5	8'482	0.29	0.71	42.36
4	<601	26	0	1	0.96	0.04	21.60
	601-1200	1'058	5	589	0.64	0.36	31.48
	>1200	42'795	50	18'808	0.69	0.31	29.88
5	<601	243	1	3	0.99	0.01	20.83
	601-1200	2'249	0	275	0.89	0.11	23.82
	>1200	17'776	7	2'568	0.87	0.13	24.35

#### 6.4.2.4.3. Carbon stocks in dead wood

As stated above, CC13 consists of different types of forests. Carbon stocks in dead wood, litter and mineral soil under unproductive forest reveal a high spatial heterogeneity, and specific data are not available.

So far, there are no data available for carbon stocks in dead wood in the land-use category unproductive forest (CC13). Dead wood on CC13 stands was assumed to be zero (Table 6-4).

#### **6.4.2.4.4. Carbon stocks in litter**

Carbon stocks in litter in the land-use category unproductive forest (CC13) were assigned to the mean value of the modelled CC12 litter stocks for the inventory period (see chp. 6.4.2.3.2). Data is given in Table 6-4.

#### **6.4.2.4.5. Carbon stocks in mineral soil**

Carbon stocks in mineral soil in the land-use category unproductive forest (CC13) were taken from Nussbaum and Burgos (2021) (compare description in chp. 6.4.2.3.3). Data is given in Table 6-4.

#### **6.4.2.4.6. Carbon stocks in organic soil**

The mean soil organic carbon stock (0–30 cm) for organic soil in the land-use category unproductive forest is  $145.6 \pm 24.1 \text{ t C ha}^{-1}$  (Wüst-Galley et al. 2016) (Table 6 4).

#### **6.4.2.4.7. Carbon stock changes in living biomass**

For unproductive forests not covered by NFI and inaccessible stands no NFI data are available. For brush forests there are only few case studies and, similarly to mountainous neighbouring countries, only incomprehensive forest inventory data available. As no harvesting is conducted in unproductive forests, gross growth and cut and mortality of these forest were assumed to be in equilibrium (Tier 1 approach). This approach is transcribed into “gains ( $\text{gainC}_{l,i,13}$ ) = losses ( $\text{lossC}_{l,i,13}$ ) = 0” and reported as “NA” in Table 6-4 and CRF Table4.A.

#### **6.4.2.4.8. Carbon stock changes in dead wood, litter and mineral soil**

Applying a Tier 1 approach, carbon stock changes in dead wood, litter, and mineral soil were assumed to be in equilibrium for unproductive forest. This approach is transcribed into “ $\text{changeC}_{d,i,13} = \text{changeC}_{h,i,13} = \text{changeC}_{s,i,13} = 0$ ” and reported as “NA” in Table 6-4 and CRF Table4.A.

#### **6.4.2.4.9. Carbon stock changes in organic soil**

3 % of organic soil on Forest land is assumed to be subject to drainage (see chp. 6.4.2.3.8). For the calculation of carbon stock changes in organic soil, the default emission factor of  $2.6 \text{ t C ha}^{-1} \text{ yr}^{-1}$  was applied for the land-use category unproductive forest (CC13; Table 6-4) according to the Wetlands Supplement (IPCC 2014a: Table 2.1).

### **6.4.2.5. Land-use change**

In the case of land-use change, the net carbon stock changes in biomass and soils of land-use categories productive forest (CC12) and unproductive forest (CC13) were calculated as described in chp. 6.1.3.

### **6.4.2.6. Non-CO<sub>2</sub> emissions from Forest land**

#### **6.4.2.6.1. Direct N<sub>2</sub>O emissions from N inputs to managed soils**

Fertilisation of forests is prohibited by the Federal Act on Forest and the adherent ordinance (Swiss Confederation 1991, 1992). The Federal Act on Forest (Art. 18) states: "The use of environmentally hazardous substances in the forest is prohibited" with a direct reference to the Federal Act on the Protection of the Environment (Swiss Confederation 1983). Details of the Federal Act on Forest Art. 18 had initially been regulated in the Ordinance on Forest (Art. 27). Since 2005, the Chemical Risk Reduction Ordinance (Swiss Confederation 2005: Art. 4) prohibits the application of fertilisers, including liming, in forests. Hence, the application of fertilisers, including liming in forests was prohibited since 1991 in Switzerland. Furthermore, these management practices have never been common practice in Swiss forestry. There is thus considerable evidence to justify the assumption that this situation is valid since 1990. Additionally, the reporting of N<sub>2</sub>O emissions from fertiliser application in the Agriculture sector encompasses all fertilisers applied in Switzerland. Therefore, no emissions were reported in category A in CRF Table4(I) (notation key "NO").

#### **6.4.2.6.2. N<sub>2</sub>O and CH<sub>4</sub> emissions from drainage of organic soil**

N<sub>2</sub>O emissions from drainage of organic soil was calculated for Forest land with an emission factor of 2.8 kg N<sub>2</sub>O-N ha<sup>-1</sup> for 3 % of the area of organic soil (see chp. 6.4.2.3.8 and chp. 6.4.2.4.9) and reported in category A in CRF Table4(II). The emission factor used is the default value given in the Wetlands Supplement (IPCC 2014a: Table 2.5) for temperate forest land.

CH<sub>4</sub> emissions were not estimated (notation key "NE") in 4(II) as reporting is not mandatory for this category.

#### **6.4.2.6.3. Direct and indirect N<sub>2</sub>O emissions from managed soils**

The calculations of direct N<sub>2</sub>O emissions from nitrogen mineralisation in mineral soil (category 4(III)A) and indirect N<sub>2</sub>O emissions from managed soils (category 4(IV)) in Forest land are described in chp. A5.4.

#### **6.4.2.6.4. CH<sub>4</sub> and N<sub>2</sub>O emissions from biomass burning**

##### **6.4.2.6.4.1. Controlled burning**

Emissions from controlled burning on Forest land covers the burning of harvest residues only since controlled burning of whole forest stands is not allowed in Switzerland.

The amount of natural residues burnt openly was estimated by INFRAS (2014). Open burning of such residues is regulated in the Ordinance on Air Pollution Control OAPC (Swiss

Confederation 1985: Art. 26b). In Switzerland cantonal authorities are responsible for the enforcement of the OAPC regulations. For INFRAS (2014), an inquiry of some cantonal authorities was performed in order to assess the activity data for these processes.

CH<sub>4</sub> and N<sub>2</sub>O emissions were calculated by a Tier 2b approach based on chp. 5.2. in Volume 5 of IPCC (2006). The emissions of burning of residues in forestry were calculated by multiplying the annual estimate of residues burnt (in kt, see FOEN 2023b: chp. 7.3) by emission factors as documented in EMIS 2023/5C2: 6.8 kg t<sup>-1</sup> for CH<sub>4</sub> and 0.180 kg t<sup>-1</sup> for N<sub>2</sub>O.

CO<sub>2</sub> emissions from controlled burning were noted "IE" in the CRF Table4(V) and are encompassed in the data in CRF Table4.A since carbon losses in living biomass are reflected in the NFI data set.

The emission factors of CH<sub>4</sub>, N<sub>2</sub>O and NMVOC of burning of residues from forestry were calculated based on the EMEP/EEA Guidebook (EMEP/EEA 2019), see also documentation in EMIS 2023/5C2 and EMIS 2023/4VA1 Abfallverbrennung in der Land- und Forstwirtschaft.

CRF Table4 also presents NO<sub>x</sub> and CO emissions from burning of residues from forestry on Forest land as described by FOEN (2023b: chp. 7.3.2).

#### 6.4.2.6.4.2. Wildfires

Data on wildfires affecting Forest land were obtained from cantonal authorities and were compiled by the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL, [Swissfire database](#)). These data are updated regularly based on analysing data from cantonal archives (Pezzatti et al. 2019). Table 6-20 shows the time series 1990 to 2021 of affected areas and associated emissions.

As controlled burning of forest stands is not allowed in Switzerland all fires in forests were considered wildfires. All fires were assigned to the land-use category productive forest. This approach reflects reality quite well, since fires in land-use category unproductive forest are rather unlikely to occur because the available fuel is small since tree cover is not very dense and there is very little dead woody material on the surface which can catch fire (Zumbrunnen et al. 2012). Moreover, in remote areas the cause of fire is restricted to lightning strikes.

CO<sub>2</sub> emissions from wildfires were noted "IE" in CRF Table4(V) and are encompassed in the data in CRF Table4.A. Losses in living biomass are reflected in the NFI data set. Carbon changes in dead wood, litter and mineral soil calculated with Yasso07 also cover the influence of forest fires and other disturbances by using NFI data as an input (see chp. 2.3.3 in Didion 2020a).

CH<sub>4</sub> and N<sub>2</sub>O emissions from wildfires (Table 6-20) were calculated using equation 2.27 in Volume 4 of IPCC (2019) with the following parameters:

- For CH<sub>4</sub> the default emission factor of 4.7 g kg<sup>-1</sup> dry matter burnt and for N<sub>2</sub>O, the default emission factor of 0.26 g kg<sup>-1</sup> dry matter burnt were applied (IPCC 2019, Volume 4, Table 2.5).
- The mass of available fuel encompasses carbon stocks in living biomass, dead wood, and litter. On average, the amount of living biomass amounts to 95.42 t C ha<sup>-1</sup> or 190.83 t biomass ha<sup>-1</sup>. This value was derived from the mean growing stock in NFI1, NFI2, NFI3 and NFI4 2015–2019 (see Table 6-16) as a weighted value over the reporting period of the regions affected by forest fires (82 % of the fires occur in the Southern Alps, 15 % in

the Central Alps). In the same way, average carbon stocks in dead wood and litter were calculated per NFI intersurvey period based on data in Table 6-17. They amounted to 19.67 t C ha<sup>-1</sup> or 39.34 t biomass ha<sup>-1</sup> on average for the reporting period.

- The fraction of the biomass combusted was 0.45 (IPCC 2019, Volume 4, Table 2.6).

CH<sub>4</sub> and N<sub>2</sub>O emissions caused by wildfires are reported in CRF Table4(V). CH<sub>4</sub> and N<sub>2</sub>O emissions from wildfires of all types of forests were reported under 4(V)A1, because it is not known which fires occur on Forest land remaining forest land and which on Land converted to forest land. Consequently, category 4(V)A2 has the notation key "IE".

CRF Table4 also presents NO<sub>x</sub> and CO emissions from wildfires on 4A Forest land as described by FOEN (2023b: chp. 7.3.2).

Table 6-20 Forest land affected by wildfires (WSL, Swissfire database) and resulting CH<sub>4</sub> and N<sub>2</sub>O emissions.

Forest land	Unit	1990	1995	2000	2005	2010					
Area burnt	ha	1'067	363	47	41	26					
CH <sub>4</sub>	t	519	177	23	20	13					
N <sub>2</sub> O	t	29	9.8	1.3	1.1	0.70					

Forest land	Unit	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Area burnt	ha	26	24	43	43	256	106	55	16	11	25
CH <sub>4</sub>	t	13	12	21	21	125	51	27	7.8	5.2	12
N <sub>2</sub> O	t	0.70	0.65	1.2	1.1	6.9	2.8	1.5	0.43	0.29	0.68

#### 6.4.2.6.5. NMVOC emissions

Estimates for annual biogenic emissions of NMVOC in Switzerland for forests include emissions from the forest stands, wildfires and emissions from burning of residues in forestry as shown in FOEN (2023b: chp. 7.3 and chp. 7.4).

The biogenic NMVOC emissions from forest stands were calculated for the years 1900–2020 and 2050 on the basis of monthly maps for the parameters temperature, vegetation period and for 12 different tree species (Meteotest 2019a and EMIS 2023/11C Wald). This corresponds to the simplified method according to chp. 11C in the EMEP/EEA guidebook (EMEP/EEA 2019). The year 2021 was interpolated between 2020 and 2050.

In 1990, NMVOC emission from forest stands was 60.83 kt; from 1990 to 2020 the emissions increased on average by 0.34 % per year. The emissions from wildfires and from burning of residues in forestry fluctuated between 0.02 and 0.74 kt over the same period.

### 6.4.3. Uncertainties and time-series consistency

#### 6.4.3.1. Uncertainties

##### Activity data

Uncertainties of activity data of category 4A Forest land are described in chp. 6.3.1.3.

Table 6-5 lists the relative uncertainties in the LULUCF sector. The relative uncertainty of the total carbon stock change for Forest land was calculated as follows.

## Carbon stock change factors

Uncertainties were estimated for the pools living biomass, dead wood, litter and soil. One source of uncertainty common to all pools is the error resulting from the estimates of changes in the pools between two NFIs based on shifting samples of sample plots common to NFI3 and five-year NFI4 subsets (see chp. 6.4.2.1.1.2), i.e. 2009–2011 (GHG inventory submission 2013), 2009–2012 (GHG inventory submission 2014), 2009–2013 (GHG inventory submissions 2015 and 2016), 2011–2015 (GHG inventory submissions 2017 and 2018), and 2013–2017 (GHG inventory submissions 2019 and 2020). This was taken into account to obtain a multi-annual uncertainty estimate.

### Living biomass

Sources of uncertainty (relative uncertainty, 2 SE) considered are:

- NFI sampling between NFIs 3 and 5-year NFI4 subsets: 30.2 %
- Carbon content in solid wood: 2 % based on 2 % relative standard deviation (RSD) in Monni et al. (2007), and 4-8 % RSD in Lamlo and Savidge (2003)
- Biomass expansion function (for Forest land in the Swiss GHG inventory, allometric functions for individual trees were applied) and conversion into mass with wood density: 21.2 % sampling uncertainty and 22.2 % model uncertainty; based on Lehtonen and Heikkinen (2016).

Thus, the total uncertainty of net carbon stock change in living biomass ( $U_{\text{liv.biom}}$ ) in terms of carbon per unit area can be calculated following equation 3.1 in chp. “Quantifying Uncertainties” (Volume 1 of IPCC 2006):

$$U_{\text{liv.biom}} = \sqrt{30.2^2 + 2^2 + 21.2^2 + 22.2^2} = 43.1 \%$$

### Dead wood, litter, soil

In the Monte Carlo simulation approach described in Didion (2020a: chp. 2.3) the following sources of uncertainty were considered:

- NFI sampling between NFIs 3 and 5-year NFI4 subsets
- carbon input estimates obtained from the NFI (measurement errors, allometries, etc.)
- decomposition parameters used in the Yasso07 model.

The resulting relative uncertainties are:

- $U_{\text{Soil}} = 37.0 \%$
- $U_{\text{Litter}} = 96.7 \%$
- $U_{\text{Dead wood}} = 16.6 \%$ .

### Overall uncertainty categories 4A1 and 4A2

The total uncertainty associated with carbon stock change in all four pools was estimated using equation 3.2 in chp. “Quantifying Uncertainties” (IPCC 2006, Volume 1):

$$U_{tot} = \frac{\sqrt{(U_{liv.biom} * X_{liv.biom})^2 + (U_{soil} * X_{soil})^2 + (U_{Litter} * X_{Litter})^2 + (U_{Deadwood} * X_{Deadwd})^2}}{|X_{liv.biom} + X_{soil} + X_{Litter} + X_{Deadwood}|}$$

with mean carbon stock changes in

- living biomass ( $X_{liv.biom}$ ): 1.060 t C ha<sup>-1</sup> yr<sup>-1</sup>
- soil ( $X_{soil}$ ): -0.002 t C ha<sup>-1</sup> yr<sup>-1</sup>
- litter ( $X_{Litter}$ ): -0.009 t C ha<sup>-1</sup> yr<sup>-1</sup>
- dead wood ( $X_{Deadwood}$ ): -0.071 t C ha<sup>-1</sup> yr<sup>-1</sup>

where positive values refer to gains in carbon stock; negative values refer to losses in carbon stock. Thus, the resulting relative uncertainty of the total carbon stock change for Forest land is 46.7 %. This value is used for categories 4A1 and 4A2 for the whole inventory period (see Table 6-5).

#### **Drainage of organic soil (CO<sub>2</sub>; pool organic soil in CRF Table4.A)**

The CO<sub>2</sub> emissions from drained organic forest soils are very small (<0.1 % of category 4A total) and were neglected in the uncertainty calculation.

#### **Drainage of organic soil (N<sub>2</sub>O; category 4(II))**

The contribution of Forest land to N<sub>2</sub>O emissions from drained organic soil (category 4(II)A) is small (around 5 %). Its uncertainty was included in the uncertainty calculation for Wetlands (see chp. 6.7.3).

#### **Biomass burning (CH<sub>4</sub>, N<sub>2</sub>O; category 4(V))**

The emission factor uncertainty for category 4(V) (biomass burning, wildfires) is 70 %. It is derived from the uncertainty of the combustion factor from IPCC (2006, Volume 4, Table 2.6, mean = 0.45, 2SE = 0.32). The activity data uncertainty for wildfires is 30 % (see chp. 6.3.1.3).

#### **6.4.3.2. Time-series consistency**

Consistent time series of annual carbon stocks in living biomass were calculated backward or forward starting from the growing stock 2005, as derived from NFI3 (see chp. 6.4.2.2).

Consistent time series of annual carbon stocks in dead wood, litter and mineral soil were calculated with the model Yasso07 (see supplement 2 to Didion 2020a and chp. 6.4.2.3.1, chp. 6.4.2.3.2 and chp. 6.4.2.3.3, respectively).

#### **6.4.4. Category-specific QA/QC and verification**

The general QA/QC measures are described in chp. 1.5.

#### **6.4.4.1. Living biomass – omission of trees <12 cm DBH and of non-tree understory vegetation**

In Forest land, trees with DBH <12 cm and non-tree understory vegetation are not considered (see chp. 6.4.2.1.1.3). The omission is justified because of their negligible effect on carbon stocks and carbon stock changes of living biomass, dead wood, litter, and soil in productive forests in Switzerland (justification in response to UNFCCC 2022, ID#L.4). In detail:

- Trees with DBH <12 cm contribute only little to total forest biomass and carbon stock (Peichl and Arain 2006). Dunger et al. (2012) estimated this contribution to 1–2 % for forests with similar forest structure as common in Switzerland. Their contribution to annual litter production and hence to carbon stock changes in dead wood, litter, and soil is small compared to mature trees with larger diameters (He et al. 2012).
- Carbon gains in biomass of trees with BDH <12 cm are implicitly accounted for in the trees above this threshold as the cumulative carbon uptake. This is a statistically valid and accurate approach, particularly for the gain/loss approach applied by Switzerland ensuring that carbon stock change factors are neither over- nor underestimated.
- Biomass of non-tree understory vegetation presents <1 % of the above ground biomass carbon pool in the Swiss NFI (Didion 2020b), and thus has a negligible contribution to annual litter production. Consistent with the inventory guidelines (IPCC 2006, Volume 4, Annex 4A.1), it can therefore be excluded from the inventory.

#### **6.4.4.2. Suitability of the soil carbon model Yasso07 for application for forests in Switzerland**

The validity of the Yasso07 model in Swiss forests was examined by Didion et al. (2014a). The study analysed, among other, the accuracy of Yasso07 for reproducing observed carbon decomposition in litter and dead wood in Swiss forests. The authors found that no significant differences existed between simulated and observed remaining carbon in foliage and fine root litter after 10 years and in lying dead trees after 14 to 21 years.

#### **6.4.4.3. Carbon stocks in mineral soil**

The trend of a very minor increase in soil carbon stocks since 1990, based on the Yasso07 simulations (chp. 6.4.2.3.7), supports the assumption that carbon stocks in mineral soil in land-use category productive forest could be considered constant over the inventory period (chp. 6.4.2.3.3).

#### **6.4.4.4. Carbon balance of two mountain forest ecosystems in Switzerland – Net ecosystem exchange and soil respiration**

Measurements of the net ecosystem exchange (NEE) and of soil respiration were conducted at a montane mixed forest over 5 years (Lägeren; 2005–2009; NFI production region 2), and at a subalpine coniferous forest over 12 years (Davos; 1997–2009; Swiss Plateau, NFI production region 4).

(1) Etzold et al. (2011) determined the net ecosystem exchange (NEE) by eddy covariance (EC) measurements. EC measurements as well as biometric estimates indicate that both sites with two different mountain forest types were significant carbon sinks in the respective

periods. NEE of the Lägeren forest ranged from  $-366$  to  $-662$  g C m<sup>-2</sup> yr<sup>-1</sup> (mean:  $-415$  g C m<sup>-2</sup> yr<sup>-1</sup>), and of the Davos forest from  $-47$  to  $-274$  g C m<sup>-2</sup> yr<sup>-1</sup> (mean:  $-154$  g C m<sup>-2</sup> yr<sup>-1</sup>).

(2) Rühr and Eugster (2009) measured soil respiration rates at these two Swiss forest sites. Modelled changes in soil carbon storage with the dynamic soil carbon model Yasso07 gave comparable results with measured soil respiration. Rühr and Eugster (2009) found that soils at the alpine site Davos acted as a significant carbon sink. Soils at the Lägeren site were neither a significant carbon sink nor a significant carbon source. This domestic study confirms the broadly spread knowledge that it is very difficult to detect short term changes in soil carbon stocks, since the uncertainty of the measurement is often higher than the actual change of the annual estimates (e.g. Falloon and Smith 2003).

#### **6.4.4.5. Carbon stock changes in mineral soil – Soil organic carbon (SOC) data set of the Swiss Soil Monitoring Network**

The objective of the Swiss Soil Monitoring Network (<http://www.nabo.ch>; NABO) is to assess soil quality in the long term, such as concentrations of harmful substances, organic carbon, the microbiology, and its development over time (Gross et al. 2023). NABO operates about 110 long-term monitoring sites throughout Switzerland covering all relevant land uses, such as cropland, grassland, and forest. Most of the monitoring sites were sampled for the first time between 1985 and 1989 and resampled every five years ever since (SAEFL 1993, 2000a; Meuli et al. 2014; Gubler et al. 2015; Gross et al. 2023).

At each site, four replicate bulked soil samples from the upper soil layer 0–20 cm are taken within an area of 10m\*10m. Each bulked sample consists of 25 single cores taken according to a stratified random sampling scheme. Further details are provided by SAEFL (2000a) and Gubler et al. (2015). Currently, results of sampling campaigns 1 to 7 are available for the cultivation types forest, grassland and cropland (Gross et al. 2023).

The spatial variation of bulk density was included in calculating the carbon stocks. Bulk density and soil skeleton (fragments >2 mm) were measured repeatedly for all monitoring sites at the occasion of sampling campaigns 4 to 7 (2000–2019), but not in the previous campaigns. The mass of fine earth (<2 mm;  $M_{FE}$ ) per total soil volume ( $V_{tot}$ , including skeleton and pores) was determined for four volumetric samples 0–20 cm per site and campaign to derive the so-called apparent density of fine earth ( $D = M_{FE} / V_{tot}$ ). Subsequently, SOC stocks (t C / ha) in 0–20 cm depth were calculated as  $D$  (g/cm<sup>3</sup>) \* SOC (%) \* 20 (cm). For each site, the site-specific apparent density was used; repeated apparent density measurements per site were used to account for the variability of the bulk density.

The data presented here are based on samples collected from 1985 to 2019 at 28 forest sites (NABO 2021). SOC stocks for the top 20 cm of forest soils ranged from 41 to 149 t C ha<sup>-1</sup> with a mean of 72 t C ha<sup>-1</sup>. Few sites have stocks higher than 90 t C ha<sup>-1</sup> (Figure 6-8 top panel). There were no significant changes in SOC stocks over time except for the periods between the second and third, and the third and fourth sampling campaigns due to the exceptionally high SOC stocks in the third campaign (Figure 6-8 bottom panel). Previous NABO studies showed that the elevated SOC stocks for the third sampling campaign must be considered as artefact, induced by sub-optimal conditions during field work (Meuli et al. 2014; Gubler et al. 2015). These samples were collected earlier in the year and, thus, soils were moister. It is known that soil carbon has a high natural variation which may be pronounced if soil moisture differences are high. For instance, six resamplings within three

years at two forest sites revealed short-term variation of SOC contents between  $\pm 1.8\%$  and  $\pm 0.6\%$  (single standard errors; Keller et al. 2006).

The monitoring scheme applied by NABO is able to detect relative changes in SOC contents of roughly 2.5 % per 10 years for mineral forest soils (minimum detectable change for 30 monitoring sites including three or more sampling campaigns). Regarding the measured SOC stocks (mean  $72 \text{ t ha}^{-1}$ ), this corresponds to a minimum detectable change of roughly  $0.18 \text{ t C ha}^{-1} \text{ yr}^{-1}$  for SOC stocks. In comparison, the mean change in SOC stocks obtained with Yasso07 for the period 1991–2010 was  $-0.00075 \pm 0.00053 \text{ t C ha}^{-1} \text{ yr}^{-1}$  (2SE; based on data in Didion and Thürig 2017). This value is several orders of magnitude smaller than the minimum detectable change that can be identified in the NABO monitoring scheme.

In conclusion, NABO data indicate that mineral soils on Forest land acted neither as a significant net source nor as a significant net sink of carbon when considered over the entire 34-year period.

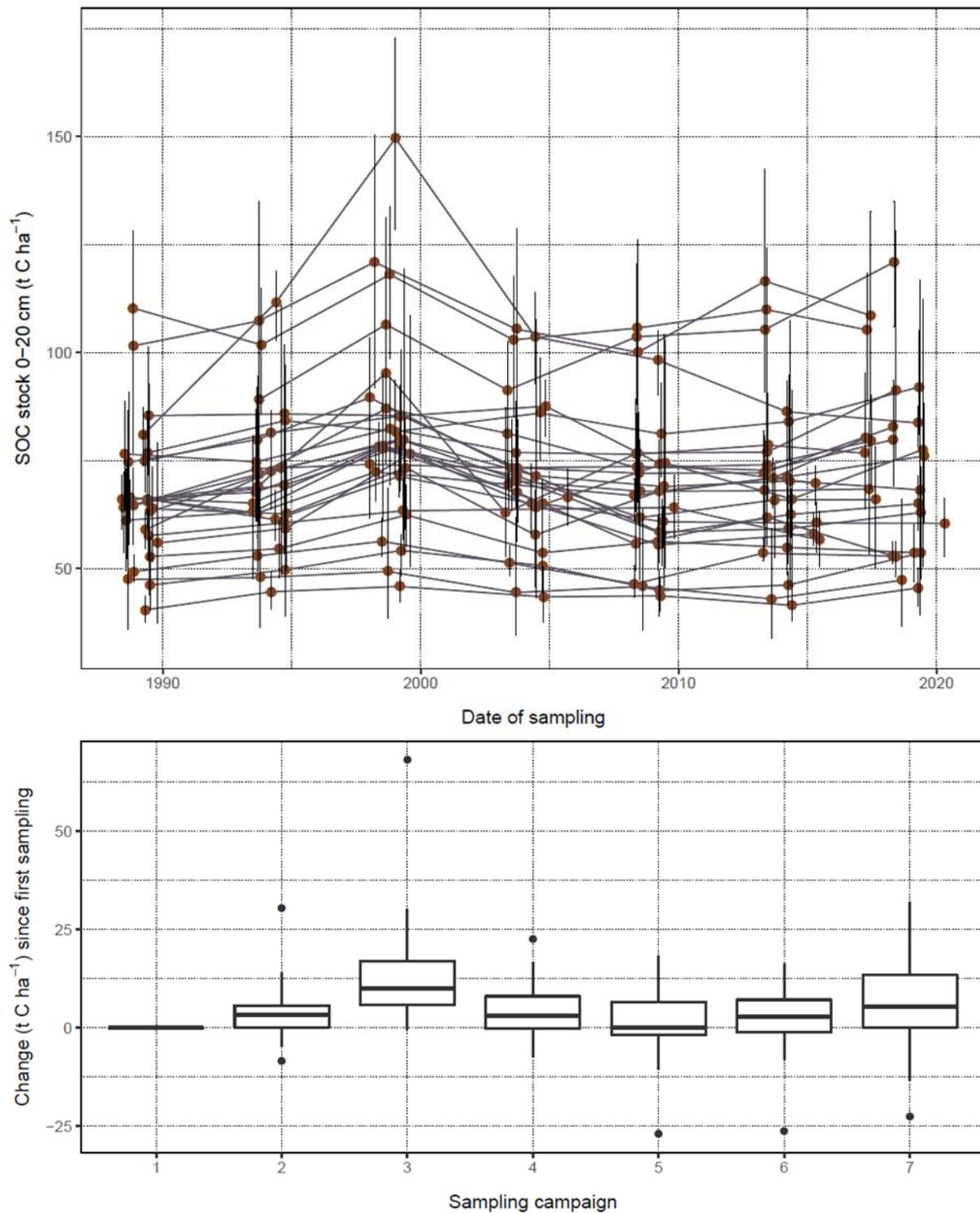


Figure 6-8 Measured SOC stocks for topsoils (0–20 cm) and their changes for 28 NABO long-term monitoring sites in forest during the time period 1985–2019. The elevation of the sites ranges from 383 to 1690 m a.s.l. Top panel: SOC stocks 0–20 cm per site and sampling; the dots indicate the mean and the bars the range of 5 % and 95 % percentiles of bootstrap samples taking into account the variability in SOC content of the individual replicates per site and sampling as well as the variations of the bulk density. Bottom panel: boxplot of changes in SOC stocks in each case related to the first sampling (boxes indicate the lower and the upper quartiles with the median indicated; lines include all observations inside the range of 1.5 times the interquartile distance, observations beyond that range are indicated as dots).

#### 6.4.4.6. Uncertainty Estimates

The uncertainty for carbon stock changes in dead wood, litter and soil organic matter reported by Finland, where the Yasso07 model is also applied, was 31.5 % for the year 2015 (Statistics Finland 2017: chp. 6.4.3.2). For the total uncertainty of change in living biomass, Finland reported 20 % (Statistics Finland 2017: chp. 6.4.3.1).

#### 6.4.5. Category-specific recalculations

- 4A: Activity data (areas) 2013–2020 were updated (see chp. 6.3.1.5). The inclusion of first data from the AREA5 survey led to small recalculations. While this is directly evident in Table 6-11 for land use category unproductive forest (CC13), the change data for land use category productive forest (CC12) is overprinted by the following additional recalculation:
- 4A: With the retirement of the Kyoto Protocol, the land-use category afforestations (CC11) was integrated in the land-use category productive forest (CC12) over the time series 1990–2020 (Table 6-11). Because of the small area sizes, this did not have a significant impact on the recalculated data in category 4A (see Figure 10-9).
- 4A: Separate values for carbon stocks in mineral soil for land-use categories productive forest (CC12) and unproductive forest (CC13) were taken from Nussbaum and Burgos (2021: Table 5; see chp. 6.4.2.3.3 and chp. 6.4.2.4.5). The use of the data set affected carbon stocks and carbon stock changes in category 4A as well as associated N<sub>2</sub>O emissions in category 4(III)A2 in a minor way.
- 4(V)A1: The time series of CH<sub>4</sub> and N<sub>2</sub>O emissions from wildfires 1990–2020 were recalculated for specific years due to updated activity data in the Swissfire database. Negligible changes resulted for the years 2016, 2018, 2019 and 2020 (see chp. 6.4.2.6.4.2).

The resulting differences of all recalculations in net emissions and removals between the latest and the previous submissions for category 4A are shown in Figure 10-9. They are very small and range from -9.9 kt CO<sub>2</sub> eq in 1993 to 11.1 kt CO<sub>2</sub> eq in 2000.

#### 6.4.6. Category-specific planned improvements

##### 6.4.6.1. Living biomass

Land-use category productive forest: As a result of the continuous monitoring of the Swiss Forests, new NFI data will be available regularly (see chp.6.4.2.1.1.2). The adoption of new NFI data (based on a shifting five-year window) can affect the estimates of all reported pools as well as the calculation of the available fuel for wildfires in forests.

Land-use category unproductive forest: For the submission 2024 data to compare the changes in growing stock of brush forest between NFIs 4 and 5 will be available. Carbon stocks change factors for brush forest will be derived based on conversion factors to biomass and carbon and backcasting for the entire time series since the base year.

### 6.4.6.2. Dead wood, litter, and mineral soil

The implementation of the soil model Yasso07 to improve the accuracy in the estimates of temporal changes in soil carbon, litter and dead wood is continuously developed. Depending on the availability of relevant data and studies, planned improvements include:

- Implementation of the new and improved version of the Yasso model, Yasso20 (Viskari et al. 2022), which has been shown to improve the accuracy of soil carbon, litter and dead wood estimates in Swiss forests compared to Yasso07 (unpublished data).

Following the availability and the evaluation of Yasso20, the following planned improvement was postponed to the submission 2024:

- Improving the uncertainty estimates for litter production by revising allometries and by estimating tree compartments using a Monte Carlo approach. This is expected to improve the accuracy of the estimates of carbon stocks and carbon stock changes.

## 6.5. Category 4B – Cropland

### 6.5.1. Description

Table 6-21 Key categories in category 4B. Combined KCA results, level for 2021 and trend for 1990–2021, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC category	Gas	Identification criteria
4B1	Cropland remaining cropland	CO <sub>2</sub>	L1, T1, L2, T2

Swiss croplands belong to the cold temperate wet climatic zone. Croplands (CC21) include annual crops and leys in arable rotations (see Table 6-2 and Table 6-6).

In the inventory period, total net emissions and removals of category 4B1 Cropland remaining cropland range from 800 kt CO<sub>2</sub> in 2014 to -28 kt CO<sub>2</sub> in 2009 (average 327 kt CO<sub>2</sub>; Figure 6-9). Fluctuations are mainly due to climatic influences on carbon stocks in living biomass and in mineral soil. In contrast, high stable carbon losses in organic soil characterise the net figures in 4B1 (although organic soil accounts only for 2.7 % of cropland area in Switzerland; Table 6-7). 2009 is the only year that 4B1 acted as a sink. Carbon stocks both in living biomass and in mineral soil in 4B1 increased over the inventory period (see upper panels in Figure 6-10 and Figure 6-11).

Category 4B2 Land converted to cropland acts as a small net source in all years (average 26 kt CO<sub>2</sub>; Figure 6-9) mainly due to carbon losses in mineral soil under category 4B2.2 Grassland converted to cropland.

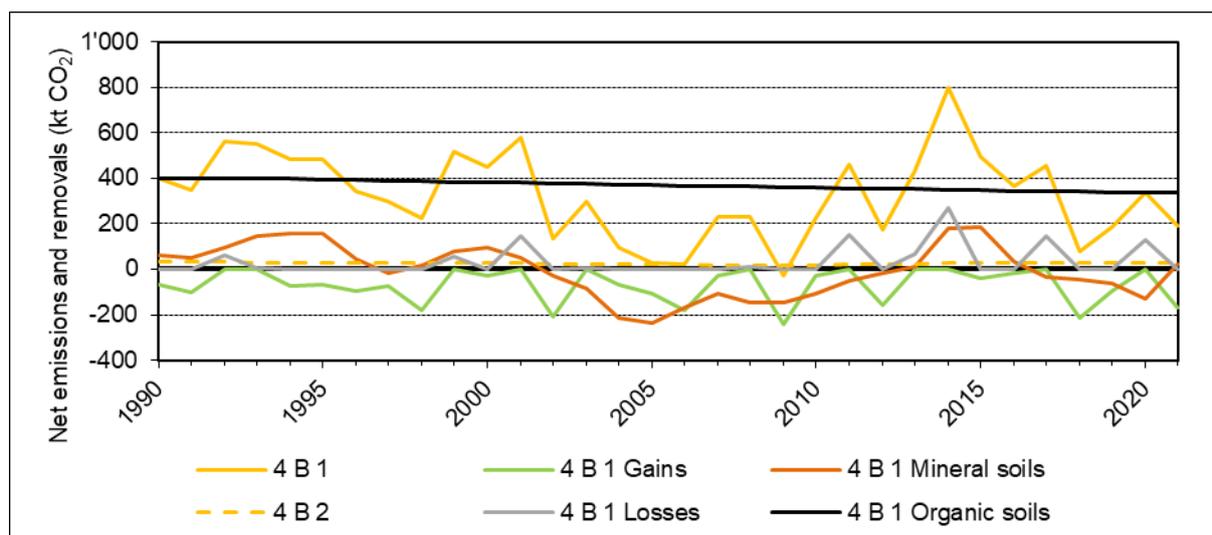


Figure 6-9 Net CO<sub>2</sub> emissions (positive values) and removals (negative values) from categories 4B1 and 4B2. Category 4B1 is broken down by gains in living biomass, losses in living biomass, net carbon stock changes in mineral soil, and net carbon stock changes in organic soil.

## 6.5.2. Methodological issues

Carbon stocks in living biomass, as well as carbon stocks and carbon stock changes in mineral soil were estimated with a Tier 3 approach using the model RothC (Wüst-Galley et al. 2020). The results were integrated in category 4B by calculating area-weighted (using the relative surface of crops) average values per elevation zone. The differences in carbon stocks (calculated as five-year moving average except for the previous and latest inventory years) between two consecutive years were reported as net changes for living biomass and for mineral soil.

### 6.5.2.1. Carbon stocks

#### 6.5.2.1.1. Carbon stocks in living biomass

Annual carbon stocks in living biomass per elevation zone (see chp. 6.2.2.2) were calculated as area-weighted means of harvested biomass for the 19 most important annual crops (barley, broad beans ("Ackerbohnen"), fallow, fodder beet, maize (grain), oat, peas ("Eiweisserbsen"), potatoes, rape (cooking oil), rye, sugar beet, silage and green corn, sun flowers (cooking oil), soybean, spelt, triticale, vegetables, wheat) and as cumulated annual harvested biomass for clover-grass (leys).

Annual values 1990–2021 for harvested yields (dt ha<sup>-1</sup>) were published by the Swiss Farmers Union (SBV 2021 and previous editions). The same allometric equation as used for soil organic carbon modelling was applied to estimate total biomass including roots (Wüst-Galley et al. 2020). A carbon fraction of 0.45 was assumed based on Bolinder et al. (2007).

Carbon stocks and carbon stock changes in living biomass were reported as moving averages over five years (from year-2 to year+2, e.g. 1988–1992 for the year 1990; the previous and latest inventory years were reported as four-year (year-2 to year+1) and three-year (year-2 to latest inventory year) moving averages, respectively). Data are shown in Table 6-22 and in Figure 6-10.

The rationale for this smoothing is that due to stockpiling, the consumption (and thus oxidation) of the biomass is levelled out between individual years (see Figure 6-10 upper panel). The resulting area-weighted (across the three elevation zones) mean carbon stock in living biomass for Cropland over the inventory time period was 6.85 t C ha<sup>-1</sup>.

Table 6-22 Area-weighted (using the relative surface of crops per elevation zone) carbon stocks (t C ha<sup>-1</sup>) and net carbon stock changes (t C ha<sup>-1</sup> yr<sup>-1</sup>) in living biomass of arable crops for land-use category Cropland (CC21), stratified for elevation zone (Elev.: Elevation zone 1 = <601 m, 2 = 601-1200 m, 3 = >1200 m; see chp. 6.2.2.2). Highlighted data for 1990 are displayed in Table 6-4.

Living biomass	Elev.	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
		CC21: carbon stock [t C ha <sup>-1</sup> ] and net change in living biomass [t C ha <sup>-1</sup> yr <sup>-1</sup> ]									
Stock	1	6.39	6.46	6.42	6.41	6.46	6.51	6.57	6.62	6.74	6.69
Stock	2	6.40	6.46	6.42	6.41	6.46	6.50	6.58	6.64	6.76	6.74
Stock	3	6.07	6.16	6.13	6.11	6.13	6.12	6.22	6.33	6.49	6.56
Net change	1	0.05	0.07	-0.04	-0.01	0.05	0.05	0.06	0.05	0.12	-0.05
Net change	2	0.04	0.06	-0.04	0.00	0.05	0.04	0.07	0.06	0.13	-0.02
Net change	3	0.08	0.08	-0.02	-0.02	0.02	-0.01	0.10	0.10	0.16	0.08

Living biomass	Elev.	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
		CC21: carbon stock [t C ha <sup>-1</sup> ] and net change in living biomass [t C ha <sup>-1</sup> yr <sup>-1</sup> ]									
Stock	1	6.71	6.60	6.75	6.75	6.79	6.87	7.00	7.02	7.01	7.20
Stock	2	6.77	6.68	6.81	6.81	6.86	6.94	7.06	7.08	7.06	7.22
Stock	3	6.63	6.60	6.73	6.78	6.87	7.03	7.13	7.15	7.12	7.21
Net change	1	0.02	-0.11	0.15	-0.01	0.05	0.07	0.13	0.02	-0.01	0.19
Net change	2	0.02	-0.09	0.14	0.00	0.05	0.08	0.12	0.02	-0.01	0.15
Net change	3	0.07	-0.04	0.14	0.05	0.09	0.15	0.10	0.02	-0.03	0.09

Living biomass	Elev.	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
		CC21: carbon stock [t C ha <sup>-1</sup> ] and net change in living biomass [t C ha <sup>-1</sup> yr <sup>-1</sup> ]									
Stock	1	7.22	7.11	7.23	7.19	6.97	7.01	7.02	6.91	7.07	7.15
Stock	2	7.23	7.11	7.23	7.16	6.98	7.00	7.00	6.89	7.08	7.14
Stock	3	7.19	7.06	7.15	7.02	6.90	6.89	6.86	6.78	7.03	7.03
Net change	1	0.03	-0.11	0.12	-0.04	-0.21	0.03	0.02	-0.12	0.16	0.08
Net change	2	0.01	-0.12	0.12	-0.07	-0.18	0.02	0.00	-0.11	0.19	0.05
Net change	3	-0.02	-0.14	0.10	-0.13	-0.12	-0.01	-0.03	-0.07	0.24	0.00

Living biomass	Elev.	2020	2021	CC21: carbon stock [t C ha <sup>-1</sup> ] and net change in living biomass [t C ha <sup>-1</sup> yr <sup>-1</sup> ]							
		Stock	1	7.08	7.24						
Stock	2	7.07	7.25								
Stock	3	6.98	7.21								
Net change	1	-0.11	0.13								
Net change	2	-0.10	0.15								
Net change	3	-0.07	0.21								

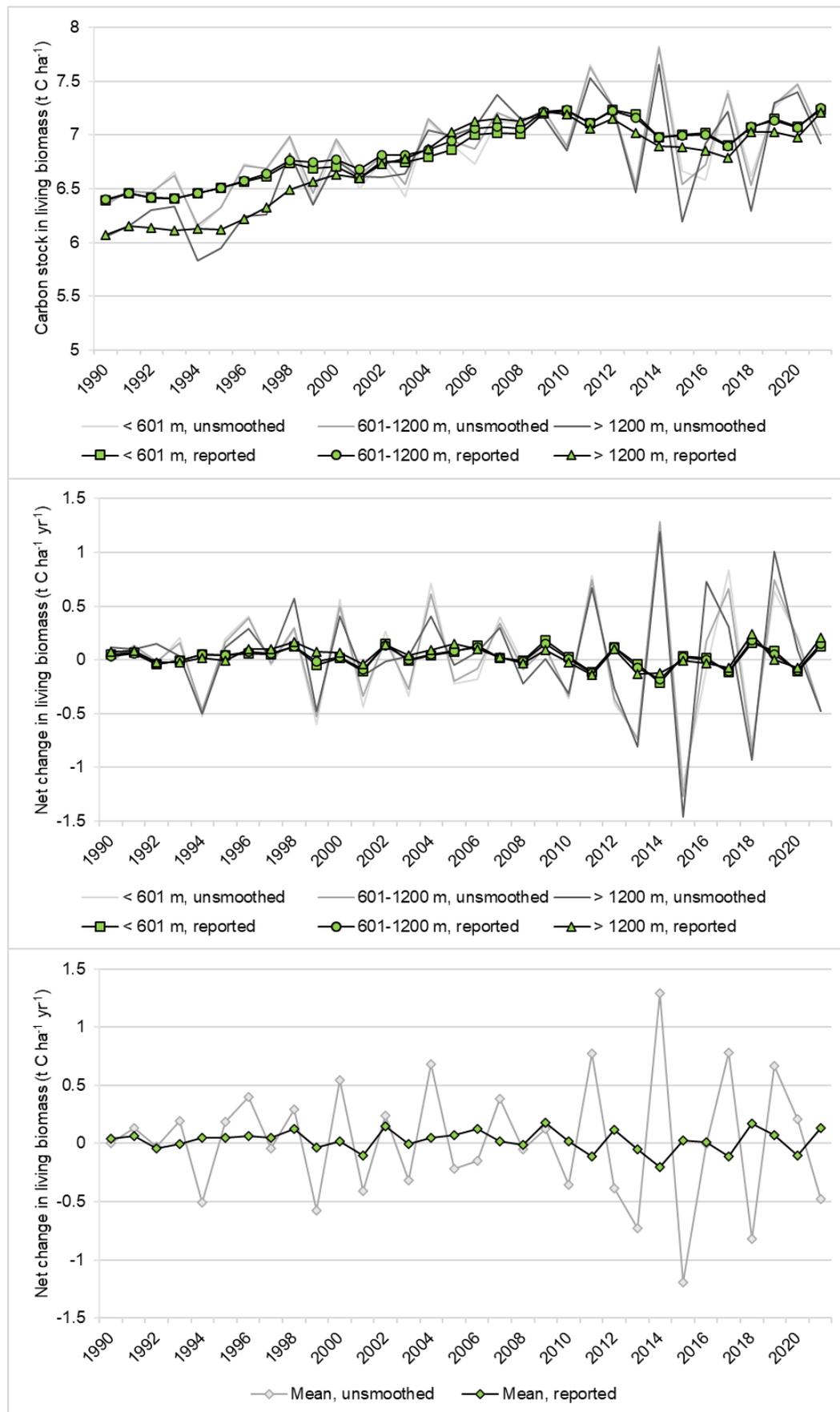


Figure 6-10 Reported carbon stocks (t C ha<sup>-1</sup>) and net carbon changes (t C ha<sup>-1</sup> yr<sup>-1</sup>) in living biomass of Cropland and underlying unsmoothed data (shown for transparency reasons), stratified for elevation zone (upper and middle panel) and area-weighted (across three elevation zones) means (lower panel). Upper and lower confidence intervals are too small to be distinguished from the mean. Elevation zone >1200 m is less important as it covers only 0.1 % of the total cropland area (see Table 6-7).

### **6.5.2.1.2. Carbon stocks in dead organic matter**

Carbon stocks in dead organic matter were assumed to be zero.

### **6.5.2.1.3. Carbon stocks in soil**

#### **6.5.2.1.3.1. Mineral soil**

##### *Initial carbon stocks*

Carbon stocks in mineral soil under Cropland were calculated based on Leifeld et al. (2003, 2005), as described in Wüst-Galley et al. (2020). The approach correlated measured soil organic carbon stocks ( $\text{t ha}^{-1}$ ) with measured clay content. The relationship was applied to the national level using soil texture information from the Swiss digital soil map (SFSO 2000a), correcting for soil depth and stone content. The median soil organic carbon stock (0–30 cm, in 1975) for Cropland is  $49.1 \text{ t C ha}^{-1}$ . The variability of carbon stocks across the country is  $8.6 \text{ t C ha}^{-1}$  (1 SD). These carbon stocks were applied to 1975 and were used for the initialisation of RothC modelling (see below).

##### *Simulation of carbon stocks through time*

Switzerland used the soil carbon model RothC (Coleman et al. 1997; Coleman and Jenkinson 1999) to estimate carbon stocks in mineral soil (0–30 cm) under Cropland for the inventory period. The implementation of RothC in the Swiss GHG inventory is described in detail in Wüst-Galley et al. (2020) and Wüst-Galley et al. (2019: pp. 71, the up-scaling to elevation zone).

RothC is a model for the turnover of organic carbon in mineral soil, implementing four active carbon pools each associated with their own decomposition rates. In addition, there is a small carbon pool that is considered to be stable (inert). The model runs and calculates soil carbon stocks on a monthly basis. The decomposition rates are altered by temperature, moisture, soil cover and the soil's clay content. RothC requires information on climate (monthly precipitation, temperature and evapotranspiration), monthly carbon inputs (from organic manures and from plants, including above- and below ground harvest residues and root exudates) and soil (clay content, monthly soil cover). Testing and validation of RothC are described in Wüst-Galley et al. (2020).

##### *Input data*

Gridded climate data were obtained from the Federal Office of Meteorology and Climatology (MeteoSwiss 2021), including monthly average temperature and monthly (total) precipitation. Monthly evapotranspiration was calculated with the Priestley-Taylor method using these two data sets as well as monthly surface incoming short wave radiation (SIS), also obtained from MeteoSwiss. The most important 19 crops (as introduced in chp. 6.5.2.1.1, covering over 99 % of Swiss cropland area) were considered. Annual crop yields ( $\text{dt ha}^{-1}$ ) were obtained from the Swiss Farmers Union (SBV 2021 and previous editions). Based on yield data from crops, plant carbon inputs to the soil from crop residues, roots and rhizodeposition were estimated using an allometric function adapted from Bolinder et al. (2007), as described in Wüst-Galley et al. (2020). Annual carbon inputs from organic manures to different types of crops or grasslands were calculated based on: (1) organic manure production, calculated as a function of excretion rate of volatile solids, using the method described in chp. 5.3.2.2.1; (2) animal herd size, described in chp. 5.3.2.5.1; (3) manure management systems, described in chp. 5.3.2.2.4 (using the data for volatile solids); (4) the tendency of farmers to apply different types of manure onto four different crop / grass categories, using information obtained from the Swiss ammonium model AGRAMMON (Kupper et al. 2022); (5) the different fertilisation

needs of individual crops or grasslands of differing management intensities (obtained from the "Principles of Fertilisation of Agricultural Crops in Switzerland" (GRUD; Richner and Sinaj 2017); (6) straw production, using annual values published by the Swiss Farmers Union (SBV 2021 and previous editions); (7) the amount of manure digested anaerobically in biogas plants, as described in chp. 5.3.2.2.3; (8) the amount of liquid and solid digestates, as described in chp. 5.5.2.2.2; and (9) the number of livestock units moving annually to the summer pasture regions, using annual data (1999 to present, prior years using extrapolation) that are collected for the calculation of subsidies for this summer grazing ("Sömmerungsbeiträge"), from the Federal Office for Agriculture. Clay content was derived from the Swiss Soil Suitability Map (Bodeneignungskarte; SFSO 2000a) as described in Wüst-Galley et al. (2020). Soil cover and the distribution of plant inputs throughout the year were determined using sowing and harvest dates from various agricultural guidelines, as described in Wüst-Galley et al. (2020).

#### *Up-scaling*

The RothC modelling was carried out for 4'560 different combinations (19 crops x 240 regions) representing similar climate, crop type, management systems and clay content, as described in Wüst-Galley et al. (2020). An average initial soil organic carbon stock was calculated for the cropland area in each of these regions. The simulated carbon stocks were then upscaled using the proportion of different crop types within each region to calculate weighted means.

#### *Reporting*

Carbon stocks in mineral soil were integrated in category 4B by calculating area-weighted (using the relative surface of crops) average values per elevation zone. The results were reported as moving averages over five years (from year-2 to year+2, e.g. 1988–1992 for the year 1990; the previous and latest inventory years were reported as four-year (year-2 to year+1) and three-year (year-2 to latest inventory year) moving averages, respectively). Data are shown in Table 6-23 and in Figure 6-11 upper panel.

Unsmoothed data mainly reflect effects of climatic conditions, whereas long-term trends related to e.g. changes in agricultural management are better visible when the data are smoothed. The resulting area-weighted (across the three elevation zones) mean carbon stock in mineral cropland soil over the inventory period was 49.97 t C ha<sup>-1</sup>.

Table 6-23 Area-weighted (using the relative surface of crops per elevation zone) carbon stocks (t C ha<sup>-1</sup>) and net carbon stock changes (t C ha<sup>-1</sup> yr<sup>-1</sup>) in mineral soil (0-30 cm) for land-use category Cropland (CC21), stratified for elevation zone (Elev: Elevation zone 1 = <601 m, 2 = 601-1200 m, 3 = >1200 m; see chp. 6.2.2.2). Highlighted data for 1990 are displayed in Table 6-4.

Mineral soil	Elev.	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
		CC21: carbon stock [t C ha <sup>-1</sup> ] and net change in mineral soil [t C ha <sup>-1</sup> yr <sup>-1</sup> ]									
Stock	1	50.10	50.06	49.98	49.86	49.73	49.60	49.56	49.57	49.54	49.48
Stock	2	50.02	50.00	49.96	49.90	49.83	49.77	49.76	49.79	49.80	49.76
Stock	3	41.47	41.56	41.65	41.70	41.75	41.82	41.95	42.13	42.39	42.67
Net change	1	-0.05	-0.04	-0.08	-0.12	-0.13	-0.13	-0.04	0.00	-0.02	-0.06
Net change	2	-0.04	-0.02	-0.04	-0.06	-0.06	-0.07	-0.01	0.03	0.01	-0.04
Net change	3	0.06	0.09	0.08	0.06	0.04	0.07	0.13	0.19	0.26	0.27

Mineral soil	Elev.	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
		CC21: carbon stock [t C ha <sup>-1</sup> ] and net change in mineral soil [t C ha <sup>-1</sup> yr <sup>-1</sup> ]									
Stock	1	49.40	49.36	49.38	49.44	49.60	49.78	49.90	49.97	50.07	50.18
Stock	2	49.71	49.69	49.71	49.77	49.92	50.08	50.22	50.32	50.44	50.56
Stock	3	42.91	43.25	43.68	44.13	44.61	45.05	45.35	45.53	45.65	45.70
Net change	1	-0.08	-0.04	0.02	0.06	0.16	0.18	0.12	0.07	0.10	0.11
Net change	2	-0.05	-0.02	0.02	0.06	0.15	0.16	0.13	0.10	0.12	0.12
Net change	3	0.25	0.34	0.43	0.45	0.48	0.44	0.31	0.18	0.12	0.05

Mineral soil	Elev.	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
		CC21: carbon stock [t C ha <sup>-1</sup> ] and net change in mineral soil [t C ha <sup>-1</sup> yr <sup>-1</sup> ]									
Stock	1	50.26	50.30	50.32	50.31	50.17	50.01	49.99	50.04	50.09	50.15
Stock	2	50.63	50.67	50.68	50.67	50.54	50.42	50.37	50.36	50.36	50.37
Stock	3	45.72	45.69	45.63	45.52	45.38	45.21	45.19	45.29	45.43	45.57
Net change	1	0.08	0.04	0.01	-0.01	-0.15	-0.15	-0.02	0.04	0.05	0.07
Net change	2	0.08	0.03	0.02	-0.02	-0.12	-0.13	-0.04	-0.01	0.00	0.01
Net change	3	0.02	-0.03	-0.07	-0.11	-0.14	-0.17	-0.02	0.10	0.14	0.14

Mineral soil	Elev.	2020	2021	CC21: carbon stock [t C ha <sup>-1</sup> ] and net change in mineral soil [t C ha <sup>-1</sup> yr <sup>-1</sup> ]							
		Stock	1	50.29	50.33						
Stock	2	50.45	50.47								
Stock	3	45.76	45.88								
Net change	1	0.12	-0.01								
Net change	2	0.06	-0.03								
Net change	3	0.27	0.17								

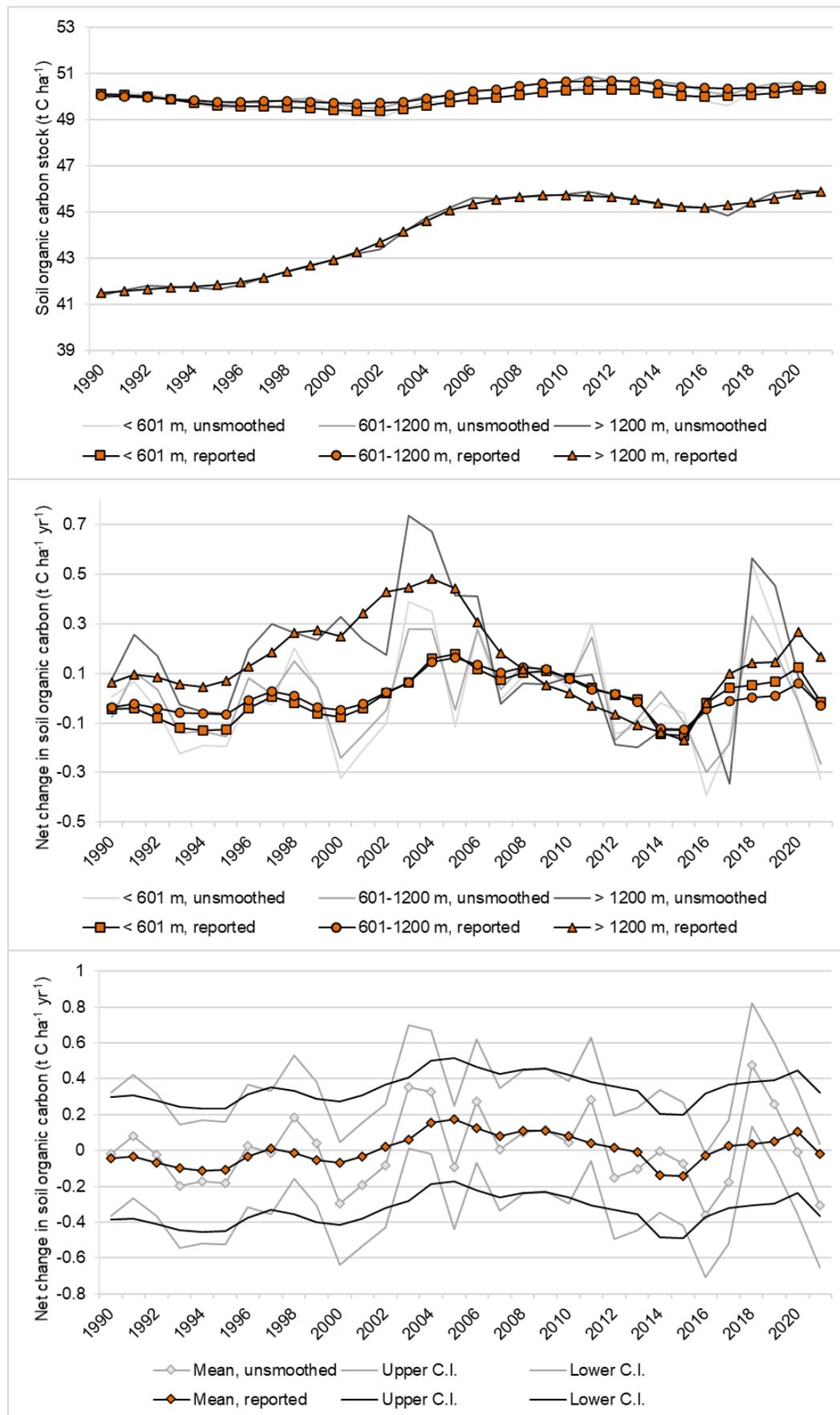


Figure 6-11 Reported carbon stocks (t C ha<sup>-1</sup>) and net carbon changes (t C ha<sup>-1</sup> yr<sup>-1</sup>) in Cropland mineral soil (0–30 cm) and underlying unsmoothed data (shown for transparency reasons), stratified for elevation zone (upper and middle panel) and area-weighted (across three elevation zones) means (lower panel) plus upper and lower confidence intervals (C.I.; see chp. 6.5.3). Elevation zone >1200 m is less important as it covers only 0.1 % of the total cropland area.

### **6.5.2.1.3.2. Organic soil**

Soil carbon stocks in organic soil under Cropland were calculated based on Leifeld et al. (2003, 2005). The approach used measured carbon stocks in Swiss organic soils. The mean soil organic carbon stock (0–30 cm) of cultivated organic soil was  $240 \pm 48 \text{ t C ha}^{-1}$  (uncertainty 20 %).

## **6.5.2.2. Changes in carbon stocks**

### **6.5.2.2.1. Carbon stock changes in living biomass**

The difference in biomass carbon stock (five-year moving average, see chp. 6.5.2.1.1) between two consecutive years was reported as net carbon stock change (gain or loss) (see Table 6-22 and Figure 6-10 middle panel). The resulting values were in the range between  $-0.21$  and  $0.24 \text{ t C ha}^{-1} \text{ yr}^{-1}$  with a mean area-weighted carbon stock change across all elevation zones of  $0.03 \text{ t C ha}^{-1} \text{ yr}^{-1}$  for the inventory time period.

### **6.5.2.2.2. Carbon stock changes in dead organic matter**

Applying a Tier 1 approach, carbon stock changes in dead organic matter were assumed to be in equilibrium for Cropland remaining cropland.

### **6.5.2.2.3. Carbon stock changes in soil**

#### **6.5.2.2.3.1. Mineral soil**

The difference in carbon stock (five-year moving average, see chp. 6.5.2.1.3.1) between two consecutive years was reported as net carbon stock change (gain or loss) in Cropland mineral soil (see Table 6-23 and Figure 6-11 middle panel). For transparency reasons, unsmoothed changes in carbon stocks were also displayed in Figure 6-11.

The mean carbon stock change in the inventory period for elevation zone 1 was  $0.004 \text{ t C ha}^{-1}$  and for elevation zone 2  $0.011 \text{ t C ha}^{-1}$  (elevation zone 3 is less important as it covers 0.1 % of Cropland; see Table 6-7). The mean area-weighted carbon stock change across all elevation zones was  $0.006 \text{ t C ha}^{-1}$ .

#### **6.5.2.2.3.2. Organic soil**

The annual net carbon stock change in organic soil was estimated to  $-9.52 \text{ t C ha}^{-1}$  according to measurements in Europe including Switzerland as compiled by Leifeld et al. (2003, 2005) and verified by ART (2009b) and Paul and Alewell (2018).

#### **6.5.2.2.4. Land-use change**

In the case of land-use change, the net carbon stock changes in biomass and soils were calculated as described in chp. 6.1.3.

### 6.5.2.3. Non-CO<sub>2</sub> emissions from Cropland

#### 6.5.2.3.1. *N<sub>2</sub>O and CH<sub>4</sub> emissions from drainage of organic soil*

N<sub>2</sub>O emissions from drainage of organic soil (category 4(II)) in Cropland were reported in the Agriculture sector (category 3Da6 Cultivation of organic soils; see chp. 5.5).

CH<sub>4</sub> emissions were not estimated (notation key "NE") in 4(II) as reporting is not mandatory for this category.

#### 6.5.2.3.2. *Direct and indirect N<sub>2</sub>O emissions from managed soils*

Direct N<sub>2</sub>O emissions from N mineralisation in Cropland remaining cropland (category 4(III)B1) are included in category 3Da5 Mineralisation (see chp. 5.5).

The calculations of direct N<sub>2</sub>O emissions from nitrogen mineralisation in mineral soil (category 4(III)B2) and indirect N<sub>2</sub>O emissions from managed soils (category 4(IV)) in Cropland are described in Annex A5.4.

#### 6.5.2.3.3. *CH<sub>4</sub> and N<sub>2</sub>O emissions from biomass burning*

CH<sub>4</sub> emissions and N<sub>2</sub>O emissions from biomass burning in Cropland (category 4(V)B) were not occurring (notation key "NO").

## 6.5.3. Uncertainties and time-series consistency

### 6.5.3.1. Uncertainties

#### Activity data

Uncertainties of activity data of category 4B Cropland are described in chp. 6.3.1.3.

For calculating the overall uncertainty of category 4B, all emissions and removals from living biomass, dead organic matter, mineral soil and organic soil were considered. The uncertainties of carbon stock change factors and emission factors were calculated for 1990 and the reporting year (see overview in Table 6-5).

#### Living biomass

The relative uncertainty in yield determination was estimated as 13 % for biomass carbon from agricultural land (Leifeld and Fuhrer 2005).

#### Dead organic matter

Emissions from the dead organic matter pool occur only by land-use changes from Forest land to Cropland as the carbon stock of dead organic matter is assumed to be zero in the non-forest land-use categories. Thus, the uncertainty of these emissions corresponds to the uncertainty of carbon stocks in litter and dead wood on Forest land. Based on the results of the NFI4, the Yasso07 model and Moeri (2007) presented by Didion (2020a), a relative

uncertainty of 6.0 % was calculated for the total carbon stock in litter and dead wood (Meteotest 2023).

### **Mineral soil**

The absolute uncertainty of  $0.344 \text{ t C ha}^{-1} \text{ yr}^{-1}$  was used for annual carbon stock changes in categories 4B1 and 4B2, as calculated by a Monte Carlo analysis (Wüst-Galley et al. 2020). That uncertainty analysis considered variation in the following input parameters: carbon inputs from farmyard manure and plants, the extent of summer pastures, and monthly temperature, precipitation and evapotranspiration. For the Monte Carlo analysis it was assumed that the extent of variation in input parameters is unchanged from one year to the next. By comparison, the range of annual SOC changes identified for 71 different treatments of Swiss agricultural long-term experiments is  $1.87 \text{ t C ha}^{-1}$  (Keel et al. 2019), suggesting that the calculated uncertainty might have been underestimated (Wüst-Galley et al. 2020).

The resulting relative uncertainty in 2021, calculated with the implied emission factors of mineral soil, is 1729.6 % for category 4B1 and 143.9 % for category 4B2.

### **Organic soil**

The uncertainty of the carbon stock change (emission factor) in organic soil is 23 % as reported by Leifeld et al. (2003: 56) and the uncertainty of the activity data (area of organic soil) is 37.3 % (see chp. 6.3.1.3).

### **Overall uncertainties categories 4B1 and 4B2**

Using the detailed input uncertainties as described above, the uncertainty propagation for categories 4B1 and 4B2 was computed using Monte Carlo simulations, following the same method as for the whole inventory (see chp. 1.6.2). The resulting overall uncertainties for categories 4B1 and 4B2 emissions and removals in 2021 are 128.4 % and 152.9 %, respectively (see Annex A2.1).

#### **6.5.3.2. Time-series consistency**

Time series for category 4B Cropland are all considered consistent; they were calculated based on consistent methods and homogenous databases (Wüst-Galley et al. 2020). Small inconsistencies in the input data for the RothC model (related to livestock husbandry, chp. 5.2.3) are barely relevant for the overall results.

#### **6.5.4. Category-specific QA/QC and verification**

The general QA/QC measures are described in chp. 1.5.

##### **6.5.4.1. Carbon stocks in living biomass**

The crop yield data for the inventory year are available always in the most recent Swiss Farmers' Union's annual report. Since this report is usually not available in time, the

inventory is prepared with a provisional value for the inventory year. The correction of this provisional value in the following submission leads by default to a recalculation for the year in question.

#### **6.5.4.2. Carbon stocks in mineral soil**

The initial SOC stocks for the latest submission are modelled, using the calculation of Leifeld et al. (2003, 2005), as described in Wüst-Galley et al. (2020). The calculation of the initial stocks is however, in general, limited by insufficient soil information at an appropriate spatial resolution across the country. This situation should be improved by the digital soil modelling project described in chp. 6.5.6.

#### **6.5.4.3. Carbon stock changes in mineral soil**

##### **6.5.4.3.1. RothC**

RothC, used to model SOC stock changes, is a relatively simple model that does not represent certain soil processes such as feedback due to microbial processes or consider other nutrient cycles. It was however the best-performing model given the available data for Switzerland, considering also temporal resolution (Wüst-Galley et al. 2020). The calibration of the allometric equations (for deriving carbon inputs from crop yields), as well as a comparison of simulated SOC stock changes with measured values from field experiments is described in Wüst-Galley et al. (2020). A sensitivity analysis of the RothC simulations and of the system used to upscale these simulations to the national scale was completed (Wüst-Galley et al. 2021).

In 2003 and 2018 mean area-weighted unsmoothed increases in SOC stocks are exceptionally high (see Figure 6-11 lower panel). The peak carbon stock changes might be explained by strongly reduced SOC decomposition in RothC caused by high soil moisture deficits (these summers were exceptionally warm and dry in Switzerland leading to high evapotranspiration relative to precipitation). Such model behaviour in RothC was also identified by Falloon et al. (2011). Recent model experiments for potato and maize in the most important cropping region of Switzerland support this explanation by showing reduced SOC stocks with irrigation. In 2003 and 2018, peak SOC values were obtained for cropland but not for permanent grassland (see Figure 6-15). This can be explained by the distribution of these two land-use types: Cropland is concentrated in regions prone to high topsoil moisture deficit (lowlands), whereas permanent grassland is distributed more evenly across the country, including wetter and cooler (upland) regions.

##### **6.5.4.3.2. Swiss Soil Monitoring Network (NABO)**

The SOC stocks measured at 30 cropland monitoring sites of the NABO (NABO 2021a; see chp. 6.4.4.5) featuring mineral soils indicate no significant changes from 1990 to 2019. The apparent decline of SOC stocks from the first to the sixth sampling campaign (see Figure 6-12 bottom panel) was identified as artefact induced by the date of sampling. In the first campaign, samplings were conducted substantially later in the year compared with the remaining campaigns, which induced higher SOC contents and, thus, SOC stocks. Changes in SOC stocks over time are less pronounced when compared to the second sampling campaign, as shown in Gubler et al. (2019). The range of the calculated SOC stocks in 0–20

cm depth was large (20–87 t C ha<sup>-1</sup>) with a mean of 47 t C ha<sup>-1</sup> (Figure 6-12 top panel). Minor changes in SOC stocks occurred only on single cropland sites, and could be assigned to changed amounts of farmyard manure applications (Gubler et al. 2019).

The monitoring scheme applied by NABO is able to detect relative changes in SOC contents of roughly 3.5 % per 10 years for mineral cropland soils (minimum detectable change for 30 monitoring sites including three or more sampling campaigns; Gubler et al. 2019). Regarding the measured SOC stocks (mean 47 t ha<sup>-1</sup>) this corresponds to a minimum detectable change of roughly 0.16 t C ha<sup>-1</sup> yr<sup>-1</sup> for SOC stocks.

The mean change in SOC which was calculated with RothC for the years 1990–2021 was 0.006±0.344 t C ha<sup>-1</sup> yr<sup>-1</sup> (area-weighted mean across three elevation zones ± absolute uncertainty based on a Monte Carlo analysis; see Figure 6-11 lower panel and chp. 6.5.3). In comparison, the modelled net carbon change is clearly smaller than the detectable change by NABO and suggests that modelled SOC stock changes agree with the repeated soil inventories in the NABO network.

In conclusion, the NABO data indicate that Cropland mineral soils acted neither as a significant net source nor as a significant net sink of carbon when considered over the entire 34-year period. Gubler et al. (2019) concluded that SOC contents in cropland sites of the NABO have approached a steady-state at sites where agricultural management and crop rotation have remained relatively constant.

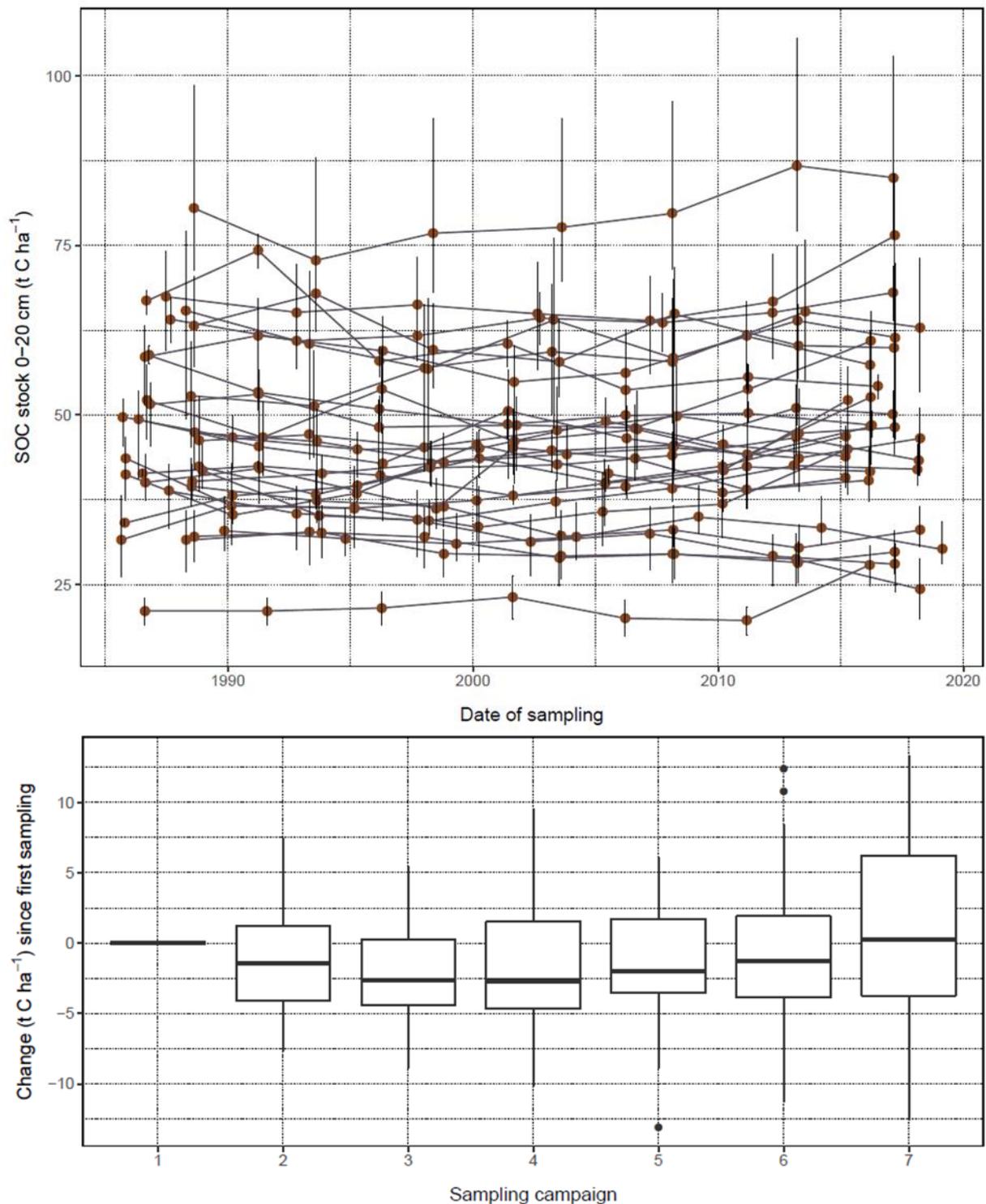


Figure 6-12 Measured SOC stocks for topsoils (0–20 cm) and their changes for 30 NABO long-term monitoring sites used as cropland during the time period 1985–2019. The elevation of the sites ranges from 324 to 945 m a.s.l. Top panel: SOC stocks 0–20 cm per site and sampling; the dots indicate the mean and the bars the range of 5 % and 95 % percentiles of bootstrap samples taking into account the variability in SOC content of the individual replicates per site and sampling as well as the variations of the bulk density. Bottom panel: boxplot of changes in SOC stocks in each case related to the first sampling (boxes indicate the lower and the upper quartiles with the median indicated; lines include all observations inside the range of 1.5 times the interquartile distance, observations beyond that range are indicated as dots).

#### 6.5.4.4. Short-term land-use changes in arable rotations

Short-term land-use changes between "Grassland" and Cropland are to be expected for leys in arable rotations. However, leys were allocated to Cropland by the Swiss Land Use Statistics (AREA) and were thus not considered grasslands in the usual sense (i.e. permanent grassland). Since only long-term land-use changes are registered by the Swiss Land Use Statistics (AREA), carbon stock changes in soils associated with land-use changes between Cropland and Grassland and vice versa were adequately reported in the Swiss GHG inventory.

#### 6.5.5. Category-specific recalculations

The following recalculations were implemented. Major recalculations which contribute significantly to the differences in net emissions and net removals of sector 4B between the latest and the previous submissions are additionally presented in chp. 10.1.2.4.

- 4B: Activity data (areas) 2013–2020 were updated (see chp. 6.3.1.5). The inclusion of first data from the AREA5 survey led to small recalculations (Table 6-11).
- 4B: Carbon stocks and carbon stock changes in living biomass were recalculated for the whole inventory period, based on updated grassland yield data (SBV 2022). This update assumed increased feed requirements, necessary because cattle sizes have on average increased over time. Because leys are dominant crops in Swiss crop rotations, this update had an effect on the biomass carbon pool and explains most of the differences between the previous and the latest submission. It affects all years, but the most marked changes are from 2006 onwards. Changes in yields (compared to values used in the previous submission) for leys in the most important cropland region range from -23 to +17 %.
- 4B: Carbon stocks and carbon stock changes in mineral soil were recalculated for the whole inventory period, applying
  - updated information used for the calculation of organic amendments (excretion rates of volatile solids) that had been implemented in the Agriculture sector in the previous submission (as described in chp. 5.2.5 of FOEN 2022), as well as updated data regarding herd sizes and updated information on animal housing and the distribution of farmyard manure, obtained from the ammonium model AGRAMMON: All changes are in line with values used in the Agriculture sector. The effect of the first adjustment especially explained most of the differences observed between the previous and the latest submission;
  - updated gridded climate data (MeteoSwiss 2021): The latest data caused almost no differences in soil carbon stocks and soil carbon stock changes between the previous and the latest submissions;
  - a new agricultural surface data set that is spatially more precise: This data set is a different version of that used in previous submissions and as described in Wüst-Galley et al. (2020), but the spatial resolution is based on the municipality boundaries from 1990 (when on average municipalities were smaller), rather than from the current year. This recalculation had a negligible effect on mineral soil carbon pools.

#### 6.5.6. Category-specific planned improvements

##### 6.5.6.1. Living biomass

Price et al. (2017) created a nationwide model for above ground tree biomass in Switzerland (both inside and outside of forest), using structural information available from airborne laser

scanning. The model offers significant opportunity for improved estimates of carbon stocks in living biomass on land-use categories where tree biomass has either not been included or only roughly estimated until now. The tree biomass model of Price et al. (2017) was calibrated and evaluated based on reference plots from the NFI. The model showed promising results at the Tier 3 level. However, further improvement could be achieved if additionally specific reference data from non-Forest land would be available. In a pioneering study, 62 felled urban reference trees with actual above ground tree biomass as well as many detailed predictor variables were surveyed (Mathys et al. 2019; Kükenbrink et al. 2021). To account for the detected differences in tree geometry and associated biomass pattern a nationwide non-Forest land field survey of above ground tree biomass at the plot level was initiated by FOEN (aiming for 1'500 reference plots within the project duration 2018–2024). The overall objective is to calculate a sound wall-to-wall above ground tree biomass database and map for Switzerland. The suitability of the obtained data for reporting in category 4B is subject to ongoing evaluation (Price 2020).

### 6.5.6.2. Mineral soil

A digital soil modelling project at the Competence Center for Soils (CCSoils) (funded by FOEN 2017–2020) built on the outcomes of the national research programme “Sustainable Use of Soil as a Resource” ([www.nfp68.ch/en](http://www.nfp68.ch/en)). It addressed the shortcomings of missing spatially inclusive and comprehensive soil information in Switzerland. Initial versions of raster data sets for soil carbon content, pH, silt content, and clay content (0–30 cm), including the respective prediction uncertainty, are available (Stumpf et al. 2021). For the submission in 2024, initial SOC stocks will be derived from a new SOC stock map provided by CCSoils. Mean SOC stocks for each stratum will still be calculated using the current approach. The use of the SOC stocks raster data set is the first step towards a switch to grid-based SOC modelling with RothC for the GHG inventory. Further steps are planned for the following years.

## 6.6. Category 4C – Grassland

### 6.6.1. Description

Table 6-24 Key categories in category 4C. Combined KCA results, level for 2021 and trend for 1990–2021, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC category	Gas	Identification criteria
4C1	Grassland remaining grassland	CO <sub>2</sub>	T1, L2, T2
4C2	Land converted to grassland	CO <sub>2</sub>	L1, T1, L2, T2

Swiss grasslands belong to the cold temperate wet climatic zone.

Grasslands were subdivided into permanent grassland (CC31), shrub vegetation (CC32), vineyards, low-stem orchards ('Niederstammobst') and tree nurseries (CC33), copse (CC34), orchards ('Hochstammobst'; CC35), stony grassland (CC36), and unproductive grassland (CC37) (see Table 6-2 and Table 6-6). In category 2 in CRF Table 4.C, the land-use types

CC32, CC33, CC34 and CC35 were merged under the notation 'woody' and CC36 and CC37 were merged under 'unproductive' (see Table 6-2).

In the inventory period, total net emissions of category 4C1 Grassland remaining grassland range from 475 kt CO<sub>2</sub> in 2013 to 17 kt CO<sub>2</sub> in 1990 (average 235 kt CO<sub>2</sub>; Figure 6-13). Whereas annual carbon stocks and carbon stock changes in living biomass and in mineral soil were calculated for permanent grassland (CC31) (however, five-year averages were reported, see below), for the remaining land-use categories CC32–CC37 carbon stocks in living biomass and in mineral soil were assumed to be in equilibrium (i.e. no carbon stock changes occur if the land use does not change; changes of grassland land-use categories among themselves, however, do contribute to net emissions and removals in 4C1). High stable carbon losses in organic soil (especially under permanent grassland) characterise the net figures in 4C1, although only 0.6 % of permanent grassland soils are organic soil (Table 6-7). Contributions of other Grassland remaining grassland land-use categories (CC32–CC37) were of minor importance except for a noticeable gain in living biomass for shrub vegetation (CC32) which can be explained mainly by the conversion of abandoned pastures (CC31) (well above 1 kha in most years, see also Table 6-9).

Carbon stocks in living biomass of the two lower elevation zones in category 4C1 decreased significantly over the inventory period, while the 1990 level in the highest elevation zone remained the same (Figure 6-14 upper panel). Carbon stocks in mineral soil decreased significantly in the two lower elevation zones, while in the highest elevation zone the stock increased moderately (Figure 6-15 upper panel).

Category 4C2 Land converted to grassland acted as a net source in all years (average 217 kt CO<sub>2</sub>; Figure 6-13). The highest individual contribution came consistently from category 4C2.1 Forest land converted to grassland. Most of this source was due to net changes in living biomass from deforestation. In contrast, the remaining categories 4C2.2 to 4C2.5 acted as net sinks mainly due to sequestration of CO<sub>2</sub> in mineral soil in the course of the conversion to grassland.

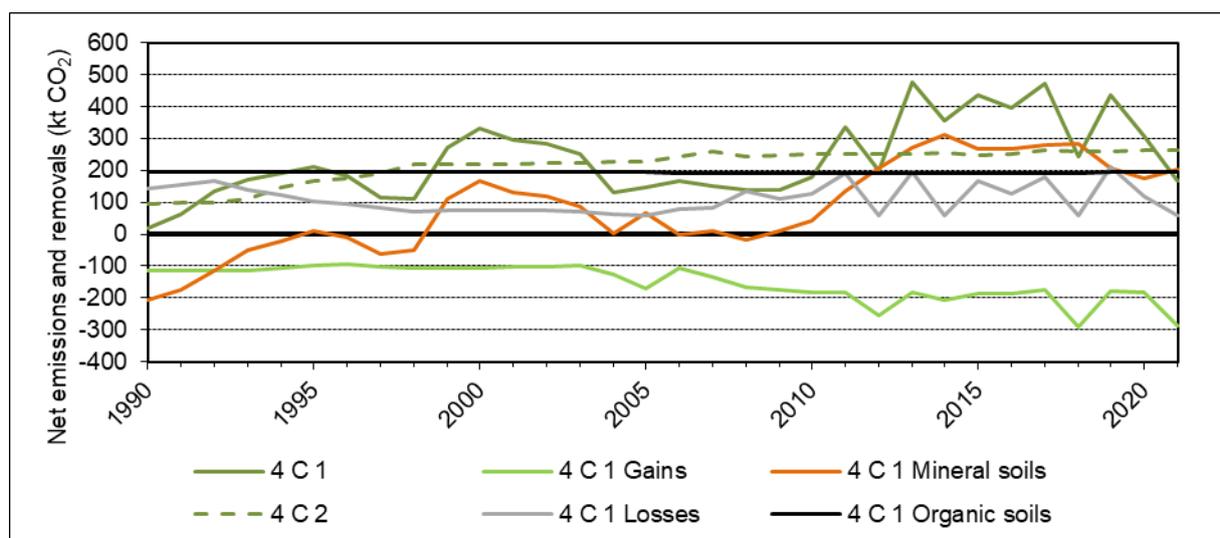


Figure 6-13 Net CO<sub>2</sub> emissions (positive values) and removals (negative values) from categories 4C1 and 4C2. Category 4C1 is broken down by gains in living biomass, losses in living biomass, net carbon stock changes in mineral soil, and net carbon stock changes in organic soil.

## 6.6.2. Methodological issues

For permanent grassland (CC31), carbon stocks in living biomass, as well as carbon stocks and carbon stock changes in mineral soil were estimated with a Tier 3 approach using the model RothC (Wüst-Galley et al. 2020). The results were integrated in category 4C by calculating area-weighted (using the relative surface of the six grassland types) average values per elevation zone (see chp. 6.5.2.1.3 for details regarding mineral soil). The differences in carbon stocks (calculated as five-year moving average except for the previous and latest inventory years) between two consecutive years were reported as net changes for living biomass and for mineral soil. For the remaining Grassland land-use categories CC32–CC37, constant carbon stocks in living biomass and in mineral soil were assumed (see Table 6-4).

### 6.6.2.1. Carbon stocks

#### 6.6.2.1.1. Carbon stocks in living biomass

##### 6.6.2.1.1.1. Permanent grassland (CC31)

Permanent grasslands range in elevation from <300 m to 3000 m above sea level. Because both biomass productivity and soil carbon dynamics rely on the prevailing climatic and pedogenic conditions, grassland stocks were calculated separately for three elevation zones (see chp. 6.2.2.2).

Standing biomass for permanent grasslands ( $t\ C\ ha^{-1}$ ) was calculated as the annual cumulative yield of six differentially managed grasslands for three elevation zones. Total harvested biomass was adopted from annual statistics of the Swiss Farmers Union (SBV 2022 and previous editions) and allocated to the below listed different grassland types and elevation zones based on standard yields from Richner and Sinaj (2017) and area data from the Farm Structure Survey (SFSO 2016g):

- extensive meadow
- less intensive meadow
- intensive meadow
- extensive pasture
- intensive pasture
- summer pasture

A carbon fraction of 0.45 was assumed (Bolinder et al. 2007). For grassland, yield was assumed to be equal to above ground biomass. Root biomass was estimated based an allometric function as described in Wüst-Galley et al. (2020).

Carbon stocks and carbon stock changes in living biomass were reported as moving averages over five years (from year-2 to year+2, e.g. 1988–1992 for the year 1990; the previous and latest inventory years were reported as four-year (year-2 to year+1) and three-year (year-2 to latest inventory year) moving averages, respectively). Data are shown in Table 6 25 and in Figure 6-14.

The rationale for this smoothing is that due to stockpiling the consumption (and thus oxidation) of the biomass is levelled out between individual years (due to the unsmoothed

curve progressions, however, to a lesser extent than with Cropland; compare Figure 6-14 upper panel with Figure 6-10 upper panel). Year-to-year variability for unsmoothed data is higher in recent years compared to earlier years, because yields are now reported annually (SBV 2022), whereas in the past they were only reported every five years.

The resulting area-weighted (across the three elevation zones) mean carbon stock in living biomass for permanent grassland over the inventory time period was 4.32 t C ha<sup>-1</sup>.

Table 6-25 Area-weighted (using the relative surface of the six grassland types) carbon stocks (t C ha<sup>-1</sup>) and net carbon stock changes (t C ha<sup>-1</sup> yr<sup>-1</sup>) in living biomass (including roots) of land-use category permanent grassland (CC31), stratified for elevation zone (Elev: Elevation zone 1 = <601 m, 2 = 601-1200 m, 3 = >1200 m; see chp. 6.2.2.2). Highlighted data for 1990 are displayed in Table 6-4. Please note: Associated data in CRF Table 4.C.1 also include land-use changes within the Grassland land-use categories CC31–CC37 and therefore differ from the data shown here (see also chp. 6.1.3.4).

Living biomass	Elev.	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
		CC31: carbon stock [t C ha <sup>-1</sup> ] and net change in living biomass [t C ha <sup>-1</sup> yr <sup>-1</sup> ]									
Stock	1	5.78	5.72	5.66	5.62	5.59	5.56	5.53	5.51	5.50	5.48
Stock	2	5.30	5.25	5.20	5.17	5.14	5.12	5.10	5.09	5.09	5.08
Stock	3	3.34	3.33	3.33	3.32	3.32	3.32	3.32	3.33	3.33	3.34
Net change	1	-0.05	-0.06	-0.06	-0.04	-0.03	-0.03	-0.02	-0.02	-0.01	-0.02
Net change	2	-0.04	-0.05	-0.05	-0.03	-0.03	-0.02	-0.02	-0.01	0.00	0.00
Net change	3	0.00	0.00	0.00	-0.01	0.00	0.00	0.00	0.01	0.01	0.01

Living biomass	Elev.	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
		CC31: carbon stock [t C ha <sup>-1</sup> ] and net change in living biomass [t C ha <sup>-1</sup> yr <sup>-1</sup> ]									
Stock	1	5.47	5.45	5.43	5.42	5.42	5.44	5.42	5.40	5.36	5.32
Stock	2	5.08	5.08	5.07	5.07	5.09	5.12	5.11	5.10	5.06	5.04
Stock	3	3.35	3.35	3.36	3.36	3.37	3.39	3.39	3.39	3.38	3.37
Net change	1	-0.02	-0.02	-0.02	-0.02	0.00	0.02	-0.02	-0.02	-0.04	-0.03
Net change	2	0.00	0.00	0.00	0.00	0.01	0.03	-0.01	-0.01	-0.03	-0.02
Net change	3	0.01	0.01	0.00	0.00	0.01	0.01	0.00	0.00	-0.01	-0.01

Living biomass	Elev.	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
		CC31: carbon stock [t C ha <sup>-1</sup> ] and net change in living biomass [t C ha <sup>-1</sup> yr <sup>-1</sup> ]									
Stock	1	5.28	5.20	5.23	5.15	5.15	5.09	5.05	4.98	5.03	4.95
Stock	2	5.01	4.95	4.98	4.92	4.93	4.88	4.85	4.80	4.85	4.78
Stock	3	3.36	3.34	3.36	3.34	3.34	3.33	3.32	3.30	3.33	3.30
Net change	1	-0.04	-0.07	0.02	-0.08	0.00	-0.06	-0.04	-0.07	0.04	-0.08
Net change	2	-0.03	-0.06	0.03	-0.06	0.01	-0.05	-0.03	-0.05	0.05	-0.07
Net change	3	-0.01	-0.02	0.01	-0.02	0.01	-0.01	-0.01	-0.02	0.02	-0.02

Living biomass	Elev.	2020	2021								
		CC31: carbon stock [t C ha <sup>-1</sup> ] and net change in living biomass [t C ha <sup>-1</sup> yr <sup>-1</sup> ]									
Stock	1	4.93	4.99								
Stock	2	4.76	4.82								
Stock	3	3.30	3.33								
Net change	1	-0.03	0.04								
Net change	2	-0.03	0.04								
Net change	3	-0.01	0.02								

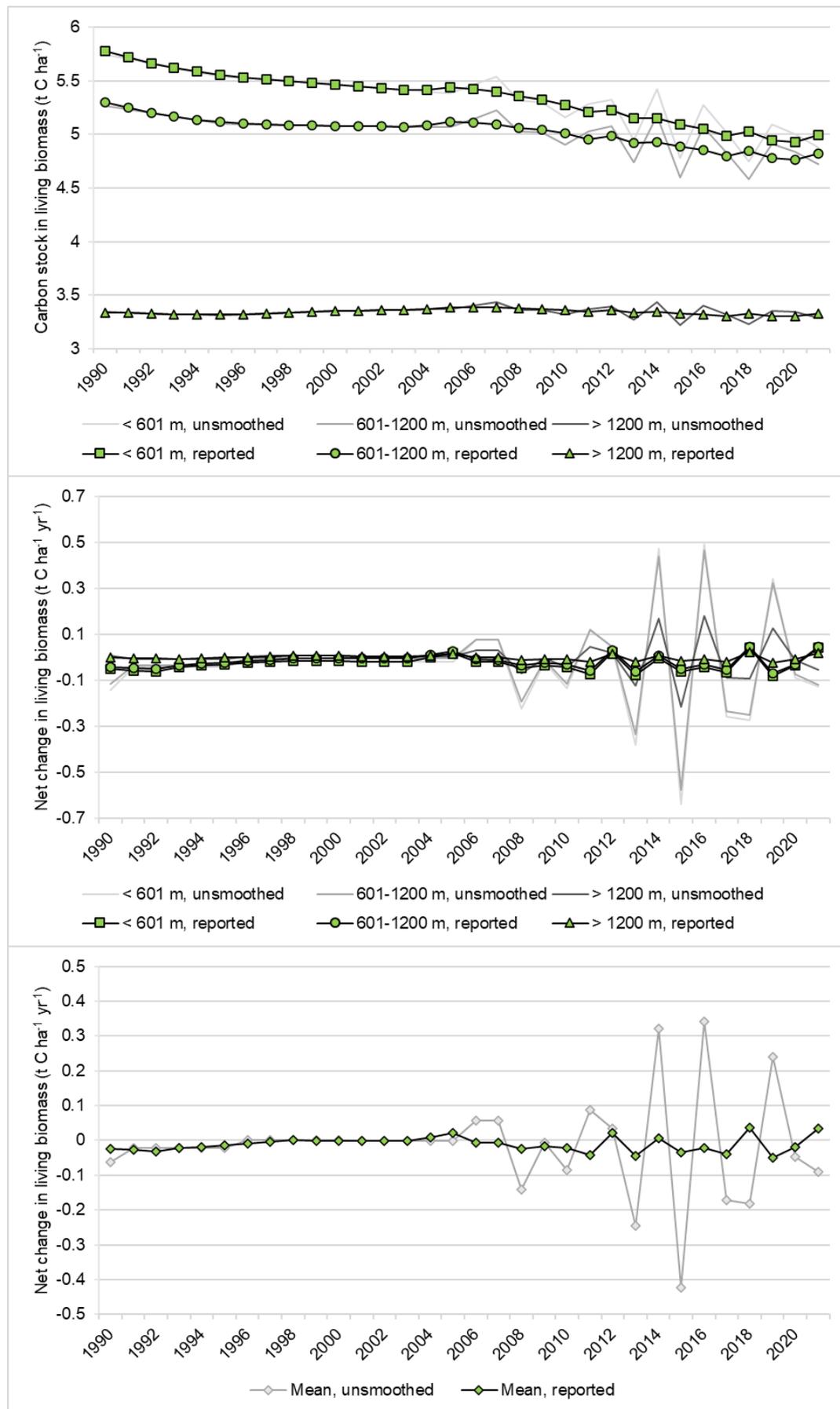


Figure 6-14 Reported carbon stocks (t C ha<sup>-1</sup>) and net carbon changes (t C ha<sup>-1</sup> yr<sup>-1</sup>) in living biomass of permanent grassland (CC31) and underlying unsmoothed data (shown for transparency reasons), stratified for elevation zone (upper and middle panel) and area-weighted (across three elevation zones) means (lower panel). Upper and lower confidence intervals are too small to be distinguished from the mean.

### 6.6.2.1.1.2. Shrub vegetation (CC32) and Copse (CC34)

Due to the lack of accurate data, the living biomass of shrub vegetation and copse was assumed to be equal to the living biomass of brush forest as described in chp. 6.4.2.4.2, where brush forest is assumed to contain 20.45 t C ha<sup>-1</sup> (Düggelin and Abegg 2011).

### 6.6.2.1.1.3. Vineyards, low-stem orchards and tree nurseries (CC33)

Low-stem orchards are small fruit trees distinguished from CC35 ('orchards') by a maximum stem height of 1 m and a much higher stand density. Only low-stem orchards and vineyards are considered in the following because no stand densities for tree nurseries are available. This is justified because tree nurseries comprise only ca. 8 % (1'378 ha tree nurseries, SFSO 2002) of the total area of CC33, i.e., 17'054 ha, 15'436 ha are vineyards (SFSO 2005) and 240 ha are low-stem orchards (Widmer 2006).

The standing carbon stock of living biomass per ha (Cl) for CC33 was therefore calculated as:

$$Cl = \frac{[(Cl_{vineyards} * area_{vineyards}) + (Cl_{low-stem orchards} * area_{low-stem orchards})]}{(area_{vineyards} + area_{low-stem orchards})}$$

Cl of vineyards (5.35 t C ha<sup>-1</sup>) was calculated as the sum of the woody biomass (3.61 t C ha<sup>-1</sup>) and the biomass in the grass layer (1.74 t C ha<sup>-1</sup>).

Woody biomass for vineyards was calculated based on the mean stand density (5'556 vines ha<sup>-1</sup>) and the mean carbon content in the woody biomass of one plant including roots (0.65 kg C; Ruffner 2005).

The mean carbon stock of the grass layer in vineyards was calculated using the following information and assumptions: (1) Most vineyards in Canton Valais (around 5'000 ha) have no grass layer, in the other cantons the share of vineyards with grass understorey is very high (95 %). Thus, it can be assumed that on the average 65 % of the Swiss vineyards exhibit a grass layer. (2) The grass layer between the vine rows has a lower carbon stock than permanent grassland. It is assumed that it is 50 % less than the carbon stock of CC31 (elevation <600 m, average of the period 1990–2020).

Cl of low-stem orchards (14.93 t C ha<sup>-1</sup>) was calculated as the sum of the woody biomass (12.25 t C ha<sup>-1</sup>) and the biomass in the grass layer (2.68 t C ha<sup>-1</sup>).

For small fruit trees on low-stem orchards, no literature value was found for biomass expansion factors. Therefore, the following assumptions were made: Diameter at breast height (DBH) of such trees was assumed to be 10 cm and the stem height was assumed to be 1 m. The bole shape of low-stem apple trees can be approximated by a cylinder shape.

$$\text{Stem wood volume} = r^2 * \pi * \text{height} = (5 \text{ cm})^2 * 3.1 * 100 \text{ cm} = 7.75 \text{ dm}^3$$

Based on expert knowledge (Kaufmann 2005), the percentage of branches was estimated as 100 %, and the percentage of roots was estimated as 30 % of the stem wood volume. This results in a BEF of 2.3. A wood density of 0.55 kg dm<sup>-3</sup> (Vorreiter 1949) and the default IPCC carbon content of 50 % (IPCC 2006, Volume 4, chp. 5.2.2.2) were assumed. With these assumptions the carbon stock of a tree of the type low-stem ('Niederstamm') was calculated as follows:

$$\begin{aligned} \text{C low-stem} &= \text{stem wood volume} * \text{BEF} * \text{wood density} * \text{carbon content} \\ &= 7.75 \text{ dm}^3 * 2.3 * 0.55 \text{ kg/dm}^3 * 0.5 = 4.9 \text{ kg C} \end{aligned}$$

The mean stand density of low-stem orchards was estimated as 2500 ha<sup>-1</sup> (Widmer 2006), resulting in a CI of 12.25 t C ha<sup>-1</sup> in woody biomass.

The mean carbon stock of the grass layer in low-stem orchards was calculated using the following information and assumptions: (1) All low-stem orchards have a grass layer. (2) The grass layer between the tree rows has a lower carbon stock than permanent grassland. It is assumed that it is 50 % less than the carbon stock of CC31 (elevation <600 m, average of the period 1990–2020).

The resulting carbon stock in living biomass (CI) for land-use category CC33 is 5.5 t C ha<sup>-1</sup>.

#### 6.6.2.1.1.4. Orchards (CC35)

Orchards consists of larger fruit trees ('Hochstammobst') planted at a low density with grass understory. CI of orchards trees was calculated as:

$$\begin{aligned} \text{CI biomass} &= (\text{carbon per fruit tree [t C]} * \text{number of fruit trees} / \text{area orchards [ha]}) \\ &+ \text{carbon in grass [t C ha}^{-1}] \end{aligned}$$

The carbon stock of a large fruit tree with a DBH of 25–35 cm was calculated as follows:

$$\text{C (Hochstamm)} = \text{Stem wood volume} * \text{KE-Factor} = 225 \text{ kg C}$$

where:

- Stem wood volume of an apple tree assuming a cylindrical stem with mean DBH of 30 cm and a stem height of 7 m amounts to 0.5 m<sup>3</sup>, and
- KE-Factor [t C m<sup>-3</sup>] = BEF \* Density \* carbon content = 0.45 (Wirth et al. 2004: 68, Table 16).

From the total fruit-growing area of 41'480 ha (SFSO 2005), the area of low-stem trees (240 ha, see CC33) was subtracted, and the remaining area of 41'240 ha was divided by the number of large fruit trees calculated as the mean of the counts in 1991 (3'616'301 trees) and 2001 (2'900'000 trees; SFSO 2002). This resulted in a mean stand density of 79 trees ha<sup>-1</sup>. The resulting carbon stock in woody biomass of CC35 is thus 17.78 t C ha<sup>-1</sup>. Because orchards typically have a grass understory, the biomass of CC31 was added to the woody biomass. The average biomass 1990–2020 of CC31 (see Table 6-25) was weighted with the area of CC35 in the three elevation zones (see Table 6-7) – resulting in 5.29 t C ha<sup>-1</sup> – and added to the woody biomass to obtain a total carbon stock of 23.1 t C ha<sup>-1</sup> for land-use category CC35.

#### 6.6.2.1.1.5. Stony grassland (CC36)

Approximately 35 % of the surface of land-use category CC36 (herbs and shrubs on stony surfaces) is covered by vegetation. No accurate data were available for this category. Therefore, the carbon stock of brush forest (20.45 t C ha<sup>-1</sup>; see chp. 6.4.2.4; Düggelein and Abegg 2011) was multiplied by 0.35 to account for the 35 % vegetation coverage. This results in a carbon stock for stony grassland of 7.2 t C ha<sup>-1</sup>.

#### **6.6.2.1.1.6. Unproductive grassland (CC37)**

Land-use category CC37 includes grass and herbaceous plants at watersides of lakes and rivers including dams and other flood protection structures, constructions to protect against avalanches and rock slides, and alpine infrastructure (e.g. for skiing). For none of these land-use types, biomass data are currently available. Therefore, the area-weighted mean (see Table 6-7) of carbon stocks of permanent grasslands (average 1990–2020) in the three elevation zones (see Table 6-25) was assumed to be representative for the carbon stock on unproductive grassland CC37. Carbon stock in living biomass in unproductive grassland appeared to be  $3.5 \text{ t C ha}^{-1}$ .

#### **6.6.2.1.2. Carbon stocks in dead organic matter**

Carbon stocks in dead organic matter were assumed to be zero.

#### **6.6.2.1.3. Carbon stocks in soil**

##### **6.6.2.1.3.1. Permanent grassland (CC31)**

###### *Mineral soil*

Carbon stocks in mineral soil under grassland were calculated based on Leifeld et al. (2003, 2005) as described in Wüst-Galley et al. (2020) and in chp. 6.5.2.1.3. The median soil organic carbon stock (0–30 cm, in 1975) for permanent grassland is  $64.3 \text{ t C ha}^{-1}$ . The variability of carbon stocks across the country is  $19.3 \text{ t C ha}^{-1}$  (1 SD). These carbon stocks were used to initialise the RothC model (see below and chp. 6.5.2.1.3) which was used to estimate carbon stocks from 1990 to the reporting year.

Switzerland used the soil carbon model RothC to estimate carbon stocks in mineral soil (0–30 cm) under permanent grassland, as described in chp. 6.5.2.1.3, in Wüst-Galley et al. (2020) and in Wüst-Galley et al. (2019: pp. 71, the upscaling to elevation zone). Six differently managed permanent grassland types (as listed in chp. 6.6.2.1.1.1, covering over 99 % of Swiss permanent grassland) were considered. Plant carbon inputs into the soil from grasslands were assumed to be constant, in accordance to the approach in Franko et al. (2011) and as detailed in Wüst-Galley et al. (2020).

Carbon stocks in mineral soil were integrated in category 4C by calculating area-weighted (using the relative surface of the six grassland types) average values per elevation zone. The results were reported as moving averages over five years (from year-2 to year+2, e.g. 1988–1992 for the year 1990; the previous and latest inventory years were reported as four-year (year-2 to year+1) and three-year (year-2 to latest inventory year) moving averages, respectively). Data are shown in Table 6-26 and in Figure 6-15 upper panel.

Unsmoothed data mainly reflect effects of climatic conditions, whereas long-term trends related to e.g. changes in agricultural management are better visible when the data are smoothed. The resulting area-weighted (across the three elevation zones) mean carbon stock in mineral soil for permanent grassland over the inventory period was  $63.19 \text{ t C ha}^{-1}$ .

Table 6-26 Area-weighted (using the relative surface of the six grassland types) carbon stocks (t C ha<sup>-1</sup>) and net carbon stock changes (t C ha<sup>-1</sup> yr<sup>-1</sup>) in mineral soil (0-30 cm) for land-use category permanent grassland (CC31), stratified for elevation zone (Elev: Elevation zone 1 = <601 m, 2 = 601-1200 m, 3 = >1200 m; see chp. 6.2.2.2). Highlighted data for 1990 are displayed in Table 6-4. Please note: Associated data in CRF Table4.C.1 also include land-use changes within the grassland land-use categories CC31–CC37 and therefore differ from the data shown here (see also chp. 6.1.3.4).

Mineral soil	Elev.	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
		CC31: carbon stock [t C ha <sup>-1</sup> ] and net change in mineral soil [t C ha <sup>-1</sup> yr <sup>-1</sup> ]									
Stock	1	60.62	60.53	60.40	60.25	60.08	59.88	59.70	59.55	59.39	59.17
Stock	2	65.69	65.59	65.47	65.35	65.21	65.07	64.94	64.83	64.73	64.58
Stock	3	63.24	63.42	63.58	63.72	63.85	63.98	64.10	64.23	64.36	64.44
Net change	1	-0.09	-0.10	-0.13	-0.16	-0.17	-0.20	-0.17	-0.15	-0.16	-0.22
Net change	2	-0.09	-0.10	-0.12	-0.13	-0.13	-0.14	-0.13	-0.11	-0.10	-0.15
Net change	3	0.19	0.18	0.16	0.14	0.13	0.13	0.12	0.13	0.13	0.09

Mineral soil	Elev.	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
		CC31: carbon stock [t C ha <sup>-1</sup> ] and net change in mineral soil [t C ha <sup>-1</sup> yr <sup>-1</sup> ]									
Stock	1	58.93	58.74	58.61	58.48	58.43	58.38	58.29	58.16	58.04	57.91
Stock	2	64.41	64.26	64.12	63.99	63.90	63.79	63.71	63.62	63.53	63.43
Stock	3	64.51	64.57	64.61	64.66	64.72	64.75	64.81	64.87	64.94	65.00
Net change	1	-0.24	-0.19	-0.13	-0.13	-0.06	-0.05	-0.09	-0.13	-0.11	-0.14
Net change	2	-0.16	-0.15	-0.14	-0.13	-0.09	-0.11	-0.08	-0.09	-0.08	-0.10
Net change	3	0.06	0.06	0.04	0.05	0.06	0.03	0.06	0.06	0.06	0.06

Mineral soil	Elev.	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
		CC31: carbon stock [t C ha <sup>-1</sup> ] and net change in mineral soil [t C ha <sup>-1</sup> yr <sup>-1</sup> ]									
Stock	1	57.74	57.55	57.32	57.10	56.88	56.66	56.50	56.38	56.23	56.08
Stock	2	63.33	63.20	63.03	62.85	62.66	62.47	62.28	62.09	61.90	61.75
Stock	3	65.05	65.06	65.06	65.03	64.98	64.95	64.92	64.85	64.79	64.76
Net change	1	-0.16	-0.19	-0.23	-0.22	-0.22	-0.21	-0.17	-0.12	-0.15	-0.15
Net change	2	-0.11	-0.13	-0.16	-0.18	-0.19	-0.18	-0.19	-0.19	-0.19	-0.16
Net change	3	0.05	0.01	0.00	-0.03	-0.05	-0.03	-0.04	-0.06	-0.06	-0.03

Mineral soil	Elev.	2020	2021								
		CC31: carbon stock [t C ha <sup>-1</sup> ] and net change in mineral soil [t C ha <sup>-1</sup> yr <sup>-1</sup> ]									
Stock	1	56.02	55.93								
Stock	2	61.66	61.56								
Stock	3	64.73	64.70								
Net change	1	-0.13	-0.18								
Net change	2	-0.15	-0.15								
Net change	3	-0.02	-0.03								

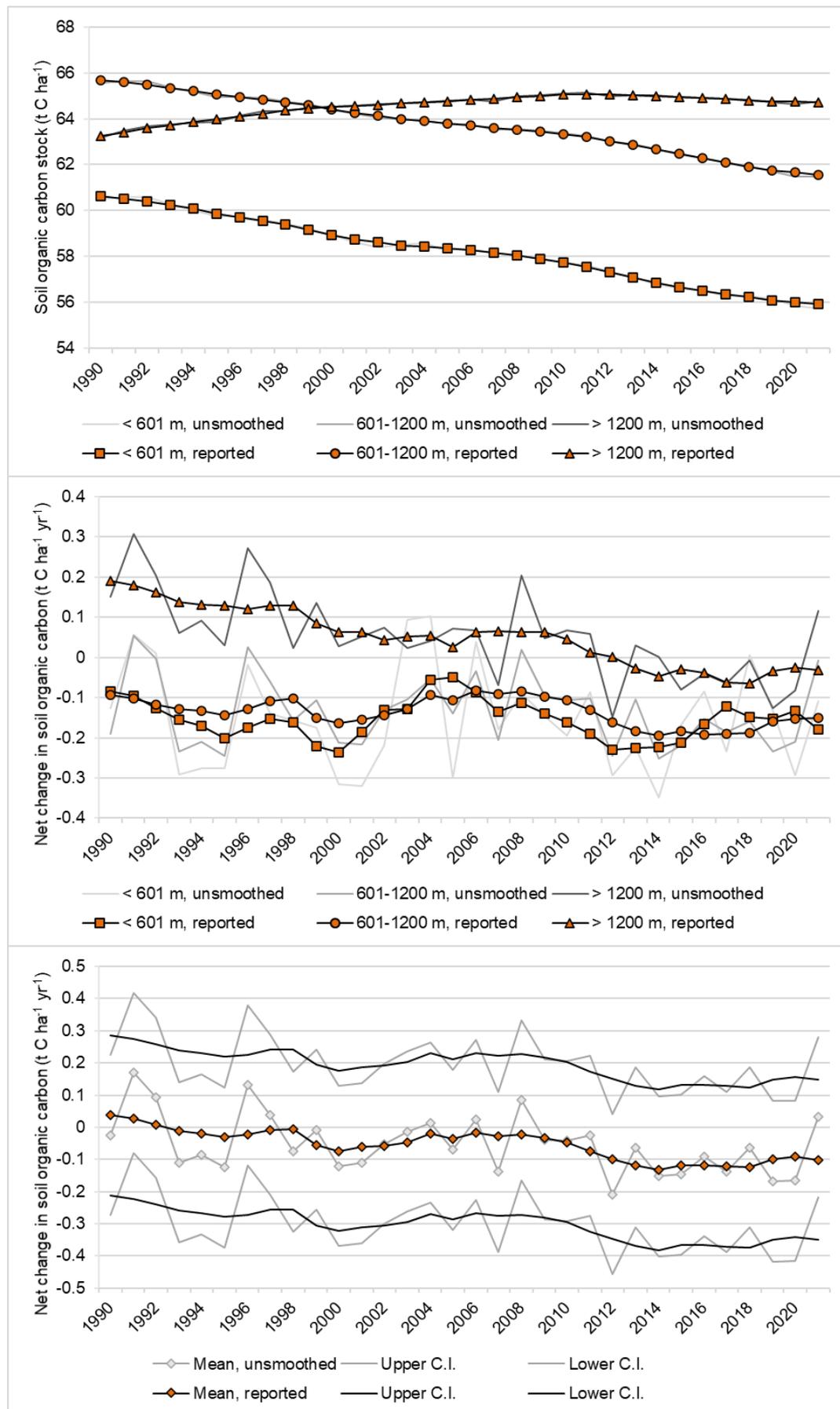


Figure 6-15 Reported carbon stocks (t C ha<sup>-1</sup>) and net carbon changes (t C ha<sup>-1</sup> yr<sup>-1</sup>) in permanent grassland mineral soil (0–30 cm) and underlying unsmoothed data (shown for transparency reasons), stratified for elevation zone (upper and middle panel) and area-weighted (across three elevation zones) means (lower panel) plus upper and lower confidence intervals (C.I.; see chp. 6.6.3).

### *Organic soil*

Soil carbon stocks in organic soil under permanent grassland were calculated based on Leifeld et al. (2003, 2005). The approach used measured carbon stocks in Swiss organic soils without differentiation between Cropland and Grassland. The mean soil organic carbon stock (0–30 cm) in organic soil is  $240 \pm 48 \text{ t C ha}^{-1}$  (uncertainty 20 %).

#### **6.6.2.1.3.2. Shrub vegetation (CC32) and Copse (CC34)**

Due to the lack of specific data, for mineral soil in land-use categories CC32 and CC34 the average carbon stocks of CC31 for each elevation zone (see Table 6-26) in the period 1990–2020 were used:

- Elevation zone 1 (<601 m a.s.l.):  $58.3 \text{ t C ha}^{-1}$
- Elevation zone 2 (601-1200 m a.s.l.):  $63.8 \text{ t C ha}^{-1}$
- Elevation zone 3 (>1200 m a.s.l.):  $63.5 \text{ t C ha}^{-1}$ .

The mean soil organic carbon stock (0–30 cm) in organic soil is  $240 \text{ t C ha}^{-1}$ .

#### **6.6.2.1.3.3. Vineyards, low-stem orchards and tree nurseries (CC33)**

No specific value for mineral soil in land-use category CC33 was available. As CC33 is only partially covered by grass understorey the average soil carbon stock of Cropland (CC21) for the period 1990–2020 was taken, weighted with the area of CC33 per elevation zone:  $49.9 \text{ t C ha}^{-1}$  (0–30 cm).

The mean soil organic carbon stock (0–30 cm) in organic soil is  $240 \text{ t C ha}^{-1}$ .

#### **6.6.2.1.3.4. Orchards (CC35)**

No specific value for mineral soil in land-use category CC35 was available. As most orchard areas have grass understorey the average soil carbon stock of permanent grassland (CC31) for the period 1990–2020 was taken, weighted with the area of CC35 per elevation zone:  $59.4 \text{ t C ha}^{-1}$  (0–30 cm).

The mean soil organic carbon stock (0–30 cm) in organic soil is  $240 \text{ t C ha}^{-1}$ .

#### **6.6.2.1.3.5. Stony grassland (CC36)**

Carbon stock in mineral soil under herbs and shrubs on stony surfaces in the land-use category CC36 was calculated according to the procedure described in chp. 6.6.2.1.1.5, i.e. it was assumed that not more than 35 % of the area of CC36 is covered with vegetation and thus only 35 % of the area bears a mineral soil while the remainder is bare rock. Land use in this category is mainly located at elevations above 1200 m a.s.l. The soil carbon stock of CC36 was calculated as average soil carbon stock of permanent grassland (CC31) for the period 1990–2020, weighted with the area of CC36 per elevation zone, considering a 35 % coverage:  $22.6 \text{ t C ha}^{-1}$  (0–30 cm).

The mean soil organic carbon stock (0–30 cm) in organic soil is  $240 \text{ t C ha}^{-1}$ . It was assumed that the small area covered by organic soil in CC36 (see Table 6-7), albeit entitled 'stony

grassland', does not contain significant contributions from stones because bogs are free of stones as a matter of nature and fens usually contain, if any, only fine mineral sediments.

#### **6.6.2.1.3.6. Unproductive grassland (CC37)**

The land-use category CC37 includes grass and herbaceous plants at watersides of lakes and rivers including dams and other flood protection structures, constructions to protect against avalanches and rock slides, and alpine infrastructure (e.g. for skiing). For none of these land-use types, soil carbon stock data are currently available. Therefore, the carbon stock in mineral soil was calculated as average soil carbon stock of permanent grassland (CC31) for the period 1990–2020, weighted with the area of CC37 per elevation zone: 64.2 t C ha<sup>-1</sup> (0–30 cm).

The mean soil organic carbon stock (0–30 cm) in organic soil is 240 t C ha<sup>-1</sup>.

### **6.6.2.2. Changes in carbon stocks**

#### **6.6.2.2.1. Carbon stock changes in living biomass**

For permanent grassland (CC31), the difference in carbon stock in living biomass (five-year moving average, see chp. 6.6.2.1.1 Permanent grassland) between two consecutive years was reported as net carbon stock change (gain or loss) (see Table 6-25 and Figure 6-14 middle panel). The resulting values were in the range between -0.08 and 0.05 t C ha<sup>-1</sup> yr<sup>-1</sup> with a mean area-weighted carbon stock change across all elevation zones of -0.011 t C ha<sup>-1</sup> yr<sup>-1</sup> for the inventory time period.

Applying a Tier 1 approach, carbon stock changes in living biomass were assumed to be in equilibrium for Grassland remaining grassland in the other land-use categories CC32–CC37.

#### **6.6.2.2.2. Carbon stock changes in dead organic matter**

Applying a Tier 1 approach, carbon stock changes in dead organic matter were assumed to be in equilibrium for Grassland remaining grassland.

#### **6.6.2.2.3. Carbon stock changes in soil**

##### **6.6.2.2.3.1. Mineral soil: Permanent grassland (CC31)**

The difference in carbon stock (five-year moving average, see chp. 6.6.2.1.3.1) between two consecutive years was reported as net carbon stock change (gain or loss) in permanent grassland mineral soil (see Table 6-26 and Figure 6-15 middle panel). For transparency reasons, unsmoothed changes in carbon stocks were also displayed in Figure 6-15.

The mean carbon stock change in the inventory period for elevation zone 1 was -0.155 t C ha<sup>-1</sup>, for elevation zone 2 -0.136 t C ha<sup>-1</sup> and for elevation zone 3 0.052 t C ha<sup>-1</sup>. The mean area-weighted carbon stock change across all elevation zones was -0.054 t C ha<sup>-1</sup>.

#### **6.6.2.2.3.2. Mineral soil: Remaining grassland land-use categories (CC32–37)**

A Tier 1 approach (changes in soil carbon stocks are in equilibrium) was assumed for carbon stock changes in mineral soil in the land-use categories CC32–37.

#### **6.6.2.2.3.3. Organic soil**

The annual net carbon stock change in organic soil on managed grassland (CC31, CC33, CC35) was estimated as  $-9.52 \text{ t C ha}^{-1}$  according to measurements in Europe including Switzerland as compiled by Leifeld et al. (2003, 2005) and verified by ART (2009b) and Paul and Alewell (2018). For extensively managed grasslands (CC32, CC34, CC36, CC37) the emission from organic soil was estimated as  $5.30 \text{ t C ha}^{-1} \text{ yr}^{-1}$  according to available domestic data (ART 2011b; Paul and Alewell 2018; Paul et al. 2021).

#### **6.6.2.2.4. Land-use change**

In the case of land-use change, the net carbon stock changes in biomass and soils of land-use categories CC31, CC32, CC33, CC34, CC35, CC36, and CC37 were calculated as described in chp. 6.1.3.

### **6.6.2.3. Non-CO<sub>2</sub> emissions from Grassland**

#### **6.6.2.3.1. N<sub>2</sub>O and CH<sub>4</sub> emissions from drainage of organic soil**

N<sub>2</sub>O emissions from drainage of organic soil (category 4(II)) in Grassland were reported in the Agriculture sector (category 3Da6 Cultivation of organic soils; see chp. 5.5).

CH<sub>4</sub> emissions were not estimated (notation key "NE") in 4(II) as reporting is not mandatory for this category.

#### **6.6.2.3.2. Direct and indirect N<sub>2</sub>O emissions from managed soils**

Direct N<sub>2</sub>O emissions from N mineralisation in Grassland remaining grassland (category 4(III)C1) are included in category 3Da5 Mineralisation (see chp. 5.5).

The calculations of direct N<sub>2</sub>O emissions from nitrogen mineralisation in mineral soil (category 4(III)C2) and indirect N<sub>2</sub>O emissions from managed soils (category 4(IV)) in Grassland are described in Annex A5.4.

#### **6.6.2.3.3. CH<sub>4</sub> and N<sub>2</sub>O emissions from biomass burning**

Data on wildfires affecting Grassland are obtained from cantonal authorities and were compiled by the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL, Swissfire database, <http://www.wsl.ch/swissfire>; Pezzatti et al. 2019). Table 6-27 shows the time series 1990 to 2021 of affected areas and associated emissions. The Swissfire database differentiates between 'grassland' and 'unproductive land'. As 'unproductive land' can partially cover the Grassland land-use categories CC32, CC34, CC36 and CC37 the sum of both categories was reported. Controlled burning is not a common practice in

Switzerland. Therefore, all fires were assigned to wildfires, and controlled burning was reported as not occurring ("NO").

The CH<sub>4</sub> and N<sub>2</sub>O emissions were calculated using equation 2.27 in Volume 4 of IPCC (2019) with the following parameters:

- The mass of available fuel encompasses the carbon stock of living biomass (litter and dead wood carbon stocks were assumed to be zero for Grassland). On average, the amount of living biomass amounted to 16.58 t biomass ha<sup>-1</sup> (7.46 t C ha<sup>-1</sup>). This value was taken from FOEN (2022: chp. 6.6.2.4). It was derived from the carbon stocks of all grassland land-use categories (CC31–CC37) as an area-weighted mean using the geographical extensions in 1990 and a carbon fraction of 0.45.
- The fraction of the biomass combusted was assumed to be 0.74 (IPCC 2019, Volume 4, Table 2.6, Savanna grasslands).
- For CH<sub>4</sub> the default emission factor of 2.3 g (kg combusted dry biomass)<sup>-1</sup> and for N<sub>2</sub>O, the default emission factor of 0.21 g (kg combusted dry biomass)<sup>-1</sup> was applied (IPCC 2019, Volume 4, Table 2.5, Savanna and Grassland).

The resulting annual CH<sub>4</sub> and N<sub>2</sub>O emissions 1990–2021 on burnt areas in category 4C Grassland are shown in Table 6-27 and are reported in CRF Table4(V).

CRF Table4 presents NO<sub>x</sub> and CO emissions from grassland wildfires as described by FOEN 2023b (chp. 7.3.2). They are included in category 4A Forest land (forest fires) (notation key "IE").

Table 6-27 Grassland areas affected by wildfires (WSL, Swissfire database) and resulting CH<sub>4</sub> and N<sub>2</sub>O emissions.

Grassland	Unit	1990	1995	2000	2005	2010
Area burnt	ha	637	82	22	20	1.3
CH <sub>4</sub>	t	18	2.3	0.62	0.55	0.038
N <sub>2</sub> O	t	1.6	0.21	0.056	0.050	0.0034

Grassland	Unit	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Area burnt	ha	14	3.6	2.6	8.0	212	38	29	16	30	10
CH <sub>4</sub>	t	0.38	0.10	0.073	0.22	6.0	1.1	0.82	0.46	0.86	0.28
N <sub>2</sub> O	t	0.035	0.0093	0.0067	0.021	0.55	0.098	0.074	0.042	0.078	0.025

#### 6.6.2.3.4. NMVOC emissions

Estimates for annual biogenic emissions of NMVOC (CRF Table4) for unproductive grassland in Switzerland are available in SAEFL (1996a). The value for those areas (unproductive vegetation) is 0.51 kt yr<sup>-1</sup>. This value was used over the entire time series.

### 6.6.3. Uncertainties and time-series consistency

#### 6.6.3.1. Uncertainties

##### Activity data

Uncertainties of activity data of category 4C Grassland are described in chp. 6.3.1.3.

For calculating the overall uncertainty of category 4C, the relevant emissions and removals from living biomass, dead organic matter, mineral soil and organic soil were considered. The uncertainties of carbon stock change factors and emission factors were calculated for 1990 and the reporting year (see overview in Table 6-5).

### Living biomass

The relative uncertainty in yield determination was estimated as 13 % for biomass carbon from both Cropland and Grassland (Leifeld and Fuhrer 2005). Data on biomass yields for different elevations and management intensities were derived from many agricultural field experiments and have a high reliability (SBV 2022; Richner and Sinaj 2017).

### Dead organic matter

Emissions from the dead organic matter pool occur only by land-use changes from Forest land to Grassland as the carbon stock of dead organic matter is assumed to be zero in the non-forest land-use categories. Thus, the uncertainty of these emissions corresponds to the uncertainty of carbon stocks in litter and dead wood on Forest land. Based on the results of the NFI4, the Yasso07 model and Moeri (2007) presented by Didion (2020a), a relative uncertainty of 6.0% was calculated for the total carbon stock in litter and dead wood (Meteotest 2023).

### Mineral soil

The absolute uncertainty of  $0.249 \text{ t C ha}^{-1} \text{ yr}^{-1}$  was used for annual carbon stock changes in categories 4C1 and 4C2. This value was calculated by a Monte Carlo analysis (Wüst-Galley et al. 2020), see chp. 6.5.3. By comparison, the range of annual SOC changes identified for 9 different treatments of Swiss agricultural long-term experiments is  $0.51 \text{ t C ha}^{-1} \text{ yr}^{-1}$  (Keel et al. 2019), indicating that the calculated uncertainty is plausible.

The resulting relative uncertainty in 2021, calculated with the implied emission factors of mineral soil, is 570.2 % for category 4C1 and 189.1 % for category 4C2.

### Organic soil

The uncertainty of the carbon stock change (emission factor) in organic soil is 23 % as reported by Leifeld et al. (2003: 56) and the uncertainty of the activity data (area of organic soil) is 68.6 % (see chp. 6.3.1.3).

### Overall uncertainties categories 4C1 and 4C2

Using the detailed input uncertainties as described above, the uncertainty propagation for categories 4C1 and 4C2 was computed using Monte Carlo simulations, following the same method as for the whole inventory (see chp. 1.6.2). The resulting overall uncertainties for categories 4C1 and 4C2 emissions and removals in 2021 are 734.2 % and 36.0 %, respectively (see Annex A2.1).

## Wildfires

For wildfires, the emission factor uncertainties of CH<sub>4</sub> and N<sub>2</sub>O were set to 70 % (same as in Forest land, see chp. 6.4.3). The activity data uncertainty is 30 % (see chp. 6.3.1.3).

### 6.6.3.2. Time-series consistency

Time series for category 4C Grassland are all considered consistent; they were calculated based on consistent methods and homogenous databases (Wüst-Galley et al. 2020). Small inconsistencies in the input data for the RothC model (related to livestock husbandry, compare chp. 5.2.3 and chp. 5.3.3) are barely relevant for the overall results.

### 6.6.4. Category-specific QA/QC and verification

The general QA/QC measures are described in chp. 1.5.

#### 6.6.4.1. Carbon stocks in mineral soil

The initial SOC stocks for the latest submission are modelled, using the calculation of Leifeld et al. (2003, 2005), as described in Wüst-Galley et al. (2020). The calculation of the initial stocks is however, in general, limited by insufficient soil information at an appropriate spatial resolution across the country. This situation should be improved by the digital soil modelling project described in chp. 6.6.6.

#### 6.6.4.2. Carbon stock changes in mineral soil

##### 6.6.4.2.1. RothC

RothC, used to model SOC stock changes, is a relatively simple model that does not represent certain soil processes such as feedback due to microbial processes or consider other nutrient cycles. It was however the best-performing model given the available data for Switzerland, considering also temporal resolution (Wüst-Galley et al. 2020). The calibration of the allometric equations (for deriving carbon inputs from the cumulative yield of six differentially managed grasslands), as well as a comparison of simulated SOC stock changes with measured values from field experiments is described in Wüst-Galley et al. (2020). A sensitivity analysis of the RothC simulations and of the system used to upscale these simulations to the national scale was completed (Wüst-Galley et al. 2021). The model performance is evaluated on an ongoing basis.

##### 6.6.4.2.2. Swiss Soil Monitoring Network (NABO)

NABO provides data from 33 monitoring sites identified as grassland (NABO 2021b; see chp. 6.4.4.5) according to the land-use categorisation used for LULUCF (see chp. 6.2). The selected sites include 26 meadows and pastures, but also 4 vineyards and 3 orchards. SOC stocks for the top 20 cm of these soils ranged from 25 to 144 t C ha<sup>-1</sup> with a mean of 75 t C ha<sup>-1</sup> (Figure 6-16 top panel). The highest carbon stocks were found for alpine pastures at high elevation. On average, a slight increase during the period 1985 to 2000 (sampling campaigns 1 to 3) and a slight decrease thereafter (campaigns 3 to 4) were observed (Figure

6-16 bottom panel). However, these minor changes were statistically non-significant. In addition, previous studies showed that the elevated SOC stocks for the third sampling campaign must be considered as an artefact, induced by sub-optimal conditions during field work (Meuli et al. 2014; Gubler et al. 2015). From sampling campaigns 4 to 7, SOC stocks remained stable.

The monitoring scheme applied by NABO is able to detect relative changes in SOC contents of roughly 2.5 % per 10 years for mineral grassland soils (minimum detectable change for 30 monitoring sites including three or more sampling campaigns). Regarding the measured SOC stocks (mean 75 t ha<sup>-1</sup>) this corresponds to a minimum detectable change of roughly 0.19 t C ha<sup>-1</sup> yr<sup>-1</sup> for SOC stocks.

The mean change in SOC which was calculated with RothC for the years 1990–2021 was  $-0.054 \pm 0.249$  t C ha<sup>-1</sup> yr<sup>-1</sup> (area-weighted mean across three elevation zones  $\pm$  the absolute uncertainty based on a Monte Carlo analysis, see Figure 6-15 and chp. 6.6.3). In comparison, the modelled net carbon change is clearly smaller than the detectable change by NABO and suggests that modelled SOC stock changes agree with the repeated soil inventories in the NABO network.

In conclusion, NABO data provide evidence that Grassland mineral soils acted neither as a significant net source nor as a significant net sink of carbon when considered over the entire 34-year period (see also Moll-Mielewczik et al. 2023).

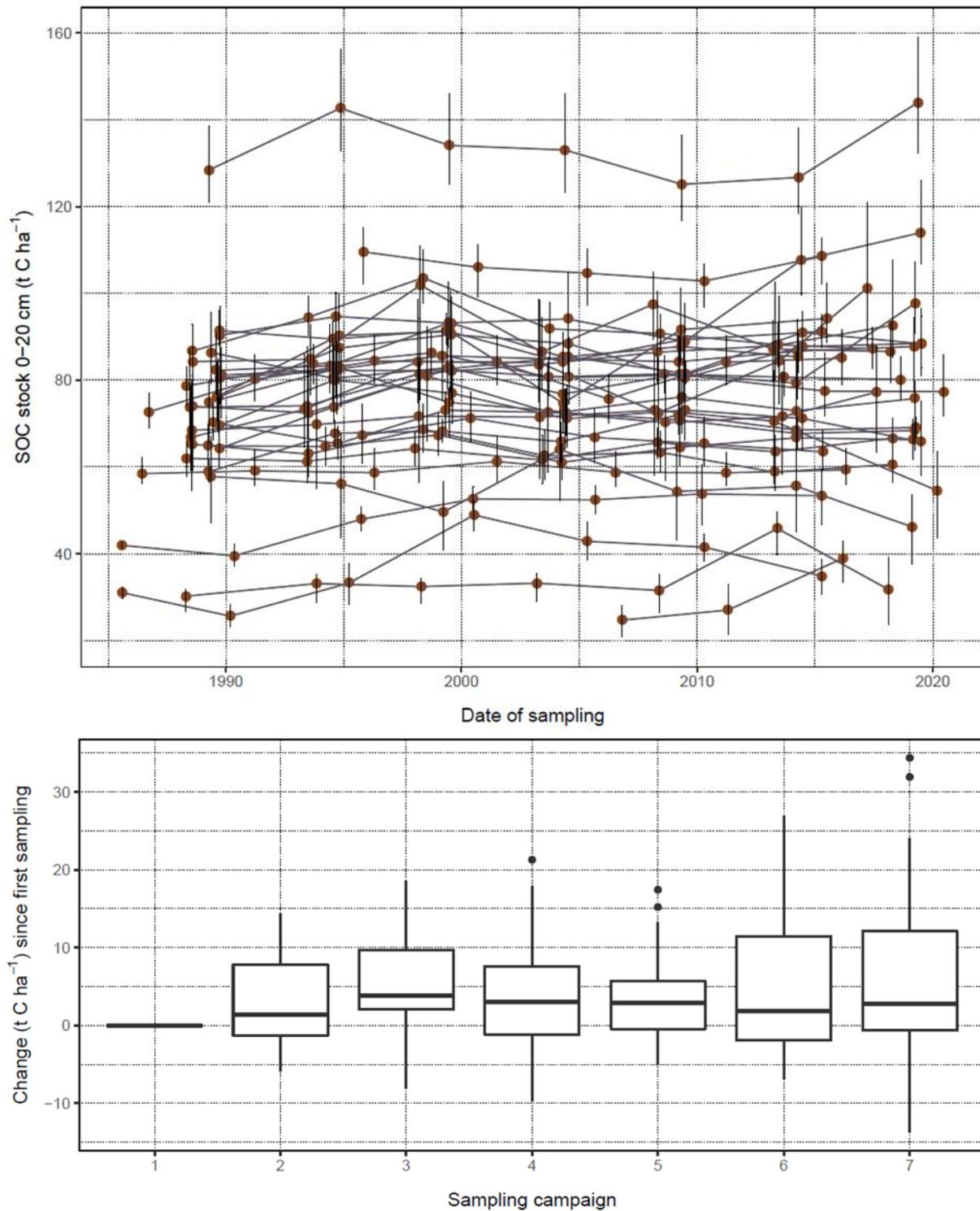


Figure 6-16 Measured SOC stocks for topsoils (0–20 cm) and their changes for 33 NABO long-term monitoring sites used as grassland during the time period 1985–2019. The elevation of the sites ranges from 265 to 2400 m a.s.l. Top panel: SOC stocks 0–20 cm per site and sampling; the dots indicate the mean and the bars the range of 5 % and 95 % percentiles of bootstrap samples taking into account the variability in SOC content of the individual replicates per site and sampling as well as the variations of the bulk density. Bottom panel: boxplot of changes in SOC stocks in each case related to the first sampling (boxes indicate the lower and the upper quartiles with the median indicated; lines include all observations inside the range of 1.5 times the interquartile distance, observations beyond that range are indicated as dots).

### 6.6.4.3. Short-term land-use changes between Grassland and Cropland

See chp. 6.5.4.4.

### 6.6.5. Category-specific recalculations

The following recalculations were implemented. Major recalculations which contribute significantly to the differences in net emissions and net removals of sector 4C between the latest and the previous submissions are additionally presented in chp. 10.1.2.4.

- 4C: Activity data (areas) 2013–2020 were updated (see chp. 6.3.1.5). The inclusion of first data from the AREA5 survey led to small recalculations (Table 6-11).
- 4C, permanent grassland (CC31): Updated yield data for 1990–2021 was used (SBV 2022). The effect on the biomass carbon pool was a higher year-to-year variability, especially in the last 15 years (see Figure 6-14 upper panel), a more strongly decreasing temporal trend ( $-0.011 \text{ t C ha}^{-1} \text{ yr}^{-1}$  against  $-0.006 \text{ t C ha}^{-1} \text{ yr}^{-1}$  in the previous submission) and consistently lower stocks compared with the previous submission ( $4.32 \text{ t C ha}^{-1}$  against  $4.43 \text{ t C ha}^{-1}$ ).
- 4C, vineyard, low-stem orchard, tree nursery (CC33), orchard (CC35), and unproductive grassland (CC37): Carbon stocks in living biomass were adjusted to the recalculated carbon stock in living biomass of permanent grassland (CC31; see above) averaged over the period 1990–2020. The effect on the biomass carbon pool was very small.
- 4C, permanent grassland (CC31): Carbon stocks and carbon stock changes in mineral soil were recalculated for the whole inventory period, applying
  - updated information used for the calculation of organic amendments (excretion rates of volatile solids) that had been implemented in the Agriculture Sector in the previous submission (as described in chp. 5.2.5, FOEN 2022), as well as updated data regarding herd sizes and updated information on animal housing and the distribution of farmyard manure, obtained from the ammonium model AGRAMMON: All changes are in line with values used in the Agriculture sector. The effect of both adjustments on the mineral soil carbon pool explained most of the differences observed between the previous and the latest submission;
  - updated gridded climate data (MeteoSwiss 2021): The latest data did not explain differences in soil carbon stocks and soil carbon stock changes between previous and the latest submissions. In fact, the updated climate data most likely dampened changes caused by updated organic amendments (see above);
  - a new agricultural surface data set that is spatially more precise: This data set is a different version of that used in previous submissions and as described in Wüst-Galley et al. (2020), but the spatial resolution is based on the municipality boundaries from 1990 (when on average municipalities were smaller), rather than from the current year. This recalculation had a negligible effect on mineral soil carbon pools.
- 4C, shrub vegetation (CC32), copse (CC34), orchard (CC35), stony grassland (CC36), and unproductive grassland (CC37): Carbon stocks in mineral soil were adjusted to the recalculated carbon stock in mineral soil of permanent grassland (CC31; see above) averaged over the period 1990–2020. The effect on the mineral soil carbon pool was small.
- 4C, vineyard, low-stem orchard, tree nursery (CC33): Carbon stock in mineral soil was adjusted to the recalculated carbon stock in mineral soil of Cropland (CC21; see chp. 6.5.5) averaged over the period 1990–2020. The effect on the mineral soil carbon pool was very small.
- 4C2, Land converted to "woody" grassland: Reconsidering the issues leading to recommendation L.5 of UNFCCC (2022) the conversion time for living biomass on areas converted to "woody" grassland was changed from 1 year to 20 years (see Table 6-3). Consequently, the former "Justification for the use of a one-year conversion period for land converted to woody grassland types" (as given in chp. 6.6.4.6 in FOEN 2022) was omitted.

- 4(V)C1: CH<sub>4</sub> and N<sub>2</sub>O emissions from wildfires were recalculated for the years 2018 based on an updated area affected by wildfires in the Swissfire database. Very small changes resulted from this recalculation.

## 6.6.6. Category-specific planned improvements

### 6.6.6.1. Living biomass

The project process to achieve a sound wall-to-wall above ground tree biomass database and map for Switzerland is described in chp. 6.5.6. The suitability of the obtained data for reporting in category 4C is subject to ongoing evaluation (Price 2020).

### 6.6.6.2. Mineral soil

The information in chp. 6.5.6.2 on the switch to grid-based SOC modelling with RothC for the GHG inventory also applies to permanent grassland mineral soil.

### 6.6.6.3. N<sub>2</sub>O and CH<sub>4</sub> emissions from biomass burning

In the next submission, the biomass fuel for 4(V) wildfires will be recalculated to be consistent with the latest carbon stocks of the grassland land-use categories CC31–CC37.

## 6.7. Category 4D – Wetlands

### 6.7.1. Description

Table 6-28 Key categories of 4D Wetlands. Combined KCA results, level for 2021 and trend for 1990–2021, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC category	Gas	Identification criteria
4D1	Wetland remaining wetland	CO <sub>2</sub>	L2

Wetlands were subdivided into surface waters (CC41) and unproductive wetlands such as shore vegetation, fens or (raised) bogs (CC42) (see Table 6-2 and Table 6-6).

Figure 6-17 shows the time series of net CO<sub>2</sub> emissions and net CO<sub>2</sub> removals from categories 4D1 Wetlands remaining wetlands and 4D2 Land converted to wetlands. Emissions from organic soil largely dominate category 4D1 alone. Net emissions from category 4D2 more than double (with losses in living biomass from Forest land converted to other wetlands as both most important and driving process). Total net emissions from category 4D Wetlands range between 89 and 113 kt CO<sub>2</sub> (in 1990 and in 2019, respectively; not shown).

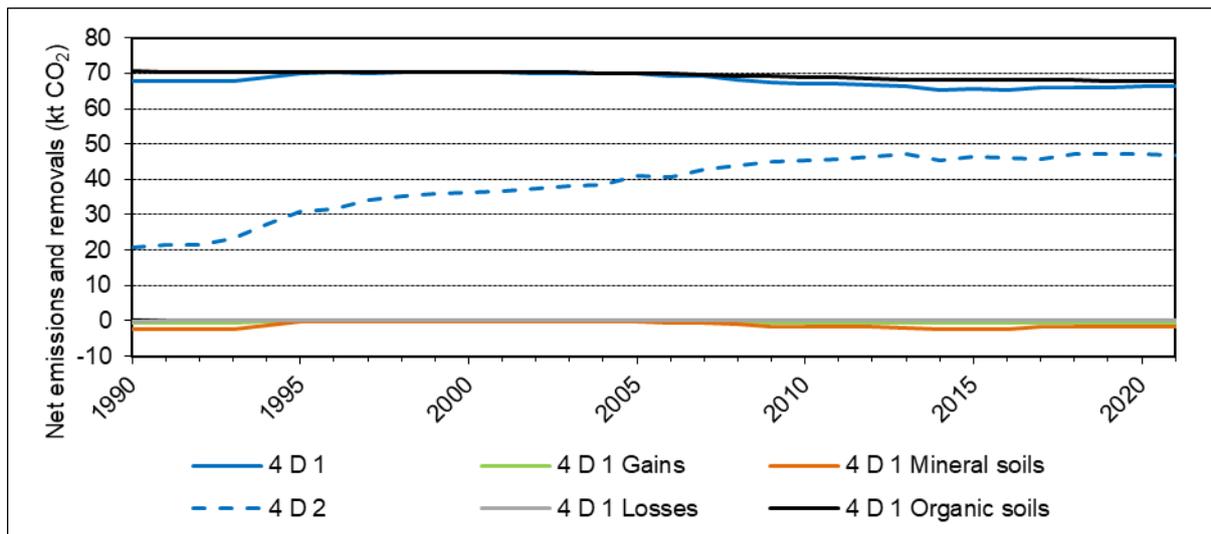


Figure 6-17 Net CO<sub>2</sub> emissions (positive values) and removals (negative values) from categories 4D1 and 4D2. Category 4D1 is broken down by gains in living biomass, losses in living biomass, net carbon stock changes in mineral soil, and net carbon stock changes in organic soil. Gains and losses in living biomass are too small to be distinguished from the zero line.

## 6.7.2. Methodological issues

### 6.7.2.1. Carbon stocks

#### 6.7.2.1.1. Carbon stocks in living biomass

##### 6.7.2.1.1.1. Surface waters (CC41)

Surface waters have no carbon stocks by definition.

##### 6.7.2.1.1.2. Unproductive wetland (CC42)

CC42 consists of (very) extensively managed grassland, bushes or tree groups. The carbon stock of living biomass was estimated as 6.50 t C ha<sup>-1</sup> (Mathys and Thüring 2010: Table 7).

##### 6.7.2.1.2. Carbon stocks in dead organic matter

Carbon stocks in dead organic matter were assumed to be zero.

### 6.7.2.1.3. Carbon stocks in soil

#### 6.7.2.1.3.1. Surface waters (CC41)

The mineral soil carbon stock for surface waters (CC41) is zero.

For CC41 situated in areas with organic soil (see chp. 6.2.2.1 and Table 6-7), a soil carbon stock of 240 t C ha<sup>-1</sup> (0–30 cm) was assumed. These surface waters were assumed to be shallow ponds as integrated parts of fens or bogs.

### **6.7.2.1.3.2. Unproductive wetland (CC42)**

Land cover in CC42 includes (raised) bogs and fens protected by Federal Legislation (Swiss Confederation 1991a, 1994) as well as reed. Nearly 15 % of the unproductive wetland are located on organic soil (see Table 6-7). In this case the soil carbon stock is  $240 \text{ t C ha}^{-1}$  (0–30 cm).

No specific soil data are available for CC42 on mineral soil. As a first approximation, it was assumed that the soil carbon stock of unproductive wetland is similar like in mineral soil of permanent grassland (CC31). Therefore, the averages 1990–2020 of CC31 (see chp. 6.6.2.1.3) were calculated and weighted with the area per elevation zone of CC42, resulting in  $63.1 \text{ t C ha}^{-1}$  (0–30 cm).

## **6.7.2.2. Changes in carbon stocks**

### **6.7.2.2.1. Carbon stock changes in living biomass, dead organic matter, and mineral soil**

Applying a Tier 1 approach, carbon stock changes in living biomass, dead organic matter, and mineral soil were assumed to be in equilibrium for Wetlands remaining wetlands.

### **6.7.2.2.2. Carbon stock changes in organic soil**

Carbon losses in organic soil in land-use category CC41 were assumed to be zero because the respective areas are not drained.

Carbon losses in organic soil in land-use category CC42 were estimated to be  $5.30 \text{ t C ha}^{-1} \text{ yr}^{-1}$  according to domestic data (ART 2011b; Paul and Alewell 2018). This value was used for weakly managed ecosystems such as fens and (very) extensively managed ecosystems such as raised bogs. Bogs and fens are protected to a large part by Federal Ordinances (Swiss Confederation 1991a, 1994) and drainage is not allowed any more. However, the impact of old drainages constructed before 1990 probably still triggers certain emissions.

### **6.7.2.2.3. Land-use change**

In the case of land-use change, the net carbon stock changes in biomass and soils of both land-use categories CC41 and CC42 were calculated as described in chp. 6.1.3.

For land converted to unproductive wetland (CC42) a conversion time of one year was chosen for the carbon stock change in living biomass and in dead organic matter (see Table 6-3). For carbon stock changes in mineral soil the conversion time is 20 years.

## **6.7.2.3. Non-CO<sub>2</sub> emissions from Wetlands**

### **6.7.2.3.1. Direct N<sub>2</sub>O emissions from N inputs to managed soils**

No emissions were reported in category D in CRF Table4(I) (notation key “NO”). Input of nitrogen fertilisers to land-use category unproductive wetlands (CC42) is very unlikely as these areas represent mostly nature conservation areas (raised bogs, fens) protected by legislation (Swiss Confederation 1991a, 1994), where fertilising is prohibited.

#### **6.7.2.3.2. *N<sub>2</sub>O and CH<sub>4</sub> emissions from drainage of organic soil***

N<sub>2</sub>O emissions from drainage of organic soil was calculated for unproductive wetlands (CC42) and reported in category D.3 Other wetlands in CRF Table4(II) (labelled as "WL drained"). Activity data correspond to the total area of organic soil for subdivision "unprod wetland" (CC42) in CRF Table4.D. The emission factor of 1.6 kg N<sub>2</sub>O-N ha<sup>-1</sup> used is the default value given in the IPCC Wetlands Supplement (IPCC 2014a: Table 2.5) for shallow-drained, nutrient-rich grassland.

An estimate of 0.4 kt CH<sub>4</sub> yr<sup>-1</sup> emitted by reservoirs (flooded lands) was given by Hiller et al. (2014). The estimate encompasses 97 artificial lakes covering a total area of 10.6 kha. This emission is reported in category D.2 Flooded lands in CRF Table4(II).

For category D.3 Other wetlands in CRF Table4(II), CH<sub>4</sub> emissions were not estimated (notation key "NE") as reporting is not mandatory for this category.

#### **6.7.2.3.3. *Direct and indirect N<sub>2</sub>O emissions from managed soils***

The calculations of direct N<sub>2</sub>O emissions from nitrogen mineralisation in mineral soil (category 4(III)D) and indirect N<sub>2</sub>O emissions from managed soils (category 4(IV)) in Wetlands are described in Annex A5.4.

#### **6.7.2.3.4. *CH<sub>4</sub> and N<sub>2</sub>O emissions from biomass burning***

CH<sub>4</sub> emissions and N<sub>2</sub>O emissions from biomass burning in Wetlands (category 4(V)D) were not occurring (notation key "NO").

### **6.7.3. Uncertainties and time-series consistency**

#### **6.7.3.1. Uncertainties in category 4D1**

##### **Activity data**

Uncertainties of activity data of category 4D Wetlands are described in chp. 6.3.1.3.

For calculating the overall uncertainty of 4D1, only the relevant emissions from organic soil were considered (see Table 6-5).

##### **Organic soil**

The uncertainty of the carbon stock change factor in organic soil is 72.2 % both for 1990 and 2021. It was calculated on the basis of measurement data compiled by ART (2011b). The uncertainty of the activity data (area of organic soil) is 90.8 % (see chp. 6.3.1.3 and Table 6-5).

#### **6.7.3.2. Uncertainties in category 4D2**

##### **Activity data**

Uncertainties of activity data of category 4D Wetlands are described in chp. 6.3.1.3.

For calculating the overall uncertainty of 4D2, the relevant emissions and removals from living biomass, dead organic matter, mineral soil and organic soil were considered (see overview in Table 6-5).

### **Living biomass**

The relative uncertainty in yield determination was estimated as 13 % for biomass carbon from both Cropland and Grassland (Leifeld and Fuhrer 2005).

### **Dead organic matter**

Emissions from the dead organic matter pool occur only by land-use changes from Forest land to Wetlands as the carbon stock of dead organic matter is assumed to be zero in the non-forest land-use categories. Thus, the uncertainty of these emissions corresponds to the uncertainty of the carbon stock in litter and dead wood on Forest land. Based on the results of the NFI4, the Yasso07 model and Moeri (2007) presented by Didion (2020a), a relative uncertainty of 6.0% was calculated for the total carbon stock of litter and dead wood (Meteotest 2023).

### **Mineral soil**

Based on expert judgement, an uncertainty of 50 % was chosen for the carbon stock changes calculated with the stock-difference approach in category 4D2.

### **Organic soil**

The uncertainty of the carbon stock change factor in organic soil is 72.2 % calculated on the basis of measurement data compiled in ART (2011b) and the uncertainty of the activity data (area of organic soil) is 90.8 % (see chp. 6.3.1.3).

### **Overall uncertainty category 4D2**

Using the detailed input uncertainties as described above, the uncertainty propagation for category 4D2 was computed using Monte Carlo simulations, following the same method as for the whole inventory (see chp. 1.6.2). The resulting overall uncertainty for 4D2 emissions is 20.1 % (see Annex A2.1).

### **Flooded lands (CH<sub>4</sub>; category 4(II))**

The emission factor uncertainty for CH<sub>4</sub> emitted by flooded lands can be very high (IPCC 2006, Volume 4, Appendix 3). As a best guess, a value of 70 % was chosen for the CH<sub>4</sub> emission factor of category 4(II)D2 (Table 6-5). The activity data uncertainty of flooded lands was set to 10 % based on an expert judgment considering the methods used by Hiller et al. (2014) for estimating the area of reservoirs/flooded land.

### **Drainage of organic soil (N<sub>2</sub>O; category 4(II))**

For N<sub>2</sub>O emissions from drainage of organic soil (category 4(II)), the emission factor uncertainty for shallow-drained, nutrient-rich grassland given in the Wetlands Supplement Guidelines (IPCC 2014a: Table 2.5) was used. It was calculated as arithmetic mean of the lower and upper bound uncertainty (66.9 %; see Table 6-5). The respective activity data uncertainty is 48.8 % (Meteotest 2023). It was calculated by area-weighting and combining the uncertainties of the areas of organic soil for Forest land (35.3 %) and for Wetlands (90.8 %) (see chp. 6.3.1.3).

#### **6.7.3.3. Time-series consistency**

Time series for category 4D Wetlands are all considered consistent; they were calculated based on consistent methods and homogenous databases.

#### **6.7.4. Category-specific QA/QC and verification**

The general QA/QC measures are described in chp. 1.5.

No category-specific QA/QC activities were carried out.

#### **6.7.5. Category-specific recalculations**

- 4D: Activity data (areas) 2013–2020 were updated (see chp. 6.3.1.5). The inclusion of first data from the AREA5 survey led to very small recalculations (Table 6-11).
- 4D: unproductive wetlands (CC42): The carbon stock in mineral soil was adjusted to the recalculated average (1990–2020) of permanent grassland mineral soil (see chp.6.6.5). The effect on the mineral soil carbon pool was very small.

The resulting differences of both recalculations in net emissions and removals between the latest and the previous submissions for category 4D are shown in Figure 10-9. They are insignificantly small and range from -0.1 kt CO<sub>2</sub> eq in 2011 to 1.1 kt CO<sub>2</sub> eq in 2014.

#### **6.7.6. Category-specific planned improvements**

##### **6.7.6.1. Living biomass**

The project process to achieve a sound wall-to-wall above ground tree biomass database and map for Switzerland is described in chp. 6.5.6. The suitability of the obtained data for reporting in category 4D is subject to ongoing evaluation (Price 2020).

##### **6.7.6.2. Mineral soil**

The progress described in chp. 6.5.6.2 will also be used to improve estimates of carbon stock in unproductive wetland mineral soil.

## 6.8. Category 4E – Settlements

### 6.8.1. Description

Table 6-29 Key categories in category 4E Settlements. Combined KCA results, level for 2021 and trend for 1990–2021, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC category	Gas	Identification criteria
4E2	Land converted to settlements	CO2	L1, L2

Settlements were subdivided into buildings/constructions (CC51), herbaceous biomass in settlements (CC52), shrubs in settlements (CC53), and trees in settlements (CC54) (see Table 6-2 and Table 6-6).

Figure 6-18 shows the time series of net CO<sub>2</sub> emissions and net CO<sub>2</sub> removals. Category 4E1 Settlements remaining settlements consistently acts as a small CO<sub>2</sub> sink, with a weak minimum formed in the middle of the inventory period. Between 2005 and 2015 net emissions in category 4E2 Land converted to settlements decline to a 18 % lower level. Forest land converted to settlements and Grassland converted to settlements together are the most important land-use changes. Total net emissions from category 4E Settlements range between 162 and 230 kt CO<sub>2</sub> (in 2016 and in 2005, respectively; not shown).

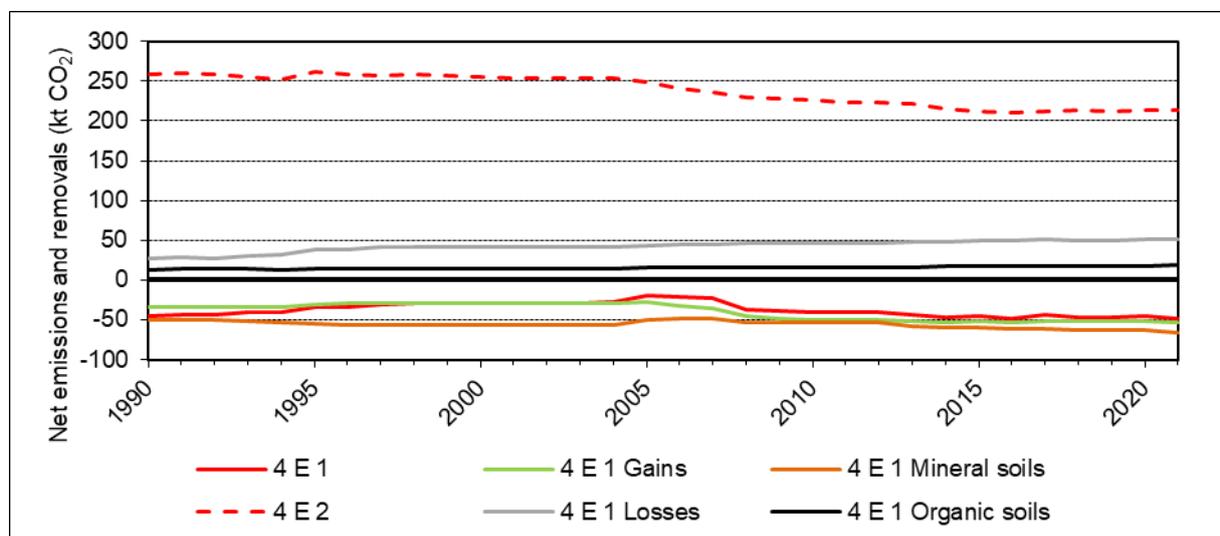


Figure 6-18 Net CO<sub>2</sub> emissions (positive values) and removals (negative values) from categories 4E1 and 4E2. Category 4E1 is broken down by gains in living biomass, losses in living biomass, net carbon stock changes in mineral soil, and net carbon stock changes in organic soil.

## 6.8.2. Methodological issues

### 6.8.2.1. Carbon stocks

#### 6.8.2.1.1. *Carbon stocks in living biomass*

##### 6.8.2.1.1.1. Buildings and constructions (CC51)

By default, buildings/constructions have no carbon stocks.

##### 6.8.2.1.1.2. Herbaceous biomass, shrubs and trees in settlements (CC52, CC53, CC54)

Carbon stocks in living biomass are: 9.54 t C ha<sup>-1</sup> for CC52, 15.43 t C ha<sup>-1</sup> for CC53, and 20.72 t C ha<sup>-1</sup> for CC54 (Mathys and Thürig 2010: Table 7).

##### 6.8.2.1.2. *Carbon stocks in dead organic matter*

Carbon stocks in dead organic matter were assumed to be zero.

#### 6.8.2.1.3. *Carbon stocks in soil*

##### 6.8.2.1.3.1. Buildings and constructions (CC51)

The carbon stocks in mineral and in organic soil for CC51 were assumed to be zero.

##### 6.8.2.1.3.2. Herbaceous biomass, shrubs and trees in settlements (CC52, CC53, CC54)

The carbon stocks in mineral soil for CC52, CC53, and CC54 are 49.7 t C ha<sup>-1</sup> (0–30 cm). This value was calculated as average soil carbon stock of Cropland (see chp. 6.5.2.1.3.1) for the period 1990–2020, weighted with the area of Settlements per elevation zone.

For organic soil, a carbon stock of 240 t C ha<sup>-1</sup> (0–30 cm) was assumed for CC52, CC53, and CC54 (see chp. 6.5.2.1.3.2).

### 6.8.2.2. Changes in carbon stocks

#### 6.8.2.2.1. *Carbon stock changes in living biomass, dead organic matter, and mineral soil*

Applying a Tier 1 approach, carbon stock changes in living biomass, dead organic matter, and mineral soil were assumed to be in equilibrium for Settlements remaining settlements.

#### 6.8.2.2.2. *Carbon stock changes in organic soil*

On organic soil, the following carbon stock change factors were applied:

- As CC51 has no carbon stock, carbon stock changes in organic soil were assumed to be zero (see Table 6-4).

- 9.52 t C ha<sup>-1</sup> yr<sup>-1</sup> for CC52. This corresponds to the value used for Cropland because CC52 areas are managed (gardens, parks) (Leifeld et al. 2003, 2005 and verified by ART 2009b and Paul and Alewell 2018).
- 5.30 t C ha<sup>-1</sup> yr<sup>-1</sup> for CC53 and CC54. This corresponds to the value used for extensively managed grasslands (ART 2011b; Paul and Alewell 2018).

### 6.8.2.2.3. Land-use change

In case of land-use changes from non-CC51 to CC51 on mineral or on organic soil a loss of 20 % of the initial carbon stock was reported following IPCC 2006 (Volume 4, chp. 8.3.3.2). The reason for this is that 20 % of the soil organic matter is assumed to be lost as a result of disturbance, removal or relocation on these areas being sealed. This assumption is supported by paragraph 7 of the federal "Ordinance against deterioration of soils" (Swiss Confederation 1998) stating that the soil material excavated on a construction site must be treated in such a way that it can be used as a soil again. When the material is re-used (e.g. for re-cultivations) the fertility of the soil must not be affected. This regulation ensures that a large part of the soil organic matter is preserved on land converted to CC51.

Thus, equation 6.8 presented in chp. 6.1.3.2 was adjusted as follows if a=CC51:

$$\Delta C_{s,i,b51} = [ 0.2 * (0 - \text{stock}_{C_{s,i,b}}) / CT ] * A_{i,b51}$$

where:

stock <sub>C<sub>s,i,b</sub></sub>	carbon stock in soil (t C ha <sup>-1</sup> )
b	land-use category before conversion (CC = b ≠ 51)
b51	land use conversion from b to CC51
i	spatial stratum
A <sub>i,b51</sub>	area of land (ha) converted from b to CC51 in the spatial stratum i (the sum of the areas converted within the last 20 years)
CT	conversion time (20 years; see Table 6-3).

In case of land-use changes from land-use category CC51 to non-CC51 land-use categories, the regular stock-difference approach and gain-loss approach, respectively, according to chp. 6.1.3.2 and Table 6-3 were applied.

In the case of land-use change from or to land-use categories CC52, CC53, and CC54, the net carbon stock changes in biomass and soils of CC52, CC53, and CC54 were calculated as described in chp. 6.1.3.2.

### 6.8.2.3. Non CO<sub>2</sub> emissions from Settlements

#### 6.8.2.3.1. Direct N<sub>2</sub>O emissions from N inputs to managed soils

Direct N<sub>2</sub>O emissions from N inputs to managed soils in Settlements (category 4(I)E) were included in the Agriculture sector (categories 3Da1 Inorganic N fertilisers and 3Da7 Other, see chp. 5.5) (notation key "IE").

#### **6.8.2.3.2. Direct and indirect N<sub>2</sub>O emissions from managed soils**

The calculations of direct N<sub>2</sub>O emissions from nitrogen mineralisation in mineral soil (category 4(III)E) and indirect N<sub>2</sub>O emissions from managed soils (category 4(IV)) in Settlements are described in Annex A5.4.

#### **6.8.2.3.3. CH<sub>4</sub> and N<sub>2</sub>O emissions from biomass burning**

CH<sub>4</sub> emissions and N<sub>2</sub>O emissions from biomass burning in Settlements (category 4(V)E) were not occurring (notation key "NO").

### **6.8.3. Uncertainties and time-series consistency**

#### **6.8.3.1. Uncertainties**

Uncertainties of activity data of category 4E Settlements are described in chp. 6.3.1.3.

Based on expert judgement, a value of 50 % was chosen for the carbon stock change factor uncertainty in category 4E (Table 6-5).

#### **6.8.3.2. Time-series consistency**

Time series for category 4E Settlements are all considered consistent; they were calculated based on consistent methods and homogenous databases.

#### **6.8.4. Category-specific QA/QC and verification**

The general QA/QC measures are described in chp. 1.5.

No category-specific QA/QC activities were carried out.

#### **6.8.5. Category-specific recalculations**

- 4E: Activity data (areas) 2013–2020 were updated (see chp. 6.3.1.5). The inclusion of first data from the AREA5 survey led to small recalculations (Table 6-11).
- 4E: The carbon stocks in mineral soil for non-sealed settlement areas (CC52, CC53, CC54) were adjusted to the recalculated average (1990–2020) of Cropland mineral soil (see chp. 6.5.5). The effect on the mineral soil carbon pool was small.

The resulting differences of both recalculations in net emissions and removals between the latest and the previous submissions for category 4E are shown in Figure 10-9. They are insignificantly small and range from -4.1 kt CO<sub>2</sub> eq in 2020 to 3.3 kt CO<sub>2</sub> eq in 1990.

## 6.8.6. Category-specific planned improvements

### 6.8.6.1. Living biomass

The project process to achieve a sound wall-to-wall above ground tree biomass database and map for Switzerland is described in chp. 6.5.6. The suitability of the obtained data for reporting in category 4E is subject to ongoing evaluation (Gardi et al. 2016; Price 2020).

### 6.8.6.2. Mineral soil

The progress described in chp. 6.5.6.2 will also be used to improve estimates of carbon stocks in Settlements mineral soil.

## 6.9. Category 4F – Other land

### 6.9.1. Description

Table 6-30 Key categories in category 4F Other land. Combined KCA results, level for 2021 and trend for 1990–2021, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC category	Gas	Identification criteria
4F2	Land converted to other land	CO <sub>2</sub>	L2, T2

As shown in Table 6-2 and in Table 6-6 Other land (CC61) covers unmanaged, non-vegetated areas such as glaciers, rocks, screes and shores.

The area of Land converted to other land has increased since 1990 from 361 ha yr<sup>-1</sup> to 523 ha yr<sup>-1</sup> in 2021 (see Table 6-9). Primarily the conversions of Forest land and Grassland to Other land lead to CO<sub>2</sub> emissions caused by the loss of biomass and soil organic carbon. Mudflows, erosion, landslides, and dynamic changes in stream beds were identified as the main processes causing the land-use changes. The trigger for the altered morphodynamics is not known, but a connection with climate change can be assumed.

It should be noted that another phenomenon strongly linked to climate change, namely the shift of vegetation zones in mountainous regions (as especially expressed in category 4C2.5 Other land converted to stony grassland (CC36), see Table 6-9), has a higher rate of land-use change, and therefore the total area of Other land has decreased by 4 % over the inventory period (Table 6-8).

Figure 6-19 shows the time series of net CO<sub>2</sub> emissions. Total emissions from category 4F Other land (= 4F2 Land converted to other land) have increased almost steadily since 1990 from 88 kt CO<sub>2</sub> in 1990 to 130 kt CO<sub>2</sub> in 2021. Forest land converted to other land and Grassland converted to other land together are the most important land-use changes.

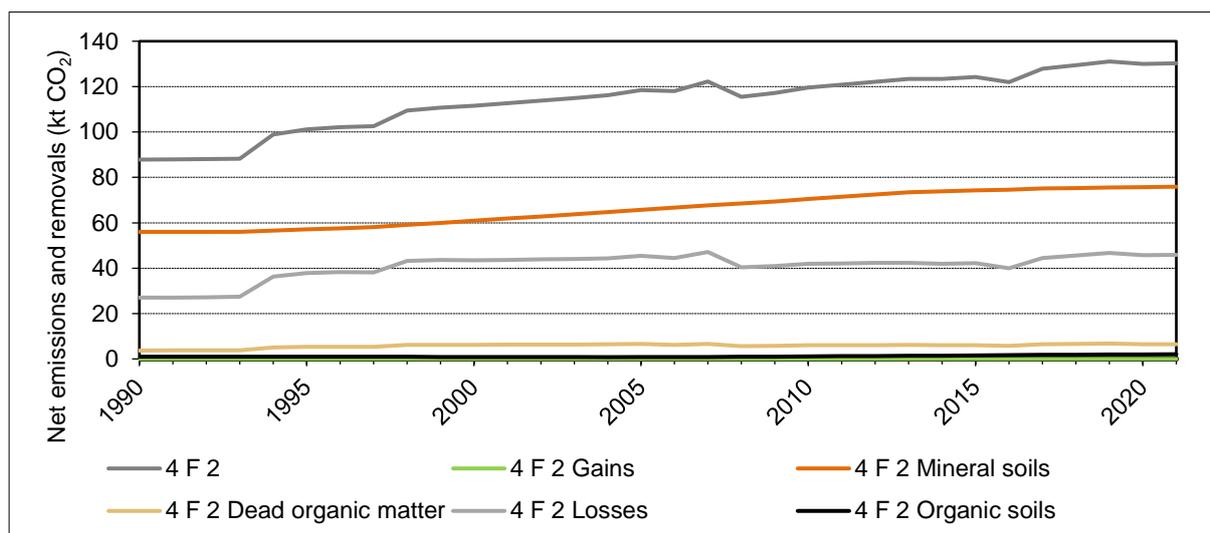


Figure 6-19 Net CO<sub>2</sub> emissions from category 4F2 Land converted to other land, broken down by gains in living biomass, losses in living biomass, net carbon stock changes in dead organic matter, net carbon stock changes in mineral soil, and net carbon stock changes in organic soil. Gains in living biomass are not occurring and changes in organic soil are too small to be distinguished from the zero line.

## 6.9.2. Methodological issues

By definition, Other land has no carbon stocks. Coherently, carbon stock changes in living biomass, dead organic matter, mineral and organic soil were assumed to be zero for Other land remaining other land (see Table 6-4).

In the case of land converted to other land, the net carbon changes in biomass and soils were calculated as described in chp. 6.1.3.

The calculations of direct N<sub>2</sub>O emissions from nitrogen mineralisation in mineral soil (category 4(III)F) and indirect N<sub>2</sub>O emissions from managed soils (category 4(IV)) in Other land are described in chp. A5.4.

## 6.9.3. Uncertainties and time-series consistency

### 6.9.3.1. Uncertainties

Uncertainties of activity data of category 4F Other Land are described in chp. 6.3.1.3.

Based on expert judgement, a value of 50 % was chosen for the carbon stock change factor uncertainty in category 4F2 (Table 6-5).

### 6.9.3.2. Time-series consistency

Time series for category 4F Other land are all considered consistent; they were calculated based on consistent methods and homogenous databases.

### 6.9.4. Category-specific QA/QC and verification

The general QA/QC measures are described in chp. 1.5.

No category-specific QA/QC activities were carried out.

### 6.9.5. Category-specific recalculations

- 4F: Activity data (areas) 2013–2020 were updated (see chp. 6.3.1.5). The inclusion of first data from the AREA5 survey led to small recalculations (Table 6-11).

The resulting differences of both recalculations in net emissions and removals between the latest and the previous submissions for category 4F are shown in Figure 10-9. They are insignificantly small and range from -0.4 kt CO<sub>2</sub> eq in 2016 to 0.4 kt CO<sub>2</sub> eq in 2004.

### 6.9.6. Category-specific planned improvements

No category-specific improvements are planned.

## 6.10. Category 4G – Harvested wood products

### 6.10.1. Description

Table 6-31 Key categories in category 4G Harvested wood products. Combined KCA results, level for 2021 and trend for 1990–2021, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC category	Gas	Identification criteria
4G	HWP Harvested Wood Products	CO <sub>2</sub>	T1, T2

Estimates of net emissions and removals from Harvested wood products (HWP) due to losses and gains of carbon, respectively, were reported. Gains refer to annual carbon inflow to the HWP pool, whereas losses refer to annual carbon outflow from the HWP pool.

The approach to calculate carbon stock changes in HWP corresponds to a production approach as described in chp. 12, Volume 4 of IPCC (2019). Changes in carbon stocks in Swiss forests are presented in chp. 6.4. The estimate covers all wood products originating from trees harvested in Switzerland (sawnwood, wood based panels, and paper and paperboard) that are processed in Switzerland and that are used for material (i.e. not for energetic) purposes.

The HWP pool includes products made from domestic harvest that were exported and are in use in other countries. Imported HWP are not included in the HWP pool.

To calculate carbon stock changes in HWP, product categories and half-lives were used following the methodologies described in IPCC (2014) and IPCC (2019). Further details and result evaluations are presented in FOEN (2023e).

The resulting CO<sub>2</sub> emissions and removals per product category are listed in Table 6-32 and shown in Figure 6-20.

Table 6-32 CO<sub>2</sub> emissions and removals from Harvested wood products derived from sawnwood (change<sub>C<sub>HWP</sub>-sawnwood</sub>), panels (change<sub>C<sub>HWP</sub>-panels</sub>), and paper and paperboard (change<sub>C<sub>HWP</sub>-paper and paperboard</sub>) in kt CO<sub>2</sub> (positive values refer to emissions, negative values refer to removals).

	Unit	1990	1995	2000	2005	2010					
HWP	kt CO <sub>2</sub>	-1'127	-442	-701	-687	-424					
change <sub>C<sub>HWP</sub>-sawnwood</sub>	kt CO <sub>2</sub>	-638	-228	-349	-272	-123					
change <sub>C<sub>HWP</sub>-panels</sub>	kt CO <sub>2</sub>	-453	-222	-378	-400	-317					
change <sub>C<sub>HWP</sub>-paper and paperboard</sub>	kt CO <sub>2</sub>	-36	8.1	26	-14	16					
	Unit	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
HWP	kt CO <sub>2</sub>	-107	77	-90	-71	-28	7.6	-75	78	-29	-39
change <sub>C<sub>HWP</sub>-sawnwood</sub>	kt CO <sub>2</sub>	65	148	51	45	51	98	29	57	7.0	5.2
change <sub>C<sub>HWP</sub>-panels</sub>	kt CO <sub>2</sub>	-176	-114	-136	-132	-100	-103	-120	6.5	-68	-67
change <sub>C<sub>HWP</sub>-paper and paperboard</sub>	kt CO <sub>2</sub>	4.9	43	-4.4	16	20	13	15	14	32	22

Fluctuations in the HWP pool are mainly caused by changes in the production of sawnwood and wood panels. The share of paper and paperboard is relatively small (see Table 6-32). Because of the strong reduction in the production of sawnwood since 2011, the relative contribution of panels and paper and paperboard to the HWP pool considerably increased (see Figure 6-20). In 2019, the production of wood panels decreased by almost 25 % and, as a consequence, HWP became a net CO<sub>2</sub> source (for the third time next to 2013 and 2017).

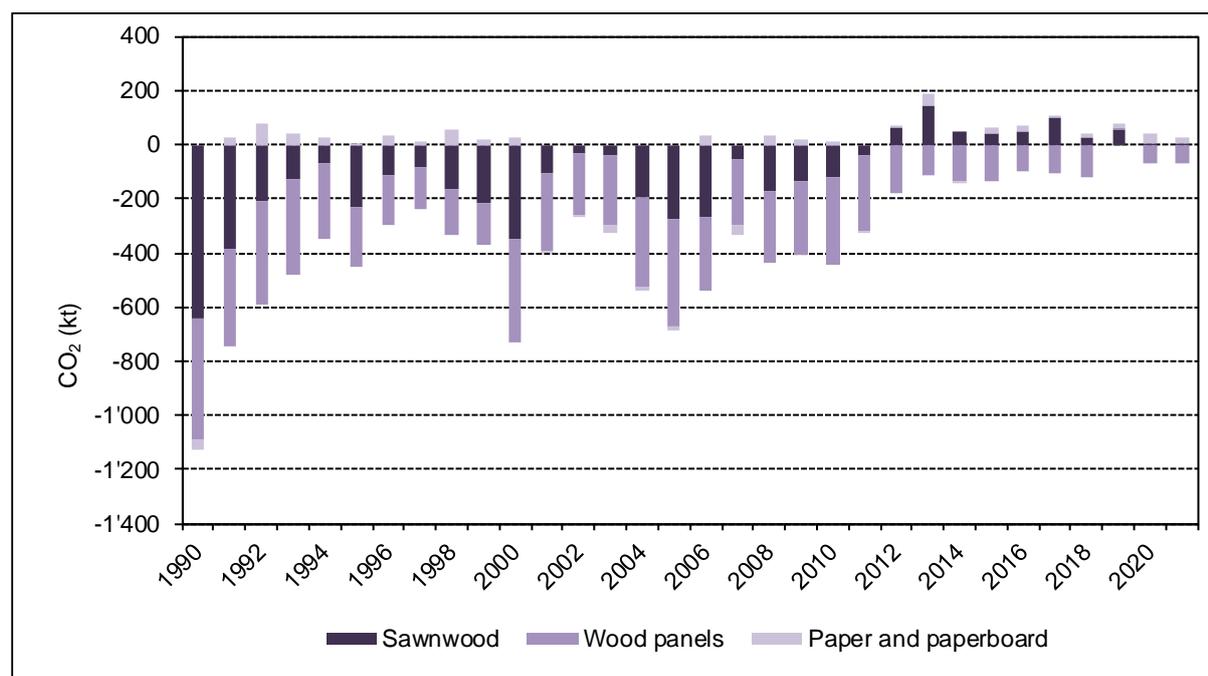


Figure 6-20 CO<sub>2</sub> emissions and removals from category 4G Harvested wood products (HWP) (in kt CO<sub>2</sub>). Positive values refer to emissions, negative values refer to removals.

## 6.10.2. Methodological issues

### 6.10.2.1. Approach

Switzerland decided to continue the HWP reporting according to the production approach that had been used under the Kyoto Protocol, including minor modifications. For the estimation of carbon stocks and carbon stock changes, the equations described in IPCC (2014: chp. 2.8) were used. A Tier 2 approach, first order decay, was applied for the product

categories sawnwood, wood based panels, and paper and paperboard according to equation 2.8.5 in IPCC (2014).

- The starting year used to estimate the delayed emissions from the existing pools is 1900.
- Emissions from wood harvested for energy purposes were accounted for on the basis of instantaneous oxidation (FOEN 2023e).
- HWP going to solid waste disposals were not included in the HWP pool for LULUCF, i.e. instantaneous oxidation is assumed. Information on wood in solid waste disposals is given in the waste sector, see chp. 7.2.2.
- Imported HWP were not included in the HWP pool.
- Exported HWP were included in the HWP pool.
- The share of industrial roundwood ( $f_{IRW}$ ) used for calculating the domestic production of HWP originating from domestic forests was derived according to equation 2.8.1 in IPCC (2014).
- For estimating the domestic HWP contribution of paper and paperboard, the feedstock factors  $f_{IRW}$  and  $f_{PULP}$  (see equation 2.8.2 in IPCC 2014) were applied according to equation 2.8.4 in IPCC (2014).
- For estimating the HWP contribution of paper and paperboard, the recovered wood pulp from recovered paper was excluded from the feedstock. For this purpose, the net consumption of recovered pulp was calculated from FAO data on production, export and import of recovered fibre pulp (see FOEN 2023e).
- The change in HWP carbon stocks was estimated separately for each product category and differentiating HWP from deforestation (biomass losses in categories 4B2.1 to 4F2.1 Forest land converted to X) and from Forest land (category 4A) by applying equation 2.8.4 in IPCC (2014). Instantaneous oxidation was assumed for HWP originating from deforestation.

#### 6.10.2.2. Activity data

The time series are shown in CRF Table4.Gs2. The activity data are described in detail in FOEN (2023e):

- Production data for all product categories (sawnwood, wood panels, paper and paperboard, and recovered fibre pulp) were retrieved from FAOSTAT for the years 1961–2020 (<http://www.fao.org/faostat/en/#data/FO>, Forestry Production and Trade).
- In order to estimate the share of industrial roundwood and the share of fibre pulp originating from domestic forests as feedstock for HWP production, data from national wood processing statistics and foreign trade statistics (import and export) available from FAOSTAT 1961–2020 were used.
- For the year 2021, FAOSTAT data were not available yet for the latest submission. Provisionally, the data of 2020 were used for 2021.

In order to estimate carbon stocks in each HWP category, default carbon conversion factors were taken from IPCC (2014: Table 2.8.1) for wood-based panels. For sawnwood, (1) country-specific wood density values measured by the wood industry and checked against the values published by the NFI (Werner 2019a) and (2) an IPCC (2019) default carbon fraction of 0.5 were used:

- Coniferous sawnwood: 0.41 t/m<sup>3</sup>
- Non-coniferous sawnwood: 0.59 t/m<sup>3</sup>.

### 6.10.2.3. Carbon stock change factors

Carbon stock change factors for specific product categories were calculated following equation 2.8.5 in IPCC (2014) using default half-lives of 25 years for wood panels, 35 years for sawnwood and 2 years for paper products (IPCC 2014: Tab. 2.8.2).

## 6.10.3. Uncertainties and time-series consistency

### 6.10.3.1. Uncertainties

For category 4G HWP, the following information on relative uncertainty was used:

#### Activity data

A mean uncertainty of 11.2 % (Table 6-5) was estimated based on the following expert judgements considering the type and reliability of data source:

- Roundwood harvest: 5 % (national activity data from the Swiss Forestry Statistics, annual complete survey)
- Sawnwood production: 5 % (national activity from survey on wood processing in sawmills, combined survey)
- Wood Panels production: 5 % (national activity from survey in the wood industry)
- Paper and Paperboard production: 5 % (activity data from FAOSTAT)
- Share of domestic wood used in the production of sawnwood, panels and paper: 10 % (based on foreign trade statistics in the FAO database)

$$U_{\text{HWPAD}} = \sqrt{5^2 + 10^2} = 11.2 \%, \text{ for each product category.}$$

#### Conversion factors (carbon stock change factors)

The uncertainties of conversion factors used to calculate emission factors were based on the following sources:

- Wood density: 20 %; a preliminary uncertainty assessment based on expert judgement results in medium to high uncertainty for the country-specific measurements of the wood industry. According to Werner (2019a), the main source of uncertainty is the water content of the HWP.
- Carbon contents in wood products: 10 % (Lamlom and Savidge 2003, assessment of carbon content in wood; IPCC 2006, Volume 4, Table 12.6).
- Half-lives: 50 % (default from IPCC 2006, Volume 4, Table 12.6).

The resulting uncertainty of the carbon stock change factors (CSCF) for HWP amounts to 54.8 % (Table 6-5):

$$U_{\text{HWP CSCF}} = \sqrt{20^2 + 10^2 + 50^2} = 54.8 \%$$

## Overall uncertainty 4G

The overall relative uncertainty of HWP was thus calculated as:

$$U_{\text{HWP Combined}} = \sqrt{11.2^2 + 54.8^2} = 55.9 \%$$

### 6.10.3.2. Time-series consistency

Time series for category 4G Harvested wood products are all considered consistent; they were calculated based on consistent methods and homogenous databases.

### 6.10.4. Category-specific QA/QC and verification

The general QA/QC measures are described in chp. 1.5.

In 2019, methods and calculations were reviewed by an external expert (Werner 2019a). Based on the review, the calculation procedure for HWP was thoroughly restructured and several improvements and recalculations were made in the course of inventory preparation for the submission 2020 (FOEN 2020).

### 6.10.5. Category-specific recalculations

- 4G: Activity data (areas) 2013–2020 were updated (see chp. 6.3.1.5). The inclusion of first data from the AREA5 survey led to small recalculations (Table 6-11) related to the split between harvests on Forest land and on deforestations.
- 4G: 1990–2020: The split between HWP from deforestations and from Forest land was recalculated. In previous submissions, only the biomass loss on deforested area fulfilling the criteria for Deforestation according to the Kyoto Protocol was considered. In the latest submission, the biomass loss on all deforested areas (= categories 4B2.1 to 4F2.1 Forest land converted to X) were considered.

The recalculations resulted in lower inflows to the HWP pool (around -3 %).

### 6.10.6. Category-specific planned improvements

Further improvement could be achieved if also plant-specific activity data could be used instead of exclusively FAO statistics, e.g. for the share of domestic wood used for producing wood panel and sawnwood. The availability and suitability of such data for reporting in category 4G is subject to ongoing evaluation.

## 7. Waste

Responsibilities for sector Waste	
Overall responsibility	Daiana Leuenberger (FOEN)
Method updates & authors	Michael Bock (FOEN, 5D), Daiana Leuenberger (FOEN)
EMIS database operation	Daiana Leuenberger (FOEN)
Annual updates (NID text, tables, figures)	Beat Rihm (Meteotest), Dominik Eggli (Meteotest)
Quality control NID (annual updates)	Dominik Eggli (Meteotest), Rainer Kegel (FOEN), Daiana Leuenberger (FOEN), Adrian Schilt (FOEN)
Internal review	Rainer Kegel (FOEN), Adrian Schilt (FOEN)

### 7.1. Overview

#### 7.1.1. Greenhouse gas emissions

Within sector 5 Waste, emissions from five source categories are considered:

- 5A Solid waste disposal
- 5B Biological treatment of solid waste
- 5C Incineration and open burning of waste
- 5D Wastewater treatment and discharge
- 5E Other (no direct GHG emissions, but indirect GHG emissions included in CRF Table6 as documented in chp. 9)

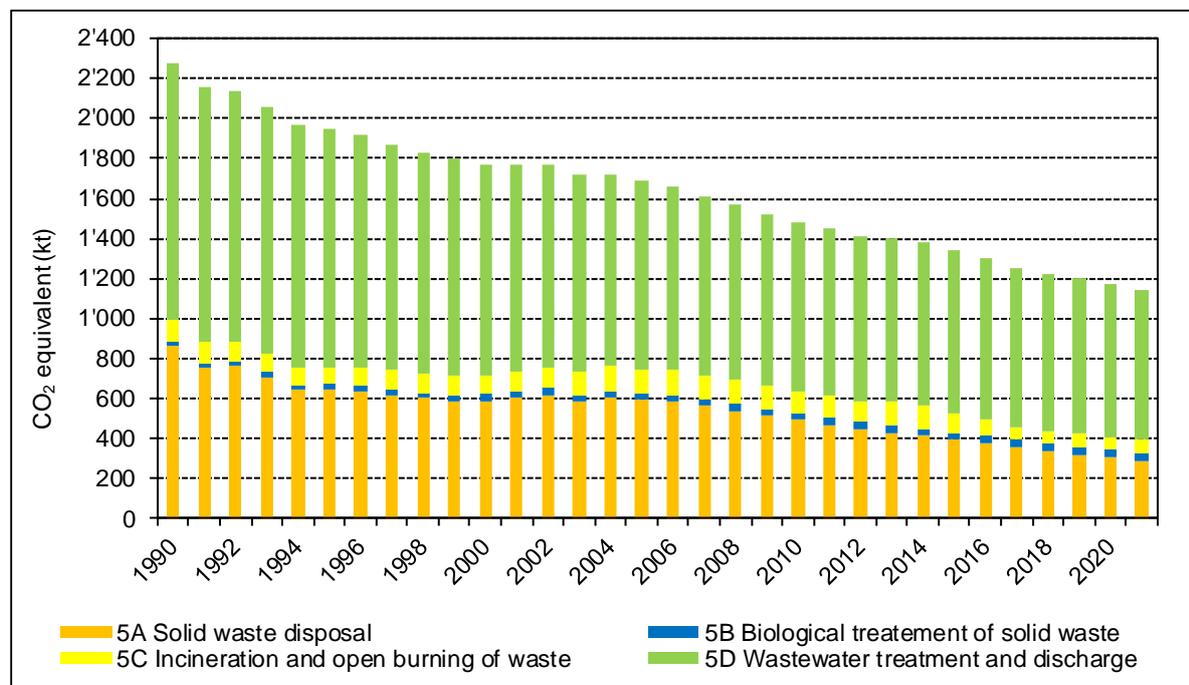


Figure 7-1 Switzerland's greenhouse gas emissions from sector 5 Waste. There are no direct greenhouse gas emissions from sector 5E Other.

The total greenhouse gas emissions from sector 5 Waste show a decrease within the reporting period. 5A Solid waste disposal and 5D Wastewater treatment and discharge are the two dominant source categories. Both show decreasing greenhouse gas emissions.

Table 7-1 Trend of total GHG emissions from sector 5 Waste in Switzerland.

Gas	1990	1995	2000	2005	2010
CO <sub>2</sub> equivalent (kt)					
CO <sub>2</sub>	40	22	17	12	11
CH <sub>4</sub>	1'094	864	801	801	708
N <sub>2</sub> O	1'144	1'059	954	874	765
Sum	2'278	1'945	1'772	1'687	1'484

Gas	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
CO <sub>2</sub> equivalent (kt)										
CO <sub>2</sub>	10	10	9.9	9.9	9.9	9.6	9.4	9.1	8.9	8.7
CH <sub>4</sub>	670	655	643	627	616	601	584	570	557	544
N <sub>2</sub> O	729	739	728	702	675	645	631	620	606	590
Sum	1'410	1'405	1'381	1'338	1'300	1'256	1'224	1'199	1'171	1'142

CH<sub>4</sub> and N<sub>2</sub>O are dominant and of similar importance in sector 5 Waste over the entire reporting period. Overall, they both show a decreasing trend. CO<sub>2</sub> is negligible.

The relative trends of all greenhouse gases are shown in Figure 7-2.

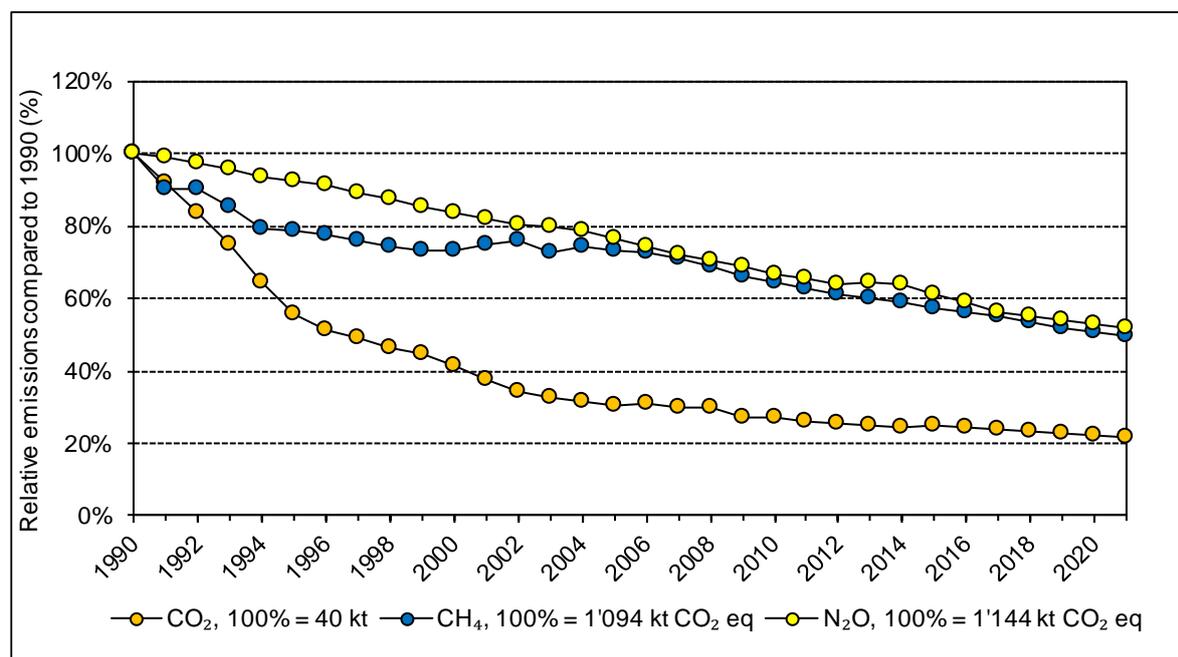


Figure 7-2 Relative trends of greenhouse gas emissions from sector 5 Waste. The base year 1990 represents 100 %.

According to the 2006 IPCC Guidelines (IPCC 2006) all emissions from waste-to-energy, i.e. emissions resulting when waste material is used directly as fuel or converted into a fuel, are reported under sector 1 Energy (see also Figure 7-5). Therefore, the largest share of waste-related emissions in Switzerland is not reported under sector 5 Waste. This is illustrated in

Figure 7-3 which provides an overview of all waste-related GHG emissions in Switzerland reported in chp. 7 and elsewhere in the NID.

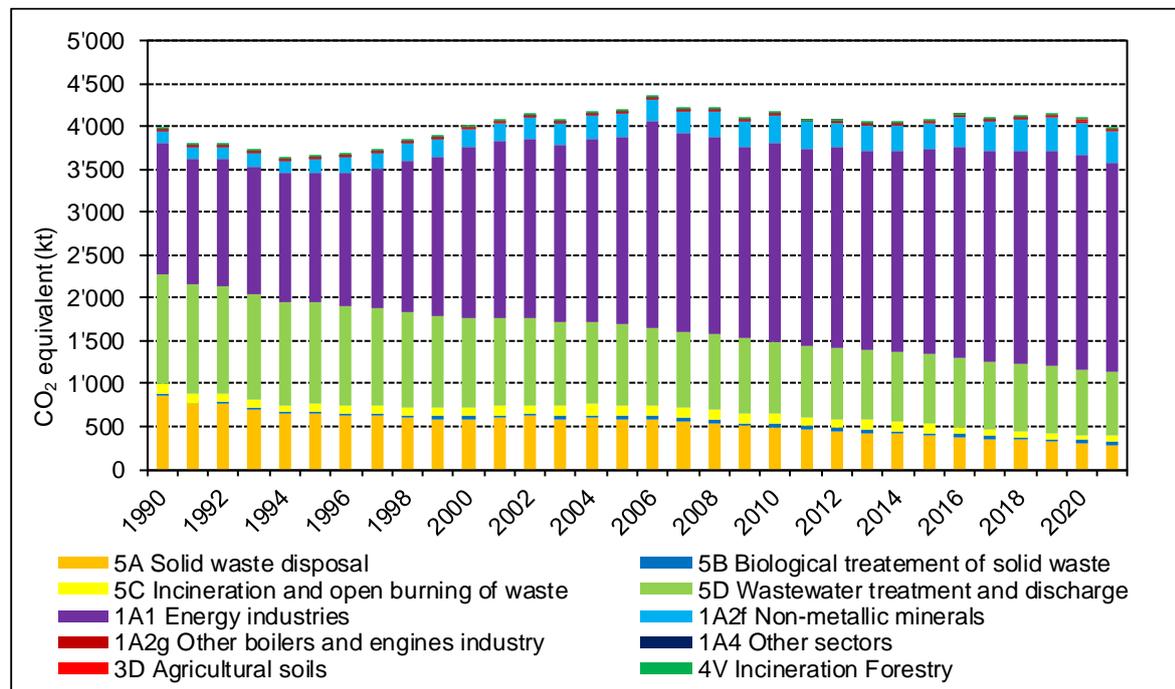


Figure 7-3 Total waste-related GHG emissions, reported in different sectors. The energetic use of waste-related biomass is not considered in this figure, as it predominantly leads to emissions of biogenic CO<sub>2</sub> (and only very minor emission of CH<sub>4</sub> and N<sub>2</sub>O).

For sector 5 Waste, there are a total of four identified key categories, emitting CH<sub>4</sub> and N<sub>2</sub>O (see Figure 7-4).

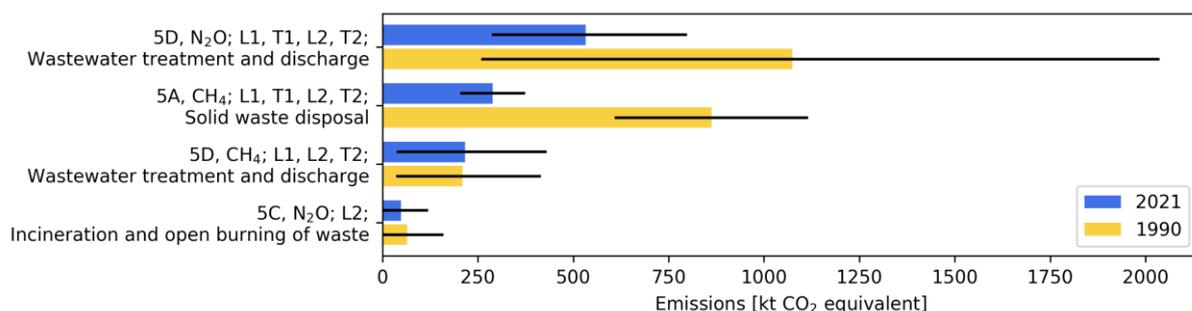


Figure 7-4 Key categories in the Swiss GHG inventory from sector 5 Waste determined by the key category analyses, approaches 1 and 2. Categories are set out in order of decreasing emissions in 2021. L1: key category according to approach 1 level in 2021; L2: same for approach 2; T1: key category according to approach 1 trend 1990–2021; T2: same for approach 2. Black uncertainty bars represent the narrowest 95 % confidence interval obtained by Monte Carlo simulations (see chp. 1.6 for details).

### 7.1.2. Overview of waste management in Switzerland

Goals and principles regarding waste management in Switzerland are stated in the Guidelines on Swiss Waste Management (BUS 1986), in the Waste Concept for Switzerland

(SAEFL 1992) and in the Ordinance on the Avoidance and the Disposal of Waste (Swiss Confederation 2015).

The four principles are:

- The generation of waste shall be avoided as far as possible.
- Pollutants from manufacturing processes and in products shall be reduced as far as possible.
- Waste shall be recycled wherever this is environmentally beneficial and economically feasible.
- Waste shall be treated in an environmentally sound way. In the long term only materials of final storage quality shall be disposed of in landfills.

Figure 7-5 gives a general overview of the type of treatment and amounts of waste treated in the respective sectors in Switzerland, including waste imports and waste exports. Only waste fractions that are relevant for emissions are shown. The figure further illustrates where the processes related to the waste management system are reported in the NID. The following details can be provided regarding the different sectors:

- **1 Energy:** In accordance with the IPCC Guidelines (IPCC 2006) emissions from waste-to-energy activities, where waste is used as an alternative fuel for energy production, are reported in 1A Fuel combustion. This applies to municipal solid waste incineration plants and special waste incineration plants, where energy is recovered (1A1a). Municipal solid waste incineration plants treat burnable municipal solid waste as well as sewage sludge, burnable construction waste and some special wastes. Cement industry uses conventional fossil fuels but also alternative fuels, which are special waste, dried sewage sludge, biomass as well as plastics collected separately or segregated from solid waste streams (1A2fi). The digestion of biomass in agricultural and industrial biogas facilities and of sewage sludge in wastewater treatment plants as well as the use of landfill gas are also reported in sector 1 Energy (source categories 1A1a, 1A2gviii and 1A4ci), as such biogas and sewage gas is used for combined heat and power generation. The energy production from renewable goods, such as the use of wood waste in wood-fired power stations, is reported under 1A1a, 1A2, 1A4ai and 1A4bi and 1A4ci.
- **3 Agriculture:** Since 2003 it is forbidden in Switzerland to use sewage sludge as a fertiliser. As of 2006, this prohibition has been made effective for all agricultural areas with a transition period to 2008. Since 2009, sewage sludge has no longer been applied; however, the use of compost (other organic fertiliser) has increased (see chp. 5.5.2.2 Direct N<sub>2</sub>O emissions from managed soils, Table 5-24).
- **5 Waste:** Only emissions from waste management activities not used for energy production are reported under sector 5 Waste. Solid waste disposal is no longer practiced in Switzerland as incineration has been mandatory for the disposal of combustible waste since 2000. Emissions from composting are described under 5B1. Emissions related to digestion, but not directly related to energy production (such as the storage of digested biomass), are reported under 5B2. 5C Waste incineration and open burning of waste accounts for a small fraction only, consisting of illegal waste incineration, sewage sludge incineration, burning of residues in agriculture and private households as well as cremations. Special waste incineration without energy recovery, such as cable incineration or hospital waste incineration plants, no longer takes place in Switzerland and is thus crossed out in the figure. These waste fractions are nowadays incinerated in municipal solid waste incineration plants and are therefore reported under sector 1 Energy. Emissions related to wastewater treatment are reported under 5D.

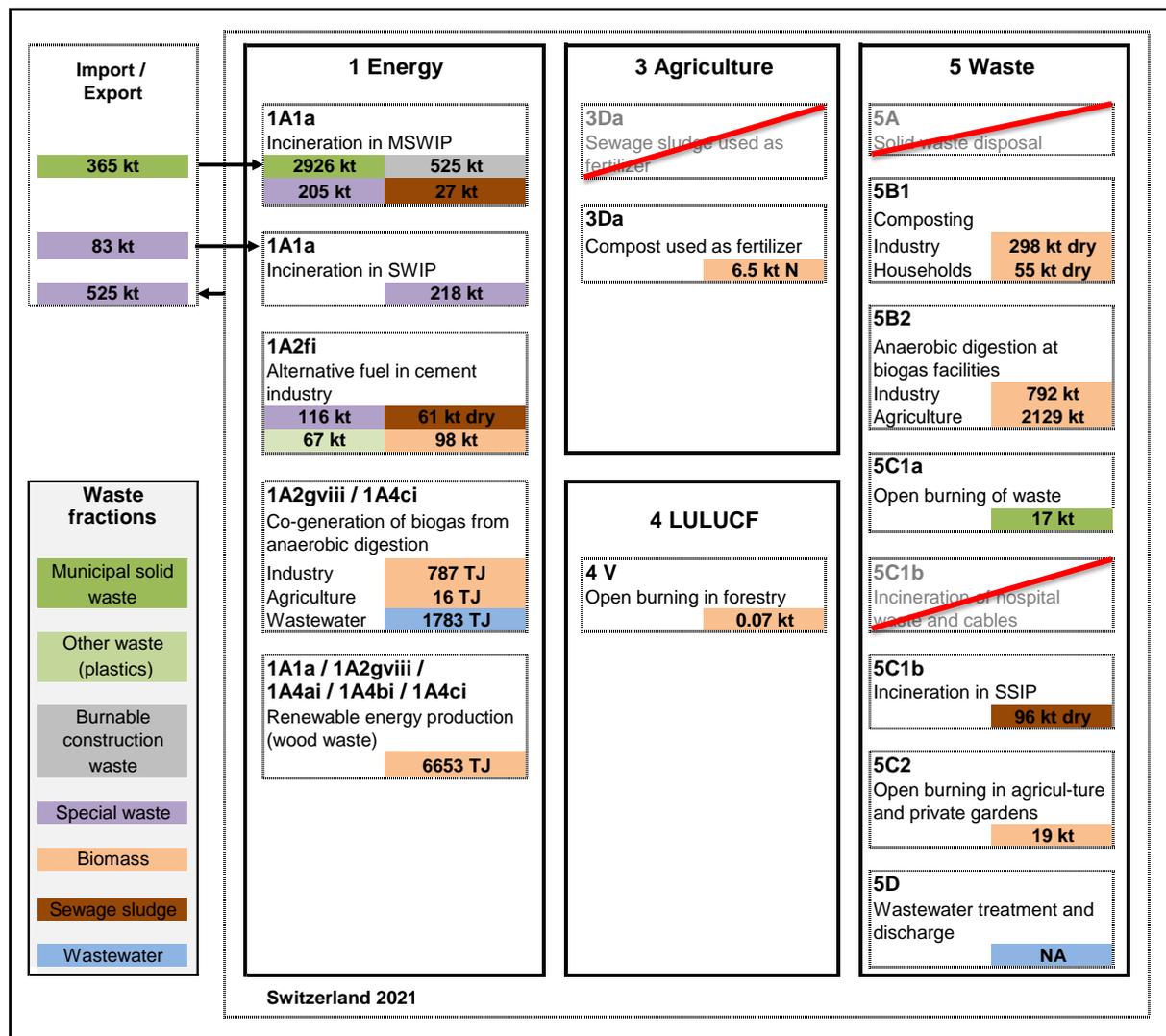


Figure 7-5 Overview on the type of treatment and amounts of waste treated in the respective sectors in Switzerland in 2021. Abbreviations: MSWIP: Municipal Solid Waste Incineration Plant, SWIP: Special Waste Incineration Plant, SSIP: Sewage Sludge Incineration Plant.

Regarding the treatment and amounts of relevant waste types the following details can be provided (recycled amounts are not shown in Figure 7-5 because they are not relevant for emissions):

- Municipal solid waste:** In Switzerland more than 50 % of the municipal solid waste is collected separately and recycled (FOEN 2022h). The amount of waste incinerated includes imported municipal solid waste, mainly from neighbouring countries such as Germany, France, Austria and Italy. The import of waste into Switzerland needs to be authorized by the Federal Office for the Environment. A part of the separately collected plastic fractions from households and industry which cannot be recycled is used as an alternative fuel in the cement industry.
- Construction waste:** More than 50 % of the construction waste is recycled. About half of the recycling takes place at the construction sites, e.g. by reusing material left after breaking up the road cover. The other half is separated at the construction sites and recycled individually, e.g. used glass, metals, concrete etc. A minor amount of combustible construction waste is incinerated in municipal solid waste incineration plants. The remaining, inert construction waste is disposed of in landfills for inert waste (ERM 2016; Wüest & Partner 2015).

- **Special waste:** Special waste refers to a highly diverse waste fraction encompassing hospital wastes, batteries, electronic waste, hazardous industrial sludge, contaminated soils, solvents, chemicals etc. Special waste is either recycled, biologically treated, landfilled, burnt or exported for landfilling in foreign countries (FOEN 2022h). Only the amount of incinerated special waste is relevant for emissions (EMIS 2023/1A1a Kehrichtverbrennungsanlagen and EMIS 2023/1A1a Sondermüllverbrennungsanlagen). Some special waste is also used as an alternative fuel in the cement production (EMIS 2023/1A2f i Zementwerke Feuerung).
- **Sewage sludge:** Since 2009 sewage sludge has not been used anymore as a fertiliser in agriculture. Such use has been prohibited due to the content of organic contaminants, heavy metals and other substances (see chp. 5.5.2.2.2). Therefore, all sewage sludge is incinerated, either in municipal solid waste incineration plants or in sewage sludge incineration plants without energy recovery (internal information provided by the waste section of FOEN). Dried sewage sludge is also used as an alternative fuel in the cement industry (EMIS 2023/1A2fi Zementwerke Feuerung).
- **Biomass:** The term biomass refers to a broad range of materials such as garden waste, grass, wood waste, liquid manure and production remains e.g. from the food industry. Biomass from agriculture, forestry and private gardens are burnt without energy recovery (EMIS 2023/5C2 & 4VA1 Abfallverbrennung Land- und Forstwirtschaft). Biomass is also digested or composted (in large-scale composting facilities or backyards). Quantities of biomass refer to dry matter. Biomass such as used wood or animal fat is used as an alternative fuel in the cement industry (EMIS 2023/1A2fi Zementwerke Feuerung). Compost is used as a fertiliser and quantities refer to dry matter (see Table 5-24 “Other organic fertilisers”).

## 7.2. Source category 5A – Solid waste disposal

### 7.2.1. Source category description

Table 7-2 Key categories of 5A Solid waste disposal. Combined KCA results, level for 2021 and trend for 1990–2021, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC category	Gas	Identification criteria
5A	Solid waste disposal	CH4	L1, T1, L2, T2

Source category 5A1 Managed waste disposal sites comprises all emissions from managed solid waste landfill sites. As incineration has been mandatory for combustible waste since 2000, inputs into managed solid waste landfill sites have dropped to zero. Remaining emissions thus originate from landfilling before 2000. Emissions from source category 5A2 Unmanaged waste disposal sites are included in source category 5A1 Managed waste disposal sites. This is motivated by the fact that in Switzerland to date no official unmanaged waste disposal sites exist. Although no reliable data is available, the effective quantity of waste not properly treated in landfills is estimated to be very small.

In Switzerland, less than four managed biogenically active landfill sites were equipped to recover landfill gas in 2020 (SFOE 2022a). While some landfill gas is used to generate heat only, the landfill gas is generally used in co-generation plants in order to produce electricity and heat. A small amount of the landfill gas is flared (Consaba 2016).

Emissions from the usage of landfill gas in combined heat and power units are reported in sector 1 Energy in source category 1A1a Public electricity and heat production (see Figure 3-18).

Table 7-3 Specification of source category 5A Solid waste disposal in Switzerland.

5A	Source category	Specification
5A1	Managed waste disposal sites	Emissions from managed solid waste landfill sites.
5A2	Unmanaged waste disposal sites	Officially no unmanaged waste disposal sites exist (included in 5A1)
5A3	Uncategorized waste disposal sites	Not occurring in Switzerland

## 7.2.2. Methodological issues

### Methodology (5A)

Emissions are calculated by a Tier 2 method based on the decision tree in the IPCC Guidelines (IPCC 2006, vol. 5, chp. 3, Fig. 3.1). The spreadsheet for the First Order Decay (FOD) model provided by IPCC (2006) has been applied and parametrised for Swiss conditions (FOEN 2023m).

The values for the parameter degradable organic carbon are provided for each waste fraction (Table 7-4). For all waste types the IPCC (2006) default values are used, except for industrial waste. For industrial waste the default value for wood and straw is used, as most of the industrial waste deposited in Switzerland is assumed to be wood waste.

Table 7-4 Degradable organic carbon values for fractions of different waste compositions (weight fraction, wet basis).

Waste composition (weight fraction, wet basis)	IPCC default value		Country-specific parameters	
	Range	Default	Swiss Value	Reference and remarks
Food waste	0.08-0.20	0.15	0.15	
Garden	0.18-0.22	0.2	0.2	
Paper	0.36-0.45	0.4	0.4	
Wood and straw	0.39-0.46	0.43	0.43	
Textiles	0.20-0.40	0.24	0.24	
Disposable nappies	0.18-0.32	0.24	NO	not relevant/no activity data
Sewage sludge	0.04-0.05	0.05	0.05	
Industrial waste	0.00-0.54	0.15	0.43	all waste wood

The methane generation rate [1/yr] is chosen according to wet temperate conditions (Table 7-5). For all waste types the IPCC (2006) default values are used, except for industrial waste. For industrial waste the default value for wood and straw is used, again based on the fact that most of it is assumed to be wood waste.

Table 7-5 Methane generation rate [1/yr] according to waste by composition for wet temperature conditions.

Waste composition (weight fraction, wet basis)	IPCC default value		Country-specific parameters	
	Range	Default	Swiss Value	Reference and remarks
Food waste	0.1–0.2	0.185	0.185	
Garden	0.06–0.1	0.1	0.1	
Paper	0.05–0.07	0.06	0.06	
Wood and straw	0.02–0.04	0.03	0.03	
Textiles	0.05–0.07	0.06	0.06	
Disposable nappies	0.06–0.1	0.1	NO	not relevant/no activity data
Sewage sludge	0.1–0.2	0.185	0.185	
Industrial waste	0.08–0.1	0.09	0.03	all waste wood

The general parameters are set as follows:

- DOCf (fraction of degradable organic carbon dissimilated) = 0.5 (IPCC (2006) default value)
- Delay time (months) = 6 (IPCC (2006) default value)
- Fraction of methane (F) in developed landfill gas = 0.5 (IPCC (2006) default value)
- Conversion factor, C to CH<sub>4</sub> = 1.33 (IPCC (2006) default value)
- Oxidation factor (OX) = 0.1

The oxidation factor has been set to 0.1 according to the 2006 IPCC Guidelines (IPCC 2006, vol. 5, chp. 3), since it is standard practice in Switzerland to cover the landfills, e.g. with soil.

For the methane correction factors (MCF) for the different solid waste disposal site types IPCC default values are used. Between 1990 and 2015 (the IPCC spreadsheet has to be parametrised from 1950 to 2030/2050) waste distribution to the following three solid waste disposal site types has taken place (for both municipal solid waste and industrial waste):

- Methane correction factor for unmanaged, shallow solid waste disposal sites (SWDS) = 0.4 (IPCC (2006) default value)
- Methane correction factor for unmanaged, deep solid waste disposal sites = 0.8 (IPCC (2006) default value)
- Methane correction factor for managed solid waste disposal sites = 1 (IPCC (2006) default value)
- The other two methane correction factor (managed, semi-aerobic and uncategorised) are not relevant because such solid waste disposal sites are not occurring in Switzerland, i.e. no waste has been distributed to such sites.

As shown in Table 7-6, the composition of municipal solid waste deposited has changed during the last 60 years.

Table 7-6 Composition of municipal solid waste going to solid waste disposal sites (BUS 1978, BUS 1984, FOEN 2014o).

Waste fraction	1950-1979	1980-1989	1990-1999	2000-2009	since 2010
Food	20.0%	26.5%	21.4%	26.6%	31.5%
Garden	8.0%	2.9%	1.6%	1.4%	1.7%
Paper	36.0%	30.6%	28.0%	21.0%	17.2%
Wood	4.0%	4.3%	5.0%	2.0%	1.8%
Textile	4.0%	3.1%	3.0%	3.0%	3.2%
Nappies	0.0%	0.0%	0.0%	0.0%	0.0%
Plastics, other inert	28.0%	32.6%	41.0%	46.0%	44.6%

With these parametrisations and the activity data for municipal solid waste, industrial waste and sewage sludge the amount of CH<sub>4</sub> generated in landfills is calculated. The amount of CH<sub>4</sub> recovered and used as fuel for combined heat and power generation or flared is then subtracted.

For combined heat and power generation and flaring, the emissions of other gases are considered to be proportional to the amount of CH<sub>4</sub> burnt (Table 7-7).

Long-term storage of carbon in waste disposal sites, annual change in total long-term storage of carbon and annual change in total long-term storage of carbon in harvested wood products has been calculated with the parametrised spreadsheet model provided by IPCC (2006) as well and is reported in CRF Table5 as memo item. As incineration has been mandatory for combustible waste since 2000 in Switzerland and solid waste disposal activities have ceased there is no annual change since 2007.

### Emission factors (5A)

Emission factors for CO<sub>2</sub>, CH<sub>4</sub>, CO, NMVOC and SO<sub>2</sub> are country-specific based on measurements and expert estimates, as documented in EMIS 2023/1A1 & 5A Kehrichtdeponien. The emission factor of NMVOC from flaring has been introduced based on a study on emissions from landfill gas installations (Butz 2003) suggesting emissions of 82.15 grams of NMVOC per tonne of CH<sub>4</sub> flared with an uncertainty of ±10 %. CO<sub>2</sub> emissions from non-biogenic waste are included, while CO<sub>2</sub> emissions from biogenic waste are excluded from total emissions. Table 7-7 presents the emission factors used in 5A1.

Table 7-7 Emission factors for 5A1 Managed waste disposal sites in 2021.

5A1 Managed waste disposal sites	Unit	CO <sub>2</sub>	CO <sub>2</sub>	CH <sub>4</sub>	NO <sub>x</sub>	CO	NMVOC	SO <sub>2</sub>
		biogen	fossil					
Direct emissions from landfill	t / t CH <sub>4</sub> produced	3.0	NA	1.0	NA	NA	0.013	NA
Flaring	kg / t CH <sub>4</sub> burned	2750	NA	NA	1.0	17	0.082	NA
Open burning	kg / t waste burned	568	520	6.0	2.5	50	16	0.75

### Activity data (5A)

There are three kinds of activity data for 5A1 Managed waste disposal sites: Waste quantities disposed on landfills, direct CH<sub>4</sub> emissions and CH<sub>4</sub> flared.

For the calculation of these three kinds of activity data, the amounts of municipal solid waste, construction waste and sewage sludge (deposited on managed waste disposal sites) are relevant.

Table 7-8 Activity data in 5A1: Waste disposed on managed waste disposal sites since 1950 (documented in EMIS 2023/1A1a & 5A Kehrichtdeponien).

5A1 Managed waste disposal sites	Unit	1950	1960	1970	1980	1990	1995	2000	2005	2010 - 2021
Municipal solid waste (MSW)	kt	570	675	864	532	650	540	292	14	NO
Construction waste (CW)	kt	9.9	11	36	85	150	60	54	1.4	NO
Sewage sludge (SS)	kt (dry)	NO	NO	3.2	30	60	28	4.2	0.98	NO
Open burned waste	kt	299	294	226	97	NO	NO	NO	NO	NO
Total waste quantity	kt	879	980	1129	744	860	628	350	16	NO

Table 7-8 documents the amounts of municipal solid waste, construction waste and sewage sludge disposed of on managed waste disposal sites since 1950 (as documented in EMIS 2023/1A1a & 5A Kehrichtdeponien). An increase of waste landfilled until 1970 can be observed. The decline of waste amounts landfilled afterwards is due to changes in the legislative framework, making incineration mandatory for disposal of combustible waste and banning the disposal of combustible waste on landfills from 1 January 2000. The amounts of combustible waste disposed of on managed waste disposal sites reached zero in 2009. While open burning of waste on managed waste disposal sites occurred in the distant past it is assumed that, by reason of legal requirements and regulations, open burning has not taken place since 1990 anymore (Consaba 2016) and is therefore NO in Table 7-8.

With these primary activity data total CH<sub>4</sub> emissions generated are calculated using the spreadsheet first order decay model provided by IPCC (2006). For the calculation of direct CH<sub>4</sub> emissions, CH<sub>4</sub> flared and used in co-generation units is determined and subtracted from total CH<sub>4</sub> emissions (Table 7-9). The landfill gas recovered and used as fuel for co-generation units is reported under 1A1 Energy in accordance with the 2006 IPCC Guidelines (IPCC 2006). The sum of landfill gas flared and landfill gas used in co-generation units is reported as being recovered in CRF Table 5.A.

The amount of CH<sub>4</sub> used in co-generation is taken from the Swiss statistics of renewable energies (SFOE 2022a). The amount of landfill gas flared has been assessed in a separate investigation (Consaba 2016). The CH<sub>4</sub> flared has been estimated as follows:

- A list of all managed waste disposal sites that are still operated or have been closed since 1990 was compiled.
- Their technical equipment was assessed and deduced (motors, torches, gas drainage, etc.).
- Four types of managed landfill sites according to their equipment and CH<sub>4</sub> management were distinguished:
  - landfills with gas recovery in combined heat and power generation, boiler and torch; category a);
  - landfills with gas recovery or thermal treatment (boiler, torch, non-catalytic oxidation, flameless oxidation; category b);
  - landfill gas recovery without methane elimination (bio filter, aerobiosation); category c);
  - landfills without gas treatment (direct release); category d).

- A survey was conducted in 14 managed waste disposal sites and data on their operation mode has been collected.
- With these data the amounts flared in managed waste disposal sites categories a) and b) were estimated.
- The amount flared on all managed waste disposal sites has been extrapolated considering the waste amounts deposited.
- A time series for the amount of methane torched relative to the total amount of CH<sub>4</sub> estimated with the Swiss first order decay IPCC 2006 model (managed and unmanaged sites) has been calculated.

The amount flared is expressed as a percentage of CH<sub>4</sub> produced in all managed waste disposal sites in Switzerland. The percentage flared varies between 5 and 15 % since 1990.

Table 7-9 Activity data in 5A1: Direct CH<sub>4</sub> emissions, CH<sub>4</sub> flared and CH<sub>4</sub> used in combined heat and power units (as documented in EMIS 2023/1A1a & 5A Kehrichtdeponien).

5A1 Managed waste disposal sites	Unit	1990	1995	2000	2005	2010					
CH <sub>4</sub> direct emissions	kt	31	23	21	21	18					
CH <sub>4</sub> flared	kt	1.8	5.3	5.6	3.4	2.4					
CH <sub>4</sub> used in co-generation units (reported under 1A1a)	kt	4.9	12	11	4.1	0.97					
5A1 Managed waste disposal sites	Unit	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
CH <sub>4</sub> direct emissions	kt	16	15	15	14	13	13	12	11	11	10
CH <sub>4</sub> flared	kt	1.8	1.6	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.3
CH <sub>4</sub> used in co-generation units (reported under 1A1a)	kt	0.88	0.76	0.62	0.42	0.25	0.13	0.12	0.17	0.078	0.078

Waste quantities disposed in landfills started to decrease in the early 1990s and have ceased completely from 2009 onwards. The continuous decrease of CH<sub>4</sub> generated by decaying waste over time, in combination with the relative increase of CH<sub>4</sub> recovery from 1990 until 2017 yields a pronounced trend of CH<sub>4</sub> emissions from source category 5A.

### 7.2.3. Uncertainties and time-series consistency

#### Uncertainty in CH<sub>4</sub> emissions from 5A Solid waste disposal

For lack of a detailed uncertainty analysis with the new first order decay model, a combined uncertainty of 30 % is assumed for the CH<sub>4</sub> emissions (EMIS 2023/1A1a & 5A Kehrichtdeponien).

Consistency: Time series for 5A Solid waste disposal are all considered consistent.

### 7.2.4. Category-specific QA/QC and verification

The general QA/QC measures are described in chp. 1.5.

### 7.2.5. Category-specific recalculations

There were no recalculations implemented in submission 2023.

## 7.2.6. Category-specific planned improvements

No category-specific improvements are planned.

## 7.3. Source category 5B – Biological treatment of solid waste

### 7.3.1. Source category description

Table 7-10 Key categories of 5B – Biological treatment of solid waste. Combined KCA results, level for 2021 and trend for 1990–2021, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Source category 5B – Biological treatment of solid waste is not a key category.

Source category 5B Biological treatment of solid waste comprises the process-related GHG emissions from composting and from digesting of organic waste.

Within 5B1 Composting two kinds of composting are distinguished, i.e. industrial composting and backyard composting. Industrial composting covers the emissions from centralized composting activities with a capacity of more than 100 tonnes of organic matter per year as well as the composting of organic material at the border of agricultural fields. Backyard composting in private households or communities is also common practice in Switzerland and therefore considered.

In 5B2 Anaerobic digestion at biogas facilities emissions occur from gas leakages as well as from digested matter (solid leftovers after completion of anaerobic microbial degradation of organic matter) which is being composted. The biogas is used for combined heat and power generation or is upgraded and used as fuel.

In 5B Biological treatment of solid waste the emissions from the composting of digested matter as well as the CH<sub>4</sub> losses from biogas facilities and emerging from biogas upgrading are included. Emissions related to the use of biogas for combined heat and power generation are reported in sector 1 Energy source categories 1A2gviii Other and 1A4ci Agriculture/forestry/fishing (see Figure 3-18). Emissions related to the use of upgraded biogas fed into the natural gas grid are reported in sector 1 Energy source categories 1A3bi-iii Road transportation and 1A4ai Commercial boilers (see Figure 3-18).

Table 7-11 Specification of source category 5B Biological treatment of solid waste.

5B	Source category	Specification
5B1	Composting	Process-related emissions from composting of organic waste
5B2	Anaerobic digestion at biogas facilities	Process-related emissions from digesting of organic waste

## 7.3.2. Methodological issues

### 7.3.2.1. Composting (5B1)

#### Methodology (5B1)

Emissions are calculated by a Tier 2 method based on the IPCC Guidelines (IPCC 2006, vol. 5, chp. 4.1.1 Biological treatment of solid waste).

Activity data and emission factors for industrial and backyard composting have been thoroughly reassessed in 2017 (Schleiss 2017), new data were gained and EMIS 2023/5B1 Kompostierung, which serves as basis for greenhouse gas emission estimates, has been revised accordingly.

#### Emission factors (5B1)

Emission factors used for source category 5B1 Composting are summarized in Table 7-12 and documented in detail in EMIS 2023/5B1 Kompostierung. Emission factors are country-specific and encompass CH<sub>4</sub>, N<sub>2</sub>O and NMVOC based on measured or estimated values reported in the literature. The emission factors are based on a recommendation by Schleiss (2017) based on Dinkel et al. (2012). They are based on measurements and taking into account the predominantly non-industrial (ban on refuse composting) origin of composted material in Switzerland resulting in a rotting process as aerobic as possible to produce compost of marketable quality. This yields a lower emission factor for CH<sub>4</sub> compared to reference values (IPCC 2006).

#### Activity data (5B1)

Activity data for source category 5B1 Composting are shown in Table 7-13 and documented in detail in EMIS 2023/5B1 Kompostierung.

Activity data for industrial composting are based on waste surveys (Schleiss 2017). For 2013 reliable data on waste quantities are available (FOEN 2016m). All cantons were addressed and data on the amounts of organic waste quantities, according to their respective treatment option, have been collected. Data on waste quantities are also available from surveys in 1989, 1993 and 2000. Activity data between these years were interpolated. The time series were validated with additional data sets from the years 2002 and 2010. After 1993 digesting of organic waste was also becoming a relevant treatment option and therefore respective amounts were subtracted. In addition, also waste wood quantities were subtracted, in order to get the amount of organic waste treated in industrial composting plants. As of 2014, activity data for industrial composting are adopted from the annual statistical reports by the inspectorate system for the composting and fermentation industry in Switzerland (CVIS) as recommended by Schleiss (2017). Since submission 2023 data are obtained from the protocol of the "Kantonstag des Vereins Inspektorat" as the association ceased to produce an annual report but presents the data during this annual meeting (CVIS 2022).

Activity data for backyard composting were reassessed in 2017 (Schleiss 2017). Basically, amounts of organic waste composted in backyards are based on expert assessments and are derived from data from a small number of cities and villages. The experts took into account different parameters affecting waste amounts composted in backyards over time, i.e. urban or rural situation, communication e.g. by community authorities and incentive programmes, and on the availability of separate door-to-door collection of organic wastes. As of 2008, activity data for backyard composting are assumed to be constant as recommended by Schleiss (2017). The unit of activity data and emission factors are reported as mass of dry

matter according to the Guidelines reference for CRF tables. A transfer factor from wet to dry matter of 54.5 % has been suggested by CVIS (2019).

### 7.3.2.2. Anaerobic digestion at biogas facilities (5B2)

#### Methodology (5B2)

In source category 5B2 Anaerobic digestion at industrial and agricultural biogas facilities are considered. The produced biogas is used for combined heat and power generation or upgraded to natural gas quality. Accordingly, biogas upgrading is considered as a separate process in 5B2. However, emissions from the use of biogas as fuel for combined heat and power generation are reported under sector 1 Energy, in accordance with the IPCC Guidelines (IPCC 2006).

For the emissions from 5B2 Anaerobic digestion at biogas facilities, a Tier 2 method is used. While industrial and agricultural biogas facilities are separately considered, the same emission factors are used (see below). As mentioned above, emissions from biogas upgrading are estimated separately, based on the amount of biogas upgraded.

Emissions of greenhouse gases from industrial and agricultural biogas facilities are estimated using a constant emission factor for each biogas facility. This is based on an evaluation of measurement data for CH<sub>4</sub> losses that has shown that those losses are not dependent on the amount of substrate processed in a particular facility. Therefore, CH<sub>4</sub> emissions are calculated based on an emission factor per plant multiplied by the number of industrial and agricultural biogas facilities, respectively.

In contrast, emissions of air pollutants are calculated based on estimates from up to seven different process steps (such as pre-storage, primary and secondary digester, interim storage, maturing, handling of biogas etc.), as documented in EMIS 2023/1A1a & 5 B 2 Vergärung LW and EMIS 2023/1A1a & 5 B 2 Vergärung IG. However, as CH<sub>4</sub>, CO and NMVOC emissions from source category 5B are of biogenic origin, no indirect CO<sub>2</sub> emissions from this source category are included in CRF Table6 as documented in chp. 9.

N<sub>2</sub>O emissions from source category 5B2 are considered to be negligible according to the IPCC Guidelines (IPCC 2006, vol. 5, chp. 4.1.3), and are therefore set to zero.

#### Emission factors (5B2)

Table 7-12 presents the emission factors used in 5B2 Anaerobic digestion at biogas facilities. As documented in FOEN (2015n), the emission factor for CH<sub>4</sub> for anaerobic digestion at industrial and agricultural biogas facilities is based on investigations performed in the framework of the greenhouse gas emission compensation projects. Field measurements indicate that there is no correlation between the produced amount of biogas and the amount of biogas lost to the atmosphere. The investigated data show that on average each biogas facility loses 1.23 t CH<sub>4</sub> per year to the atmosphere. This value is used to estimate the emissions from industrial and agricultural biogas facilities in Switzerland.

The emission factor for losses of CH<sub>4</sub> from biogas upgrading is based on official regulations regarding maximal CH<sub>4</sub> leakage, as well as studies focussing on CH<sub>4</sub> emissions from biogas upgrading. Accordingly, regulations by the Swiss Gas and Water Association (SGWA 2016a) set an emission limit value for CH<sub>4</sub> losses from biogas upgrading. In 1990, such losses were

allowed to be 5 % of the upgraded amount, in 2014 the limit was lowered to 2.5 %. Measurements in a few biogas upgrade installations in 2007, 2013 and 2014 showed the following losses: 2007 one plant: 2.6 %, 2013 one plant: 1 %, 2014 three plants: 1.3 %, 1.8 %, and 3.5 %. The measurements showed that the emission limits were respected (with the exception of one plant in 2014) and therefore Switzerland decided to set the losses from biogas upgrading to the emission limit value with the assumption of a linear improvement between the 1990 and the 2014 value. The continuous improvement seems plausible, as newer plants show fewer losses and values of less than 1 % to 2.5 % are state of the art.

### Activity data (5B2)

Activity data for 5B2 Anaerobic digestion at biogas facilities, as shown in Table 7-13, are based on data from the Swiss renewable energy statistics (SFOE 2022a). Relevant are the number of industrial and agricultural biogas facilities, as well as the total amount of biogas upgraded.

Table 7-12 Emission factors for 5B Biological treatment of solid waste in 2021.

5B Biological treatment of solid waste	Unit	CH <sub>4</sub>	N <sub>2</sub> O	NO <sub>x</sub>	CO	NM VOC	SO <sub>2</sub>
Composting (industrial)	g/t composted waste	1'835	92	NA	NA	550	NA
Composting (backyard)	g/t composted waste	1'835	92	NA	NA	550	NA
Digestion (industrial biogas facilities)	t/facility	1.23	NA	NA	NA	NA	NA
Digestion (agricultural biogas facilities)	t/facility	1.23	NA	NA	NA	NA	NA
Biogas up-grade	g/GJ	500	NA	NA	NA	NA	NA

Table 7-13 Activity data in 5B Biological treatment of solid waste.

5B Biological treatment of solid waste	Unit	1990	1995	2000	2005	2010					
Composting (industrial)	kt (dry)	131	196	283	287	289					
Composting (backyard)	kt (dry)	60	84	98	93	65					
Digestion (industrial biogas facilities)	number	NO	4	11	14	22					
Digestion (agricultural biogas facilities)	number	102	76	68	72	72					
Biogas up-grade	GJ	NO	NO	19'866	40'637	121'627					

5B Biological treatment of solid waste	Unit	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Composting (industrial)	kt (dry)	291	292	261	234	274	267	259	296	285	298
Composting (backyard)	kt (dry)	55	55	55	55	55	55	55	55	55	55
Digestion (industrial biogas facilities)	number	26	26	25	26	27	28	28	29	27	28
Digestion (agricultural biogas facilities)	number	89	97	98	99	98	106	111	112	119	121
Biogas up-grade	GJ	236'074	277'700	337'415	408'038	442'665	456'665	473'538	551'924	600'094	624'825

To improve transparency the CH<sub>4</sub> and N<sub>2</sub>O emissions of source category 5B Biological treatment of solid waste are shown on a completely disaggregated level in Table 7-14.

Table 7-14 CH<sub>4</sub> and N<sub>2</sub>O emissions of 5B Biological treatment of solid waste.

5B Biological treatment of solid waste	Gas	Unit	1990	1995	2000	2005	2010					
Composting (industrial)	CH <sub>4</sub>	t	240	360	519	526	530					
	N <sub>2</sub> O	t	12	18	26	26	27					
Composting (backyard)	CH <sub>4</sub>	t	110	155	180	170	120					
	N <sub>2</sub> O	t	5.5	7.8	9.0	8.5	6.0					
Digestion (industrial)	CH <sub>4</sub>	t	NO	4.9	14	17	27					
Digestion (agricultural)	CH <sub>4</sub>	t	125	93	84	89	89					
Biogas up-grade	CH <sub>4</sub>	t	NO	NO	16	28	71					

5B Biological treatment of solid waste	Gas	Unit	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Composting (industrial)	CH <sub>4</sub>	t	534	536	478	430	503	490	475	544	523	548
	N <sub>2</sub> O	t	27	27	24	22	25	25	24	27	26	27
Composting (backyard)	CH <sub>4</sub>	t	100	100	100	100	100	100	100	100	100	100
	N <sub>2</sub> O	t	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Digestion (industrial)	CH <sub>4</sub>	t	32	32	31	32	33	34	34	36	33	34
Digestion (agricultural)	CH <sub>4</sub>	t	110	119	121	122	121	130	137	138	146	149
Biogas up-grade	CH <sub>4</sub>	t	128	145	169	204	221	228	237	276	300	312

### 7.3.3. Uncertainties and time-series consistency

#### Uncertainty in CH<sub>4</sub> and N<sub>2</sub>O emissions from composting and digestion

The uncertainty of all emission factors in source category 5B1 Composting is estimated at 30 % for industrial composting and at 100 % for backyard composting. The uncertainty of the related activity data is estimated at 30 % for industrial composting and at 100 % for backyard composting (EMIS 2023/5B1 Kompostierung).

For 5B2 Anaerobic digestion at biogas facilities the uncertainty takes into account the different process steps on one hand and emission factors on the other hand (EMIS 2023/1A1a & 5 B 2 Vergärung LW and EMIS 2023/1A1a & 5 B 2 Vergärung IG).

The overall uncertainty for 5B Biological treatment of solid waste for activity data as well as for emission factor is 30 %.

Consistency: Time series for 5B Biological treatment of solid waste are all considered consistent.

### 7.3.4. Category-specific QA/QC and verification

The general QA/QC measures are described in chp. 1.5.

### 7.3.5. Category-specific recalculations

There were no recalculations implemented in submission 2023.

### 7.3.6. Category-specific planned improvements

5B: A research project in the framework of a joint European research programme is investigating the CH<sub>4</sub> emissions from agricultural biogas facilities. Results will be implemented in the greenhouse gas inventory, if applicable, after completion of the project.

## 7.4. Source category 5C – Incineration and open burning of waste

### 7.4.1. Source category description

Table 7-15 Key categories of 5C Incineration and open burning of waste. Combined KCA results, level for 2021 and trend for 1990–2021, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC category	Gas	Identification criteria
5C	Incineration and open burning of waste	N2O	L2

There is a long tradition in Switzerland to incinerate waste. Since 1991, the incineration of waste has only been legally permitted in appropriate plants with a rated thermal input of at least 350 kW (Ordinance on Air Pollution Control (Swiss Confederation 1985)).

Consequently, the open burning of waste has been prohibited. The heat generated during the incineration has to be recovered in accordance with the Ordinance on the Avoidance and the Disposal of Waste (Swiss Confederation 2015). Following the IPCC Guidelines (IPCC 2006) emissions from waste-to-energy activities are dealt with in 1A1a Public electricity and heat production.

5C1 encompasses incineration of hospital wastes, illegal waste incineration, incineration of insulation material from cables, of sewage sludge and cremations.

5C2 consists of emissions from open burning of branches in agriculture and gardening. Natural agricultural and gardening residues consist of fallen fruit trees, part of diseased residue which are cut up, collected and burnt off-site. Field burning of agricultural residues does not occur in Switzerland. Emissions from open burning of residues in forestry are reported in LULUCF sector 4V (chp. 6.4.2.6.4.1).

Table 7-16 Overview of waste incineration sources reported under 5C.

5C	Source category	Specification
5C1	Hospital waste incineration	Emissions from incinerating hospital waste in hospital incinerators
	Municipal waste incineration (illegal)	Emissions from illegal incineration of municipal solid wastes at home. Emissions from waste incineration at construction sites (open burning)
	Industrial waste incineration	Emissions from incinerating cable insulation materials
	Sewage sludge incineration	Emissions from sewage sludge incineration plants
	Cremation	Emissions from the burning of bodies in crematoria
5C2	Open burning of natural residues in agriculture and private households	Open burning of branches in agriculture and gardening.

## 7.4.2. Methodological issues

### Methodology (5C)

Emissions are calculated using Tier 2 methods based on the IPCC Guidelines (IPCC 2006, vol. 5, chp. 5.2). In general, the greenhouse gas emissions are calculated by multiplying the waste quantity incinerated by emission factors. For crematoria, the greenhouse gas emissions are calculated by multiplying the number of cremations by emission factors.

For sewage sludge incineration plants the respective waste quantities are based on reliable statistical data. The emission factors are based on emission declarations from three incineration plants in 2002 and 2015, respectively that covered approximately one third of the Swiss capacities. Due to the lack of better or newer data these emission factors are kept constant since then and no improvement in flue gas cleaning standards is assumed.

For hospital waste incineration, municipal waste incineration (illegal) and industrial waste incineration (consists of cable insulation materials), the waste quantities used are based on expert estimates.

Emissions from burning of residues in agriculture and gardening are calculated using a Tier 1 method based on the IPCC Guidelines (IPCC 2006, vol. 5, chp. 5.2). Emission factors are taken from the EMEP/EEA guidebook (EMEP/EEA 2019, EMEP/EEA 2002).

Indirect CO<sub>2</sub> emissions resulting from fossil CH<sub>4</sub>, CO and NMVOC emissions from hospital waste incineration, municipal waste incineration (illegal) and industrial waste incineration (consists of cable insulation materials) are included in CRF Table6 as documented in chp. 9.

### Emission factors (5C)

Table 7-17 presents an overview of the emission factors for 5C for the latest inventory year. Documentation and sources are given in: EMIS 2023/5 C 1 (5 C 1 b iii UNECE)\_Spitalabfallverbrennung, EMIS 2023/5 C 1 (5 C 1 a UNECE)\_ Abfallverbrennung illegal, EMIS 2023/5 C 1 (5 C 1 b i UNECE)\_Kabelabbrand, EMIS2023/5 C 1\_(5 C 1 b iv UNECE)\_Klärschlammverbrennung, EMIS2023/ 5 C 2\_4 V A 1\_Abfallverbrennung Land- und Forstwirtschaft and EMIS 2023/5 C 1 (5 C 1 b v UNECE)\_Krematorien.

Table 7-17 Emission factors for 5C Waste incineration and open burning of waste in 2021.

5C Waste incineration and open burning of waste	CO <sub>2</sub>	CH <sub>4</sub>	N <sub>2</sub> O	NO <sub>x</sub>	CO	NMVOC	SO <sub>2</sub>
	t/t	kg/t					
Hospital waste incineration	0.90	NA	0.06	1.5	1.4	0.30	1.3
Municipal waste incineration (illegal)	0.52	6.0	0.15	2.5	50	16	0.75
Industrial waste incineration	1.3	NA	NE	1.3	2.5	0.50	6.0
Sewage sludge incineration	NA	0.10	1.85	0.40	0.10	0.1890	0.16
Open burning of natural residues in agriculture	NA	6.8	0.18	1.4	49	1.5	0.030
Open burning of natural residues in private households	NA	6.8	0.18	1.4	49	1.5	0.030

	CO <sub>2</sub>	CH <sub>4</sub>	N <sub>2</sub> O	NO <sub>x</sub>	CO	NMVOC	SO <sub>2</sub>
	t/crem.	kg/crem.					
Cremation	NA	NA	NA	0.21	0.040	0.0059	NA

Comments on CO<sub>2</sub> emission factors:

- For all waste incineration categories, only CO<sub>2</sub> emissions from non-biogenic waste are taken into account.
- Hospital waste incineration: The waste is mainly of fossil origin. The default value for the CO<sub>2</sub> emission factor is taken from SAEFL (2000). Since 2002 no emissions from hospital waste incineration have occurred, as all hospital waste incinerator plants have been closed and hospital waste is incinerated in municipal solid waste incineration plants (accounted for in 1A1a).
- Municipal waste incineration (illegal): The CO<sub>2</sub> emission factor is estimated by using the same assumption as in case of municipal solid waste incineration: The C-content is based on the study by FOEN (2014I) and the fossil carbon fraction was determined by Rytec (2014). See also chp. 3.2.5.2 and detailed information in EMIS 2023/1A1a Kehrlichtverbrennungsanlagen (pp. 5–7).
- Industrial waste incineration (consists of cable insulation materials): The CO<sub>2</sub> emission factor is based on measurements of the flue gas treatment of a cable disassembling site where O<sub>2</sub> was measured in the flue gas. Assuming that the ratio of CO<sub>2</sub>/O<sub>2</sub> is the same as in municipal solid waste incineration plants, a fraction of 7 % of CO<sub>2</sub> results. Based on these assumptions, an emission factor of 1.3 kg/kg cable can be derived. Since 1995 no emissions from incinerating cable insulation materials have occurred.
- Sewage sludge incineration plants: As sewage sludge is biogenic waste, the emission factor for CO<sub>2</sub> is zero. It is assumed that the share of fossil fuel used during the start-ups is negligible.

Additional information on emission factors of all other (non-CO<sub>2</sub>) gases:

- Hospital waste incineration: All emission factors are taken from SAEFL (2000). Following IPCC (2006), no CH<sub>4</sub> emissions are estimated (see issue W.8 in UNFCCC 2023)
- Municipal waste incineration (illegal): The emission factor for N<sub>2</sub>O is taken from the IPCC Guidelines (IPCC 2006, vol. 5), the emission factors for CH<sub>4</sub>, NO<sub>x</sub>, NMVOC and SO<sub>2</sub> from SAEFL (2000) and USEPA (1995a).
- Industrial waste incineration (consists of cable insulation materials): All emission factors are adopted from SAEFL (2000). Following IPCC (2006), no CH<sub>4</sub> emissions are estimated (see issue W.8 in UNFCCC 2023). Due to low relevance, and considering that the process ceased in 1995, no N<sub>2</sub>O emission factor has been estimated for 1990–1994 (see issue W.9 in UNFCCC 2023).
- Sewage sludge incineration plants: For 1990, emission factors are taken from SAEFL (2000). From 2002 to 2015, constant emission factors are used, which are deduced from measurements (LHA 2004) taken at the largest sewage sludge incineration plant incinerating at that time roughly one third of Switzerland's sewage sludge. In 2015 new emission factors for all pollutants other than CO<sub>2</sub> and CH<sub>4</sub> have been deduced based on measurements on three sewage sludge incineration plants (EMIS 2023/5C1 Klärschlammverbrennung). Between 1990 and 2002 as well as between 2002 and 2015, the emission factors are interpolated. Emission factors for CH<sub>4</sub>, NO<sub>x</sub>, CO and SO<sub>2</sub> decrease due to gradual technical improvements. Emission factors for N<sub>2</sub>O have been deduced differently (EMIS 2023/5C1 Klärschlammverbrennung): From 1990 to 2014, the evaluation of results from 7 emissions measurements over the years 2005–2013 on three sewage sludge incineration plants yielded an N<sub>2</sub>O emission factor of 4.10 kg/t (Meyer 2016, Wunderlin 2013). No indications suggested changes in emissions reductions technology over this period. In 2015, one plant accounting for incinerating 30 % of the total sewage sludge in Switzerland applied a new emissions reduction technology resulting in N<sub>2</sub>O emissions of only 0.03 kg/t (TBF 2021). By accounting for this

improvement, the N<sub>2</sub>O emission factor for 2015–2016 was reduced to 3.3 kg/t. TBF (2021) investigated that as of 2017 two additional sewage sludge incineration plants, accounting for the incineration of additional 30 % of Switzerland's sewage sludge, have implemented emissions reductions measures. This led to the implementation of a new N<sub>2</sub>O emission factor of 1.85 kg/t from 2017 onwards.

- Crematoria: NMVOC and CO emissions were reduced by technical improvements. A large number of measurements were analysed (crematoria as well as other types of installations are obliged to monitor their emissions by the Swiss Federal Ordinance on Air Pollution Control (Swiss Confederation 1985) such that plant-specific emission factors are available for installations with retrofitted flue gas treatment as well as non-retrofitted installations. The emission factors are calculated as weighted averages of cremations taking place in retrofitted and non-retrofitted cremation plants (EMIS 2023/5C1 Krematorien). Following IPCC (2006), no CH<sub>4</sub> emissions are estimated. There is no methodology for N<sub>2</sub>O emissions from cremation in the IPCC Guidelines (IPCC 2006). Hence, there is no explanation required according to the UNFCCC reporting guidelines (UNFCCC 2019, paragraph 30) and no N<sub>2</sub>O emissions from cremation are estimated.
- The emission factors of burning of branches in agriculture and gardening are calculated based on the EMEP/EEA guidebook (EMEP/EEA 2019) except for CH<sub>4</sub> and N<sub>2</sub>O for which emission factors are based on EMEP/CORINAIR (EMEP/EEA 2002), see also documentation in EMIS 2023/5C2 & 4VA1 Abfallverbrennung in der Land- und Forstwirtschaft.
- General remark: In years with no specific data for activity data or emission factors the respective data are interpolated.
- General remark: Indirect CO<sub>2</sub> emissions resulting from fossil CH<sub>4</sub>, CO and NMVOC emissions in this source category are included in CRF Table6 as documented in chp. 9.

### Activity data (5C)

The activity data for 5C Waste incineration are the quantities of waste incinerated, see Table 7-18. Activity data for open burning are split into open burning of natural residues in agriculture as well as into open burning of natural residues in private households, while respective activity data in CRF Table5.C are aggregated.

Table 7-18 Activity data for the different emission sources within source category 5C Waste incineration and open burning of waste.

5C Incineration and open burning of waste	Unit	1990	1995	2000	2005	2010					
Hospital waste incineration	kt	15.0	8.8	2.5	NO	NO					
Municipal waste incineration (illegal)	kt	32.3	26.2	24.9	21.7	21.0					
Industrial waste incineration	kt	7.5	NO	NO	NO	NO					
Sewage sludge incineration	kt (dry)	57.0	50.2	64.3	94.9	89.8					
Open burning of natural residues in agriculture	kt	16.5	15.2	14.0	12.8	11.5					
Open burning of natural residues in private households	kt	6.1	4.9	3.6	2.4	1.2					
Total	kt	134.3	105.2	109.3	131.7	123.6					
Cremation	Numb.	37'513	40'968	44'821	48'169	52'813					

5C Incineration and open burning of waste	Unit	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Hospital waste incineration	kt	NO									
Municipal waste incineration (illegal)	kt	20.3	19.9	19.3	19.3	19.0	18.3	17.9	17.3	17.0	16.7
Industrial waste incineration	kt	NO									
Sewage sludge incineration	kt (dry)	75.5	93.7	92.8	97.3	99.4	102.0	97.9	100.4	97.4	96.4
Open burning of natural residues in agriculture	kt	11.3	11.2	11.1	11.0	10.8	10.7	10.6	10.5	10.4	10.4
Open burning of natural residues in private households	kt	1.2	1.2	1.2	1.2	1.1	1.1	1.1	1.1	1.1	1.1
Total	kt	108.2	125.9	124.3	128.7	130.4	132.1	127.6	129.3	125.9	124.6
Cremation	Numb.	50'567	53'205	55'616	59'664	54'634	57'694	54'842	57'746	68'148	64'106

Hospital waste incineration: Does not occur anymore in specific hospital waste incineration plants since 2002. Such waste is nowadays incinerated in municipal solid waste incineration plants and is therefore reported under sector 1 Energy. The amount of hospital waste burnt in 1990 stems from BUS (1988).

Municipal waste incineration (illegal): As waste incineration outside incineration plants is forbidden in Switzerland, no data is available. Illegal incineration of waste e.g. in wood stoves, garden fires, construction sites etc. is decreasing due to surveillance by authorities but also by citizens that would report open burning. However, there still are cases of illegal waste incineration. It is assumed that 1 % of all waste in Switzerland has been burnt illegally in 1990 and that this value linearly decreases to 0.25 % in 2030 (and then remains constant).

Industrial waste incineration (consists of cable insulation materials): Does not occur anymore since 1995. Such waste is nowadays incinerated in municipal solid waste incineration plants and is therefore reported under sector 1 Energy. The amount burnt in 1990 is estimated by the amount reported by a company that was supposed to burn approx. 1/3 of all cable insulation materials in Switzerland.

Sewage sludge incineration: Activity data for sewage sludge incineration for the years 1990, 1994, and 1999 are taken from Külling et al. (2002a). As of 2000 the total amount of sewage sludge produced in Switzerland is calculated by multiplying the sludge production per person and year as reported by VBSA (2017) with the total population. The per capita sewage sludge production for 2000, 2004, 2008, 2012, 2016 and 2017 (VBSA 2017) have been derived by compiling the respective amounts of sewage sludge incinerated in municipal solid waste incineration plants, sewage sludge incineration plants and used as alternative fuel in the cement industry and dividing it by the total population count (VBSA 2017). Per capita sludge productions for the intervening years were interpolated linearly. As of 2016, annual per capita sludge production amounted to 21.2 kg (VBSA 2017).

Open burning of natural residues: The amount of natural residues burnt openly has been estimated in a study (INFRAS 2014) as briefly described in the following. Open burning of

such residues is regulated in the Ordinance on Air Pollution Control (Swiss Confederation 1985), Article 26b. In Switzerland, cantonal authorities are responsible for the implementation of these regulations. Since there is no nationwide data available for the activity data of open burning of natural residues, cantonal authorities have been interviewed. Based on the available statistics for many cantons on the number of permitted fires and sanctions due to non-permitted fires, the amount of burnt material in those cantons has been quantified. Since there is also a significant number of unreported cases, it has been assumed that the actual amount of material burnt is three times as large as the amount approved by the authorities. Based on the evaluated numbers from the cantons, an extrapolation to the amount burnt in Switzerland has been made. For the extrapolation the statistics on the harvesting of wood has been used (FOEN 2012i). For the determination of a time series of natural residues burnt, senior experts with historical knowledge in agriculture and forestry have been interviewed. Furthermore, statistical data on agricultural and forestry activities has been used to estimate the potential of material available for burning at a certain time. With this approach a time series since 1900 has been compiled. Emissions from open burning of natural residues in forestry (5C2ii) are reported in LULUCF sector 4V (chp. 6.4.2.6.4.1).

Cremations: Activity data is reported by the Swiss Cremation Association. These statistics are updated every year.

#### **7.4.3. Uncertainties and time-series consistency**

The uncertainty assessment, based on expert judgment, results in high combined uncertainties for CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O of 40 %, 60 % and 150 % of emission estimates, respectively (see Table 1-8 for quantification of “high”). In addition, the expert estimate for the activity data uncertainty is 50 % for CH<sub>4</sub> and 30 % for CO<sub>2</sub> and N<sub>2</sub>O (see details in Annex A2.1).

Consistency: Time series for 5C Waste incineration and open burning of waste are all considered consistent.

#### **7.4.4. Category-specific QA/QC and verification**

The general QA/QC measures are described in chp. 1.5.

#### **7.4.5. Category-specific recalculations**

There were no recalculations implemented in submission 2023.

#### **7.4.6. Category-specific planned improvements**

No category-specific improvements are planned.

## 7.5. Source category 5D – Wastewater treatment and discharge

### 7.5.1. Source category description

Table 7-19 Key categories of 5D Wastewater treatment and discharge. Combined KCA results, level for 2021 and trend for 1990–2021, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC category	Gas	Identification criteria
5D	Wastewater treatment and discharge	CH <sub>4</sub>	L1, L2, T2
5D	Wastewater treatment and discharge	N <sub>2</sub> O	L1, T1, L2, T2

Source category 5D1 Domestic wastewater comprises all emissions from liquid waste handling and sludge from housing and commercial sources (including grey water and night soil). Since submission 2023 also emissions from decentralised wastewater treatment are estimated.

In Switzerland, municipal wastewater treatment (WWT) plants treat wastewater from single cities or several cities and municipalities together. Here, wastewater in general is treated in three steps:

- Mechanical treatment
- Biological treatment
- Chemical treatment

The treated wastewater flows into a receiving system (lake, river or stream). Pre-treated industrial effluents are also handled for final treatment in municipal wastewater treatment plants (see Figure 7-6). In the following, these are called "domestic wastewater treatment plants" according to the terminology of 5D1 Domestic wastewater.

Switzerland's wastewater management infrastructure – comprising about 850 wastewater treatment plants and 40'000–50'000 km of public sewers – is practically complete today (FOEN 2017I). The vast majority of wastewater treatment plants apply an anaerobic sludge treatment with sewage gas recovery, and use the sewage gas for heat production. About 290 wastewater treatment plants also apply combined heat and power units. See also EMIS 2023/5D1 Wastewater Treatment Plants.

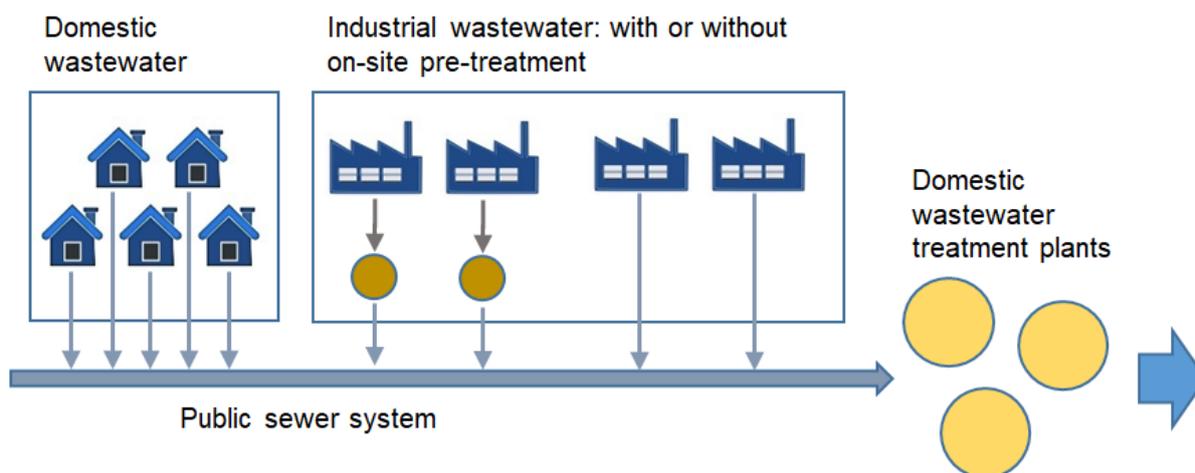


Figure 7-6 Graphical representation of domestic and industrial wastewater streams towards centralised wastewater treatment plants. Decentralised wastewater treatment is not shown here.

Source category 5D2 Industrial wastewater comprises all emissions from liquid waste handling and sludge from industrial processes such as food processing, textiles, car-washing places, electroplating plants, and pulp/paper production. These processes may result in effluents with a high load of organics. Depending on the contaminants, an on-site pre-treatment is necessary in order to reduce the load of pollutants in the wastewater to meet the regulatory standards (which are in place to preclude disruptions of the domestic wastewater treatment plants) and to reduce discharge fees. The on-site pre-treatment is generally anaerobic, in order to use the sewage gas as source for heat and power production. Currently, about 20 industrial wastewater treatment plants pre-treat wastewater before its discharge to the domestic sewage system, where the industrial wastewater is additionally treated together with domestic wastewater in domestic wastewater treatment plants (see Figure 7-6 and Figure 7-7). Due to this strong connection with domestic wastewater treatment, industrial wastewater is not identified as separate wastewater stream for the calculation of GHG emissions, but joined to the domestic wastewater treatment. For the calculation of emissions of other gases (NO<sub>x</sub>, CO, NMVOC, SO<sub>2</sub>), domestic and industrial wastewater streams are distinguished (i.e. different emission factors are applied, see below). See also EMIS 2023/5D2 Kläranlagen industriell (Luftschadstoffe).

Table 7-20 Specification of source category 5D Wastewater treatment and discharge.

5D	Source category	Specification
5D1	Domestic wastewater	Emissions from liquid waste handling and sludge from housing and commercial sources
5D2	Industrial wastewater	Emissions of precursors from handling of liquid wastes and sludge from industrial processes (emissions of CH <sub>4</sub> and N <sub>2</sub> O are implemented in 5D1)
5D3	Other	Not occurring in Switzerland

Category 5D contains all direct emissions from wastewater handling, including direct emissions of sewage gas (leakage), torching and upgrading of sewage gas to natural gas quality (to be fed into the natural gas network and/or used as fuel). Emissions from the usage

of sewage gas in combined heat and power (CHP) units and boilers (only heat production) are reported in sector 1 Energy in source category 1A2gviii Other (see Figure 3-18).

Wastewater treatment also leads to emissions reported in other categories, as illustrated in Figure 7-7. Emissions associated with sewage sludge drying are assumed to be negligible. The discharge of sewage sludge from centralised wastewater treatment plants on agricultural soils has been phased out since 2003 and is generally forbidden since 2009. Therefore, this process is crossed out in Figure 7-7. The same applies to solid waste disposal sites (5A). All sewage sludge is incinerated either in municipal solid waste incineration plants (1A1a), sewage sludge incineration plants (5C) or used as alternative fuel in the cement industry (1A2f).

According to legislation (Swiss Confederation 1992b and Swiss Federal Council 1992b) and as stated in Vuna (2023) also all sludge from on-site wastewater treatment in small scale wastewater treatment plants is routed via the path mentioned above. On-site wastewater management is here defined as a solution for the collection, treatment and/or disposal of wastewater at or near its point of generation, without the connection to a public sewer network. On-site wastewater management systems are often called decentralised or small-scale sanitation systems. CH<sub>4</sub> and N<sub>2</sub>O emissions from such systems are estimated for the first time in Switzerland's greenhouse gas inventory in submission 2023 according to a desk study (Vuna 2023).

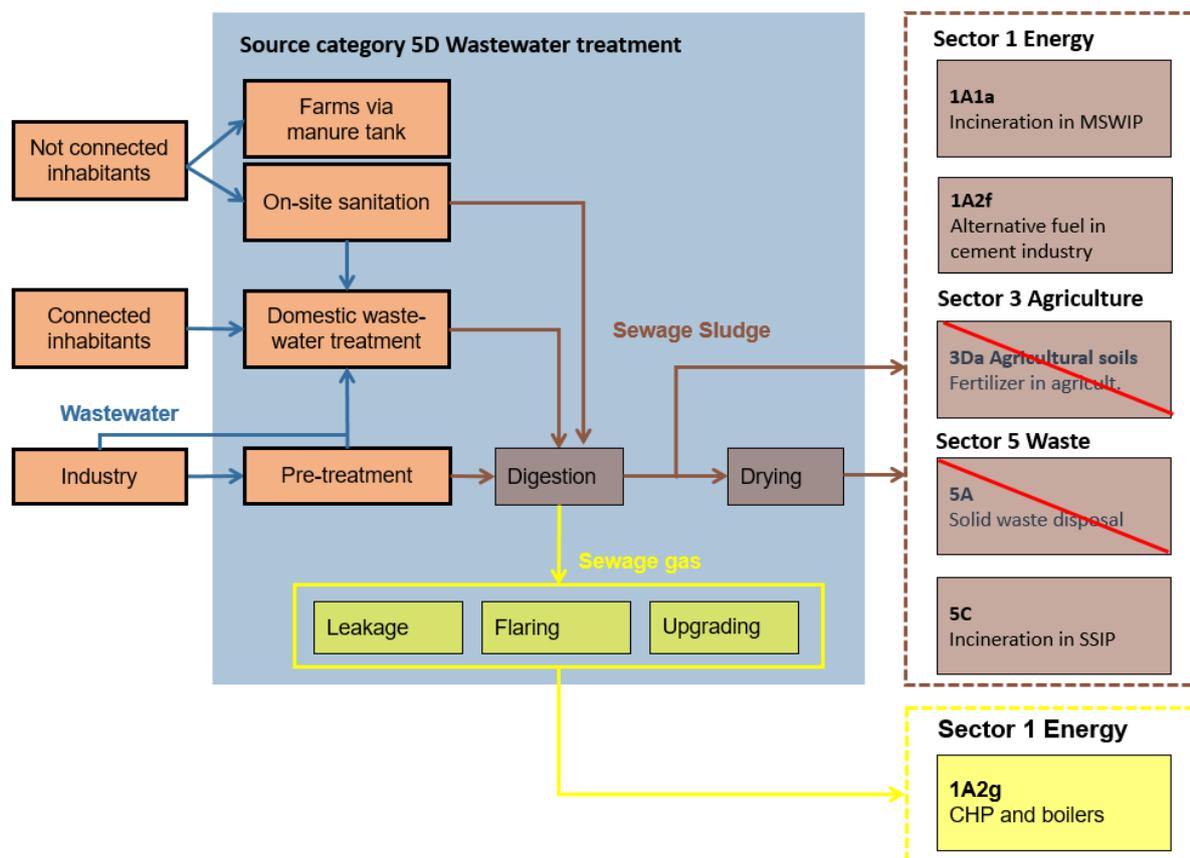


Figure 7-7 System boundaries of processes related to wastewater treatment. CHP = Combined heat and power generation. MSWIP = Municipal solid waste incineration plant. SSIP = Sewage sludge incineration plant.

## 7.5.2. Methodological issues

Since submission 2023 emissions from wastewater treatment are estimated according to Gruber et al. (2021) for the centralised system and according to Vuna (2023) for decentralised wastewater management.

Centralised CH<sub>4</sub> emissions are calculated by a Tier 2 method based on the decision tree of the IPCC Guidelines (IPCC 2006, vol. 5, chp. 6, Fig. 6.2 and Fig. 6.3). N<sub>2</sub>O emissions are calculated using a country-specific method according to IPCC (2006). Details regarding the calculation of CH<sub>4</sub> and N<sub>2</sub>O emissions are provided in the following.

In Switzerland, 90 % of all inhabitants (urban and rural) were connected to wastewater treatment plants in 1990, and this share reached 97 % in 2007 and is assumed to be at 97.3 % since 2011 (FOEN 2021m). Hence, about 2.7 % of the population are currently not connected to public sewer networks and can be distinguished as follows:

- Farms that cannot be connected to public sewer networks and hold at least eight cows or pigs are qualified to connect their domestic wastewater to the liquid manure (slurry) tank and to dispose of the manure and sewage by land application.
- Residents that cannot be connected to public networks and rely on on-site or decentralised sanitation solutions, such as septic tanks, holding tanks or small-scale wastewater treatment plants.

An overview concerning emissions from wastewater treatment via manure tanks on the one hand and on-site sanitation systems (including their characteristics and rough estimates on their penetration rates in Switzerland) on the other hand is presented in a desk study (Vuna 2023). Therein, Table 2 provides an overview of the on-site sanitation technologies used in Switzerland. However, it is stated that not all the technologies are relevant in terms of CH<sub>4</sub> or N<sub>2</sub>O emissions, either because they are rare or because their emission potential is negligible. Table 4 thus compiles the relevant technologies, taking into account their occurrence in Switzerland and their emission potentials (Vuna 2023).

Finally, it is assumed that residents connected to the sewer system may spend time in rural areas. Vuna (2023) takes this into account for two reasons. Firstly, people connected to the centralised wastewater treatment system should neither be overlooked nor double counted if they temporarily use on-site sanitation systems. It is assumed that the wastewater of an estimated 0.7 % of the Swiss population is actually managed in decentralised systems, although these residents are connected to sewers most of the time (Vuna 2023). Secondly, the emission factors for on-site sanitation systems are higher than for well-managed centralised wastewater treatment plants. Emission estimates for CH<sub>4</sub> and N<sub>2</sub>O for the entire time series take these considerations into account. See Vuna (2023) for a detailed presentation of the corresponding calculations.

### 7.5.2.1. CH<sub>4</sub> emissions

#### 7.5.2.1.1. Methodology for centralised wastewater treatment (5D, CH<sub>4</sub>)

CH<sub>4</sub> emissions from centralised wastewater treatment and discharge take into account emissions from organically degradable material in wastewater and emissions related to sewage gas production (and recovery) from sewage sludge (in domestic as well as industrial installations). Accordingly, the contribution of industrial wastewater is taken into account in the calculation of CH<sub>4</sub> emissions from domestic wastewater by means of a correction factor for additional industrial chemical oxygen demand (COD) discharged into the domestic sewer

system. Industries handling wastewater with high chemical oxygen demand usually use anaerobic digesters to produce sewage gas. The emissions related to sewage gas production (and recovery) during industrial pre-treatment of wastewater are also taken into account in the calculation of emissions from domestic wastewater treatment plants, because the underlying Swiss renewable energy statistics (see below) does not differentiate between sewage gas production in domestic and industrial wastewater treatment plants. Three pathways for CH<sub>4</sub> emissions are characterised according to Gruber et al. (2021, see chapter 4.2.1 in the report) and summed up, namely emissions from:

- The sewer system (CH<sub>4, SEWER</sub>)
- Wastewater treatment (water line and sludge line) (CH<sub>4, WWTP</sub>)
- Sewage gas (leakage losses, treatment/upgrading, torches) (CH<sub>4, SEWAGE GAS</sub>)

In short, CH<sub>4,SEWER</sub> is calculated by multiplying total organically degradable material in sewer (TOW<sub>SEWER</sub>) with an emission factor for the sewer system (EF<sub>CH<sub>4</sub>, SEWER</sub>). CH<sub>4</sub> emissions from wastewater treatment is calculated by multiplying TOW<sub>SEWER</sub> with an emission factor for whole wastewater treatment plants (EF<sub>CH<sub>4</sub>, WWTP</sub>).

The CH<sub>4</sub> emissions resulting from sewage gas treatment (aiming at stabilizing the sewage sludge and producing sewage gas) are calculated based on a country-specific implied emission factor ( $EF_{CH_4, sewage\ gas}$ , see below), which is normalized with population (P).

### Emission factors (centralised 5D, CH<sub>4</sub>)

Emission factors for CH<sub>4</sub> are chosen according to chp. 3.2.2. in Gruber et al. (2021).

#### *Sewer system*

For the sewer system, a CH<sub>4</sub> emission factor (EF<sub>CH<sub>4</sub>, SEWER</sub>) is chosen that represents the average of different assessments: 0.00255 kg CH<sub>4</sub> / kg COD (Gruber 2021).

#### *Wastewater treatment (water line and sludge line)*

Gruber et al. (2021) discuss different CH<sub>4</sub> emission factors for the water line and sludge line and conclude that an emission factor representing whole plant measurements is most appropriate (EF<sub>CH<sub>4</sub>, WWTP</sub>). Hence, the median value according to Gruber et al. (2021) is used: 0.0094 kg CH<sub>4</sub> / kg COD.

#### *Sewage gas*

To calculate the country-specific implied emission factor  $EF_{CH_4, sewage\ gas}$  for CH<sub>4</sub> emissions from sewage gas treatment the total sewage gas production (in domestic and industrial systems) is taken into account based on detailed Swiss renewable energy statistics (SFOE 2022a). These statistics provide the amount of sewage gas used in furnaces and combined heat and power installations, as well as the amount of sewage gas upgraded to natural gas quality. It is assumed that 2 % of the total amount of sewage gas is flared and 0.75 % of the total amount is leaking. It is further assumed that the leakage of upgraded gas linearly decreases from 5 % in 1990 to 2.5 % in 2014, remaining constant thereafter. The implied

emission factor  $EF_{CH_4, \text{sewage gas}}$  is adapted on a yearly basis due to the respective annual changes in population and the total production of sewage gas.

#### *Values of emission factors referred to the number of inhabitants*

The implied CH<sub>4</sub> emission factors for 5D Wastewater treatment and discharge (centralised and decentralised) are summarized in Table 7-21.

Table 7-21 Country-specific CH<sub>4</sub> emission factors for source category 5D Wastewater treatment and discharge in 2021 referred to the total number of inhabitants. Detailed information is given in EMIS 2023/5D1 5D2 Abwasserbehandlung GHG.

<b>5D Wastewater treatment and discharge</b>	<b>Unit</b>	<b>2021</b>
Population	inhabitants in 1000	8'705
Emissions from wastewater treatment in centralised plants	kg CH <sub>4</sub> /person/a	0.63
Emissions from decentralised wastewater treatment	kg CH <sub>4</sub> /person/a	0.17
Emissions from losses during sludge treatment	kg CH <sub>4</sub> /person/a	0.088

#### **Activity data (centralised 5D, CH<sub>4</sub>)**

Activity data for CH<sub>4</sub> are specified according to chp. 2.2.2. in Gruber et al. (2021).

#### *Sewer system and wastewater treatment (water line and sludge line)*

Total organically degradable material (TOW) is used as activity data for emissions from both, sewers and wastewater treatment plants. TOW is calculated by multiplying the number of persons, connection rate to sewer system, per capita load of organically degradable material, and a correction factor ( $I = 1.25$  (default IPCC 2006)) for additional industrial COD discharged into sewers (Gruber 2021, p. 14).

Time series of the activity data are shown in Table 7-22.

#### *Sewage gas*

As elaborated above, a per capita implied emission factor ( $EF_{CH_4, \text{sewage gas}}$ ) is calculated for CH<sub>4</sub> emissions from separate sewage sludge treatment, and the respective activity data is total population (Table 7-22).

#### **7.5.2.1.2. Methodology for decentralised wastewater treatment (5D, CH<sub>4</sub>)**

Concerning CH<sub>4</sub> emissions from decentralised wastewater treatment two pathways are considered: handling via manure tanks on remote farms and other housing with on-site sanitation systems with anaerobic primary treatment stages are relevant (Vuna 2023).

- CH<sub>4</sub> emissions from remote farms (via manure handling) are estimated based on the methodology of the agriculture model for manure management (chp.5.3), but still reported under 5D.
- CH<sub>4</sub> emissions from on-site sanitation systems are estimated by multiplying total organically degradable material (TOW) by emission factors for primary and secondary treatments.

Furthermore, Vuna (2023) confirms that it is valid to assume that all sludge of unconnected inhabitants which is not discharged on farm land after storage in manure tanks, is transported to large-scale, centralised wastewater treatment plants. There, the sludge is typically fed into the sludge thickener or digester for treatment together with the primary and secondary sludge of the plant.

### **Emission factors (decentralised 5D, CH<sub>4</sub>)**

To estimate the CH<sub>4</sub> emissions for wastewater treatment via manure handling on remote farms, a separate run of the agriculture model was evaluated, where the number of fattening pigs was increased according to the estimated additional nitrogen load from decentralised wastewater. Based on the resulting increase in CH<sub>4</sub> emissions, a respective emission factor (in kg CH<sub>4</sub> per person per year) can be derived (for further details see chp. 5.3). This is a reasonable approach given the similarity of the respective digestive systems of pigs and humans.

For primary and secondary treatments in different on-site sanitation systems, CH<sub>4</sub> emission factors are used according to IPCC Guidelines (IPCC 2006, 2014a, 2019) as described in Vuna (2023, chp. 3.3.3 Emission factors of SSWWTPs, and in particular also Table 7).

### **Activity data (decentralised 5D, CH<sub>4</sub>)**

According to Vuna (2023) about 1.44 % of the Swiss population's wastewater is treated via manure tanks on remote farms today. Based on this fraction and the nitrogen load per person, estimates for sludge going to manure tanks/slurry, as well as total nitrogen loads in sludge are established.

According to Vuna (2023) about 1.26 % of the Swiss population's wastewater is treated in on-site sanitation systems today. Relevant on-site technologies in terms of CH<sub>4</sub> are listed in Table 4 of Vuna (2023) and fractions for secondary treatment techniques are quantified in Figure 3 of Vuna (2023). Hereof only constructed wetlands (according to IPCC 2014a) are considered relevant for CH<sub>4</sub> emissions.

The ratio of the two given fractions is assumed to be constant over the time series as no data is available (Vuna 2023). Together with time series for total population and the share of people not connected to the centralised system, the ratio is used to calculate the number of people living in remote farms or using on-site sanitation systems.

## **7.5.2.2. N<sub>2</sub>O emissions**

### **7.5.2.2.1. Methodology for centralised wastewater treatment (5D, N<sub>2</sub>O)**

Direct N<sub>2</sub>O emissions from centralized wastewater treatment plants and N<sub>2</sub>O emissions from wastewater effluent are calculated using a country-specific method in accordance with the IPCC Guidelines (IPCC 2006).

The method is described in detail in Gruber et al. (2021) and Gruber (2022). Therein, two pathways for N<sub>2</sub>O emissions are characterised (see chapter 4.1.1 in Gruber et al. (2021)) and summed up, namely emissions from:

- Wastewater treatment plants ( $N_2O_{\text{PLANT}}$ )
- Effluent ( $N_2O_{\text{EFFLUENT-WATERBODY}}$ )

In short,  $N_2O$  emissions from wastewater treatment plants ( $N_2O_{\text{PLANT}}$ ) are calculated by multiplying nitrogen load in the influent ( $N_{\text{INFLUENT}}$ ) by an emission factor ( $EF_{N_2O, \text{PLANT}}$ ).  $N_2O$  emissions from the effluent are calculated by multiplying nitrogen load in the effluent ( $N_{\text{EFFLUENT}}$ ) by an emission factor ( $EF_{N_2O, \text{EFFLUENT-WATERBODY}}$ ).

### Emission factors (centralised 5D, $N_2O$ )

#### *Wastewater treatment plants ( $EF_{N_2O, \text{PLANT}}$ )*

Gruber et al. (2021) selected a suite of wastewater treatment plants representative for Switzerland. They then set up an off-gas monitoring system and measured  $N_2O$  emissions from each selected plant throughout the year. The latter is important as it was shown that seasonal emission patterns are evident. The authors assessed emission factors evaluating 14 monitoring campaigns. Accordingly, three emission factors from wastewater treatment plants were derived, corresponding to three different nutrient removal categories: (a) carbon removal, (b) nitrification only, (c) year-round nitrogen removal (see Table 3 of Gruber et al. (2021)). It is generally assumed that a lower nitrogen removal results in higher  $N_2O$  emissions. The estimation of the country-wide emission factor ( $EF_{N_2O, \text{PLANT}}$ ) is calculated by multiplying the respective share of nitrogen load treated in wastewater treatment plants belonging to a nutrient removal category by the respective emission factor. The categorization used is described in a written communication by Gruber (2022) updating Figure 9 of Gruber et al. (2021). As such, technical development over the time series is reflected with increasing nitrogen removal from 1990 to today.

In addition,  $N_2O$  emissions from unaerated process stages are considered. Gruber et al. (2021) assume that the respective share of emissions ( $F_{N_2O, \text{UNAERATED}}$ ) corresponds to 25 % of the emission from aerated processes (calculated with  $EF_{N_2O, \text{PLANT}}$ , see above). The authors assume a constant share over the whole reporting period.

#### *Effluent ( $EF_{N_2O, \text{EFFLUENT}}$ )*

Following Gruber et al. (2021) the emission factor for  $N_2O$  emitted from nitrogen in the effluent of wastewater treatment plants is kept at the default value given in the IPCC Guidelines (IPCC 2006):  $EF_{N_2O, \text{EFFLUENT}} = 0.005 \text{ kg } N_2O\text{-N/kg N}$ .

### Activity data (centralised 5D, $N_2O$ )

Nitrogen loads for wastewater treatment plants are interpolated linearly following references and data presented in Table 1 of Gruber et al. (2021). Influent nitrogen load to wastewater treatment plants ( $N_{\text{INFLUENT}}$ ) is then calculated by multiplying population, nitrogen load (kg/person/year) and connection rate ( $T_{\text{PLANT}}$ ).

An average nitrogen removal rate ( $r_{\text{NITROGEN REMOVAL RATE}}$ ) is calculated based on Table 1 of Gruber et al. (2021) and is used to calculate nitrogen load in the effluent ( $N_{\text{EFFLUENT}} = N_{\text{INFLUENT}} * (1 - r_{\text{NITROGEN REMOVAL RATE}})$ ).

#### **7.5.2.2.2. Methodology for decentralised wastewater treatment (5D, N<sub>2</sub>O)**

Concerning N<sub>2</sub>O emissions from decentralised wastewater treatment two pathways are considered: handling via manure tanks on remote farms and other housing with on-site sanitation systems with secondary treatment stages are relevant (Vuna 2023).

N<sub>2</sub>O emissions from remote farms (via manure handling) are estimated based on the methodology of the agriculture model for manure management (chp. 5.3), but still reported under 5D.

According to Vuna (2023) and references therein N<sub>2</sub>O emissions from on-site sanitation systems are estimated as follows:

- Nitrogen influent to on-site sanitation systems is calculated by multiplying the number of persons served by on-site sanitation with nitrogen load per person (as in chp. 7.5.2.2.1) in accordance with Gruber et al. (2021).
- Nitrogen removed in primary treatment is subtracted (5 %) to receive nitrogen influent to secondary treatments.
- Several secondary treatment technologies are differentiated for different small scale wastewater treatment plants leading to different N<sub>2</sub>O emission strengths.
- Nitrogen removal in secondary treatment is set to 25 % as a weighted average of the various relevant treatment technologies.
- A constant emission factor for N<sub>2</sub>O from effluents is assumed (as in chp. 7.5.2.2.1), based on the IPCC Guidelines (2006) and in accordance with Gruber et al. (2021), and multiplied with residual nitrogen in effluent to yield in N<sub>2</sub>O emissions from effluents.

#### **Emission factors (decentralised 5D, N<sub>2</sub>O)**

To estimate the N<sub>2</sub>O emission factor for wastewater treatment via manure handling on remote farms, a separate run of the agriculture model was evaluated, where the number of fattening pigs was increased according to the estimated additional nitrogen load from decentralised wastewater. Based on the resulting increase in N<sub>2</sub>O emissions, a respective emission factor (in kg N<sub>2</sub>O per person per year) can be derived (for further details see chp. 5.3). This is a reasonable approach given the similarity of the respective digestive systems of pigs and humans.

No N<sub>2</sub>O is emitted from primary treatments of on-site sanitation systems (IPCC 2019, Vuna 2023).

For different on-site technologies using secondary treatments and for effluents, N<sub>2</sub>O emission factors are used according to IPCC Guidelines (IPCC 2006, 2014a, 2019) as described in Vuna (2023, chp. 3.3.3 Emission factors of SSWWTPs, and in particular also Table 7).

#### **Activity data (decentralised 5D, N<sub>2</sub>O)**

According to Vuna (2023) about 1.44 % of the Swiss population's wastewater is treated via manure tanks on remote farms today. Based on this fraction and the nitrogen load per person, estimates for sludge going to manure tanks/slurry, as well as total nitrogen loads in sludge are established.

According to Vuna (2023) about 1.26 % of the Swiss population's wastewater is treated in on-site sanitation systems today. Relevant on-site technologies in terms of N<sub>2</sub>O are listed in

Table 4 of Vuna (2023) and fractions for secondary treatment techniques are quantified in Figure 3 of Vuna (2023).

The ratio of the two given fractions is assumed to be constant over the time series as no data is available (Vuna 2023). Together with time series for total population and the share of people not connected to the centralised system, the ratio is used to calculate the number of people living in remote farms or using on-site sanitation systems.

Table 7-22 Activity data for source category 5D Wastewater treatment and discharge (source EMIS 2023/5D1 Wastewater Treatment Plants and EMIS 2023/5D2 Pre-treatment of industrial wastewater). Time series for population, connected persons and protein consumption are given for the centralised and decentralised wastewater treatment systems, while numbers for N removal, N directly emitted and TOW are presented for the centralised wastewater treatment system only.

5D Wastewater treatment and discharge	Unit	1990	1995	2000	2005	2010						
Population	persons in 1000	6'712	7'041	7'184	7'437	7'825						
Fraction of population connected to wastewater treatment plants	%	90.0	93.7	95.4	96.8	97.2						
Connected persons	persons in 1000	6'041	6'597	6'854	7'199	7'606						
Protein consumption	kg/inhab./a	43	42	40	38	36						
N removed with sludge (N <sub>sludge</sub> )	N in t/a	9'465	9'009	9'374	9'222	8'578						
N directly emitted (N <sub>WWT</sub> )	N in t/a	2'387	2'226	1'953	1'696	1'462						
Total org. degr. material (TOW)	t/a	328'419	358'680	372'604	391'387	413'508						

5D Wastewater treatment and discharge	Unit	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Population	persons in 1000	7'997	8'089	8'189	8'282	8'373	8'452	8'514	8'575	8'638	8'705
Fraction of population connected to wastewater treatment plants	%	97.3	97.3	97.3	97.3	97.3	97.3	97.3	97.3	97.3	97.3
Connected persons	persons in 1000	7'781	7'871	7'968	8'058	8'147	8'224	8'284	8'343	8'405	8'470
Protein consumption	kg/inhab./a	36	35	35	35	34	34	34	33	33	33
N removed with sludge (N <sub>sludge</sub> )	N in t/a	8'034	7'952	7'908	7'817	7'721	7'795	7'852	7'908	7'965	8'026
N directly emitted (N <sub>WWT</sub> )	N in t/a	1'415	1'392	1'370	1'347	1'323	1'297	1'268	1'239	1'210	1'172
Total org. degr. material (TOW)	t/a	423'032	427'899	433'189	438'108	442'922	447'101	450'381	453'608	456'940	460'484

### 7.5.2.3. Other gases

The sewage gas production generates emissions of further gases from flaring: CO<sub>2</sub> (biogenic), NO<sub>x</sub>, CO, NMVOC, and SO<sub>2</sub>. The emissions are calculated by multiplying population (as activity data, see Table 7-22) with country-specific emission factors based on measurements and expert estimates, documented in EMIS 2023/5D1 Wastewater Treatment Plants and EMIS 2023/5D2 Pre-treatment of industrial wastewater. The emission factors used are summarized in Table 7-23.

Table 7-23 Emission factors of CO<sub>2</sub> (biogenic), CH<sub>4</sub>, N<sub>2</sub>O, NO<sub>x</sub>, CO, NMVOC and SO<sub>2</sub> for 5D Wastewater treatment and discharge in 2021.

5D Wastewater treatment and discharge	CO <sub>2</sub> biog.	N <sub>2</sub> O	CH <sub>4</sub>	NO <sub>x</sub>	CO	NMVOC	SO <sub>2</sub>
	kg/person	g/person					
5D1 Domestic wastewater	0.41	231	890	0.55	0.28	0.011	0.0028
5D2 Industrial wastewater	0.09	IE	IE	0.13	0.064	0.0026	0.00065

### 7.5.3. Uncertainties and time-series consistency

#### Uncertainty in CH<sub>4</sub> and N<sub>2</sub>O emissions from 5D

Uncertainty input data (see Annex A2.1) for both gases has been estimated as follows:

- According to Gruber et al. (2021) for centralised wastewater treatment.
- According to Vuna (2023) for on-site sanitation.
- According to the EMEP/EEA guidebook (EMEP/EEA 2019, part A, chp. 5, Table 2-2) and expert judgement for wastewater treatment via manure tanks.

#### 7.5.3.1. CH<sub>4</sub> emissions

Combined uncertainty input for CH<sub>4</sub> for relative uncertainties for wastewater treatment in the centralised system (106 %), in on-site sanitation systems (200 %) and via manure tank (200 %) has been weighted by the respective shares of population, leading to a rounded value of 100 %. For the assumption of a gamma distribution the uncertainty analyses resulted in a combined uncertainty U(Em CH<sub>4</sub>) of -73 % to +119 % for approach 1 and of -83 % to +98 % for approach 2 (see Annexes A2.2 and A2.3).

#### 7.5.3.2. N<sub>2</sub>O emissions

Combined uncertainty input for N<sub>2</sub>O for relative uncertainties for wastewater treatment in the centralised system (54 %), in on-site sanitation systems (200 %) and via manure tank (200 %) has been weighted by the respective shares of population, leading to a rounded value of 50 %. For the assumption of a gamma distribution the uncertainty analyses resulted in a combined uncertainty U(Em CH<sub>4</sub>) of -43 % to +106 % for approach 1 and of -46 % to +50 % for approach 2 (see Annexes A2.2 and A2.3).

Consistency: Time series for 5D Wastewater treatment and discharge are all considered consistent.

### 7.5.4. Category-specific QA/QC and verification

Concerning N<sub>2</sub>O emissions, year-round measurement campaigns on representative Swiss wastewater treatment plants have been performed and evaluated (Gruber et al. 2021) leading to the recalculations reported in submission 2023 (chp. 7.5.5).

Concerning CH<sub>4</sub> and N<sub>2</sub>O emissions from decentralised wastewater treatment a desk study has been undertaken and its results lead to emission estimates for the first time in submission 2023 (chp. 7.5.2).

### 7.5.5. Category-specific recalculations

The following recalculations were implemented in submission 2023. Major recalculations which contribute significantly to the total differences emissions of sector 5D between the latest and the previous submissions are presented also in chp. 10.1.2.5.

5D1 Domestic wastewater treatment: A new country-specific method has been established based on the following main features:

- Activity data: Quantity structures of persons considering their connection to respective wastewater treatment technologies (centralised, decentralised small-scale wastewater treatment and decentralised wastewater treatment via manure management).
- Activity data N<sub>2</sub>O: Assessment of per capita nitrogen load to wastewater.
- Activity data N<sub>2</sub>O: Rates of nitrogen removal for centralised wastewater treatment and decentralised primary and secondary treatments, respectively, taking into account different treatment technologies.
- Activity data CH<sub>4</sub>: Total organically degradable material in wastewater (TOW) now given in unit chemical oxygen demand (COD) instead of biological oxygen demand (BOD). A transfer factor of 2 kg COW / kg BOD is applied.
- Emission factors N<sub>2</sub>O: For centralised and decentralised wastewater treatment different types of treatment technologies and their development over time are considered, particularly in centralised wastewater treatment. The N<sub>2</sub>O emission factor for wastewater treatment via manure management is based on the agricultural model for liquid manure storage and spreading.
- Different CH<sub>4</sub> emission factors are used for the centralised treatment (sewer system and wastewater treatment process) and for the decentralised treatment (primary and secondary treatment). The latter takes into account different treatment technologies. The CH<sub>4</sub> emission factor for wastewater treatment via manure management is based on the agricultural model for liquid manure storage and spreading.

The combined changes in emission factors and activity data for N<sub>2</sub>O and CH<sub>4</sub> lead to the following changes in emissions:

- Emissions N<sub>2</sub>O 1990: +1398 % (+ 3.784 kt N<sub>2</sub>O), of which 91.7 % from centralised and 8.3 % from decentralised wastewater treatment.
- Emissions N<sub>2</sub>O 2020: +493 % (+ 1.721 kt N<sub>2</sub>O), of which 94.8 % from centralised and 5.2 % from decentralised wastewater treatment.
- Emissions CH<sub>4</sub> 1990: +44.7 % (+ 2.308 kt CH<sub>4</sub>), of which 55.4 % from centralised and 44.6 % from decentralised wastewater treatment.
- Emissions CH<sub>4</sub> 2020: + 0.4 % (+ 0.029 kt CH<sub>4</sub>), of which 81.2 % from centralised and 18.8 % from decentralised wastewater treatment.

#### **7.5.6. Category-specific planned improvements**

In a future submission it is planned to implement CH<sub>4</sub> emissions from receiving waters according to the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2019).

## 7.6. Source category 5E – Other

### 7.6.1. Source category description

Table 7-24 Key categories of 5E Other. Combined KCA results, level for 2021 and trend for 1990–2021, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Source category 5E Other is not a key category.

The source category 5E Other comprises NMVOC and CO emissions from car shredding stemming from residues of fuels (gasoline, diesel oil) and motor oil in the tanks and motors of the shredded vehicles. Direct GHG emissions do not occur.

Table 7-25 Specification of source category 5E Other (car shredding)

5E	Source category	Specification
5E	Car shredding plants	Emissions from car shredding plants

### 7.6.2. Methodological issues

#### Methodology (5E)

For the emissions from car shredding a Tier 1 method is used.

Indirect CO<sub>2</sub> emissions resulting from fossil CO and NMVOC emissions in this source category are included in CRF Table6 as documented in chp. 9.

#### Emission factors (5E)

An emission factor of 100 g NMVOC per tonne of shredded vehicle is applied for the period 1990–1995. From 2000 onward, 200 g/t are used. Between 1995 and 2000 the values are linearly interpolated. The NMVOC emission factor are based on measurements at four plants in the years from 2002 to 2008 (EMIS 2023/5E Shredder Anlagen). For CO a constant emission factor is applied over the entire reporting period.

Table 7-26 CO and NMVOC emission factors for 5E Other (car shredding) in 2021.

5E Other waste	Unit	CH <sub>4</sub>	N <sub>2</sub> O	NO <sub>x</sub>	CO	NMVOC	SO <sub>2</sub>
Shredding	g/t scrap	NA	NA	NA	5.0	200	NA

#### Activity data (5E)

The waste quantities from 1990 to 1999 are provided by the Swiss Shredding Association. The data from 2000 to 2007 are taken from Swiss waste statistics. From then onwards the quantities are assumed to remain constant due to the lack of data (see also EMIS 2023/5E Shredder Anlagen).

Table 7-27 Activity data 5E Other (car shredding).

5E Other waste	Unit	1990	1995	2000	2005	2010					
Shredding	kt	280	300	300	300	300					
5E Other waste	Unit	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Shredding	kt	300	300	300	300	300	300	300	300	300	300

### 7.6.3. Uncertainties and time-series consistency

Uncertainties of CO and NMVOC emissions are documented in Switzerland's Informative Inventory Report 2023 (FOEN 2023b). The uncertainties of the emission factors are partly based on values provided by the EMEP/EEA guidebook (EMEP/EEA 2019, part A, chp. 5, Table 2-2) and expert judgements (see detailed input uncertainties in Annex A2.1).

Consistency: Time series for 5E Other are all considered consistent.

### 7.6.4. Category-specific QA/QC and verification

The general QA/QC measures are described in chp. 1.5.

### 7.6.5. Category-specific recalculations

There were no recalculations implemented in submission 2023.

### 7.6.6. Category-specific planned improvements

No category-specific improvements are planned.

## 8. Other

Responsibilities for chapter Other	
Overall responsibility	Michael Bock (FOEN)
Authors	Michael Bock (FOEN), Daiana Leuenberger (FOEN)
EMIS data base operation	Daiana Leuenberger (FOEN)
Annual updates (NID text, tables, figures)	Beat Rihm (Meteotest)
Quality control (NID annual updates)	Michael Bock (FOEN), Dominik Egli (Meteotest), Adrian Schilt (FOEN)
Internal review	Daiana Leuenberger (FOEN), Adrian Schilt (FOEN)

### 8.1. Overview

Within the sector 6 Other emissions from two sources are considered:

- Fire damage estates
- Fire damage motor vehicles

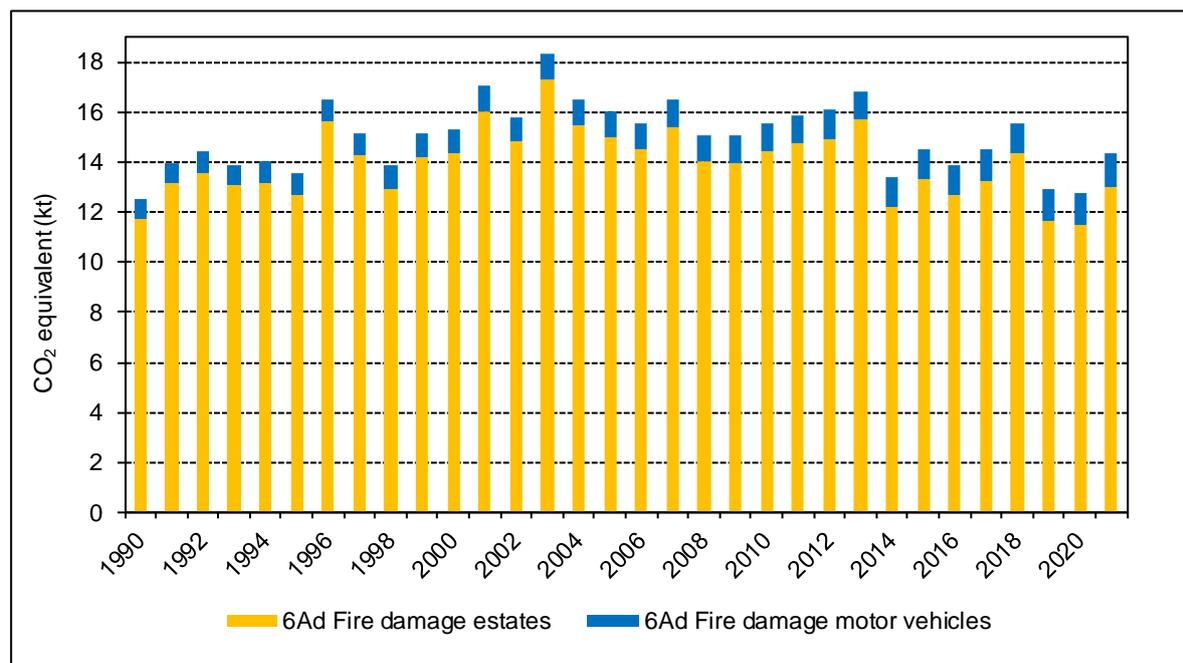


Figure 8-1 Switzerland's greenhouse gas emissions in sector 6 Other.

Table 8-1 Trend of total GHG emissions from sector 6 Other in Switzerland.

Gas	1990	1995	2000	2005	2010					
	CO <sub>2</sub> equivalent (kt)									
CO <sub>2</sub>	11	12	14	15	14					
CH <sub>4</sub>	0.76	0.77	0.81	0.85	0.83					
N <sub>2</sub> O	0.54	0.55	0.58	0.60	0.58					
Sum	13	14	15	16	16					

Gas	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
	CO <sub>2</sub> equivalent (kt)									
CO <sub>2</sub>	15	15	12	13	13	13	14	12	12	13
CH <sub>4</sub>	0.86	0.90	0.73	0.78	0.75	0.78	0.84	0.70	0.70	0.78
N <sub>2</sub> O	0.60	0.63	0.49	0.53	0.51	0.53	0.58	0.47	0.46	0.52
Sum	16	17	13	15	14	15	16	13	13	14

In sector 6 Other, Fire damage estates account for most of the emissions, the rest originates from Fire damage motor vehicles. The total greenhouse gas emissions of this sector show variations between 13 and 18 kt CO<sub>2</sub> eq during the reporting period. Consequently, sector 6 Other is an emission source of minor importance for the national total.

## 8.2. Source category 6A – Other

### 8.2.1. Source category description

Table 8-2 Key categories of 6A – Other. Combined KCA results, level for 2021 and trend for 1990–2021, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Source category 6A – Other is not a key category.
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The sources reported in source category 6A Other are shown in Table 8-3.

Table 8-3 Specification of source category 6A Other.

6A	Source category	Specification
6Ad	Fire damage estates	Emissions from fires in buildings.
6Ad	Fire damage motor vehicles	Emissions from fires in motor vehicles.

### 8.2.2. Methodological issues

#### Methodology (6A Other)

CO<sub>2</sub> emissions are calculated by a Tier 1 method based on the decision tree of the IPCC Guidelines (IPCC 2006, vol. 5, chp. 5, Fig. 5.1). Emission factors are country-specific.

CH<sub>4</sub> emissions are calculated by a Tier 1 method based on the decision tree of the IPCC Guidelines (IPCC 2006, vol. 5, chp. 5, Fig. 5.2). Emission factors are taken from a US study

(FM Global 2010) (“OTH”, fire damage estates) and from USEPA 1992 (“OTH”, fire damage motor vehicles).

N<sub>2</sub>O emissions are calculated by a Tier 1 method based on the decision tree of the IPCC Guidelines (IPCC 2006, vol. 5, chp. 5, Fig. 5.2). Emission factors are taken from a US study (FM Global 2010) (“OTH”, fire damage estates). N<sub>2</sub>O emissions from fire damages of motor vehicles have not been estimated.

The estimation of GHG emissions are based on damage sums and fires reported from insurance companies.

## Emission factors (6A Other)

### *a) Fire damage estates*

Emission factors for CO<sub>2</sub>, CO, NO<sub>x</sub> and SO<sub>2</sub> are country-specific based on measurements and expert estimates originally gained for illegal waste incineration. It is assumed that for fire damage in estates emission factors are the same as for illegal waste incineration (EMIS 2023/6Ad Brand- und Feuerschäden Immobilien).

The ratio of fossil to biogenic CO<sub>2</sub> emissions is assumed constant since 2000, with 80 % being fossil and 20 % being biogenic CO<sub>2</sub> emissions. Before 2000, it is assumed that the fraction of fossil CO<sub>2</sub> emissions from burnt goods increased linearly from 20 % in 1950 to 80 % in 2000. The interpolated emission factors for fossil CO<sub>2</sub> were thus between 400 and 1'500 t CO<sub>2</sub> / kt burnt good between 1950 and 2000, respectively. Vice versa, the emission factors for biogenic CO<sub>2</sub> were between 1'500 and 400 t CO<sub>2</sub> / kt burnt good between 1950 and 2000, respectively.

Indirect CO<sub>2</sub> emissions resulting from fossil CH<sub>4</sub>, CO and NMVOC emissions in this source category are included in CRF Table6 as documented in chp. 9.

### *b) Fire damage motor vehicles*

Emission factors for CO<sub>2</sub>, NO<sub>x</sub>, CO and SO<sub>2</sub> are country-specific based on measurements and expert estimates originally gained for the combustion of cable insulation materials, documented in EMIS 2023/6Ad Brand- und Feuerschäden Motorfahrzeuge.

The emission factor for CH<sub>4</sub> from fire damage in motor vehicles is based on USEPA (1992), while N<sub>2</sub>O emissions have not been estimated for this source category.

Indirect CO<sub>2</sub> emissions resulting from fossil CH<sub>4</sub>, CO and NMVOC emissions in this source category are included in CRF Table6 as documented in chp. 9.

Table 8-4 Emission factors for fire damages in 2021 (EMIS 2023/6Ad).

6A Other	Unit	CO <sub>2</sub>		CH <sub>4</sub>	N <sub>2</sub> O	NO <sub>x</sub>	CO	NMVOC	SO <sub>2</sub>
		biogenic	fossil						
6Ad Fire damage estates	t / kt burnt good	400	1'500	3	0.25	2	100	16	1
6Ad Fire damage motor vehicles	t / kt burnt good	NO	1'500	5	NE	1.3	2	2	5

## Activity data (6A Other)

### a) Fire damage estates

Activity data are estimated yearly based on annually published information by the fire insurance association of the cantons (Vereinigung kantonaler Feuerversicherungen, VKF). VKF publishes the number of fire incidents in buildings each year and the total sum of monetary damage.

Statistical insurance data from 1992 to 2001 show that the average damage sum per fire incident in buildings amounts to approximately CHF 15'600. This corresponds – based on the assumption of typical damage costs of CHF 20'000 per 1'000 kg of burnt material – to 780 kg of flammable material per case. It is further assumed that on average 50 % of the flammable material gets destroyed during an incident because of the intervention of the fire brigade, yet without actually being set on fire. Thus, an average amount of 400 kg of burnt material per fire case is estimated and held constant throughout the time series. With these assumptions, the amount of burnt material for each year can be estimated using the total sum of monetary damage published by VKF (EMIS 2023/6Ad Brand- und Feuerschäden Immobilien), divided by the average damage sum (CHF 20'000) and multiplied by the burnt material (400 kg) per fire incident. The resulting value of 8 kt burnt goods is used for the year 1990. Additional statistical data published annually by the fire insurance association is available for the years 1990–2021. They are used to calculate the activity data on an annual basis.

### b) Fire damage motor vehicles

Activity data are estimated yearly based on the vehicle number published annually by the Federal Statistical Office FSO (EMIS 2023/6Ad Brand- und Feuerschäden Motorfahrzeuge).

Based on data from a Swiss insurance company with 25 % market share in 2002, the number of reported cases of fire damage to vehicles was extrapolated to the total vehicle number in Switzerland. This results in one fire case per 790 vehicles for the year 2002. It is assumed that this ratio has remained constant during the reporting period. By applying this ratio to the actual vehicle number published annually by the FSO, the total number of vehicles with fire damages in Switzerland can be calculated for each year.

During a car fire incident, a car burns down only partially. It is assumed that approximately 100 kg of material burns down during a car fire. With these assumptions, the total number of material burnt is calculated from the total number of car fire incidents in Switzerland.

Table 8-5 Activity data of burnt goods (documented in EMIS 2023/6Ad).

6A	Unit	1990	1995	2000	2005	2010					
6Ad Fire damage estates	kt	8.2	8.3	8.7	9.1	8.8					
6Ad Fire damage motor vehicles	kt	0.48	0.52	0.58	0.64	0.68					
6A	Unit	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
6Ad Fire damage estates	kt	9.1	9.5	7.4	8.1	7.7	8.0	8.7	7.1	7.0	7.9
6Ad Fire damage motor vehicles	kt	0.71	0.72	0.73	0.75	0.76	0.77	0.77	0.78	0.79	0.80

## 8.2.3. Uncertainties and time series consistency

Input values for combined uncertainties of CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O emissions are estimated to be high (according to Table 1-8). Further it is assumed that activity data have an uncertainty of 20 % for all gases (see also Table A – 2).

Consistency: Time series for 6Ad Fire damages are all considered consistent.

#### **8.2.4. Category-specific QA/QC and verification**

The general QA/QC measures are described in chp. 1.5.

#### **8.2.5. Category-specific recalculations**

The following recalculation was implemented in submission 2023:

- 6Ad Fire damages estates: Activity data for the years 1990–1995 (amount of burnt material) have been recalculated based on newly available data from the fire insurance association of the cantons (Vereinigung kantonaler Feuerversicherungen, VKF). Activity data for the years 1990–2020 (amount of burnt material) increased by 20 % (1'442 t) on average (11–38 %, 710 t to 2'584 t), due to changes in the underlying statistics by VKF.

#### **8.2.6. Category-specific planned improvements**

No category-specific improvements are planned.

## 9. Indirect CO<sub>2</sub> and N<sub>2</sub>O emissions

Responsibilities for chapter Indirect CO <sub>2</sub> and N <sub>2</sub> O emissions	
Overall responsibility	Adrian Schilt (FOEN)
Authors	Adrian Schilt (FOEN) and sector experts
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Annual updates (NID text, tables, figures)	Dominik Eggli (Meteotest), Felix Weber (INFRAS)
Quality control (NID annual updates)	Dominik Eggli (Meteotest), Adrian Schilt (FOEN)
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### 9.1. Overview

In this chapter, indirect CO<sub>2</sub> emissions that result from the atmospheric oxidation of CH<sub>4</sub>, CO and NMVOC as well as indirect N<sub>2</sub>O emissions that are induced by the deposition of NO<sub>x</sub> and NH<sub>3</sub> are documented. While indirect CO<sub>2</sub> emissions of fossil origin reported in this chapter are accounted for in the national total, indirect N<sub>2</sub>O emissions are not.

Indirect emissions of CO<sub>2</sub> and N<sub>2</sub>O are shown in CRF Table6, together with the emissions of the precursor gases CH<sub>4</sub>, CO, NMVOC, NO<sub>x</sub> and NH<sub>3</sub>. While all emissions of precursor gases are shown in both CRF Table6 and in the respective sectors, the indirect emissions of CO<sub>2</sub> and N<sub>2</sub>O shown in CRF Table6 only represent emissions not already included in direct emissions in other sectors (in order to avoid double counting). Further, in the case of indirect CO<sub>2</sub> emissions, only carbon of fossil origin is considered. Accordingly, while CH<sub>4</sub>, CO and NMVOC of biogenic origin are shown as precursor gases in CRF Table6, they are not included for the calculation of indirect CO<sub>2</sub> emissions. Consequently, the implied emission factors may vary from sector to sector and also from year to year.

Chapter 9.2 explains in detail the methodological issues to derive indirect CO<sub>2</sub> and N<sub>2</sub>O emissions based on the emissions of the precursor gases CH<sub>4</sub>, CO and NMVOC as well as NO<sub>x</sub> and NH<sub>3</sub> from the different sectors. As an overview, the resulting indirect CO<sub>2</sub> emissions are shown in Table 9-1, as well as in Figure 9-1 and Figure 9-2. The resulting indirect N<sub>2</sub>O emissions are shown in Table 9-2, as well as in Figure 9-3 and Figure 9-4.

To provide further details with regard to the CH<sub>4</sub>, CO and NMVOC emissions relevant for the indirect CO<sub>2</sub> emissions as shown in CRF Table6, the emissions of these precursor gases are shown for each sector, disaggregated by source category, in Table 9-3 (for sector 1 Energy), in Table 9-4 (for sector 2 Industrial processes and product use), in Table 9-5 (for sector 5 Waste) and in Table 9-6 (for sector 6 Other). In these tables, the percentages provided in parentheses reflect the share of emissions of precursor gases that are relevant for indirect CO<sub>2</sub> emissions, i.e. the share of fossil emissions of precursor gases not already considered under the direct CO<sub>2</sub> emissions. This information – together with the factors for the stoichiometric conversion of CH<sub>4</sub>, CO and NMVOC to indirect CO<sub>2</sub> as provided in chp. 9.2.1 – allows for an interpretation of the implied emission factors.

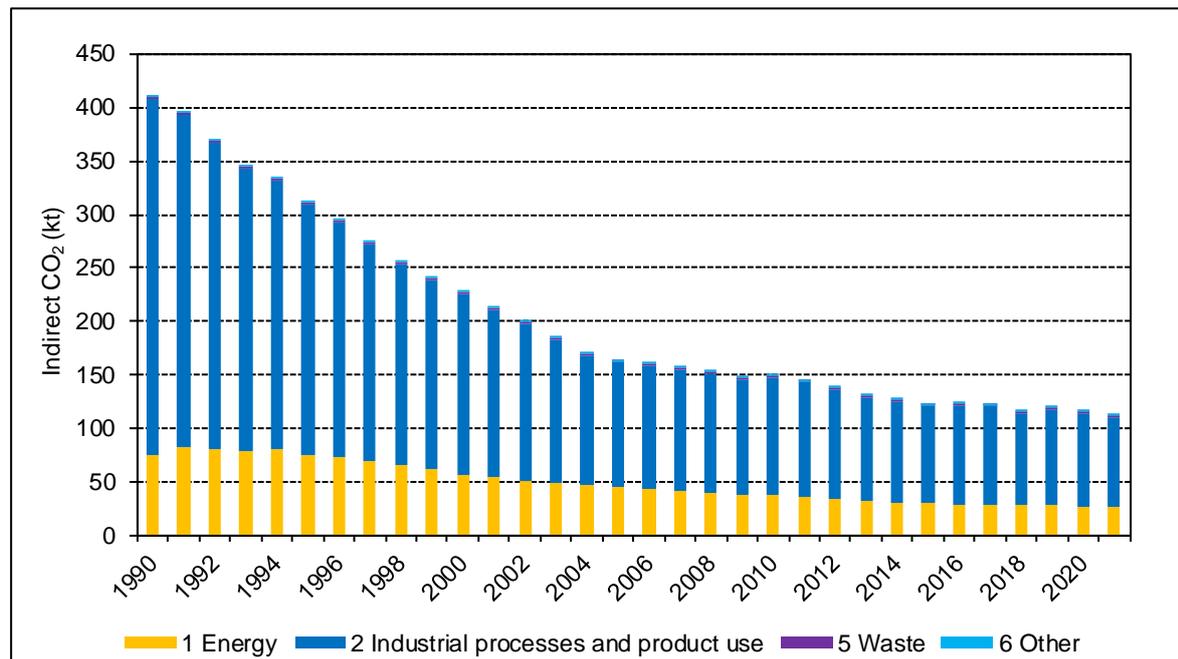
Indirect CO<sub>2</sub> emissions are considered for both the uncertainty analysis (see chp. 1.6) and the key category analysis (see chp. 1.4). Indirect N<sub>2</sub>O emissions are neither considered for the uncertainty analysis (see chp. 1.6), nor for the key category analysis (see chp. 1.4).

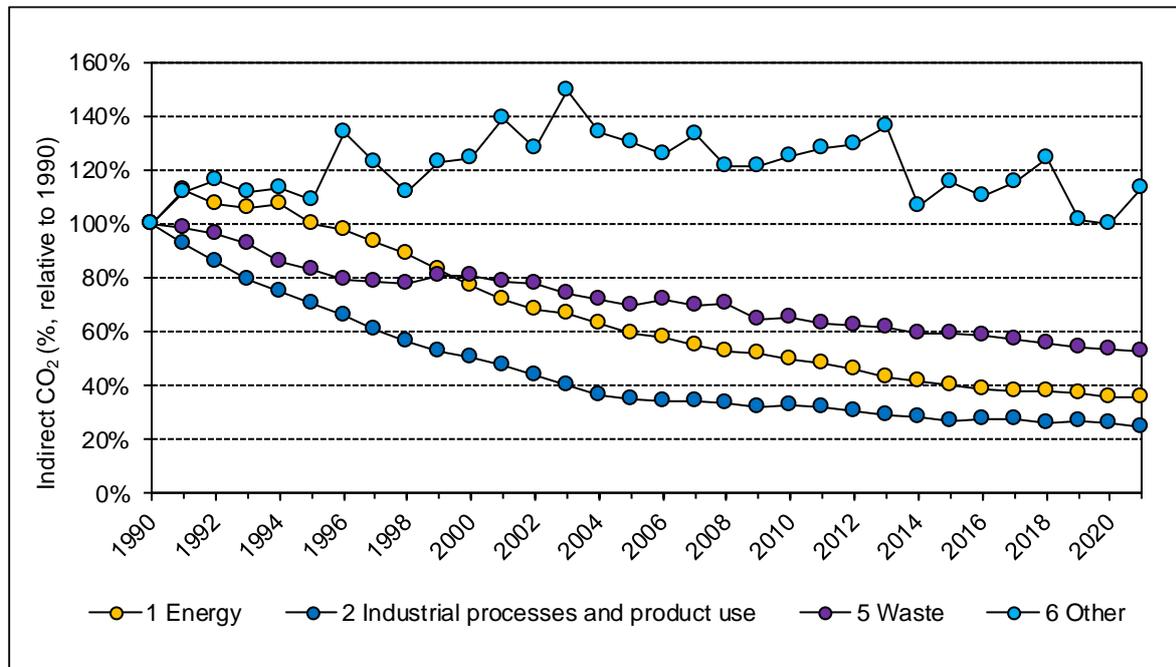
Table 9-1 Indirect fossil CO<sub>2</sub> emissions.

Indirect fossil CO <sub>2</sub> emissions by source category	1990	1995	2000	2005	2010
	kt CO <sub>2</sub>				
<b>1 Energy</b>	<b>74</b>	<b>74</b>	<b>57</b>	<b>44</b>	<b>37</b>
1B Fugitive emissions from fuels	74	74	57	44	37
<b>2 Industrial processes and product use</b>	<b>334</b>	<b>236</b>	<b>170</b>	<b>117</b>	<b>110</b>
2A Mineral industry	0.15	0.12	0.11	0.11	0.12
2B Chemical industry	8.0	6.8	8.4	7.3	8.1
2C Metal industry	3.4	2.4	2.2	1.3	0.93
2D Non-energy products from fuels and solvent use	194	127	92	51	49
2G Other product manufacture and use	126	97	65	57	50
2H Other	2.8	2.0	1.9	1.3	2.3
<b>5 Waste</b>	<b>2.2</b>	<b>1.9</b>	<b>1.8</b>	<b>1.6</b>	<b>1.5</b>
5C Waste incineration and open burning of waste	2.2	1.7	1.7	1.4	1.3
5E Other	0.064	0.10	0.13	0.13	0.13
<b>6 Other</b>	<b>1.1</b>	<b>1.2</b>	<b>1.4</b>	<b>1.5</b>	<b>1.4</b>
6Ad Fire damages	1.1	1.2	1.4	1.5	1.4
<b>Total</b>	<b>411</b>	<b>313</b>	<b>230</b>	<b>164</b>	<b>150</b>

Indirect fossil CO <sub>2</sub> emissions by source category	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
	kt CO <sub>2</sub>									
<b>1 Energy</b>	<b>34</b>	<b>32</b>	<b>31</b>	<b>30</b>	<b>29</b>	<b>28</b>	<b>28</b>	<b>27</b>	<b>27</b>	<b>27</b>
1B Fugitive emissions from fuels	34	32	31	30	29	28	28	27	27	27
<b>2 Industrial processes and product use</b>	<b>103</b>	<b>98</b>	<b>95</b>	<b>91</b>	<b>93</b>	<b>93</b>	<b>86</b>	<b>91</b>	<b>88</b>	<b>84</b>
2A Mineral industry	0.11	0.10	0.10	0.092	0.095	0.094	0.094	0.094	0.089	0.089
2B Chemical industry	7.7	6.1	6.6	7.1	13.8	14	8.1	13.0	11	7
2C Metal industry	0.81	0.80	0.78	0.67	0.63	0.65	0.64	0.46	0.41	0.43
2D Non-energy products from fuels and solvent use	45	44	42	39	37	37	36	36	35	35
2G Other product manufacture and use	47	45	43	42	40	40	40	40	40	40
2H Other	2.1	2.0	2.0	1.9	1.0	1.0	1.1	0.94	0.88	0.9
<b>5 Waste</b>	<b>1.4</b>	<b>1.4</b>	<b>1.3</b>	<b>1.3</b>	<b>1.3</b>	<b>1.3</b>	<b>1.2</b>	<b>1.2</b>	<b>1.2</b>	<b>1.2</b>
5C Waste incineration and open burning of waste	1.3	1.2	1.2	1.2	1.2	1.1	1.1	1.1	1.1	1.0
5E Other	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
<b>6 Other</b>	<b>1.4</b>	<b>1.5</b>	<b>1.2</b>	<b>1.3</b>	<b>1.2</b>	<b>1.3</b>	<b>1.4</b>	<b>1.1</b>	<b>1.1</b>	<b>1.3</b>
6Ad Fire damages	1.4	1.5	1.2	1.3	1.2	1.3	1.4	1.1	1.1	1.3
<b>Total</b>	<b>139</b>	<b>133</b>	<b>128</b>	<b>123</b>	<b>124</b>	<b>123</b>	<b>117</b>	<b>120</b>	<b>117</b>	<b>113</b>

Figure 9-1 Switzerland's indirect fossil CO<sub>2</sub> emissions.

Figure 9-2 Relative trends of the indirect fossil CO<sub>2</sub> emissions by sector. The base year 1990 represents 100 %.Table 9-2 Indirect N<sub>2</sub>O emissions.

Indirect N <sub>2</sub> O emissions by source category	1990	1995	2000	2005	2010
kt N <sub>2</sub> O					
<b>1 Energy</b>	<b>1.7</b>	<b>1.4</b>	<b>1.3</b>	<b>1.2</b>	<b>1.1</b>
1A Fuel combustion activities	1.7	1.4	1.3	1.2	1.1
1B Fugitive emissions from fuels	0.0025	0.0038	0.0038	0.0035	0.0014
<b>2 Industrial processes and product use</b>	<b>0.018</b>	<b>0.014</b>	<b>0.017</b>	<b>0.015</b>	<b>0.012</b>
2A Mineral industry	0.00021	0.00017	0.00015	0.00016	0.00018
2B Chemical industry	0.0014	0.0012	0.0012	0.0011	0.0012
2C Metal industry	0.0038	0.0023	0.0024	0.0025	0.0026
2G Other product manufacture and use	0.0069	0.0068	0.0080	0.0081	0.0035
2H Other	0.0054	0.0038	0.0051	0.0035	0.0044
<b>5 Waste</b>	<b>0.033</b>	<b>0.030</b>	<b>0.031</b>	<b>0.032</b>	<b>0.032</b>
5A Solid waste disposal	0.020	0.015	0.014	0.014	0.012
5B Biological treatment of solid waste	0.0059	0.0086	0.012	0.012	0.014
5C Waste incineration and open burning of waste	0.0040	0.0030	0.0026	0.0027	0.0027
5D Wastewater handling and discharge	0.0032	0.0034	0.0034	0.0036	0.0039
<b>6 Other</b>	<b>0.00020</b>	<b>0.00020</b>	<b>0.00022</b>	<b>0.00023</b>	<b>0.00023</b>
6Ad Fire damages	0.00020	0.00020	0.00022	0.00023	0.00023
<b>Total</b>	<b>1.8</b>	<b>1.5</b>	<b>1.4</b>	<b>1.3</b>	<b>1.1</b>

Indirect N <sub>2</sub> O emissions by source category	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
kt N <sub>2</sub> O										
<b>1 Energy</b>	<b>1.0</b>	<b>1.0</b>	<b>1.0</b>	<b>0.90</b>	<b>0.88</b>	<b>0.83</b>	<b>0.78</b>	<b>0.74</b>	<b>0.65</b>	<b>0.63</b>
1A Fuel combustion activities	1.0	1.0	1.0	0.90	0.88	0.83	0.78	0.74	0.65	0.63
1B Fugitive emissions from fuels	0.00079	0.00094	0.00113	0.00065	0.000038	0.000029	0.000031	0.000021	0.000022	0.000018
<b>2 Industrial processes and product use</b>	<b>0.012</b>	<b>0.010</b>	<b>0.012</b>	<b>0.010</b>	<b>0.0092</b>	<b>0.010</b>	<b>0.0092</b>	<b>0.0088</b>	<b>0.0080</b>	<b>0.0082</b>
2A Mineral industry	0.00016	0.00016	0.00016	0.00015	0.00015	0.00015	0.00015	0.00015	0.00014	0.00014
2B Chemical industry	0.0011	0.0008	0.00094	0.00070	0.00094	0.00101	0.0004	0.00025	0.00022	0.00017
2C Metal industry	0.0026	0.0026	0.0027	0.0027	0.0026	0.0026	0.0027	0.0024	0.0023	0.0026
2G Other product manufacture and use	0.0033	0.0027	0.0025	0.0023	0.0024	0.0026	0.0029	0.0029	0.0028	0.0030
2H Other	0.0047	0.0041	0.0051	0.0040	0.0031	0.0036	0.0030	0.0031	0.0025	0.0022
<b>5 Waste</b>	<b>0.032</b>	<b>0.032</b>	<b>0.031</b>	<b>0.031</b>	<b>0.032</b>	<b>0.031</b>	<b>0.031</b>	<b>0.032</b>	<b>0.032</b>	<b>0.032</b>
5A Solid waste disposal	0.011	0.011	0.010	0.010	0.0092	0.0088	0.0083	0.0078	0.0075	0.0071
5B Biological treatment of solid waste	0.014	0.015	0.014	0.014	0.016	0.016	0.016	0.018	0.018	0.019
5C Waste incineration and open burning of waste	0.0025	0.0028	0.0028	0.0029	0.0026	0.0022	0.0018	0.0018	0.0018	0.0018
5D Wastewater handling and discharge	0.0040	0.0041	0.0041	0.0042	0.0042	0.0043	0.0043	0.0043	0.0044	0.00439
<b>6 Other</b>	<b>0.00024</b>	<b>0.00025</b>	<b>0.00020</b>	<b>0.00022</b>	<b>0.00021</b>	<b>0.00022</b>	<b>0.00023</b>	<b>0.00019</b>	<b>0.00019</b>	<b>0.00021</b>
6Ad Fire damages	0.00024	0.00025	0.00020	0.00022	0.00021	0.00022	0.00023	0.00019	0.00019	0.00021
<b>Total</b>	<b>1.1</b>	<b>1.1</b>	<b>1.0</b>	<b>0.94</b>	<b>0.92</b>	<b>0.87</b>	<b>0.82</b>	<b>0.78</b>	<b>0.69</b>	<b>0.67</b>

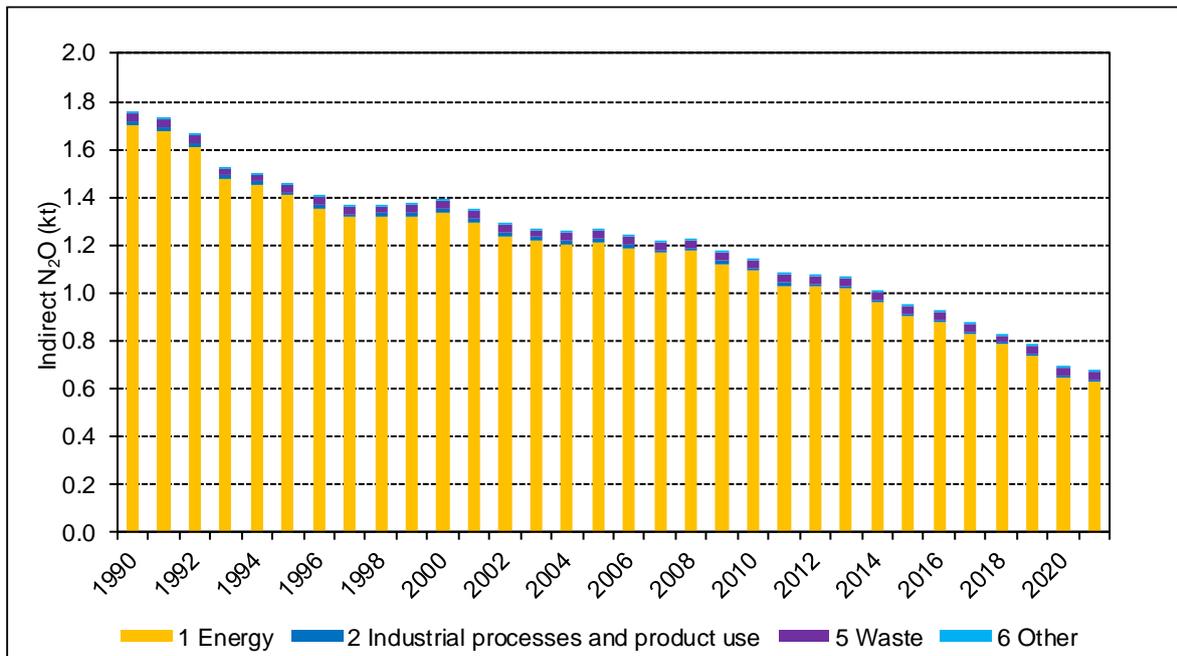


Figure 9-3 Switzerland's indirect N<sub>2</sub>O emissions.

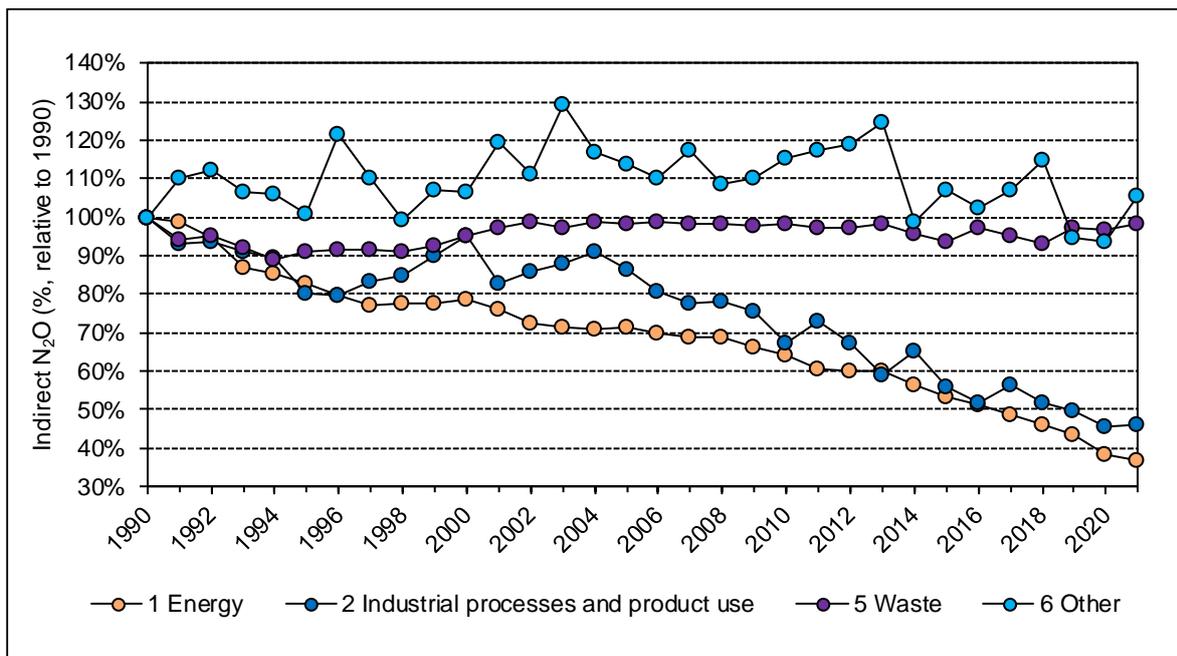


Figure 9-4 Relative trends of the indirect N<sub>2</sub>O emissions by sector. The base year 1990 represents 100 %.

Table 9-3 Switzerland's emissions of the precursor gases CH<sub>4</sub>, CO and NMVOC in the source categories of sector 1 Energy, together with the respective indirect CO<sub>2</sub> emissions. The numbers in parentheses indicate the fractions of precursor gases that are relevant for indirect CO<sub>2</sub>, i.e. the share of fossil emissions of precursor gases not already considered under the direct CO<sub>2</sub> emissions. To derive the indirect CO<sub>2</sub> emissions, the emissions of precursor gases need to be multiplied by the provided fractions as well as by the factors for the stoichiometric conversion of CH<sub>4</sub>, CO and NMVOC to indirect CO<sub>2</sub> as given in the text (chp. 9.2.1). As an illustrative example, an emission of NMVOC indicated as "150 (40.0 %)" leads to indirect CO<sub>2</sub> emissions of 132 kt (150 kt \* 40.0 % \* 0.6 \* 44/12 = 132 kt).

Emissions of NMVOC, CO and CH <sub>4</sub> as well as indirect CO <sub>2</sub>	1990	1995	2000	2005	2010
	kt				
<b>1 Energy: NMVOC</b>	<b>136 (12.4%)</b>	<b>87.3 (16.1%)</b>	<b>66.3 (15.0%)</b>	<b>45.8 (16.0%)</b>	<b>31.9 (15.9%)</b>
1A Fuel combustion	119 (0.0%)	73.2 (0.0%)	56.4 (0.0%)	38.4 (0.0%)	26.8 (0.0%)
1B Fugitive emissions from fuels	16.8 (99.9%)	14.1 (99.8%)	9.9 (99.8%)	7.4 (99.7%)	5.1 (99.8%)
<b>1 Energy: CO</b>	<b>802 (0.0%)</b>	<b>521 (0.0%)</b>	<b>406 (0.0%)</b>	<b>310 (0.0%)</b>	<b>242 (0.0%)</b>
1A Fuel combustion	802 (0.0%)	521 (0.0%)	406 (0.0%)	310 (0.0%)	242 (0.0%)
1B Fugitive emissions from fuels	0.0 (0.0%)	0.1 (0.0%)	0.1 (0.0%)	0.1 (0.0%)	0.0 (0.0%)
<b>1 Energy: CH<sub>4</sub></b>	<b>25.3 (53.1%)</b>	<b>24.9 (62.5%)</b>	<b>20.4 (62.8%)</b>	<b>16.8 (60.4%)</b>	<b>14.8 (62.8%)</b>
1A Fuel combustion	11.8 (0.0%)	9.3 (0.0%)	7.6 (0.0%)	6.6 (0.0%)	5.5 (0.0%)
1B Fugitive emissions from fuels	13.4 (99.9%)	15.6 (99.9%)	12.8 (99.8%)	10.2 (99.8%)	9.3 (99.9%)
<b>1 Energy: Total indirect CO<sub>2</sub></b>	<b>73.9</b>	<b>73.9</b>	<b>56.9</b>	<b>44.0</b>	<b>36.8</b>
1A Fuel combustion	NO	NO	NO	NO	NO
1B Fugitive emissions from fuels	73.9	73.9	56.9	44.0	36.8
<b>1 Energy: Indirect CO<sub>2</sub> from NMVOC</b>	<b>37.0</b>	<b>31.0</b>	<b>21.8</b>	<b>16.2</b>	<b>11.2</b>
1A Fuel combustion	NO	NO	NO	NO	NO
1B Fugitive emissions from fuels	37.0	31.0	21.8	16.2	11.2
<b>1 Energy: Indirect CO<sub>2</sub> from CO</b>	<b>NO</b>	<b>NO</b>	<b>NO</b>	<b>NO</b>	<b>NO</b>
1A Fuel combustion	NO	NO	NO	NO	NO
1B Fugitive emissions from fuels	NO	NO	NO	NO	NO
<b>1 Energy: Indirect CO<sub>2</sub> from CH<sub>4</sub></b>	<b>36.9</b>	<b>42.9</b>	<b>35.0</b>	<b>27.9</b>	<b>25.6</b>
1A Fuel combustion	NO	NO	NO	NO	NO
1B Fugitive emissions from fuels	36.9	42.9	35.0	27.9	25.6

Emissions of NMVOC, CO and CH <sub>4</sub> as well as indirect CO <sub>2</sub>	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
	kt									
<b>1 Energy: NMVOC</b>	<b>27.6 (17.7%)</b>	<b>26.1 (17.8%)</b>	<b>23.5 (19.1%)</b>	<b>21.8 (18.2%)</b>	<b>20.8 (17.0%)</b>	<b>19.8 (16.9%)</b>	<b>19.1 (17.5%)</b>	<b>18.4 (17.1%)</b>	<b>16.6 (17.1%)</b>	<b>16.6 (16.8%)</b>
1A Fuel combustion	22.7 (0.0%)	21.5 (0.0%)	19.0 (0.0%)	17.8 (0.0%)	17.3 (0.0%)	16.5 (0.0%)	15.7 (0.0%)	15.2 (0.0%)	13.8 (0.0%)	13.8 (0.0%)
1B Fugitive emissions from fuels	4.9 (99.8%)	4.7 (99.8%)	4.5 (99.8%)	4.0 (99.8%)	3.5 (99.9%)	3.3 (99.9%)	3.3 (99.8%)	3.2 (99.8%)	2.8 (99.9%)	2.8 (99.9%)
<b>1 Energy: CO</b>	<b>211 (0.0%)</b>	<b>205 (0.0%)</b>	<b>184 (0.0%)</b>	<b>175 (0.0%)</b>	<b>172 (0.0%)</b>	<b>165 (0.0%)</b>	<b>160 (0.0%)</b>	<b>156 (0.0%)</b>	<b>142 (0.0%)</b>	<b>143 (0.0%)</b>
1A Fuel combustion	211 (0.0%)	205 (0.0%)	184 (0.0%)	175 (0.0%)	172 (0.0%)	165 (0.0%)	160 (0.0%)	156 (0.0%)	142 (0.0%)	143 (0.0%)
1B Fugitive emissions from fuels	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)
<b>1 Energy: CH<sub>4</sub></b>	<b>13.1 (64.5%)</b>	<b>12.6 (62.6%)</b>	<b>11.5 (66.8%)</b>	<b>11.5 (66.3%)</b>	<b>11.6 (65.8%)</b>	<b>11.3 (66.5%)</b>	<b>11.1 (68.0%)</b>	<b>10.9 (68.0%)</b>	<b>10.6 (69.7%)</b>	<b>10.9 (68.9%)</b>
1A Fuel combustion	4.6 (0.0%)	4.7 (0.0%)	3.8 (0.0%)	3.9 (0.0%)	4.0 (0.0%)	3.8 (0.0%)	3.5 (0.0%)	3.5 (0.0%)	3.2 (0.0%)	3.4 (0.0%)
1B Fugitive emissions from fuels	8.5 (100.0%)	7.9 (99.9%)	7.7 (99.9%)	7.6 (100.0%)	7.6 (100.0%)	7.5 (100.0%)	7.5 (100.0%)	7.4 (100.0%)	7.4 (100.0%)	7.5 (100.0%)
<b>1 Energy: Total indirect CO<sub>2</sub></b>	<b>34.0</b>	<b>31.9</b>	<b>31.0</b>	<b>29.6</b>	<b>28.7</b>	<b>28.0</b>	<b>28.0</b>	<b>27.3</b>	<b>26.5</b>	<b>26.7</b>
1A Fuel combustion	NO									
1B Fugitive emissions from fuels	34.0	31.9	31.0	29.6	28.7	28.0	28.0	27.3	26.5	26.7
<b>1 Energy: Indirect CO<sub>2</sub> from NMVOC</b>	<b>10.7</b>	<b>10.2</b>	<b>9.9</b>	<b>8.7</b>	<b>7.8</b>	<b>7.4</b>	<b>7.3</b>	<b>6.9</b>	<b>6.3</b>	<b>6.1</b>
1A Fuel combustion	NO									
1B Fugitive emissions from fuels	10.7	10.2	9.9	8.7	7.8	7.4	7.3	6.9	6.3	6.1
<b>1 Energy: Indirect CO<sub>2</sub> from CO</b>	<b>NO</b>									
1A Fuel combustion	NO									
1B Fugitive emissions from fuels	NO									
<b>1 Energy: Indirect CO<sub>2</sub> from CH<sub>4</sub></b>	<b>23.3</b>	<b>21.6</b>	<b>21.1</b>	<b>20.9</b>	<b>20.9</b>	<b>20.7</b>	<b>20.7</b>	<b>20.4</b>	<b>20.3</b>	<b>20.6</b>
1A Fuel combustion	NO									
1B Fugitive emissions from fuels	23.3	21.6	21.1	20.9	20.9	20.7	20.7	20.4	20.3	20.6

Table 9-4 Switzerland's emissions of the precursor gases CH<sub>4</sub>, CO and NMVOC in the source categories of sector 2 Industrial processes and product use, together with the respective indirect CO<sub>2</sub> emissions. The numbers in parentheses indicate the fractions of precursor gases that are relevant for indirect CO<sub>2</sub>, i.e. the share of fossil emissions of precursor gases not already considered under the direct CO<sub>2</sub> emissions. To derive the indirect CO<sub>2</sub> emissions, the emissions of precursor gases need to be multiplied by the provided fractions as well as by the factors for the stoichiometric conversion of CH<sub>4</sub>, CO and NMVOC to indirect CO<sub>2</sub> as given in the text (chp. 9.2.1). As an illustrative example, an emission of NMVOC indicated as "150 (40.0 %)" leads to indirect CO<sub>2</sub> emissions of 132 kt (150 kt \* 40.0 % \* 0.6 \* 44/12 = 132 kt).

Emissions of NMVOC, CO and CH <sub>4</sub> as well as indirect CO <sub>2</sub>	1990	1995	2000	2005	2010
	kt				
<b>2 IPPU: NMVOC</b>	<b>150 (98.6%)</b>	<b>106 (98.0%)</b>	<b>74.6 (97.2%)</b>	<b>51.8 (95.9%)</b>	<b>48.0 (95.4%)</b>
2A Mineral industry	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)
2B Chemical industry	0.6 (96.5%)	0.2 (90.7%)	0.0 (30.9%)	0.0 (21.4%)	0.0 (32.9%)
2C Metal industry	1.1 (92.0%)	0.8 (92.7%)	0.7 (89.9%)	0.5 (82.1%)	0.3 (75.6%)
2D Non-energy products from fuels and solvent use	88.2 (100.0%)	57.7 (100.0%)	42.0 (100.0%)	23.0 (100.0%)	22.3 (100.0%)
2G Other product manufacture and use	57.1 (99.9%)	44.4 (99.8%)	29.4 (99.7%)	25.9 (99.8%)	22.8 (99.7%)
2H Other	2.7 (26.7%)	2.6 (24.2%)	2.4 (18.9%)	2.4 (17.3%)	2.5 (19.7%)
<b>2 IPPU: CO</b>	<b>11.1 (50.2%)</b>	<b>7.1 (66.2%)</b>	<b>9.1 (66.9%)</b>	<b>8.1 (58.8%)</b>	<b>7.2 (78.4%)</b>
2A Mineral industry	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)
2B Chemical industry	4.0 (100.0%)	3.7 (100.0%)	4.9 (100.0%)	4.2 (100.0%)	4.6 (100.0%)
2C Metal industry	5.3 (13.3%)	2.0 (26.7%)	2.6 (19.0%)	2.9 (9.8%)	1.1 (20.7%)
2D Non-energy products from fuels and solvent use	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)
2G Other product manufacture and use	0.9 (0.7%)	0.9 (0.9%)	0.9 (1.3%)	0.7 (1.4%)	0.7 (1.8%)
2H Other	0.9 (94.6%)	0.4 (91.4%)	0.6 (96.8%)	0.3 (94.1%)	0.8 (97.8%)
<b>2 IPPU: CH<sub>4</sub></b>	<b>0.1 (100.0%)</b>	<b>0.2 (100.0%)</b>	<b>0.2 (100.0%)</b>	<b>0.3 (100.0%)</b>	<b>0.3 (100.0%)</b>
2B Chemical industry	0.1 (100.0%)	0.2 (100.0%)	0.2 (100.0%)	0.3 (100.0%)	0.3 (100.0%)
<b>2 IPPU: Total indirect CO<sub>2</sub></b>	<b>334</b>	<b>236</b>	<b>170</b>	<b>117</b>	<b>110</b>
2A Mineral industry	0.1	0.1	0.1	0.1	0.1
2B Chemical industry	8.0	6.8	8.4	7.3	8.1
2C Metal industry	3.4	2.4	2.2	1.3	0.9
2D Non-energy products from fuels and solvent use	194	127	92.4	50.6	49.0
2G Other product manufacture and use	126	97.5	64.6	56.8	50.0
2H Other	2.8	2.0	1.9	1.3	2.3
<b>2 IPPU: Indirect CO<sub>2</sub> from NMVOC</b>	<b>325</b>	<b>228</b>	<b>159</b>	<b>109</b>	<b>101</b>
2A Mineral industry	0.1	0.1	0.07	0.08	0.08
2B Chemical industry	1.3	0.4	0.02	0.01	0.03
2C Metal industry	2.3	1.6	1.4	0.8	0.6
2D Non-energy products from fuels and solvent use	194	127	92.4	50.6	49.0
2G Other product manufacture and use	125	97.5	64.6	56.8	50.0
2H Other	1.6	1.4	1.0	0.9	1.1
<b>2 IPPU: Indirect CO<sub>2</sub> from CO</b>	<b>8.8</b>	<b>7.4</b>	<b>9.5</b>	<b>7.5</b>	<b>8.9</b>
2A Mineral industry	0.04	0.04	0.03	0.04	0.04
2B Chemical industry	6.3	5.8	7.8	6.6	7.3
2C Metal industry	1.1	0.9	0.8	0.4	0.3
2D Non-energy products from fuels and solvent use	0.001	0.001	0.001	0.0004	0.001
2G Other product manufacture and use	0.01	0.01	0.02	0.02	0.02
2H Other	1.3	0.6	0.9	0.4	1.2
<b>2 IPPU: Indirect CO<sub>2</sub> from CH<sub>4</sub></b>	<b>0.4</b>	<b>0.6</b>	<b>0.6</b>	<b>0.7</b>	<b>0.8</b>
2B Chemical industry	0.4	0.6	0.6	0.7	0.8

Emissions of NMVOC, CO and CH <sub>4</sub> as well as indirect CO <sub>2</sub>	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
	kt									
<b>2 IPPU: NMVOC</b>	<b>44.7 (95.1%)</b>	<b>43.2 (95.0%)</b>	<b>41.7 (94.8%)</b>	<b>39.7 (94.6%)</b>	<b>37.8 (94.4%)</b>	<b>37.4 (94.3%)</b>	<b>37.2 (94.2%)</b>	<b>36.8 (94.2%)</b>	<b>36.9 (94.2%)</b>	<b>36.9 (94.2%)</b>
2A Mineral industry	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)
2B Chemical industry	0.0 (10.8%)	0.0 (11.1%)	0.0 (22.8%)	0.0 (12.4%)	0.0 (5.6%)	0.0 (8.7%)	0.0 (10.0%)	0.0 (13.2%)	0.0 (15.3%)	0.0 (10.4%)
2C Metal industry	0.3 (72.6%)	0.3 (72.6%)	0.3 (70.8%)	0.3 (68.3%)	0.3 (67.8%)	0.3 (68.0%)	0.3 (67.3%)	0.2 (63.7%)	0.2 (61.1%)	0.2 (59.3%)
2D Non-energy products from fuels and solvent use	20.6 (100.0%)	20.0 (100.0%)	19.1 (100.0%)	17.9 (100.0%)	16.8 (100.0%)	16.8 (100.0%)	16.5 (100.0%)	16.4 (100.0%)	16.1 (100.0%)	16.1 (100.0%)
2G Other product manufacture and use	21.2 (99.7%)	20.4 (99.7%)	19.7 (99.7%)	19.1 (99.7%)	18.4 (99.7%)	18.3 (99.7%)	18.3 (99.7%)	18.2 (99.7%)	18.2 (99.7%)	18.3 (99.7%)
2H Other	2.5 (18.1%)	2.4 (17.5%)	2.4 (17.2%)	2.4 (17.2%)	2.3 (13.7%)	2.3 (13.9%)	2.3 (13.7%)	2.3 (12.3%)	2.2 (11.5%)	2.3 (12.5%)
<b>2 IPPU: CO</b>	<b>7.0 (77.1%)</b>	<b>6.0 (74.1%)</b>	<b>6.2 (75.4%)</b>	<b>6.5 (76.9%)</b>	<b>10.1 (85.5%)</b>	<b>10.1 (85.1%)</b>	<b>6.5 (77.2%)</b>	<b>9.5 (85.7%)</b>	<b>8.4 (83.5%)</b>	<b>5.7 (73.7%)</b>
2A Mineral industry	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)
2B Chemical industry	4.4 (100.0%)	3.5 (100.0%)	3.8 (100.0%)	4.1 (100.0%)	8.3 (100.0%)	8.2 (100.0%)	4.6 (100.0%)	7.8 (100.0%)	6.7 (100.0%)	3.9 (100.0%)
2C Metal industry	1.1 (17.8%)	1.1 (18.0%)	1.1 (16.5%)	1.1 (14.6%)	1.0 (14.3%)	1.0 (14.3%)	1.0 (13.8%)	0.9 (11.4%)	0.9 (9.9%)	1.0 (9.2%)
2D Non-energy products from fuels and solvent use	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)
2G Other product manufacture and use	0.7 (2.0%)	0.7 (2.5%)	0.6 (2.2%)	0.6 (2.1%)	0.6 (1.5%)	0.6 (2.1%)	0.6 (2.3%)	0.6 (1.3%)	0.6 (1.3%)	0.6 (1.4%)
2H Other	0.7 (97.7%)	0.7 (97.7%)	0.7 (97.5%)	0.7 (97.5%)	0.2 (92.5%)	0.2 (93.1%)	0.3 (93.8%)	0.2 (92.7%)	0.2 (92.1%)	0.2 (91.8%)
<b>2 IPPU: CH<sub>4</sub></b>	<b>0.3 (100.0%)</b>	<b>0.2 (100.0%)</b>	<b>0.2 (100.0%)</b>	<b>0.2 (100.0%)</b>	<b>0.3 (100.0%)</b>	<b>0.2 (100.0%)</b>				
2B Chemical industry	0.3 (100.0%)	0.2 (100.0%)	0.2 (100.0%)	0.2 (100.0%)	0.3 (100.0%)	0.3 (100.0%)	0.3 (100.0%)	0.3 (100.0%)	0.3 (100.0%)	0.2 (100.0%)
<b>2 IPPU: Total indirect CO<sub>2</sub></b>	<b>103</b>	<b>97.8</b>	<b>94.8</b>	<b>91.1</b>	<b>92.9</b>	<b>92.7</b>	<b>86.3</b>	<b>90.6</b>	<b>88.0</b>	<b>83.7</b>
2A Mineral industry	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
2B Chemical industry	7.7	6.1	6.6	7.1	13.8	13.6	8.1	13.0	11.2	6.8
2C Metal industry	0.8	0.8	0.8	0.7	0.6	0.6	0.6	0.5	0.4	0.4
2D Non-energy products from fuels and solvent use	45.3	43.9	42.1	39.4	37.0	37.0	36.3	36.1	35.4	35.4
2G Other product manufacture and use	46.6	44.9	43.3	41.9	40.4	40.3	40.1	40.0	40.0	40.1
2H Other	2.1	2.0	2.0	1.9	1.0	1.0	1.1	0.9	0.9	0.9
<b>2 IPPU: Indirect CO<sub>2</sub> from NMVOC</b>	<b>93.4</b>	<b>90.3</b>	<b>86.9</b>	<b>82.7</b>	<b>78.5</b>	<b>78.5</b>	<b>77.1</b>	<b>77.1</b>	<b>76.3</b>	<b>76.5</b>
2A Mineral industry	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
2B Chemical industry	0.01	0.01	0.01	0.01	0.002	0.002	0.003	0.005	0.01	0.004
2C Metal industry	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3
2D Non-energy products from fuels and solvent use	45.3	43.9	42.1	39.4	37.0	37.0	36.3	36.1	35.4	35.4
2G Other product manufacture and use	46.6	44.8	43.3	41.9	40.4	40.2	40.0	40.0	40.0	40.1
2H Other	1.0	0.9	0.9	0.9	0.7	0.7	0.7	0.6	0.6	0.6
<b>2 IPPU: Indirect CO<sub>2</sub> from CO</b>	<b>8.4</b>	<b>7.0</b>	<b>7.3</b>	<b>7.8</b>	<b>13.6</b>	<b>13.5</b>	<b>7.9</b>	<b>12.8</b>	<b>11.0</b>	<b>6.6</b>
2A Mineral industry	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02
2B Chemical industry	7.0	5.5	6.0	6.5	13.0	12.8	7.2	12.3	10.5	6.1
2C Metal industry	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.1	0.1
2D Non-energy products from fuels and solvent use	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
2G Other product manufacture and use	0.02	0.03	0.02	0.02	0.01	0.02	0.02	0.01	0.01	0.01
2H Other	1.1	1.1	1.0	1.0	0.3	0.4	0.4	0.3	0.3	0.3
<b>2 IPPU: Indirect CO<sub>2</sub> from CH<sub>4</sub></b>	<b>0.7</b>	<b>0.6</b>	<b>0.6</b>	<b>0.6</b>	<b>0.8</b>	<b>0.8</b>	<b>0.8</b>	<b>0.8</b>	<b>0.7</b>	<b>0.7</b>
2B Chemical industry	0.7	0.6	0.6	0.6	0.8	0.8	0.8	0.8	0.7	0.7

Table 9-5 Switzerland's emissions of the precursor gases CH<sub>4</sub>, CO and NMVOC in the source categories of sector 5 Waste, together with the respective indirect CO<sub>2</sub> emissions. The numbers in parentheses indicate the fractions of precursor gases that are relevant for indirect CO<sub>2</sub>, i.e. the share of fossil emissions of precursor gases not already considered under the direct CO<sub>2</sub> emissions. To derive the indirect CO<sub>2</sub> emissions, the emissions of precursor gases need to be multiplied by the provided fractions as well as by the factors for the stoichiometric conversion of CH<sub>4</sub>, CO and NMVOC to indirect CO<sub>2</sub> as given in the text (chp. 9.2.1). As an illustrative example, an emission of NMVOC indicated as "150 (40.0 %)" leads to indirect CO<sub>2</sub> emissions of 132 kt (150 kt \* 40.0 % \* 0.6 \* 44/12 = 132 kt).

Emissions of NMVOC, CO and CH <sub>4</sub> as well as indirect CO <sub>2</sub>	1990	1995	2000	2005	2010
	kt				
<b>5 Waste: NMVOC</b>	<b>1.1 (25.6%)</b>	<b>1.0 (25.8%)</b>	<b>1.0 (25.3%)</b>	<b>1.0 (22.7%)</b>	<b>1.2 (18.8%)</b>
5A Solid waste disposal	0.4 (0.0%)	0.3 (0.0%)	0.3 (0.0%)	0.3 (0.0%)	0.2 (0.0%)
5B Biological treatment of solid waste	0.2 (0.0%)	0.2 (0.0%)	0.3 (0.0%)	0.3 (0.0%)	0.5 (0.0%)
5C Incineration and open burning of waste	0.6 (47.4%)	0.5 (47.3%)	0.4 (48.1%)	0.4 (47.0%)	0.4 (45.2%)
5D Waste water treatment and discharge	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)
5E Other	0.0 (100.0%)	0.0 (100.0%)	0.1 (100.0%)	0.1 (100.0%)	0.1 (100.0%)
<b>5 Waste: CO</b>	<b>2.8 (29.8%)</b>	<b>2.4 (27.7%)</b>	<b>2.2 (28.7%)</b>	<b>1.9 (28.6%)</b>	<b>1.7 (29.3%)</b>
5A Solid waste disposal	0.0 (0.0%)	0.1 (0.0%)	0.1 (0.0%)	0.1 (0.0%)	0.0 (0.0%)
5B Biological treatment of solid waste	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)
5C Incineration and open burning of waste	2.8 (90.2%)	2.3 (28.8%)	2.1 (30.0%)	1.9 (28.5%)	1.7 (30.0%)
5D Waste water treatment and discharge	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)
5E Other	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)
<b>5 Waste: CH<sub>4</sub></b>	<b>39.1 (0.2%)</b>	<b>30.9 (0.3%)</b>	<b>28.6 (0.3%)</b>	<b>28.6 (0.2%)</b>	<b>25.3 (0.2%)</b>
5A Solid waste disposal	30.8 (0.0%)	23.1 (0.0%)	21.0 (0.0%)	21.2 (0.0%)	17.6 (0.0%)
5B Biological treatment of solid waste	0.5 (0.0%)	0.6 (0.0%)	0.8 (0.0%)	0.8 (0.0%)	0.8 (0.0%)
5C Incineration and open burning of waste	0.4 (27.1%)	0.3 (26.4%)	0.3 (27.8%)	0.2 (27.1%)	0.2 (27.7%)
5D Waste water treatment and discharge	7.5 (0.0%)	6.8 (0.0%)	6.5 (0.0%)	6.4 (0.0%)	6.7 (0.0%)
<b>5 Waste: Total indirect CO<sub>2</sub></b>	<b>2.2</b>	<b>1.9</b>	<b>1.8</b>	<b>1.6</b>	<b>1.5</b>
5A Solid waste disposal	NO	NO	NO	NO	NO
5B Biological treatment of solid waste	NO	NO	NO	NO	NO
5C Incineration and open burning of waste	2.2	1.7	1.7	1.4	1.3
5D Waste water treatment and discharge	NO	NO	NO	NO	NO
5E Other	0.1	0.1	0.1	0.1	0.1
<b>5 Waste: Indirect CO<sub>2</sub> from NMVOC</b>	<b>0.6</b>	<b>0.6</b>	<b>0.6</b>	<b>0.5</b>	<b>0.5</b>
5A Solid waste disposal	NO	NO	NO	NO	NO
5B Biological treatment of solid waste	NO	NO	NO	NO	NO
5C Incineration and open burning of waste	0.6	0.5	0.5	0.4	0.4
5D Waste water treatment and discharge	NO	NO	NO	NO	NO
5E Other	0.1	0.1	0.1	0.1	0.1
<b>5 Waste: Indirect CO<sub>2</sub> from CO</b>	<b>1.3</b>	<b>1.1</b>	<b>1.0</b>	<b>0.9</b>	<b>0.8</b>
5A Solid waste disposal	NO	NO	NO	NO	NO
5B Biological treatment of solid waste	NO	NO	NO	NO	NO
5C Incineration and open burning of waste	1.3	1.1	1.0	0.9	0.8
5D Waste water treatment and discharge	NO	NO	NO	NO	NO
5E Other	0.002	0.002	0.002	0.002	0.002
<b>5 Waste: Indirect CO<sub>2</sub> from CH<sub>4</sub></b>	<b>0.3</b>	<b>0.2</b>	<b>0.2</b>	<b>0.2</b>	<b>0.2</b>
5A Solid waste disposal	NO	NO	NO	NO	NO
5B Biological treatment of solid waste	NO	NO	NO	NO	NO
5C Incineration and open burning of waste	0.3	0.2	0.2	0.2	0.2
5D Waste water treatment and discharge	NO	NO	NO	NO	NO

Emissions of NMVOC, CO and CH <sub>4</sub> as well as indirect CO <sub>2</sub>	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
	kt									
<b>5 Waste: NMVOC</b>	<b>1.3 (16.6%)</b>	<b>1.3 (15.7%)</b>	<b>1.4 (15.1%)</b>	<b>1.4 (14.7%)</b>	<b>1.5 (13.6%)</b>	<b>1.5 (13.1%)</b>	<b>1.6 (12.5%)</b>	<b>1.7 (11.5%)</b>	<b>1.7 (11.0%)</b>	<b>1.8 (10.6%)</b>
5A Solid waste disposal	0.2 (0.0%)	0.2 (0.0%)	0.2 (0.0%)	0.2 (0.0%)	0.2 (0.0%)	0.2 (0.0%)	0.2 (0.0%)	0.2 (0.0%)	0.1 (0.0%)	0.1 (0.0%)
5B Biological treatment of solid waste	0.7 (0.0%)	0.7 (0.0%)	0.8 (0.0%)	0.8 (0.0%)	0.9 (0.0%)	1.0 (0.0%)	1.0 (0.0%)	1.1 (0.0%)	1.2 (0.0%)	1.3 (0.0%)
5C Incineration and open burning of waste	0.3 (44.4%)	0.3 (44.1%)	0.3 (43.9%)	0.3 (43.8%)	0.3 (43.4%)	0.3 (42.8%)	0.3 (42.4%)	0.3 (42.2%)	0.3 (42.3%)	0.3 (42.2%)
5D Waste water treatment and discharge	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)
5E Other	0.1 (100.0%)	0.1 (100.0%)	0.1 (100.0%)	0.1 (100.0%)	0.1 (100.0%)	0.1 (100.0%)	0.1 (100.0%)	0.1 (100.0%)	0.1 (100.0%)	0.1 (100.0%)
<b>5 Waste: CO</b>	<b>1.7 (28.9%)</b>	<b>1.7 (28.8%)</b>	<b>1.6 (28.7%)</b>	<b>1.6 (28.8%)</b>	<b>1.6 (28.8%)</b>	<b>1.5 (28.5%)</b>	<b>1.5 (28.4%)</b>	<b>1.5 (28.2%)</b>	<b>1.5 (28.1%)</b>	<b>1.4 (27.9%)</b>
5A Solid waste disposal	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)
5B Biological treatment of solid waste	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)
5C Incineration and open burning of waste	1.6 (29.5%)	1.6 (29.3%)	1.6 (29.1%)	1.6 (29.3%)	1.6 (29.3%)	1.5 (29.0%)	1.5 (28.9%)	1.4 (28.7%)	1.4 (28.6%)	1.4 (28.4%)
5D Waste water treatment and discharge	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)
5E Other	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)
<b>5 Waste: CH<sub>4</sub></b>	<b>23.9 (0.2%)</b>	<b>23.4 (0.2%)</b>	<b>23.0 (0.2%)</b>	<b>22.4 (0.2%)</b>	<b>22.0 (0.2%)</b>	<b>21.5 (0.2%)</b>	<b>20.9 (0.2%)</b>	<b>20.4 (0.2%)</b>	<b>19.9 (0.2%)</b>	<b>19.4 (0.2%)</b>
5A Solid waste disposal	16.0 (0.0%)	15.3 (0.0%)	14.7 (0.0%)	14.1 (0.0%)	13.4 (0.0%)	12.8 (0.0%)	12.1 (0.0%)	11.4 (0.0%)	10.9 (0.0%)	10.3 (0.0%)
5B Biological treatment of solid waste	0.9 (0.0%)	0.9 (0.0%)	0.9 (0.0%)	0.9 (0.0%)	1.0 (0.0%)	1.0 (0.0%)	1.1 (0.0%)	1.1 (0.0%)	1.1 (0.0%)	1.1 (0.0%)
5C Incineration and open burning of waste	0.2 (27.2%)	0.2 (26.9%)	0.2 (26.6%)	0.2 (26.7%)	0.2 (26.6%)	0.2 (26.2%)	0.2 (26.1%)	0.2 (25.8%)	0.2 (25.8%)	0.2 (25.6%)
5D Waste water treatment and discharge	6.8 (0.0%)	6.9 (0.0%)	7.1 (0.0%)	7.2 (0.0%)	7.4 (0.0%)	7.5 (0.0%)	7.6 (0.0%)	7.7 (0.0%)	7.7 (0.0%)	7.8 (0.0%)
<b>5 Waste: Total indirect CO<sub>2</sub></b>	<b>1.4</b>	<b>1.4</b>	<b>1.3</b>	<b>1.3</b>	<b>1.3</b>	<b>1.3</b>	<b>1.2</b>	<b>1.2</b>	<b>1.2</b>	<b>1.2</b>
5A Solid waste disposal	NO									
5B Biological treatment of solid waste	NO									
5C Incineration and open burning of waste	1.3	1.2	1.2	1.2	1.1	1.1	1.1	1.1	1.1	1.0
5D Waste water treatment and discharge	NO									
5E Other	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
<b>5 Waste: Indirect CO<sub>2</sub> from NMVOC</b>	<b>0.5</b>	<b>0.5</b>	<b>0.5</b>	<b>0.5</b>	<b>0.5</b>	<b>0.4</b>	<b>0.4</b>	<b>0.4</b>	<b>0.4</b>	<b>0.4</b>
5A Solid waste disposal	NO									
5B Biological treatment of solid waste	NO									
5C Incineration and open burning of waste	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
5D Waste water treatment and discharge	NO									
5E Other	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
<b>5 Waste: Indirect CO<sub>2</sub> from CO</b>	<b>0.8</b>	<b>0.7</b>	<b>0.6</b>	<b>0.6</b>						
5A Solid waste disposal	NO									
5B Biological treatment of solid waste	NO									
5C Incineration and open burning of waste	0.8	0.7	0.7	0.7	0.7	0.7	0.7	0.6	0.6	0.6
5D Waste water treatment and discharge	NO									
5E Other	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
<b>5 Waste: Indirect CO<sub>2</sub> from CH<sub>4</sub></b>	<b>0.2</b>	<b>0.2</b>	<b>0.2</b>	<b>0.2</b>	<b>0.1</b>	<b>0.1</b>	<b>0.1</b>	<b>0.1</b>	<b>0.1</b>	<b>0.1</b>
5A Solid waste disposal	NO									
5B Biological treatment of solid waste	NO									
5C Incineration and open burning of waste	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1
5D Waste water treatment and discharge	NO									

Table 9-6 Switzerland's emissions of the precursor gases CH<sub>4</sub>, CO and NMVOC in the source categories of sector 6 Other, together with the respective indirect CO<sub>2</sub> emissions. The numbers in parentheses indicate the fractions of precursor gases that are relevant for indirect CO<sub>2</sub>, i.e. the share of fossil emissions of precursor gases not already considered under the direct CO<sub>2</sub> emissions. To derive the indirect CO<sub>2</sub> emissions, the emissions of precursor gases need to be multiplied by the provided fractions as well as by the factors for the stoichiometric conversion of CH<sub>4</sub>, CO and NMVOC to indirect CO<sub>2</sub> as given in the text (chp. 9.2.1). As an illustrative example, an emission of NMVOC indicated as "150 (40.0 %)" leads to indirect CO<sub>2</sub> emissions of 132 kt (150 kt \* 40.0 % \* 0.6 \* 44/12 = 132 kt).

Emissions of NMVOC, CO and CH <sub>4</sub> as well as indirect CO <sub>2</sub>	1990	1995	2000	2005	2010
	kt				
6 Other: NMVOC	0.1 (67.6%)	0.1 (73.4%)	0.1 (79.1%)	0.1 (79.1%)	0.1 (79.1%)
6 Other: CO	0.8 (67.4%)	0.8 (73.2%)	0.9 (79.0%)	0.9 (79.0%)	0.9 (79.0%)
6 Other: CH <sub>4</sub>	0.0 (70.3%)	0.0 (75.7%)	0.0 (81.1%)	0.0 (81.2%)	0.0 (81.4%)
6 Other: Total indirect CO <sub>2</sub>	1.1	1.2	1.4	1.5	1.4
6 Other: Indirect CO <sub>2</sub> from NMVOC	0.2	0.2	0.2	0.3	0.2
6 Other: Indirect CO <sub>2</sub> from CO	0.9	1.0	1.1	1.1	1.1
6 Other: Indirect CO <sub>2</sub> from CH <sub>4</sub>	0.1	0.1	0.1	0.1	0.1

Emissions of NMVOC, CO and CH <sub>4</sub> as well as indirect CO <sub>2</sub>	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
	kt									
6 Other: NMVOC	0.1 (79.2%)	0.2 (79.1%)	0.1 (79.2%)	0.1 (79.2%)	0.1 (79.2%)	0.1 (79.2%)	0.1 (79.2%)	0.1 (79.2%)	0.1 (79.2%)	0.1 (79.2%)
6 Other: CO	0.9 (79.0%)	1.0 (79.0%)	0.7 (79.0%)	0.8 (79.0%)	0.8 (79.0%)	0.8 (79.0%)	0.9 (79.0%)	0.7 (79.0%)	0.7 (79.0%)	0.8 (79.0%)
6 Other: CH <sub>4</sub>	0.0 (81.4%)	0.0 (81.3%)	0.0 (81.9%)	0.0 (81.8%)	0.0 (81.9%)	0.0 (81.8%)	0.0 (81.7%)	0.0 (82.2%)	0.0 (82.3%)	0.0 (82.0%)
6 Other: Total indirect CO <sub>2</sub>	1.4	1.5	1.2	1.3	1.2	1.3	1.4	1.1	1.1	1.3
6 Other: Indirect CO <sub>2</sub> from NMVOC	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
6 Other: Indirect CO <sub>2</sub> from CO	1.1	1.2	0.9	1.0	1.0	1.0	1.1	0.9	0.9	1.0
6 Other: Indirect CO <sub>2</sub> from CH <sub>4</sub>	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1

## 9.2. Indirect CO<sub>2</sub> and N<sub>2</sub>O emissions from all source categories of the GHG inventory

Table 9-7 Key categories of indirect CO<sub>2</sub> emissions. Combined KCA results, level for 2021 and trend for 1990–2021, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC category	Gas	Identification criteria
2D	Non-energy products from fuels and solvent use	Indirect CO <sub>2</sub> from NMVOC	T1, T2
2G	Other product manufacture and use	Indirect CO <sub>2</sub> from NMVOC	T2

As described in chp. 9.1, indirect CO<sub>2</sub> emissions cover all emissions that result from the atmospheric oxidation of CH<sub>4</sub>, CO and NMVOC, while indirect N<sub>2</sub>O emissions reflect emissions that are induced by the deposition of NO<sub>x</sub> and NH<sub>3</sub>. Accordingly, a large number of source categories – contributing the precursor gases CH<sub>4</sub>, CO, NMVOC, NO<sub>x</sub> and NH<sub>3</sub> – are involved (see Table 9-1 and Table 9-2 for an overview as well as Table 9-3 to Table 9-6 for the full details). Only the contributions of two source categories were identified as key categories of indirect CO<sub>2</sub> emissions as shown in Table 9-7.

### 9.2.1. Methodological issues to derive indirect CO<sub>2</sub> emissions

Indirect CO<sub>2</sub> emissions resulting from the atmospheric oxidation of CH<sub>4</sub> and CO are calculated based on the stoichiometric conversion (molecular weight of CO<sub>2</sub> divided by the molecular weight of CH<sub>4</sub> or CO, respectively). Indirect CO<sub>2</sub> emissions from the atmospheric oxidation of NMVOC are also calculated based on the stoichiometric conversion (carbon content fraction multiplied by the molecular weight of CO<sub>2</sub> divided by the molecular weight of carbon). Thereby, a constant carbon content of NMVOC of 60 % is assumed, based on the IPCC Guidelines (IPCC 2006). Thus, indirect CO<sub>2</sub> emissions (Em) result from the following equations:

- $Em_{CO_2, \text{ indirect from } CH_4} = Em_{CH_4, \text{ fossil}} * 44/16$
- $Em_{CO_2, \text{ indirect from } CO} = Em_{CO, \text{ fossil}} * 44/28$
- $Em_{CO_2, \text{ indirect from } NMVOC} = Em_{NMVOC, \text{ fossil}} * 0.6 * 44/12$

#### *Activity data for the calculation of indirect CO<sub>2</sub> emissions*

Activity data to calculate indirect CO<sub>2</sub> emissions consists of CH<sub>4</sub>, CO and NMVOC emissions as reported in each individual sector and source category, carefully excluding CH<sub>4</sub>, CO and NMVOC emissions of biogenic origin and emissions already included as direct CO<sub>2</sub> emissions (e.g. when using an oxidation factor of 100 %). For the different sectors and source categories, the situation is as follows:

**1A Energy:** Since according to the IPCC Guidelines (IPCC 2006) emission factors in source category 1A Energy are based on the assumption of complete oxidation (100 %), CO<sub>2</sub> resulting from the atmospheric oxidation of CH<sub>4</sub>, CO and NMVOC emitted from this source

category is already accounted for in the corresponding emission factors for direct CO<sub>2</sub> emissions. The respective emissions are thus implicitly reported as direct CO<sub>2</sub> emissions in 1A and no indirect CO<sub>2</sub> emissions from 1A Energy are reported (see chp. 3.2.4.4.1).

**1B Fugitive emissions from fuels:** CO<sub>2</sub> resulting from the atmospheric oxidation of CH<sub>4</sub>, CO and NMVOC emitted from source category 1B is reported as indirect CO<sub>2</sub> emissions unless it is already accounted for implicitly as direct CO<sub>2</sub> emissions in 1B (chp. 3.3). For 1B, Table 9-8 illustrates in which processes CH<sub>4</sub>, CO and NMVOC emissions occur, and whether the related CO<sub>2</sub> emissions are reported as indirect CO<sub>2</sub> emissions or implicitly as direct CO<sub>2</sub> emissions. In summary, all CO<sub>2</sub> resulting from the atmospheric oxidation of CO emitted from 1B is implicitly included in 1B as direct CO<sub>2</sub> and is therefore not reported as indirect CO<sub>2</sub>. CO<sub>2</sub> resulting from the atmospheric oxidation of CH<sub>4</sub> and NMVOC emitted from 1B is reported as indirect CO<sub>2</sub>, except for source category 1B2c, where an oxidation factor of 100 % is applied to calculate direct CO<sub>2</sub> emissions.

Table 9-8 Sources of indirect CO<sub>2</sub> emissions from source category 1B Fugitive emissions from fuels. Only relevant source categories are shown. Blue cells mark processes for which CO<sub>2</sub> emissions resulting from the atmospheric oxidation of CH<sub>4</sub>, CO or NMVOC emissions are not accounted for as indirect CO<sub>2</sub> emissions because they are already considered under the direct CO<sub>2</sub> emissions.

1B Fugitive emissions from fuels		CO <sub>2</sub> resulting from CH <sub>4</sub>	CO <sub>2</sub> resulting from CO	CO <sub>2</sub> resulting from NMVOC
1B2a Oil	Transport (1B2aiii)	Reported as indirect CO <sub>2</sub>	NO	Reported as indirect CO <sub>2</sub>
	Refining/storage (1B2aiv)			
	Distribution of oil products (1B2av)	NO		
1B2b Natural gas	Production (1B2bii)	Reported as indirect CO <sub>2</sub>	NO	Reported as indirect CO <sub>2</sub>
	Transmission and storage (1B2biv)			
	Distribution (1B2bv)			
	Other leakage (1B2bvi)			
1B2c Venting and flaring	Flaring Oil (1B2cii1)	Included in direct CO <sub>2</sub> emissions (CO <sub>2</sub> emission factors assume full oxidation)	Included in direct CO <sub>2</sub> emissions (CO <sub>2</sub> emission factors assume full oxidation)	Included in direct CO <sub>2</sub> emissions (CO <sub>2</sub> emission factors assume full oxidation)
	H <sub>2</sub> Production refinery (1B2ci)	NO	NO	NO
	Flaring from gas production (1B2cii2)	Included in direct CO <sub>2</sub> emissions (CO <sub>2</sub> emission factors assume full oxidation)		Included in direct CO <sub>2</sub> emissions (CO <sub>2</sub> emission factors assume full oxidation)

**2 Industrial processes and product use:** CO<sub>2</sub> resulting from the atmospheric oxidation of CH<sub>4</sub>, CO and NMVOC emitted from sector 2 IPPU is reported as indirect CO<sub>2</sub> emissions unless it is of biogenic origin or already accounted for implicitly as direct CO<sub>2</sub> emissions in sector 2 (chp. 4). For sector 2 IPPU, Table 9-9 illustrates in which processes CH<sub>4</sub>, CO and NMVOC emissions occur, and whether the related CO<sub>2</sub> emissions are reported as indirect CO<sub>2</sub> emissions or implicitly as direct CO<sub>2</sub> emissions. In summary, only few of the CO<sub>2</sub> emissions resulting from the atmospheric oxidation of CH<sub>4</sub>, CO and NMVOC emitted from sector 2 IPPU are already considered under the direct CO<sub>2</sub> emissions and thus not accounted for as indirect CO<sub>2</sub> emissions, namely:

- Emissions that are based on a carbon mass balance or material flows (including the carbon content) considering all carbon sources and sinks of the process. Examples are NMVOC from the cracker in source category 2B8b Ethylene or NMVOC and CO from steel production in electric arc furnaces in source category 2C1 Iron and steel production.
- Emissions from processes where full oxidation is assumed. An example is CO from source category 2C3 Aluminium production, where full oxidation of the anodes is assumed. In contrast, NMVOC emissions from this process solely originate from the

production of the electrodes at the plants. Therefore, these emissions are considered for the calculation of indirect CO<sub>2</sub> emissions.

- Emissions of biogenic origin. Examples are biogenic CO and NMVOC from tobacco consumption in source category 2G4 Other or from source category 2H2 Food and beverages industry.

The source categories 2D3a and 2G4 include direct CO<sub>2</sub> emissions from post-combustion of NMVOC as well as indirect CO<sub>2</sub> emissions from oxidation of NMVOC in the atmosphere. Thereby, the CO<sub>2</sub> emissions resulting from NMVOC destroyed in post-combustion facilities are reported as direct CO<sub>2</sub> emissions (the respective NMVOC are therefore not part of the reported NMVOC emissions of the source categories 2D3a and 2G4).

Table 9-9 Sources of indirect CO<sub>2</sub> emissions from sector 2 Industrial processes and product use (IPPU). Only relevant source categories are shown. Blue cells mark processes for which CO<sub>2</sub> emissions resulting from the atmospheric oxidation of CH<sub>4</sub>, CO or NMVOC emissions are not accounted for as indirect CO<sub>2</sub> emissions, either because they are already considered under the direct CO<sub>2</sub> emissions or because they are of biogenic origin.

2 Industrial processes and product use		CO <sub>2</sub> resulting from CH <sub>4</sub>	CO <sub>2</sub> resulting from CO	CO <sub>2</sub> resulting from NMVOC
2A Mineral industry		NO	Reported as indirect CO <sub>2</sub>	Reported as indirect CO <sub>2</sub>
2B Chemical industry	2B5 Carbide production	Reported as indirect CO <sub>2</sub>	Reported as indirect CO <sub>2</sub>	NO
	2B8 Petrochemical and carbon black production	NO	NO	Included in direct CO <sub>2</sub> emissions (carbon mass balance)
	2B10 Other	Reported as indirect CO <sub>2</sub>	Reported as indirect CO <sub>2</sub>	Reported as indirect CO <sub>2</sub>
2C Metal industry	2C1 Iron and steel production	Steel production in electric arc furnaces	NO	Included in direct CO <sub>2</sub> emissions (carbon mass balance)
		Remaining emission sources	NO	Reported as indirect CO <sub>2</sub>
	2C3 Aluminium production	NO	Included in direct CO <sub>2</sub> emissions (full oxidation of anodes assumed)	Reported as indirect CO <sub>2</sub>
	2C7 Other	NO	Reported as indirect CO <sub>2</sub>	Reported as indirect CO <sub>2</sub>
2D Non-energy products from fuels and solvent use	2D3a Solvent use	NO	NO	Reported as indirect CO <sub>2</sub>
	2D3b Road paving with asphalt	NO	NO	Reported as indirect CO <sub>2</sub>
	2D3c Asphalt roofing	NO	Reported as indirect CO <sub>2</sub>	Reported as indirect CO <sub>2</sub>
2G Other product manufacture and use	2G4 Other	Tobacco consumption	NO	Not reported as indirect CO <sub>2</sub> emissions (biogenic origin)
		Remaining emission sources	NO	Reported as indirect CO <sub>2</sub>
2H Other	2H1 Pulp and paper	NO	NO	Reported as indirect CO <sub>2</sub>
	2H2 Food and beverages industry	NO	Not reported as indirect CO <sub>2</sub> emissions (biogenic origin)	Not reported as indirect CO <sub>2</sub> emissions (biogenic origin)
	2H3 Other	NO	Reported as indirect CO <sub>2</sub>	Reported as indirect CO <sub>2</sub>

**3 Agriculture and 4 LULUCF:** CH<sub>4</sub>, CO and NMVOC emissions from the sectors 3 Agriculture and 4 LULUCF are of biogenic origin. Accordingly, no indirect CO<sub>2</sub> emissions are reported for these sectors.

**5 Waste:** CH<sub>4</sub>, CO and NMVOC emissions from sector 5 Waste contain fossil and biogenic shares. Only indirect CO<sub>2</sub> resulting from the atmospheric oxidation of fossil CH<sub>4</sub>, CO and NMVOC is included in CRF Table6. Emissions of fossil CH<sub>4</sub>, CO and NMVOC originate from the following processes:

- Hospital waste incineration (CO and NMVOC emissions): Completely fossil, see chp. 7.4 Incineration and open burning of waste (5C1), since 2002 no emissions from hospital waste incineration have occurred.

- Municipal solid waste incineration (illegal) (CH<sub>4</sub>, CO and NMVOC emissions): Partly fossil, fossil share is assumed to be the same as for waste incinerated in municipal solid waste incineration plants, see chp. 7.4 Incineration and open burning of waste (5C1).
- Industrial waste incineration (consists of cable insulation materials) (CO and NMVOC emissions): Completely fossil, see chp. 7.4 Incineration and open burning of waste (5C1), since 1995 no emissions from incinerating cable insulation materials have occurred.
- Shredding (CO and NMVOC emissions): Completely fossil, see chp. 7.6 Other (5E).

Further emissions of CH<sub>4</sub>, CO and NMVOC from sector 5 Waste – such as from solid waste disposal (5A), biological treatment of solid waste (5B) and wastewater treatment and discharge (5D) – are of biogenic origin and therefore not considered for the calculation of indirect CO<sub>2</sub> emissions as presented in CRF Table6.

**6 Other:** CH<sub>4</sub>, CO and NMVOC emissions from sector 6 Other contain fossil and biogenic shares. Only CO<sub>2</sub> resulting from the atmospheric oxidation of fossil CH<sub>4</sub>, CO and NMVOC is reported as indirect CO<sub>2</sub>. Emissions of fossil CH<sub>4</sub>, CO and NMVOC originate from the following processes:

- Fire damage estate: The share of fossil CH<sub>4</sub>, CO and NMVOC emissions is assumed to be equal to the share of fossil CO<sub>2</sub> emissions, which increased linearly from 20 % in 1950 to 80 % in 2000 and is assumed to have remained constant since then, see chp. 8.2 (6Ad).
- Fire damage motor vehicles: The share of fossil CH<sub>4</sub>, CO and NMVOC emissions is assumed to be 100 %, see chp. 8.2 (6Ad).

### 9.2.2. Methodological issues to derive indirect N<sub>2</sub>O emissions

Indirect N<sub>2</sub>O emissions are estimated using a country-specific method according to a study of indirect N<sub>2</sub>O emissions induced by nitrogen deposition in Switzerland (Bühlmann 2014, Bühlmann et al. 2015). In this study, ecosystem-specific emission factors for indirect N<sub>2</sub>O resulting from nitrogen deposition were developed, based on a comprehensive literature survey. Thereby, the land cover types forests, grassland and wetlands were distinguished. In a next step, the ecosystem-specific emission factors were combined with a highly-resolved nitrogen deposition map of Switzerland as well with the geo-referenced data set of the Swiss Land Use Statistics (allowing for the localisation and estimation of spatial extent of the different ecosystems). This resulted in detailed and spatially resolved indirect N<sub>2</sub>O emissions for Switzerland. To facilitate a simple application in the greenhouse gas inventory, the resulting total emissions were used to come up with a total emission factor expressed as indirect N<sub>2</sub>O-N per N-deposition (deposited in form of NO<sub>x</sub> or NH<sub>3</sub>, see also chp. 5.3.2.4). The resulting total emission factor is in the order of 2.5 % and slightly varies with time as the shares of the different ecosystems are not constant over time. Based on this country-specific emission factor, higher indirect N<sub>2</sub>O emissions result compared to the emissions that would result by applying the IPCC Guidelines (IPCC 2006, see also Bühlmann et al. 2015).

To calculate indirect N<sub>2</sub>O emissions induced by the deposition of NO<sub>x</sub> and NH<sub>3</sub> according to Bühlmann (2014) and Bühlmann et al. (2015), total N-deposition is needed. It is derived from NO<sub>x</sub> (which is always reported in NO<sub>2</sub> equivalents) and NH<sub>3</sub> emissions using the stoichiometric conversion according to the following equation:

$$\text{Mass-N} = \text{Mass-NO}_{2,\text{eq}} * 14/46 + \text{Mass-NH}_3 * 14/17$$

Note: The emissions referred to as indirect N<sub>2</sub>O emissions in CRF Table3.B and in CRF Table3.D are not addressed in this chapter, as they are not reported as indirect N<sub>2</sub>O emissions in CRF Table6 and in CRF Table10 (these emissions are instead included in Sector 3 Agriculture along with direct N<sub>2</sub>O emissions).

#### *Activity data for the calculation of indirect N<sub>2</sub>O emissions*

The activity data to calculate indirect N<sub>2</sub>O emissions from a specific sector corresponds to the NO<sub>x</sub> and NH<sub>3</sub> emissions reported in the respective source categories. However, the following exceptions need to be considered:

- Indirect N<sub>2</sub>O emissions from sector 3 Agriculture are reported in the respective sector together with direct N<sub>2</sub>O emissions (chp. 5.3.2.5.4 Volatilisation of NH<sub>3</sub> and NO<sub>x</sub> from manure management systems, chp. 5.5.2.3 Indirect N<sub>2</sub>O emissions from atmospheric deposition of N volatilised from managed soils (3Db1) and chp. 5.5.2.4 Indirect N<sub>2</sub>O emissions from leaching and run-off from managed soils (3Db2)).
- For sector 6, the only indirect N<sub>2</sub>O emissions to be considered are those resulting from NO<sub>x</sub> emissions in source category 6Ad Fire damages.

### **9.2.3. Uncertainties and time series consistency**

Indirect CO<sub>2</sub> emissions are included in the uncertainty analysis, but indirect N<sub>2</sub>O emissions are not included.

Uncertainties of indirect CO<sub>2</sub> emissions are based on respective uncertainties of CH<sub>4</sub>, CO and NMVOC emissions. Uncertainties of CH<sub>4</sub> emissions are described in the respective chapters above. Uncertainties of CO and NMVOC emissions are documented in Switzerland's Informative Inventory Report 2023 (FOEN 2023b). The uncertainties of the emission factors are partly based on values provided by the EMEP/EEA guidebook (EMEP/EEA 2019, part A, chp. 5, Table 2-2) and expert judgements. The estimated uncertainties distinguish between fossil and biogenic shares.

Combined uncertainties of indirect CO<sub>2</sub> emissions, for each category, are given in Annex A2.1.

Consistency: Time series for indirect CO<sub>2</sub> and N<sub>2</sub>O emissions are all considered consistent.

### **9.2.4. Category-specific QA/QC and verification**

The same QA/QC and verification procedures are conducted as for CH<sub>4</sub>, CO, NMVOC, NO<sub>x</sub> and NH<sub>3</sub> related source categories in chp. 3 (Energy), chp. 4 (Industrial processes and product use), chp. 7 (Waste) and chp. 8 (Other).

### **9.2.5. Category-specific recalculations**

The following recalculations were implemented in submission 2023. Major recalculations which contribute significantly to the total differences in indirect emissions between the latest and the previous submissions are presented also in chp. 10.1.2.7.

- 2 IPPU: A calculation error for the determination of indirect N<sub>2</sub>O emissions from NH<sub>3</sub> was corrected for all years from 1990 onwards. The influence on emissions is negligible.

- See CH<sub>4</sub> related recalculations reported in chp. 3 (Energy), chp. 4 (Industrial processes and product use), chp. 7 (Waste) and chp. 8 (Other).
- See CO related recalculations reported in chp. 4 (Industrial processes and product use), chp. 6 (Waste) and chp. 7 (Other) in Switzerland's Informative Inventory Report 2023 (FOEN 2023b).
- See NMVOC related recalculations reported in chp. 3 (Energy), chp. 4 (Industrial processes and product use), chp. 6 (Waste) and chp. 7 (Other) in Switzerland's Informative Inventory Report 2023 (FOEN 2023b).
- See NO<sub>x</sub> and NH<sub>3</sub> related recalculations reported in chp. 3 (Energy), chp. 4 (Industrial processes and product use), chp. 6 (Waste) and chp. 7 (Other) in Switzerland's Informative Inventory Report 2023 (FOEN 2023b).

### **9.2.6. Category-specific planned improvements**

No category-specific improvements are planned.

## 10. Recalculations and improvements

Responsibilities for chapter Recalculations and improvements	
Overall responsibility	Regine Röthlisberger (FOEN)
Authors & annual updates (NID text, tables, figures)	Michael Bock (FOEN, chp. 10.1), Regine Röthlisberger (FOEN), Nele Rogiers (FOEN), Andreas Schellenberger (FOEN), Daniel Bretscher (Agroscope)
EMIS database operation	Adrian Schilt (FOEN)
Quality control NID (annual updates)	Adrian Schilt (FOEN)
Internal review	Anouk-Aimée Bass (FOEN), Rainer Kegel (FOEN), Daiana Leuenberger (FOEN), Sabine Schenker (FOEN), sector experts

### 10.1. Explanations and justifications for recalculations, including in response to the review process

The implementation of recommendations and encouragements from the UNFCCC review process are listed in chp. 10.1.1. Additionally, major recalculations are presented in chp. 10.1.2. In the relevant sectoral chapters, also minor recalculations are listed and a brief explanation for each is provided. A list with all recalculations and specifics of the recalculations is compiled by the EMIS experts and available to the reviewers on demand (partly in German).

#### 10.1.1. Recommendations and encouragements from ERT and their implementation

The most recent in-depth review of the inventory was based on the submission of April 2022 (UNFCCC 2023). The recommendations and encouragements could already be addressed and implemented in the submission at hand (see Table 10-1 and Table 10-2).

Table 10-1 Implementation of recommendations from the in-depth review in 2022 (UNFCCC 2023).

ID	classification	Recommendation from ARR 2022 (UNFCCC 2023)	Answer including reference to chapter in NID
<b>IPPU</b>			
I.1	2.F.1 Refrigeration and air conditioning – HFCs	The ERT recommends that Switzerland provide in the NIR the reasons for the decreasing trends in the EFs and emissions for this category and the drivers behind the trends (in AD and EFs) in the most significant subcategories.	Text added in NID chp. 4.7.1 starting with: "From 2015 onwards there is a decline in emissions as a result of the regulations from the Chemical Risk Reduction Ordinance (Swiss Confederation 2005)...."
<b>Agriculture</b>			
A.2	3.B.1 Cattle – N2O (A.6, 2021) Transparency	Provide information in the NIR on the algorithms and background input data (e.g. crude protein intake, milk protein content and N retention, to the extent possible) used to evaluate the Nex rates for cattle (by subcategory).	Additional text as well as additional references to background literature for individual animal categories has been added to chp. 5.3.2.5.2.
A.3	3.D.a.4 Crop residues – N2O (A.7, 2021) Transparency	Clarify the model used to estimate N2O emissions from crop residues left on fields by including in the NIR information on the reference source for the model, the data sources and the calculation parameters used.	More specific references to the data tables in FAL/RAC (2001) and Richner et al. (2017) are provided in chp. 5.5.2.2.2. An additional paragraph on nitrogen in straw used as bedding material was added in chp. 5.5.2.2.2. Reference sources have been added to the headers of the tables on crop residues in Annex A5.3.
A.5	3.A.1 Cattle – CH4, N2O	The ERT recommends that Switzerland report in NIR table 5.5 and CRF table 3.As2 milk production for mature dairy cattle based on annual milk production, that is, a period covering 365 days, rather than on a lactation period of 305 days.	Milk production reported in the NID and CRF table 3.As2 is now calculated by dividing yearly milk production by 365 days instead of 305 days (which would be the standard lactation period). The respective paragraphs and tables in NID section 5.2.2.2.1 were updated
<b>Waste</b>			
W.4	5.D.1 Domestic wastewater – CH4 (W.5, 2021) Completeness	Estimate CH4 emissions from wastewater treatment systems not connected to the public sewer system, specifically from those systems that are very similar to centralized wastewater treatment plants, and include the emissions in the national total.	According to the mentioned desk study (Vuna 2023) emissions from decentralised wastewater treatment do occur and are estimated as explained in chapter 7.5 of the NID.
W.5	5.D.1 Domestic wastewater – CH4 (W.6, 2021) Transparency	Provide in the NIR a justification that simple systems serving as alternatives for wastewater treatment plants not connected to the public sewer system do not produce CH4 emissions, for example by providing air and soil temperature profiles for the regions where these systems are typically used.	According to the mentioned desk study (Vuna 2023) emissions from decentralised wastewater treatment do occur and are estimated as explained in chapter 7.5 of the NID.
W.6	5.D.1 Domestic wastewater – CH4 (W.7, 2021) Transparency	Explain in the NIR that the sewage sludge treated in centralized wastewater treatment plants or municipal waste incineration plants includes all sludge from wastewater treatment systems not connected to the public sewer system.	According to the mentioned desk study (Vuna 2023) all sludge from on-site sanitation systems is included in centralised treatment. Please see chapters 7.5.1 and 7.5.2.1.2 of the NID.
W.7	5.D.1 Domestic wastewater – CH4 (W.7, 2021) Transparency	Include in the NIR additional information on the fraction of wastewater in rural areas not connected to the public sewer system that is possibly spread to agricultural soils as a fraction of slurry	According to the mentioned desk study (Vuna 2023) activity data for emissions from decentralised wastewater treatment via manure tank storage and usage are estimated. Emissions are estimated according to the agricultural model as explained in chapter 7.5 of the NID.
W.8	5.C.1 Waste incineration – CH4	The ERT recommends that Switzerland include in the NIR the explanation provided during the review as to why CH4 emissions from the incineration of hospital waste, the incineration of industrial waste and cremation are not estimated, that is, that incineration of these sources is performed at high temperature with complete combustion processes and therefore CH4 EFs can be considered as zero, in accordance with the 2006 IPCC Guidelines (vol. 5, chap. 5, section 5.2.2.3, p.5.13).	A note on the applicability of an emission factor for CH4 was included in the section describing emission factors for the incineration of hospital waste, the incineration of industrial waste and cremation, respectively, in Chp. 7.4.2
W.9	5.C.1 Waste incineration – N2O	The ERT recommends that Switzerland correct the notation keys reported in CRF table 5.C for industrial waste for 1990–1994 (from "NO" to "NE" for the N2O IEFs and N2O emissions) and in NIR table 7-16 (from "NA" to "NE" for the N2O EFs). The ERT recommends that the Party either estimate and report these emissions for industrial waste or justify the use of "NE" based on the likely level of emissions, in accordance with paragraph 37(b) of the UNFCCC Annex I inventory reporting guidelines. The ERT also encourages the Party to explain in the NIR why N2O emissions from cremation were not estimated.	A note on the omission of an emission factor for N2O was included in the section describing emission factors for the incineration of industrial waste in Chp. 7.4.2 Also a note is added, stating why N2O from cremation is not estimated.

Table 10-2 Implementation of encouragements from the in-depth review in 2022 (UNFCCC 2023).

ID	classification	Encouragement from ARR 2022 (UNFCCC 2023)	Answer including reference to chapter in NID
<b>Energy</b>			
E.1	1. General (energy sector) – CO <sub>2</sub> , CH <sub>4</sub> and N <sub>2</sub> O	The ERT encourages Switzerland to consult with the secretariat on how to use CRF Reporter to report "NO" in CRF tables 1.A(a)s1, 1.A(a)s3–1.A(a)s4, 1.A(b) and 1.A(d) in all cases where cells have been left blank when the corresponding fuel is not used in the country (and thus there are no AD).	We consulted with the helpdesk (ANAIS-4120) and could fill some of the gaps. However, as there is no option in the CRF reporter to auto fill "NO" for empty cells, there are still empty cells. It has been decided to use the available resources for QC efforts instead of filling empty cells manually.
<b>IPPU</b>			
I.2	2.F.1 Refrigeration and air conditioning – HFCs	The ERT encourages Switzerland to provide in its NIR a rationale for the main driver(s) of the high share (33 per cent) of emissions for category 2.F.1.e (mobile air conditioning) in the total emissions for category 2.F.1.	Text added in NID chapter 4.7.2.1. A comparison to neighbour countries shows higher stock and emissions from mobile air-conditioning in Switzerland. Model parameters were checked and a higher rate of air-conditioning of >95% in vehicles is assumed plausible and is confirmed by companies dismantling vehicles.

### 10.1.2. Major recalculations and improvements implemented in the latest submission

In this chapter, the most important recalculations are presented. The figures show the differences between net emissions and removals in submission 2022 (previous) and submission 2023 (latest). Explanations are provided for categories that underwent recalculations larger than 2 % of the corresponding category emissions and resulted in absolute changes larger than 5 kt CO<sub>2</sub> eq (approximately 0.01 % of the national total emissions) for the Energy, IPPU, Agriculture and Waste sectors, and larger than approximately |10| kt CO<sub>2</sub> eq for the LULUCF sector. Additional recalculations and corrections of minor errors, which had a smaller impact than the above thresholds, are listed in the relevant sectoral chapters.

Additional to the recalculations presented below, Switzerland has adopted the 100-year time-horizon global warming potentials (GWP<sub>100</sub>) from the IPCC Fifth Assessment Report (Myhre 2013), according to paragraph 37 of the MPG (UNFCCC 2019).

#### 10.1.2.1. Energy

The total changes in emissions in the energy sector due to all recalculations are shown in Figure 10-1 for CO<sub>2</sub>, Figure 10-2 for CH<sub>4</sub> and Figure 10-3 for N<sub>2</sub>O.

The largest recalculations in the energy sector resulted from the reassessment of the fugitive emissions from petrol stations, resulting in smaller NMVOC emissions in 1B2a in 1990 and higher NMVOC emissions from 1993 onwards. Correspondingly, this leads to lower CO<sub>2</sub> emissions in 1A3 of up to 15 kt CO<sub>2</sub> eq from 1993 onwards. In addition, the time series for marine bunkers has been harmonised with the data of the energy statistics, resulting in changes of the order of up to ±10 kt CO<sub>2</sub> eq in single years. Consideration of the latest statistical data in the road transportation model led to small changes in the fuel allocation to sub-categories in 1A3b. While this has no effect on total CO<sub>2</sub> emissions, there was a small effect on CH<sub>4</sub> and N<sub>2</sub>O emissions in 1A3 of the order of a few kt CO<sub>2</sub> eq. Furthermore, an error in the country-specific emission factor model for wood combustion was corrected, resulting in higher CH<sub>4</sub> emissions predominantly in 1A4b of up to 16 kt CO<sub>2</sub> eq. All other recalculations had an impact that was smaller than 5 kt CO<sub>2</sub> eq (see Figure 10-1, Figure 10-2, Figure 10-3).

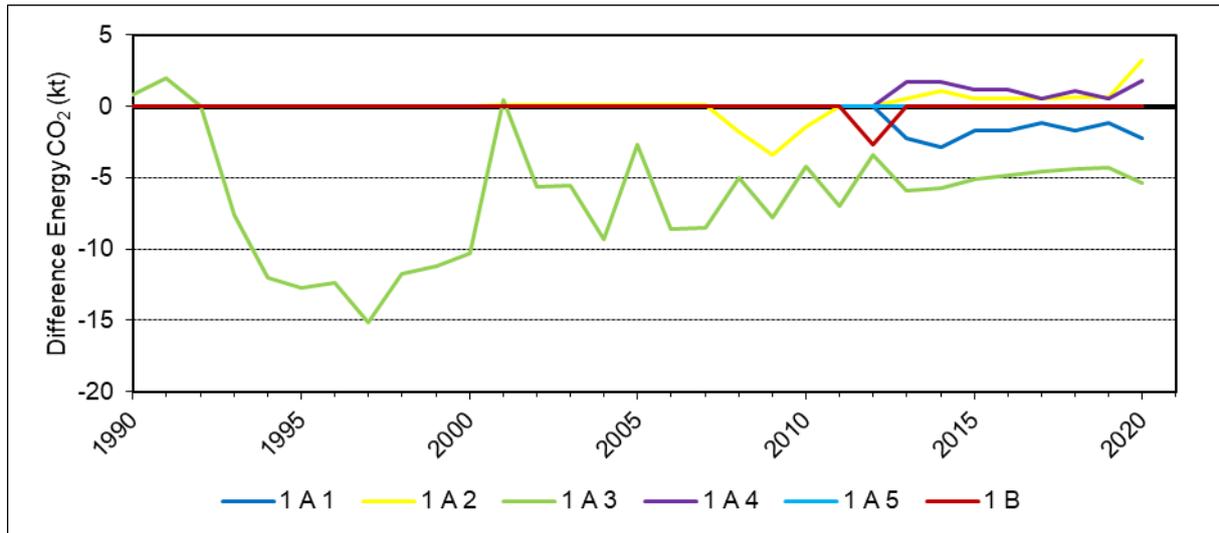


Figure 10-1 Differences in CO<sub>2</sub> emissions (in kt CO<sub>2</sub>) between the latest and the previous submissions for various source categories in the energy sector. Positive values refer to higher emissions and negative values to lower emissions in the latest submission compared to the previous submission.

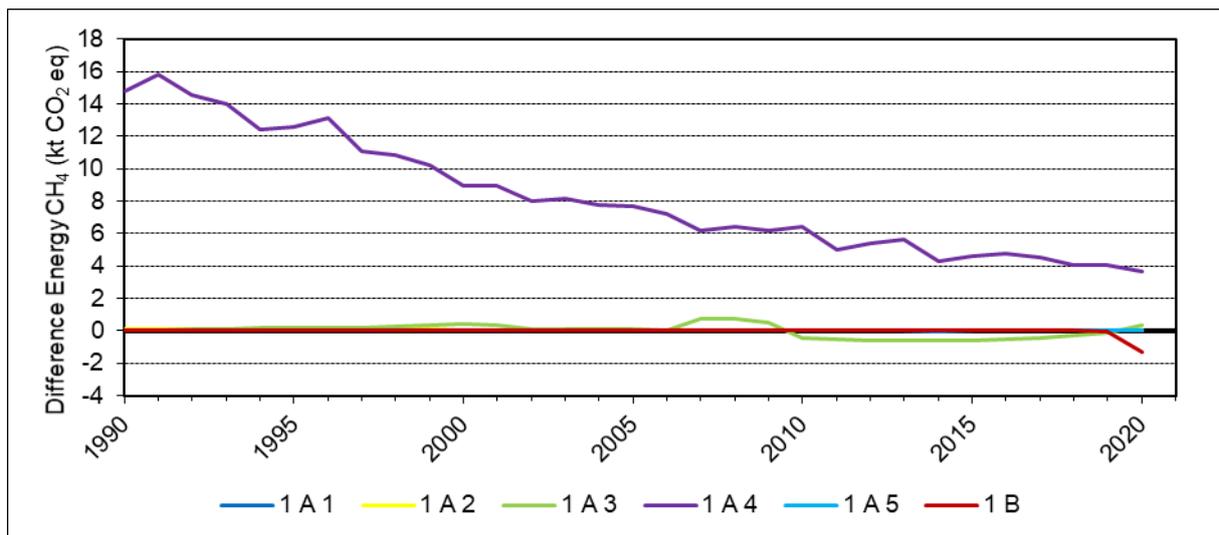


Figure 10-2 Differences in CH<sub>4</sub> emissions (in kt CO<sub>2</sub> eq) between the latest and the previous submissions for various source categories in the energy sector. Positive values refer to higher emissions and negative values to lower emissions in the latest submission compared to the previous submission.

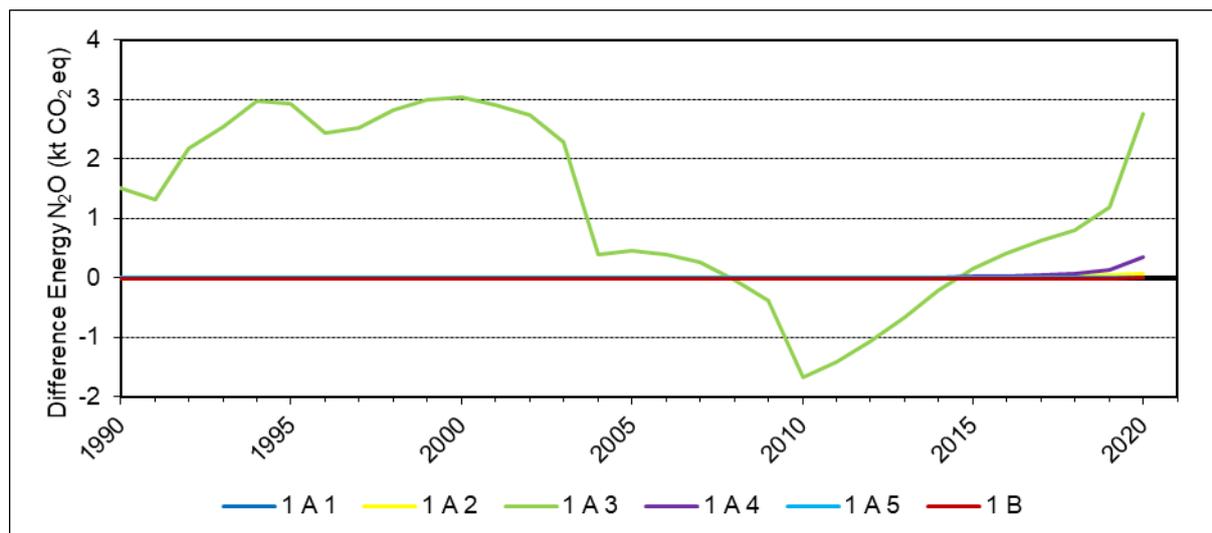


Figure 10-3 Differences in N<sub>2</sub>O emissions (in kt CO<sub>2</sub> eq) between the latest and the previous submissions for various source categories in the energy sector. Positive values refer to higher emissions and negative values to lower emissions in the latest submission compared to the previous submission.

#### 10.1.2.2. Industrial processes and other product use

The total changes in emissions in the IPPU sector due to all recalculations are shown in Figure 10-4 for CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O, and in Figure 10-5 for HFCs, PFCs, SF<sub>6</sub>, and NF<sub>3</sub>.

Thanks to new information based on monitoring reports from the Swiss emissions trading system, N<sub>2</sub>O emissions from 2G4 Rock wool production are now also reported, leading to additional N<sub>2</sub>O emissions of up to 9 kt CO<sub>2</sub>eq. A smaller change of less than 5 kt CO<sub>2</sub> in total resulted from revising CO<sub>2</sub> emission factors for 2C1 Secondary steel production and 2A3 Glass wool production based on monitoring reports from the Swiss emissions trading system. The revision of the model calculation of a specific application of SF<sub>6</sub> in category 2G based on more detailed data from the company led to changes in the emissions of that particular process, ranging from -24 kt CO<sub>2</sub>eq to +21 kt CO<sub>2</sub>eq. New information regarding stationary cooling equipment, vehicle statistics (mobile air-conditioning) and data from a programme to promote replacement of refrigerants with high global warming potential led to a revision of the activity data used to model HFC emissions in 2F1 Refrigeration and air-conditioning in the past couple of years, ranging from -30 kt CO<sub>2</sub>eq to +14 kt CO<sub>2</sub>eq. All other recalculations had an impact that was smaller than 5 kt CO<sub>2</sub> eq (see Figure 10-4 and Figure 10-5).

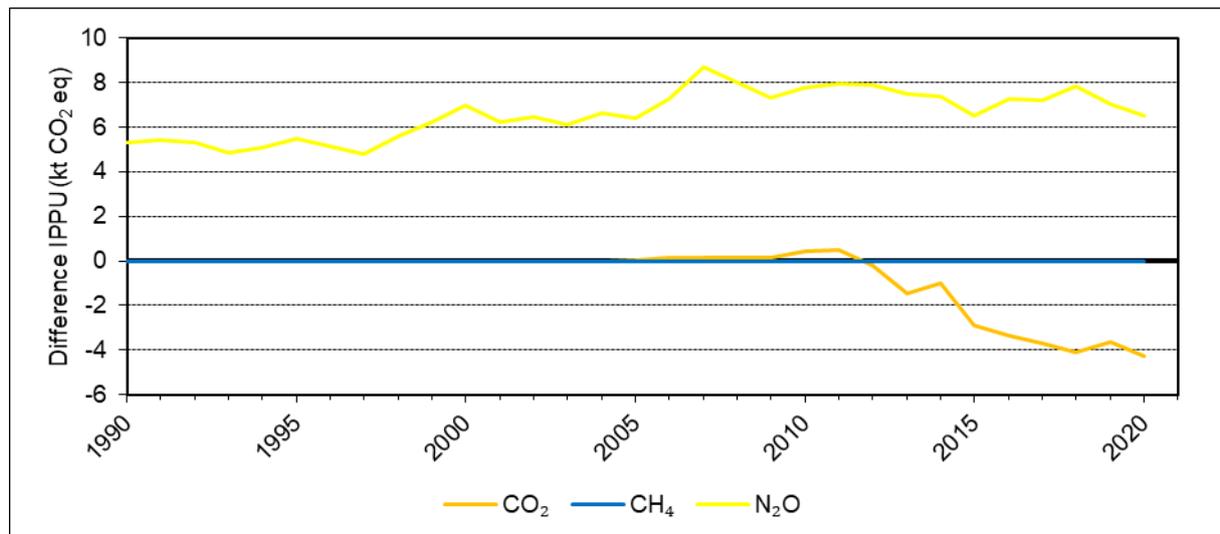


Figure 10-4 Differences in CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O emissions (in kt CO<sub>2</sub> eq) between the latest and the previous submissions for sector IPPU. Positive values refer to higher emissions and negative values to lower emissions in the latest submission compared to the previous submission.

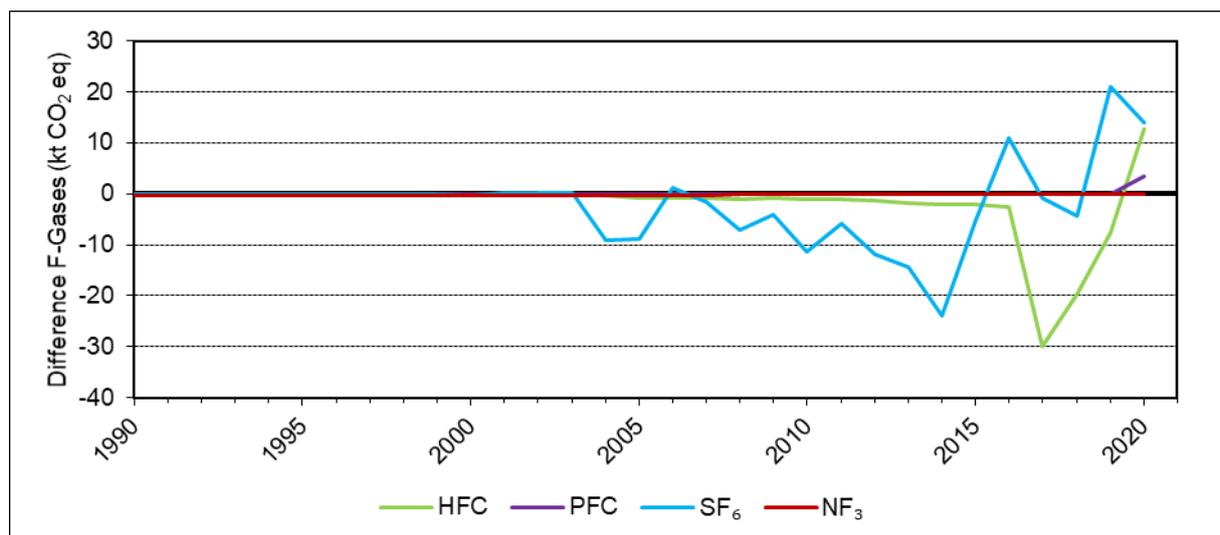


Figure 10-5 Differences in HFC, PFC, SF<sub>6</sub> and NF<sub>3</sub> emissions (in kt CO<sub>2</sub> eq) between the latest and the previous submissions for the sector IPPU. Positive values refer to higher emissions and negative values to lower emissions in the latest submission compared to the previous submission.

### 10.1.2.3. Agriculture

The total changes in emissions in the Agriculture sector due to all recalculations are shown in Figure 10-6 for CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O, and for the most important recalculations aggregated for all greenhouse gases in Figure 10-7.

The largest recalculations resulted from the update of the emission factor for N<sub>2</sub>O from pasture, range and paddock (EF<sub>3PRP</sub>) (see chp.5.5.2.2.1) and the update of the emission factor for N<sub>2</sub>O from leaching and run-off (see chp.5.5.2.4.1).

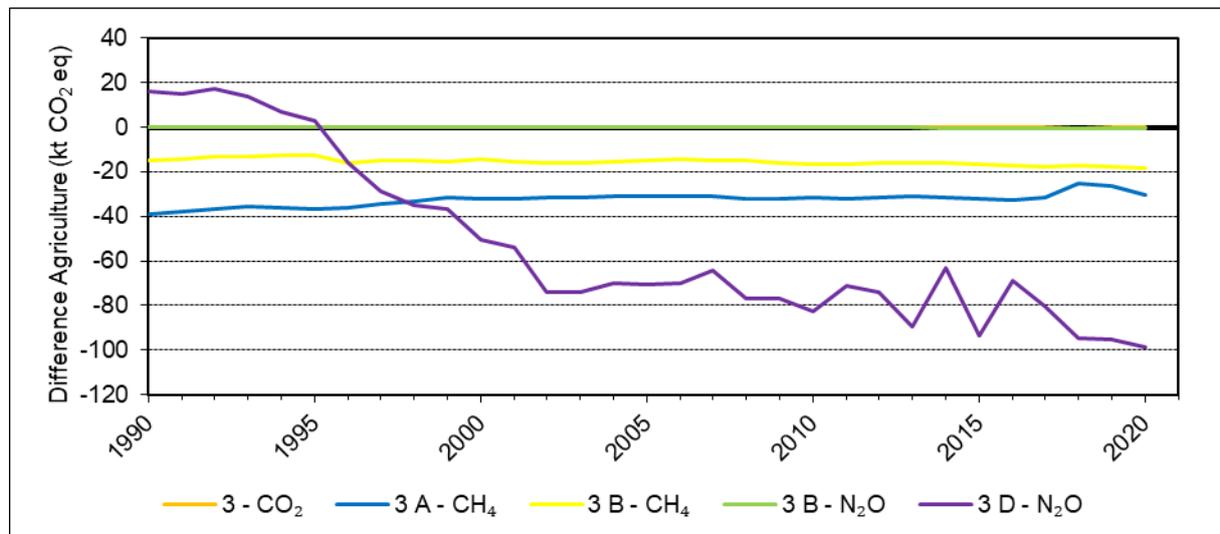


Figure 10-6 Differences in CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O emissions (in kt CO<sub>2</sub> eq) between the latest and the previous submissions for sector Agriculture. Positive values refer to higher emissions and negative values to lower emissions in the latest submission compared to the previous submission.

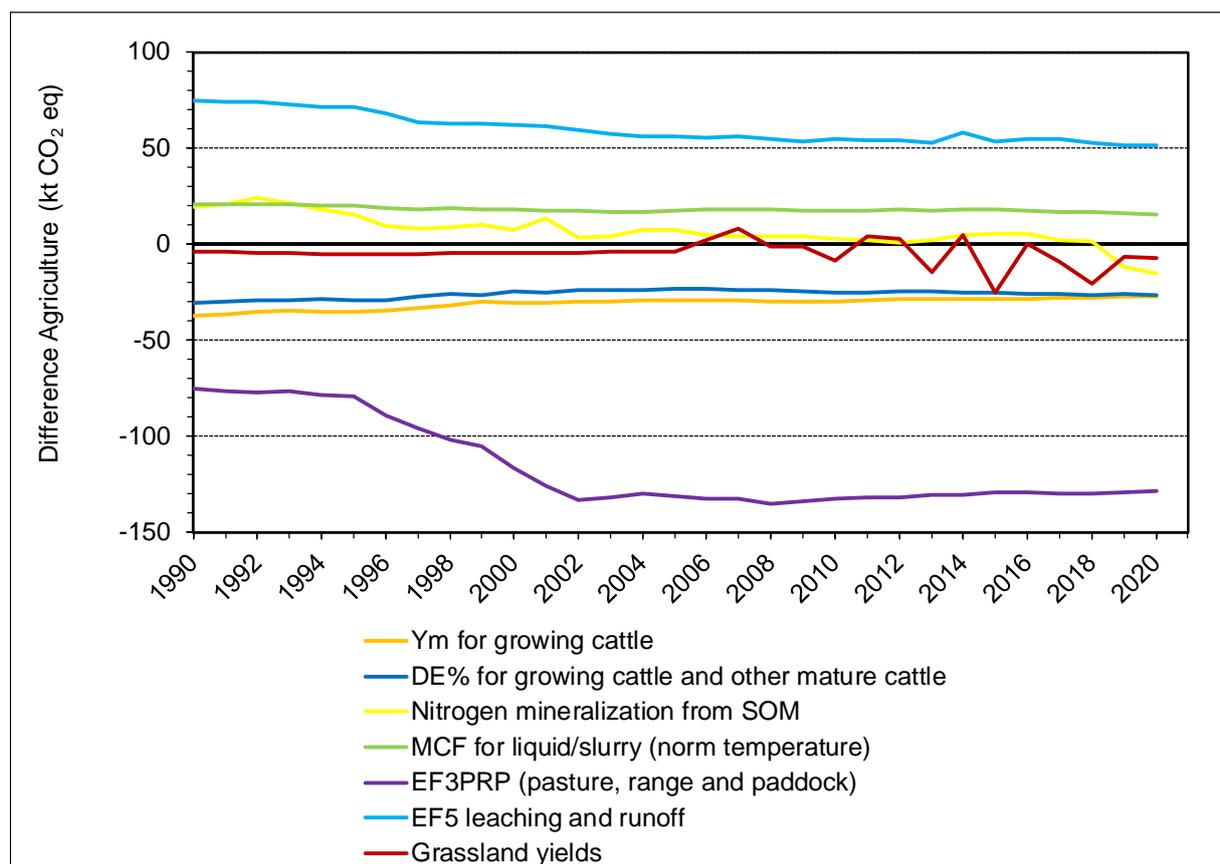


Figure 10-7 Differences in overall GHG emissions (in kt CO<sub>2</sub> eq) between the latest and the previous submissions for sector Agriculture due to the most important recalculations. Positive values refer to higher emissions and negative values to lower emissions in the latest submission compared to the previous submission. Note that due to the successive implementation of the different recalculations the amounts are not always exact but must be understood as approximations.

- CH<sub>4</sub> emissions from enteric fermentation of growing cattle and other mature cattle were recalculated for the whole time series. New methane conversion rates (Y<sub>m</sub>) were adopted

from the 2019 IPCC Refinement (IPCC 2019). Overall emissions declined by -30.6 kt CO<sub>2</sub> eq on average.

- CH<sub>4</sub> emissions from manure management of growing cattle and other mature cattle were recalculated for the whole time series. Emission factors were revised in the course of the adoption of the 2019 Refinement to the 2006 IPCC Guidelines (IPCC 2019) by adjusting the values for feed digestibility when calculating excretion of volatile solids (VS). New values for feed digestibility are higher for all animal categories concerned leading to lower estimates of excretion of VS and a reduction of overall emissions of -26.0 kt CO<sub>2</sub> equivalents on average.
- CH<sub>4</sub> emissions from liquid manure management and anaerobic digestion were recalculated for the whole time series. Emission factors were revised due to new monthly norm temperature values from MeteoSwiss (2022) for estimating the methane conversion factor (MCF) for liquid systems. The impact on overall emissions ranges from +15.7 to +21.2 kt CO<sub>2</sub> equivalents.
- N<sub>2</sub>O emissions from Urine and dung deposited by grazing animals were recalculated for the whole time series. New emission factors for pasture, range and paddocks (EF<sub>3</sub>'s) from the 2019 IPCC Refinement were adopted. The impact on overall emissions ranges from -135.4 to -75.4 kt CO<sub>2</sub> equivalents.
- N<sub>2</sub>O emissions from nitrogen in crop residues returned to soils were recalculated for the whole time series. Activity data was revised due to updated values for grassland yields in the LULUCF sector. The impact on overall emissions ranges from -25.2 to +7.9 kt CO<sub>2</sub> equivalents.
- N<sub>2</sub>O emissions from mineralization/immobilization associated with loss/gain of soil organic matter were recalculated for the whole time series. Activity data was revised due to new values for the amount of nitrogen mineralized in the LULUCF sector. The impact on overall emissions ranges from -15.4 to +23.9 kt CO<sub>2</sub> equivalents.
- N<sub>2</sub>O emissions from nitrogen leaching and run-off were recalculated for the whole time series. The respective emission factor (EF<sub>5</sub>) from the 2019 IPCC Refinement was adopted. The impact on overall emissions ranges from +51.7 to +74.8 kt CO<sub>2</sub> equivalents.

#### 10.1.2.4. Land Use, Land-Use change and Forestry

Overall changes in GHG emissions by sources and removals by sinks in the LULUCF sector due to all recalculations realised for the latest submission are shown in Figure 10-8.

The trend in net emissions and removals remains largely the same (Figure 10-20). The pattern of the deviation of CO<sub>2</sub> eq net emissions and removals between the latest and the previous submissions (range from 353.3 kt CO<sub>2</sub> eq in 2019 to -178.5 kt CO<sub>2</sub> eq in 2018) is controlled by recalculations in categories 4B, 4C, and 4G (Figure 10-9), which have the greatest impact at the beginning and end of the inventory period (Figure 10-8). Around the year 2005 and in 2012, the changes are low and largely offset each other.

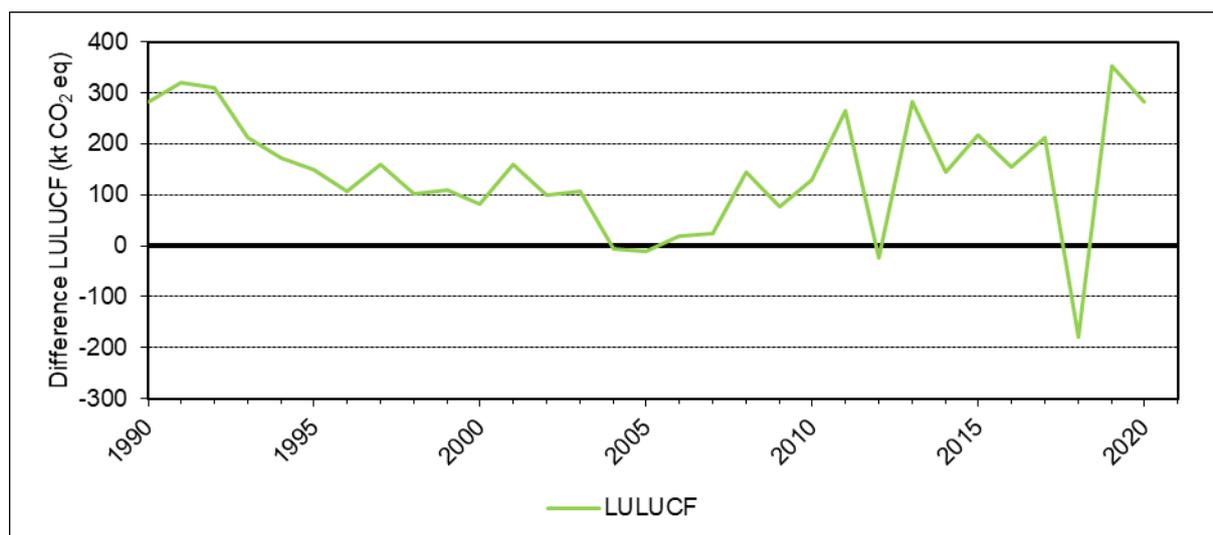


Figure 10-8 Differences in net emissions and removals (in kt CO<sub>2</sub> eq) between the latest and the previous submissions for the LULUCF sector. Positive values refer to higher emissions/lower removals and negative values to lower emissions/higher removals in the latest submission compared to the previous submission.

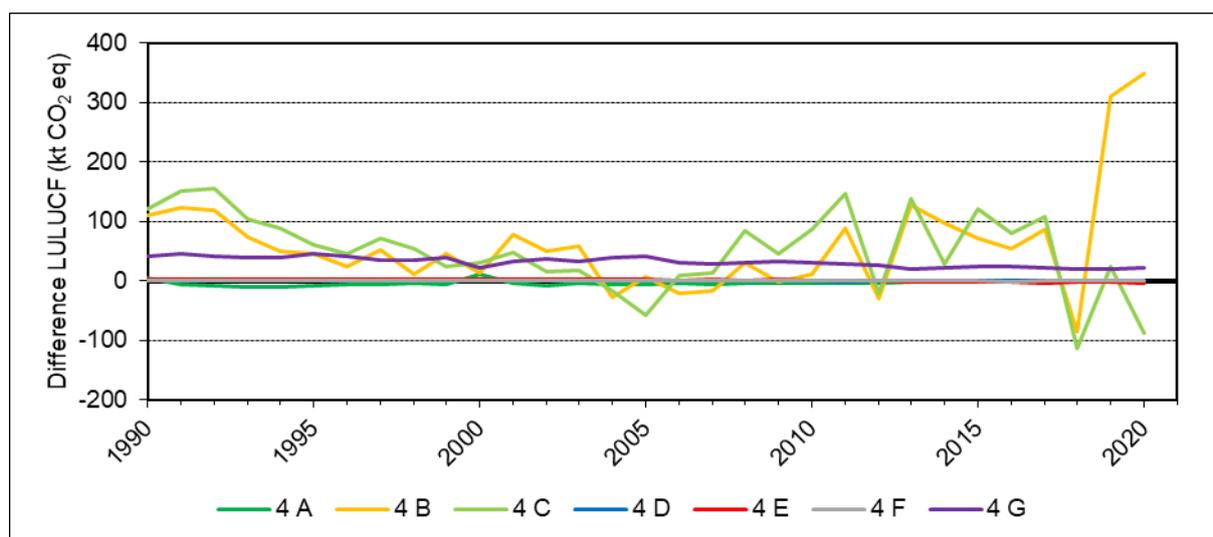


Figure 10-9 Differences in net emissions and removals (in kt CO<sub>2</sub> eq) between the latest and the previous submissions for categories 4A–4G in the LULUCF sector. Positive values refer to higher emissions/lower removals and negative values to lower emissions/higher removals in the latest submission compared to the previous submission. Categories 4A, 4D, 4E and 4F all fall close to the zero line and are therefore hardly distinguishable.

In category 4B Cropland two recalculations dominated the changes in CO<sub>2</sub> net emissions and removals (chp. 6.5.5).

- 4B1: Updated grassland yield data (SBV 2022) affected carbon stocks and carbon stock changes in living biomass in the land-use category cropland because leys are dominant crops in Swiss crop rotations. The recalculation has been evident mainly since 2005 and fluctuates in absolute terms within 60 kt CO<sub>2</sub> for carbon gains and carbon losses, respectively (Figure 10-10). Higher deviations are observed in the last inventory years (also due to the effects of moving multi-year averaging).
- 4B1: An adjustment (reduction) of the excretion rate of volatile solids (VS) was made, causing a circa 15 % reduction in the amount of carbon estimable as available as farmyard manure. This caused a reduction in the soil organic carbon stocks in mineral

soil. This adjustment recalculation is a direct result of a recalculation that was implemented in the Agriculture sector in the previous submission already (see chp. 5.3.5 in FOEN 2022). The recalculation led to a difference between the latest and the previous submissions ranging from -4.8 kt CO<sub>2</sub> in 2006 to 174.0 kt CO<sub>2</sub> in 2020 (Figure 10-10).

The two recalculations are almost entirely responsible for the curve progression of category 4B shown in Figure 10-9. The resulting time series of CO<sub>2</sub> net emissions and removals in the affected pools are shown in comparison to the previous submission in Figure 10-11.

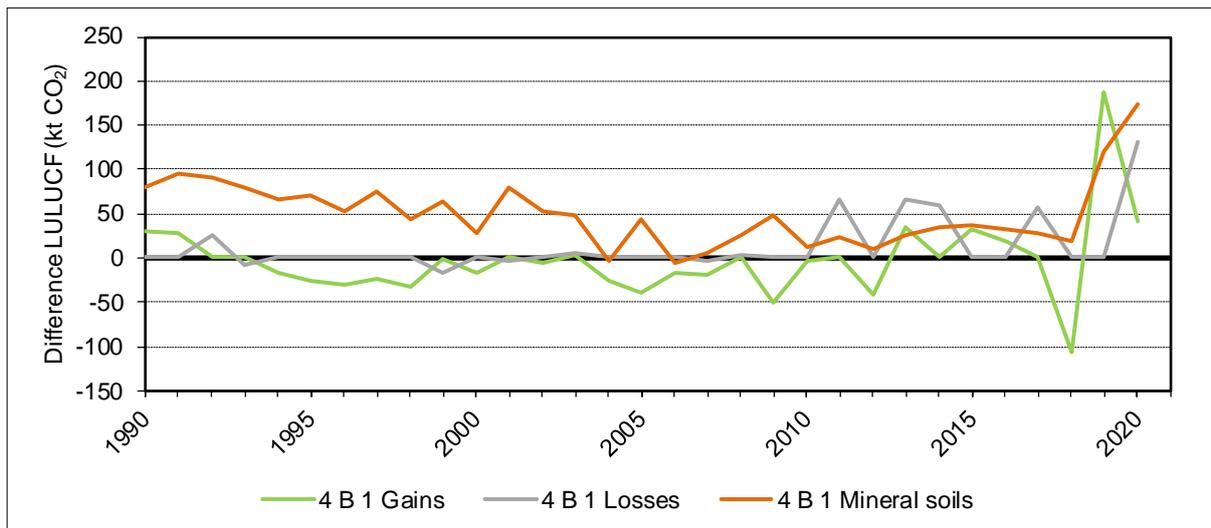


Figure 10-10 Differences in net emissions and removals (in kt CO<sub>2</sub>) between the latest and the previous submissions for category 4B1 Gains in living biomass, category 4B1 Losses in living biomass, and category 4B1 Net carbon stock change in mineral soil. Positive values refer to higher emissions/lower removals and negative values to lower emissions/higher removals in the latest submission compared to the previous submission.

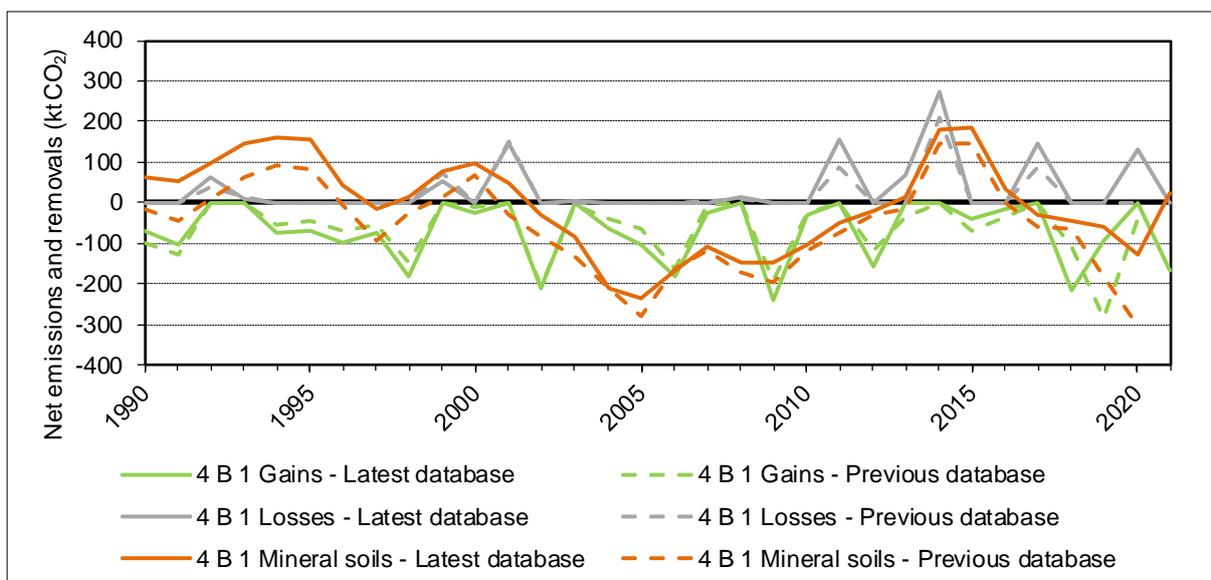


Figure 10-11 Comparison of net emissions (positive values) and net removals (negative values) from category 4B1 Gains in living biomass, category 4B1 Losses in living biomass, and category 4B1 Mineral soil as reported in the previous and the latest submissions.

In category 4C Grassland the same recalculations as in category 4B Cropland dominated the changes in CO<sub>2</sub> net emissions and removals (chp. 6.6.5). Similar to 4B Cropland, for gains and losses in living biomass the effects are more pronounced from 2005 onwards (Figure 10-12). Their differences between the latest and the previous submissions fluctuate in absolute terms within 120 kt. The recalculation with regard to mineral soil led to a difference ranging from -119.0 kt CO<sub>2</sub> in 2020 to 95.2 kt CO<sub>2</sub> in 1991 (Figure 10-12). With the exception of the last two years, the curve is similar to category 4B1 (see Figure 10-10).

The two recalculations are almost entirely responsible for the curve progression of category 4C shown in Figure 10-9. The resulting time series of CO<sub>2</sub> net emissions and removals in the affected pools are shown in comparison to the previous submission in Figure 10-13.

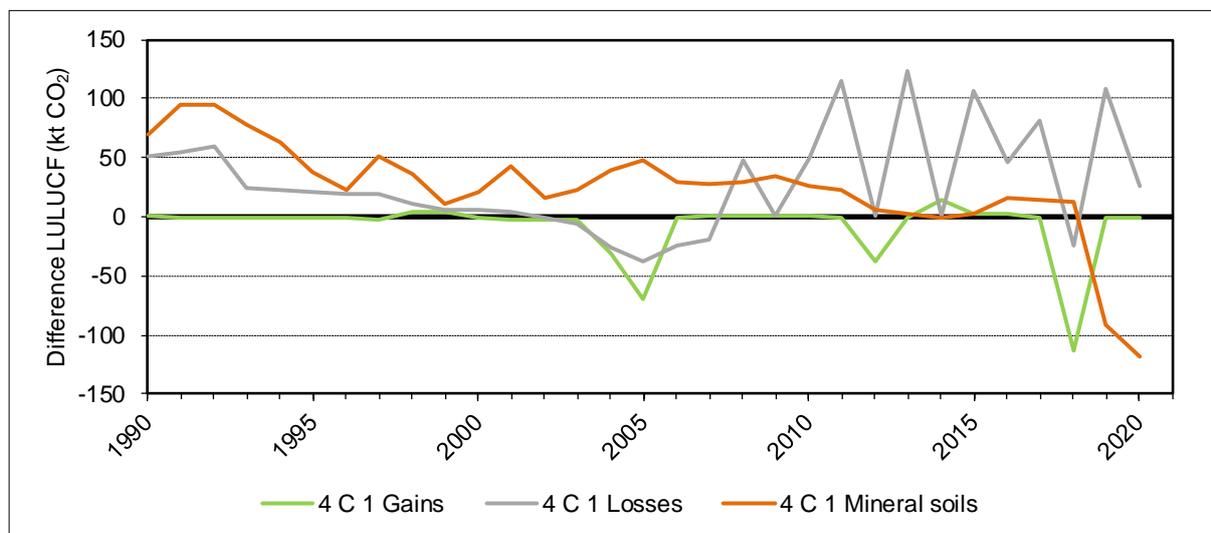


Figure 10-12 Differences in net emissions and removals (in kt CO<sub>2</sub>) between the latest and the previous submissions for the category 4C1 Gains in living biomass, category 4C1 Losses in living biomass, and 4C1 Net carbon stock change in mineral soil. Positive values refer to higher emissions/lower removals and negative values to lower emissions/higher removals in the latest submission compared to the previous submission.

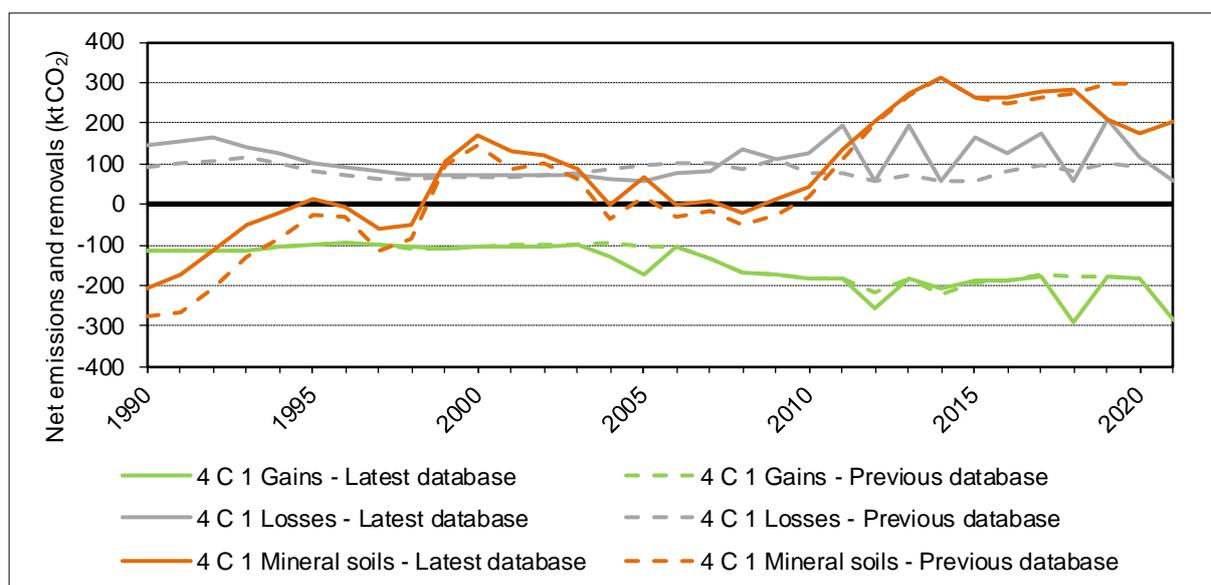


Figure 10-13 Comparison of net emissions (positive values) and net removals (negative values) from category 4C1 Gains in living biomass, category 4C1 Losses in living biomass, and category 4C1 Mineral soil as reported in the previous and the latest submissions.

In category 4G Harvested wood products one recalculation dominated the changes in CO<sub>2</sub> net emissions and removals (chp. 6.10.5). Whereas in previous submissions only the biomass loss on deforested areas fulfilling the criteria for Deforestation according to the Kyoto Protocol was considered, in the latest submission the biomass loss on all deforested areas was considered. The recalculated split between HWP from deforestations and from Forest land resulted in lower inflows to the HWP pool (around -3 %) and, finally, in reduced removals and higher emissions, respectively (hardly pronounced, however, in category 4G2 Paper and paperboard, where the differences run along the zero line). The differences in category 4G range from 18.9 kt CO<sub>2</sub> in 2013 to 45.1 kt CO<sub>2</sub> in 1995 (Figure 10-14). In contrast to the first years of the inventory period, this means a high relative change since 2011 (Figure 10-15).

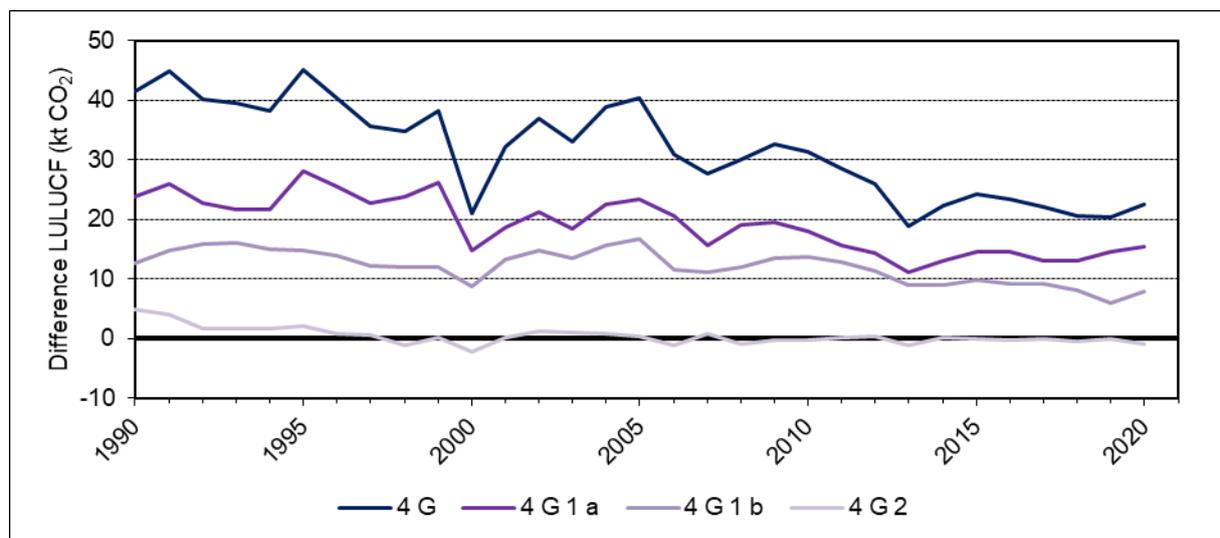


Figure 10-14 Differences in net emissions and removals (in kt CO<sub>2</sub>) between the latest and the previous submissions for category 4G Harvested wood products broken down for 4G1a Sawnwood, 4G1b Wood panels, and 4G2 Paper and paperboard. Positive values refer to higher emissions/lower removals and negative values to lower emissions/higher removals in the latest submission compared to the previous submission.

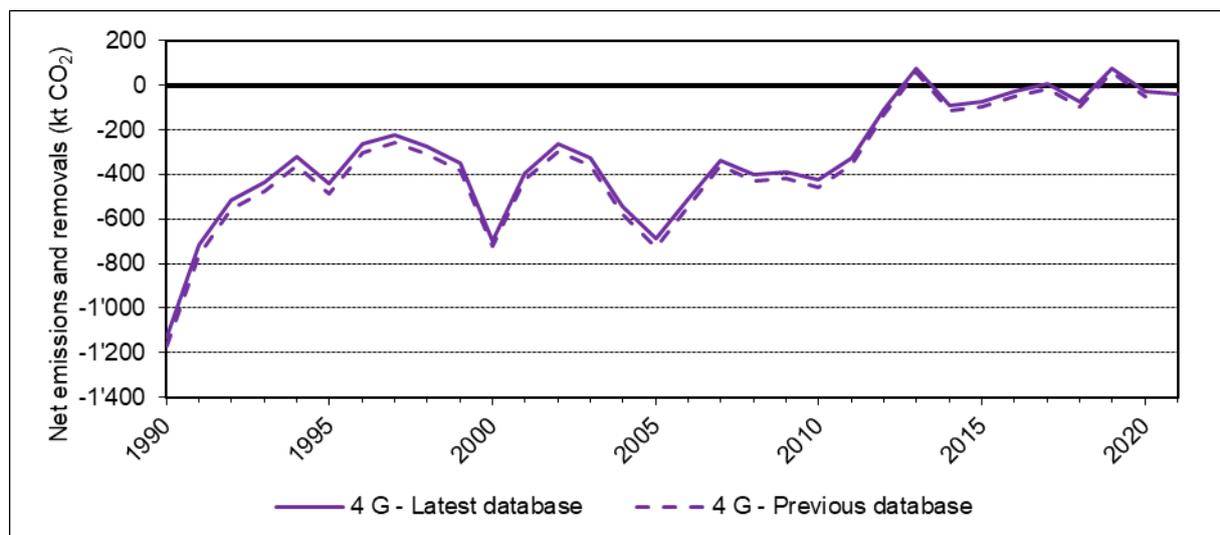


Figure 10-15 Comparison of net emissions (positive values) and net removals (negative values) from category 4G Harvested wood products as reported in the previous and the latest submissions.

### 10.1.2.5. Waste

The total changes in emissions in the Waste sector due to all recalculations are shown in Figure 10-16 for CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O.

Major recalculations are due to the implementation of new country-specific methods for estimating CH<sub>4</sub> and N<sub>2</sub>O emissions from 5D Wastewater treatment and discharge (see chp.7.5.2 and chp. 7.5.5). Research commissioned by FOEN led to the development of country-specific N<sub>2</sub>O emission factors for different types of centralized wastewater treatment plants. The new emission factors are much larger than the default N<sub>2</sub>O emission factors provided by the 2006 IPCC Guidelines (IPCC 2006), resulting in an increase ranging from +432 kt CO<sub>2</sub>eq to +920 kt CO<sub>2</sub>eq (i.e. 2020 to 1990, respectively). A supplementary study commissioned in response to a recommendation from a previous expert review team led to the development of a country-specific methodology to estimate emissions from decentralized wastewater treatment. This resulted in additional CH<sub>4</sub> emissions of the order of 93 kt CO<sub>2</sub>eq in 1990 and 144 kt CO<sub>2</sub>eq in 2020 as well as additional N<sub>2</sub>O emissions in the order of 90 kt CO<sub>2</sub>eq in 1990 and 29 kt CO<sub>2</sub>eq in 2020. The described recalculations are summed up in Figure 10-16.

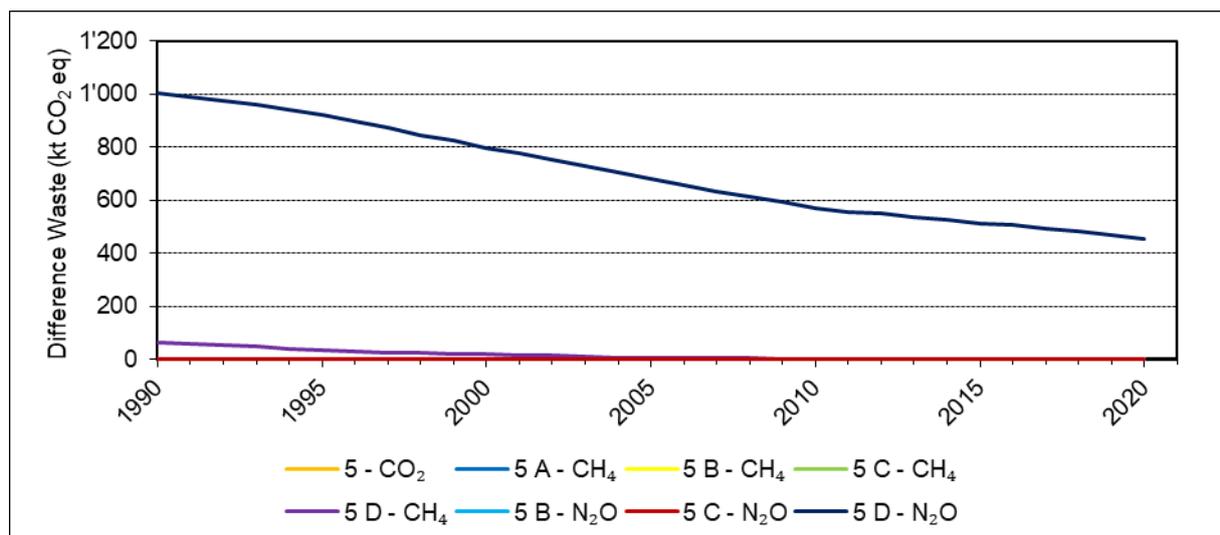


Figure 10-16 Differences in CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O emissions (in kt CO<sub>2</sub> eq) between the latest and the previous submissions for sector Waste. Positive values refer to higher emissions and negative values to lower emissions in the latest submission compared to the previous submission.

### 10.1.2.6. Other

The recalculations implemented for source category 6 Other based on new activity data from the fire insurance association resulted in changes smaller than 5 kt CO<sub>2</sub>eq.

### 10.1.2.7. Indirect CO<sub>2</sub> Emissions

The total changes in indirect CO<sub>2</sub> emissions due to all recalculations are shown in Figure 10-17.

The resulting recalculation is the sum of an increase in NMVOC emissions in 1B2a (see also chp. 3.3.3.5 and chp. 10.1.2.1), and a decrease in NMVOC emissions in 2G4 resulting from a

reassessment of NMVOC emissions in 2D3 (NFR) and 2G (NFR) (see FOEN 2023b, chp. 4.5.3 and chp. 4.6.3).

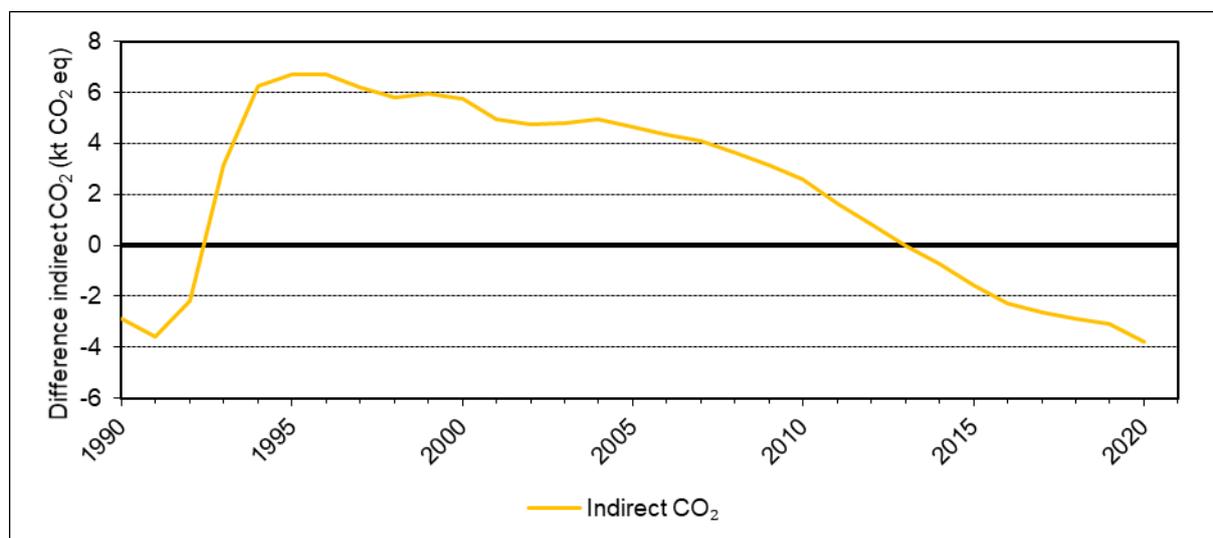


Figure 10-17 Differences in indirect CO<sub>2</sub> emissions (in kt CO<sub>2</sub> eq) between the latest and the previous submissions. Positive values refer to higher emissions and negative values to lower emissions in the latest submission compared to the previous submission.

## 10.2. Implications for emission and removal levels

Table 10-3 and Table 10-4 show the aggregated effect of all recalculations on the emission estimates for the base year 1990 and for the year 2020, respectively. According to information provided via e-mail by the helpdesk (ANAIS-4180), the current CRF reporter does not consistently use AR5 GWPs for the previous submission. HFCs and PFCs for the previous submission are shown based on AR4 GWPs, while all other gases are shown using AR5 GWPs. Therefore, the numbers in Table 10-3 and Table 10-4, which consistently use AR5 GWP for both the previous and the latest submissions, are slightly different from CRF table 8 with regard to F-Gases (see also Table A – 26).

Table 10-3 Implications of recalculations for emission levels in 1990. Emissions are shown for the previous submission (FOEN 2022) and the latest submission. The difference refers to absolute values (Latest - Previous).

Emissions for 1990	CO <sub>2</sub>			CH <sub>4</sub>			N <sub>2</sub> O			F-Gases			Sum of all gases		
	Latest	Previous	Difference	Latest	Previous	Difference	Latest	Previous	Difference	Latest	Previous	Difference	Latest	Previous	Difference
CO <sub>2</sub> equivalent (kt)															
1 Energy	40'908	40'907	0.9	707.1	692.1	15.0	283.7	282.2	1.5				41'899	41'881	17.3
2 IPPU	3'153	3'153	0.0	4.0	4.0	0.0	540.5	535.2	5.3	246.0	246.0	0.0	3'943	3'938	5.3
3 Agriculture	48.9	48.9	0.0	4'706	4'760	-53.7	2'046	2'030	15.8				6'801	6'839	-37.9
5 Waste	40.2	40.2	0.0	1'094	1'030	64.6	1'144	140.9	1'003				2'278	1'211	1'067
6 Other	11.2	11.0	0.3	0.8	0.7	0.0	0.5	0.5	0.0				12.5	12.2	0.3
CO <sub>2</sub> indirect	411.1	414.0	-2.9										411.1	414.0	-2.9
<b>Total excluding LULUCF</b>	<b>44'572</b>	<b>44'574</b>	<b>-1.8</b>	<b>6'513</b>	<b>6'487</b>	<b>25.9</b>	<b>4'014</b>	<b>2'989</b>	<b>1'025</b>	<b>246</b>	<b>246</b>	<b>0.0</b>	<b>55'345</b>	<b>54'296</b>	<b>1'049</b>
	<b>100.0%</b>	<b>100.0%</b>	<b>0.0%</b>	<b>100.4%</b>	<b>100.0%</b>	<b>0.4%</b>	<b>134.3%</b>	<b>100.0%</b>	<b>34.3%</b>	<b>100.0%</b>	<b>100.0%</b>	<b>0.0%</b>	<b>101.9%</b>	<b>100.0%</b>	<b>1.9%</b>
4 LULUCF	-1'848	-2'128	280.0	31.7	31.7	0.0	52.0	49.1	2.9				-1'764	-2'047	282.8
<b>Total including LULUCF</b>	<b>42'725</b>	<b>42'446</b>	<b>278.2</b>	<b>6'544</b>	<b>6'519</b>	<b>25.9</b>	<b>4'066</b>	<b>3'038</b>	<b>1'028</b>	<b>246.0</b>	<b>246.0</b>	<b>0.0</b>	<b>53'581</b>	<b>52'249</b>	<b>1'332</b>
	<b>100.7%</b>	<b>100.0%</b>	<b>0.7%</b>	<b>100.4%</b>	<b>100.0%</b>	<b>0.4%</b>	<b>133.8%</b>	<b>100.0%</b>	<b>33.8%</b>	<b>100.0%</b>	<b>100.0%</b>	<b>0.0%</b>	<b>102.5%</b>	<b>100.0%</b>	<b>2.5%</b>

Emissions for 1990	HFC			PFC			SF <sub>6</sub>			NF <sub>3</sub>		
	Latest	Previous	Difference	Latest	Previous	Difference	Latest	Previous	Difference	Latest	Previous	Difference
CO <sub>2</sub> equivalent (kt)												
2 IPPU	0.0	0.0	0.0	104.8	104.8	0.0	141.2	141.2	0.0	0.0	0.0	0.0

Table 10-4 Implications of recalculations for emission levels in 2020. Emissions are shown for the previous submission (FOEN 2022) and the latest submission. The difference refers to the absolute values (Latest - Previous).

Emissions for 2020	CO <sub>2</sub>			CH <sub>4</sub>			N <sub>2</sub> O			F-Gases			Sum of all gases		
	Latest	Previous	Difference	Latest	Previous	Difference	Latest	Previous	Difference	Latest	Previous	Difference	Latest	Previous	Difference
CO <sub>2</sub> equivalent (kt)															
1 Energy	32'148	32'150	-2.5	296.0	293.3	2.8	215.7	212.5	3.2				32'660	32'656	3.4
2 IPPU	2'022	2'026	-4.3	7.2	7.2	0.0	544.8	538.2	6.5	1'513	1'483	30.2	4'087	4'055	32.5
3 Agriculture	44.9	44.8	0.0	4'232	4'281	-48.8	1'581	1'680	-98.9				5'859	6'006	-147.7
5 Waste	8.9	8.9	0.0	556.6	555.8	0.8	605.9	149.8	456.1				1'171	714.5	456.9
6 Other	11.7	10.6	1.1	0.7	0.6	0.1	0.5	0.4	0.0				12.8	11.6	1.2
CO <sub>2</sub> indirect	116.8	120.6	-3.8										116.8	120.6	-3.8
<b>Total excluding LULUCF</b>	<b>34'352</b>	<b>34'362</b>	<b>-9.5</b>	<b>5'093</b>	<b>5'138</b>	<b>-45.2</b>	<b>2'948</b>	<b>2'581</b>	<b>366.9</b>	<b>1'513</b>	<b>1'483</b>	<b>30.2</b>	<b>43'907</b>	<b>43'564</b>	<b>342.4</b>
	<b>100.0%</b>	<b>100.0%</b>	<b>0.0%</b>	<b>99.1%</b>	<b>100.0%</b>	<b>-0.9%</b>	<b>114.2%</b>	<b>100.0%</b>	<b>14.2%</b>	<b>102.0%</b>	<b>100.0%</b>	<b>2.0%</b>	<b>100.8%</b>	<b>100.0%</b>	<b>0.8%</b>
4 LULUCF	-1'488	-1'768	279.5	13.3	13.3	0.0	48.1	44.9	3.2				-1'427	-1'709	282.7
<b>Total including LULUCF</b>	<b>32'864</b>	<b>32'594</b>	<b>270.0</b>	<b>5'106</b>	<b>5'151</b>	<b>-45.2</b>	<b>2'996</b>	<b>2'626</b>	<b>370.1</b>	<b>1'513</b>	<b>1'483</b>	<b>30.2</b>	<b>42'480</b>	<b>41'855</b>	<b>625.1</b>
	<b>100.8%</b>	<b>100.0%</b>	<b>0.8%</b>	<b>99.1%</b>	<b>100.0%</b>	<b>-0.9%</b>	<b>114.1%</b>	<b>100.0%</b>	<b>14.1%</b>	<b>102.0%</b>	<b>100.0%</b>	<b>2.0%</b>	<b>101.5%</b>	<b>100.0%</b>	<b>1.5%</b>

Emissions for 2020	HFC			PFC			SF <sub>6</sub>			NF <sub>3</sub>		
	Latest	Previous	Difference	Latest	Previous	Difference	Latest	Previous	Difference	Latest	Previous	Difference
CO <sub>2</sub> equivalent (kt)												
2 IPPU	1'323	1'310	12.8	34.4	31.1	3.4	155.8	141.8	14.0	0.39	0.39	0.0

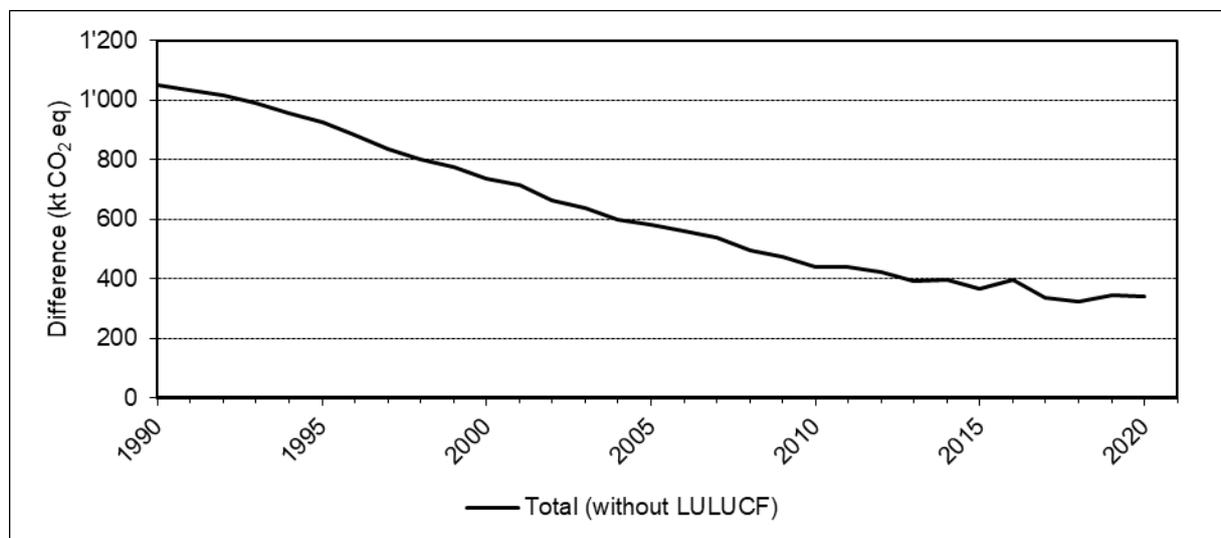


Figure 10-18 Implications of recalculations for the national total emissions (including indirect CO<sub>2</sub>, without LULUCF). Positive values refer to higher emissions and negative values to lower emissions in the latest compared to the previous submission. For the implications of recalculations for LULUCF see Figure 10-8.

Figure 10-18 shows the aggregated effect of all the recalculations on national total emissions without LULUCF. The effect of the recalculations ranges from +1049 kt CO<sub>2</sub> eq in 1990 to +342 kt CO<sub>2</sub> eq in 2020, corresponding to 1.9 % of annual total emissions in 1990 and 0.8 % in 2020.

The aggregated effect of all recalculations on total net emissions and net removals from LULUCF are shown in Figure 10-8.

To further visualize the aggregated effect of all the recalculations, the following figures compare total emissions as reported in the previous and the latest submissions in absolute terms (instead of showing differences as in the figures above): Total emissions (without LULUCF) in Figure 10-19, and total net emissions and net removals from LULUCF in Figure 10-20.

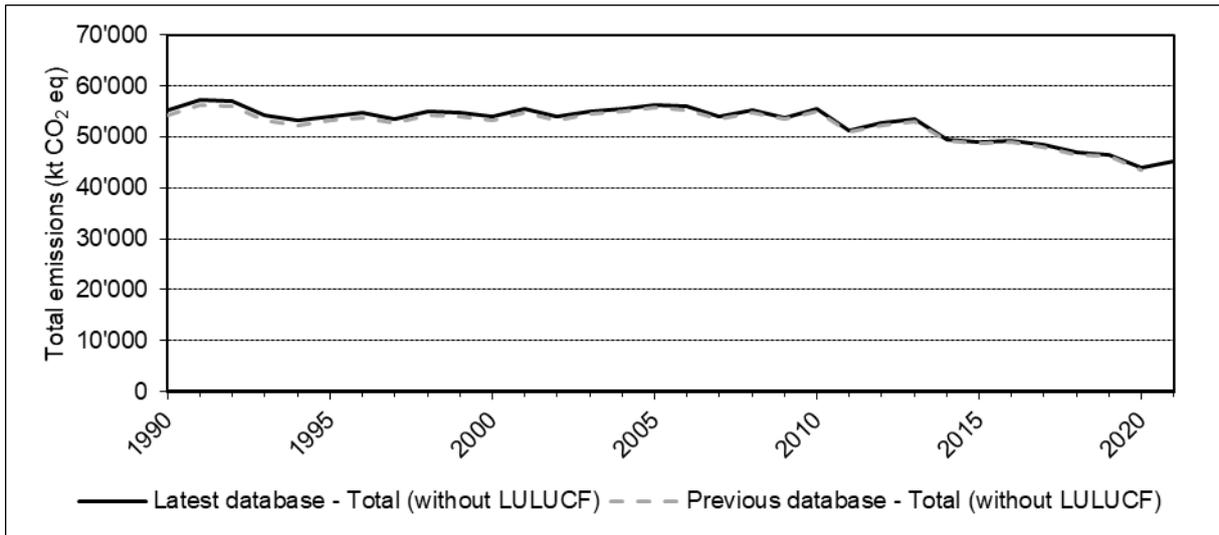


Figure 10-19 Comparison of total emissions (including indirect CO<sub>2</sub>, without LULUCF) as reported in the previous and the latest submissions.

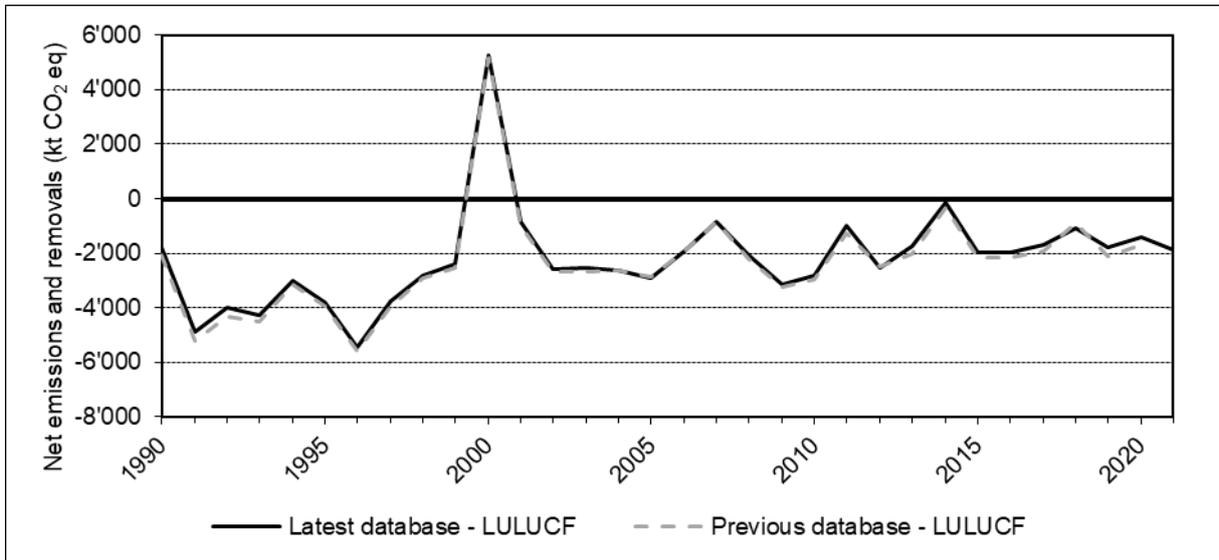


Figure 10-20 Comparison of net emissions (positive values) and net removals (negative values) from LULUCF as reported in the previous and the latest submissions.

### 10.3. Implications for emission and removal trends, including time series consistency

As recalculations are applied to the entire time series (as appropriate), time series consistency is maintained. The emission trend for the total emissions (including indirect CO<sub>2</sub>, excluding LULUCF) from 1990–2020 has changed (see Table 10-5) due to the recalculation of N<sub>2</sub>O emissions from 5D Wastewater treatment and discharge (see also Figure 10-16).

Table 10-5 Estimated emission trends 1990–2020, calculated based on national total emissions including indirect CO<sub>2</sub> as shown in the previous and the latest submission (for additional details see Table 10-3 and Table 10-4).

Trend	1990		2020		Change 1990/2020	
	Latest	Previous	Latest	Previous	Latest	Previous
	CO <sub>2</sub> equivalent (kt)				%	
Total excluding LULUCF	55'345	54'296	43'907	43'564	-20.7%	-19.8%
Total including LULUCF	53'581	52'249	42'480	41'855	-20.7%	-19.9%

### 10.4. Areas of improvement, including in response to the review process

All categories mentioned hereafter have been identified as key categories, or contain categories identified as key categories, according to the key category analysis except category 5B Biological treatment of solid waste (see overview of key categories in Table 1-6).

- 2F1: Improvements of HFC emission calculations from refrigeration and air conditioning equipment.
- 2F1: Changes are expected and will be analysed in this area due to the revision of the Chemical Risk Reduction Ordinance and CO<sub>2</sub> compensation programmes (share of products with HFC, recycling of HFC, early replacement of HFC).
- 3D: Since 2019, FOEN funds the development and evaluation of a process-oriented model for N<sub>2</sub>O emissions (LACHSIM) in agricultural soils subject to common Swiss management practices. Additional N<sub>2</sub>O-measurements with automated static chambers on cropland support the calibration and validation of the simulation model (LACHMESS).
- 3D: Development of a country-specific emission factor for direct N<sub>2</sub>O emissions from urine and dung deposited by grazing animals.
- 3D: Adjust the calculation of emissions from nitrogen in crop residues returned to soils in order to improve consistency between the Agriculture and LULUCF sectors.
- 4: The new Land Use Statistics (AREA5) will reduce the interval between successive surveys in the future to six years.
- 4: The suitability of satellite data for land area representation in Switzerland is being evaluated.
- 4A: First data on carbon dynamics in brush forests will be derived from NFIs 4 and 5.
- 4A: Planned progress on Yasso focuses on the implementation of Yasso20, including the improvement of the uncertainty estimates for litter production.
- 4B, 4C, 4D, 4E: Price et al. (2017) created a nationwide model for tree biomass in Switzerland (both inside and outside of forest), using structural information available from airborne laser scanning. The suitability of the obtained data for reporting in categories 4B, 4C, 4D, and 4E, respectively, is subject to ongoing evaluation (Mathys et al. 2019; Price 2020; Kükenbrink et al. 2021). To account for the detected differences in tree geometry

and associated biomass pattern a nationwide non-Forest land field survey of above ground tree biomass at the plot level was initiated by FOEN (2018–2024). The methodological approach is pursued with the overall objective to calculate a sound wall-to-wall above ground tree biomass database and map for Switzerland.

- 4B, 4C, 4D, 4E: A digital soil modelling project at the Competence Center for Soils (CCSoils) addressed the shortcomings of missing spatially inclusive and comprehensive soil information in Switzerland. An ongoing LULUCF module at CCSoils aims at improving the estimates of soil carbon stocks in Swiss non-forest soils. Results should be available for the GHG submission in 2024. The use of the SOC stocks raster data set is the first step towards a switch to grid-based SOC modelling with RothC for the GHG inventory.
- 4G: Increased implementation of data from domestic industry is being explored.
- 5B: A research project in the framework of a joint research programme is investigating the CH<sub>4</sub> emissions from agricultural biogas facilities. Results will be implemented in the greenhouse gas inventory after completion of the project as appropriate.
- 5D: It is planned to implement CH<sub>4</sub> emissions from receiving waters according to the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2019).

# Annexes

## Annex 1 Key categories

Table A – 1 Overview of Switzerland's key category analysis, including LULUCF categories and indirect CO<sub>2</sub> emissions. Columns A (category code) and B (category name) contain the complete disaggregation level of categories used for the key category analysis. L: level assessment (2021); T: trend assessment (1990–2021); 1: KCA approach 1; 2: KCA approach 2. For none of the categories, SF<sub>6</sub> and NF<sub>3</sub> are key (therefore, the respective columns for SF<sub>6</sub> and NF<sub>3</sub> are disabled in the columns C and D). Results of the level assessment for the base year are not reported in this table. Columns A to D are labelled according to Table 4-4 in the 2006 IPCC Guidelines, vol.1, chp. 4 (IPCC 2006).

SUMMARIES TO IDENTIFY KEY CATEGORIES							
A	B	C & D					
Code	IPCC category	CO2	CH4	N2O	HFCs	PFCs	Indirect CO2
1A1	Energy industries; Biomass						
1A1	Energy industries; Gaseous fuels	L1, T1					
1A1	Energy industries; Liquid fuels	L1, T1					
1A1	Energy industries; Other fuels	L1, T1, L2, T2					
1A1	Energy industries; Solid fuels						
1A2	Manufacturing industries and construction; Biomass						
1A2	Manufacturing industries and construction; Gaseous fuels	L1, T1, L2, T2					
1A2	Manufacturing industries and construction; Liquid fuels	L1, T1					
1A2	Manufacturing industries and construction; Other fuels	L1, T1, T2					
1A2	Manufacturing industries and construction; Solid fuels	L1, T1, T2					
1A3a	Domestic aviation; Kerosene fossil	T1					
1A3b	Road transportation; Biomass						
1A3b	Road transportation; Diesel oil	L1, T1, L2, T2		T1			
1A3b	Road transportation; Gaseous fuels						
1A3b	Road transportation; Gasoline	L1, T1	T1, T2	T1, T2			
1A3b	Road transportation; Liquefied petroleum gas						
1A3c	Railways; Biomass						
1A3c	Railways; Liquid fuels						
1A3d	Water-borne navigation; Biomass						
1A3d	Water-borne navigation; Liquid fuels						
1A3e	Other transportation; Gaseous fuels						
1A4a	Commercial; Biomass						
1A4a	Commercial; Gaseous fuels	L1, T1, L2, T2					
1A4a	Commercial; Liquid fuels	L1, T1					
1A4b	Residential; Biomass						
1A4b	Residential; Gaseous fuels	L1, T1, L2, T2					
1A4b	Residential; Liquid fuels	L1, T1					
1A4b	Residential; Solid fuels						
1A4c	Agriculture and forestry; Biomass						
1A4c	Agriculture and forestry; Gaseous fuels						
1A4c	Agriculture and forestry; Liquid fuels	L1, T1					
1A5	Non-specified; Biomass						
1A5	Non-specified; Liquid fuels						
1B	Fugitive emissions from fuels; All fuels; Indirect CO2 from CH4						
1B	Fugitive emissions from fuels; All fuels; Indirect CO2 from NMVOC						
1B2a	Oil; All fuels						
1B2b	Natural gas; All fuels		L1, T1, L2, T2				
1B2c	Venting and flaring; All fuels						
2A	Mineral industry; Indirect CO2 from CO						
2A	Mineral industry; Indirect CO2 from NMVOC						
2A1	Cement production	L1, T1, L2					
2A2	Lime production						
2A3	Glass production						
2A4	Other process uses of carbonates						
2B	Chemical industry; Indirect CO2 from CH4						
2B	Chemical industry; Indirect CO2 from CO						
2B	Chemical industry; Indirect CO2 from NMVOC						
2B2	Nitric acid production						
2B5	Carbide production						
2B8	Petrochemical and carbon black production						
2B10	Chemical industry, other			L1, T1, L2, T2			
2C	Metal industry; Indirect CO2 from CO						
2C	Metal industry; Indirect CO2 from NMVOC						
2C1	Iron and steel production						
2C3	Aluminium production	T1				T1	
2C4	Magnesium production						
2C7	Rare earths						
2D	Non-energy products from fuels and solvent use; Indirect CO2 from CO						
2D	Non-energy products from fuels and solvent use; Indirect CO2 from NMVOC						T1, T2
2D1	Lubricant use						
2D2	Paraffin wax use						
2D3	Other						
2E1	Integrated circuit or semiconductor						
2E3	Photovoltaics						
2E5	Electronics industry, other						
2F1	Refrigeration and air conditioning				L1, T1, L2, T2		
2F2	Foam blowing agents						
2F4	Aerosols						
2F5	Solvents						
2G	Other product manufacture and use						
2G	Other product manufacture and use; Indirect CO2 from CO						
2G	Other product manufacture and use; Indirect CO2 from NMVOC						T2
2G3	N2O from product uses			T2			
2G4	Other product manufacture and use, other						
2H	Other; Indirect CO2 from CO						
2H	Other; Indirect CO2 from NMVOC						
2H3	Other						

Table A – 1 (continued)

SUMMARIES TO IDENTIFY KEY CATEGORIES							
A	B	C & D					
Code	IPCC category	CO2	CH4	N2O	HFCs	PFCs	Indirect CO2
3A	Enteric fermentation		L1, T1, L2, T2				
3B1-4	Manure management, all livestock, direct		L1, L2	L2			
3B5	Manure management, indirect			L1, L2, T2			
3Da	Direct emissions from managed soils			L1, L2			
3Db	Indirect emissions from managed soils			L1, T1, L2, T2			
3G	Liming						
3H	Urea application						
4A1	Forest land remaining forest land	L1, T1, L2, T2					
4A2	Land converted to forest land	L1, L2					
4B1	Cropland remaining cropland	L1, T1, L2, T2					
4B2	Land converted to cropland						
4C1	Grassland remaining grassland	T1, L2, T2					
4C2	Land converted to grassland	L1, T1, L2, T2					
4D1	Wetland remaining wetland	L2					
4D2	Land converted to wetland						
4E1	Settlements remaining settlements						
4E2	Land converted to settlements	L1, L2					
4F2	Land converted to other land	L2, T2					
4G	HWP Harvested Wood Products	T1, T2					
4Ii	Drainage and rewetting						
4Iii	Direct N2O from disturbance			L2			
4Ii	Drainage and rewetting						
4IV	Indirect N2O						
4V	Biomass burning						
5A	Solid waste disposal		L1, T1, L2, T2				
5B	Biological treatment of solid waste						
5C	Incineration and open burning of waste			L2			
5C	Incineration and open burning of waste; Indirect CO2 from CH4						
5C	Incineration and open burning of waste; Indirect CO2 from CO						
5C	Incineration and open burning of waste; Indirect CO2 from NMVOC						
5D	Wastewater treatment and discharge		L1, L2, T2	L1, T1, L2, T2			
5E	Waste, other; Indirect CO2 from CO						
5E	Waste, other; Indirect CO2 from NMVOC						
6A	Other						
6A	Other; Indirect CO2 from CH4						
6A	Other; Indirect CO2 from CO						
6A	Other; Indirect CO2 from NMVOC						

## Annex 2 Uncertainty assessment

### A2.1 Input uncertainty values

Table A – 2 Input uncertainties for the year 2021, including LULUCF categories and indirect CO<sub>2</sub> emissions. Input uncertainties are assigned to activity data (column E) and emissions factors (column F) or, if unknown, to emissions only (column G). The uncertainties are given considering a 95 % confidence interval (from 2.5 % to 97.5 %) and expressed as the distance from edge to mean, in percentage of the mean. Columns are labelled according to Table 3-2 in the 2006 IPCC Guidelines, vol.1, chp. 3 (IPCC 2006).

A Code	B Gas	E Activity data uncertainty year 2021					F Emission factor uncertainty year 2021					G Emission uncertainty year 2021				
		Distribu- tion type	2*std. dev. %	(-)%	(+)%	Corr.	Distribu- tion type	2*std. dev. %	(-)%	(+)%	Corr.	Distribu- tion type	2*std. dev. %	(-)%	(+)%	Corr.
1A1; Biomass	CH4	normal	10.0	10.0	10.0	no	normal	28.3	28.3	28.3	yes					
1A1; Biomass	N2O	normal	10.0	10.0	10.0	no	normal	79.4	79.4	79.4	yes					
1A1; Gaseous fuels	CO2	normal	5.0	5.0	5.0	no	normal	0.3	0.3	0.3	no					
1A1; Gaseous fuels	CH4	normal	5.0	5.0	5.0	no	normal	29.6	29.6	29.6	yes					
1A1; Gaseous fuels	N2O	normal	5.0	5.0	5.0	no	normal	79.8	79.8	79.8	yes					
1A1; Liquid fuels	CO2	normal	0.7	0.7	0.7	no	normal	0.1	0.1	0.1	yes					
1A1; Liquid fuels	CH4	normal	0.7	0.7	0.7	no	normal	30.0	30.0	30.0	yes					
1A1; Liquid fuels	N2O	normal	0.7	0.7	0.7	no	normal	80.0	80.0	80.0	yes					
1A1; Other fuels	CO2	normal	5.0	5.0	5.0	no	normal	16.9	16.9	16.9	yes					
1A1; Other fuels	N2O	normal	5.0	5.0	5.0	no	normal	79.8	79.8	79.8	no					
1A1; Solid fuels	CO2	normal	5.0	0.0	0.0	no	normal	5.1	0.0	0.0	yes					
1A1; Solid fuels	CH4	normal	5.0	0.0	0.0	no	normal	29.6	0.0	0.0	yes					
1A1; Solid fuels	N2O	normal	5.0	0.0	0.0	no	normal	79.8	0.0	0.0	yes					
1A2; Biomass	CH4	normal	10.0	10.0	10.0	no	normal	28.3	28.3	28.3	yes					
1A2; Biomass	N2O	normal	10.0	10.0	10.0	no	normal	79.4	79.4	79.4	yes					
1A2; Gaseous fuels	CO2	normal	5.0	5.0	5.0	no	normal	0.3	0.3	0.3	no					
1A2; Gaseous fuels	CH4	normal	5.0	5.0	5.0	no	normal	29.6	29.6	29.6	yes					
1A2; Gaseous fuels	N2O	normal	5.0	5.0	5.0	no	normal	79.8	79.8	79.8	yes					
1A2; Liquid fuels	CO2	normal	0.7	0.7	0.7	no	normal	0.1	0.1	0.1	yes					
1A2; Liquid fuels	CH4	normal	0.7	0.7	0.7	no	normal	30.0	30.0	30.0	yes					
1A2; Liquid fuels	N2O	normal	0.7	0.7	0.7	no	normal	80.0	80.0	80.0	yes					
1A2; Other fuels	CO2	normal	5.0	5.0	5.0	no	normal	9.2	9.2	9.2	yes					
1A2; Other fuels	CH4	normal	5.0	5.0	5.0	no	normal	29.6	29.6	29.6	yes					
1A2; Other fuels	N2O	normal	5.0	5.0	5.0	no	normal	79.8	79.8	79.8	no					
1A2; Solid fuels	CO2	normal	5.0	5.0	5.0	no	normal	5.1	5.1	5.1	yes					
1A2; Solid fuels	CH4	normal	5.0	5.0	5.0	no	normal	29.6	29.6	29.6	yes					
1A2; Solid fuels	N2O	normal	5.0	5.0	5.0	no	normal	79.8	79.8	79.8	yes					
1A3a; Kerosene fossil	CO2	normal	1.0	1.0	1.0	no	normal	0.2	0.2	0.2	no					
1A3a; Kerosene fossil	CH4	normal	1.0	1.0	1.0	no	normal	60.0	60.0	60.0	yes					
1A3a; Kerosene fossil	N2O	normal	1.0	1.0	1.0	no	gamma	150.0	90.0	191.4	yes					
1A3b; Biomass	CH4	normal	10.0	10.0	10.0	no	normal	59.2	59.2	59.2	yes					
1A3b; Biomass	N2O	normal	10.0	10.0	10.0	no	gamma	149.7	90.0	190.9	yes					
1A3b; Diesel oil	CO2	normal	0.9	0.9	0.9	no	normal	0.1	0.1	0.1	no					
1A3b; Diesel oil	CH4	normal	0.9	0.9	0.9	no	normal	20.0	20.0	20.0	yes					
1A3b; Diesel oil	N2O	normal	0.9	0.9	0.9	no	normal	22.0	22.0	22.0	yes					
1A3b; Gaseous fuels	CO2	normal	5.0	5.0	5.0	no	normal	0.3	0.3	0.3	no					
1A3b; Gaseous fuels	CH4	normal	5.0	5.0	5.0	no	normal	29.6	29.6	29.6	yes					
1A3b; Gaseous fuels	N2O	normal	5.0	5.0	5.0	no	normal	79.8	79.8	79.8	yes					
1A3b; Gasoline	CO2	normal	0.7	0.7	0.7	no	normal	0.1	0.1	0.1	no					
1A3b; Gasoline	CH4	normal	0.7	0.7	0.7	no	normal	37.0	37.0	37.0	yes					
1A3b; Gasoline	N2O	normal	0.7	0.7	0.7	no	normal	50.0	50.0	50.0	yes					
1A3b; Liquefied petroleum gas	CO2	normal	0.7	0.7	0.7	no	normal	10.0	10.0	10.0	yes					
1A3b; Liquefied petroleum gas	CH4	normal	0.7	0.7	0.7	no	normal	30.0	30.0	30.0	yes					
1A3b; Liquefied petroleum gas	N2O	normal	0.7	0.7	0.7	no	normal	80.0	80.0	80.0	yes					
1A3c; Biomass	CH4	normal	10.0	10.0	10.0	no	normal	59.2	59.2	59.2	yes					
1A3c; Biomass	N2O	normal	10.0	10.0	10.0	no	gamma	149.7	90.0	190.9	yes					
1A3c; Liquid fuels	CO2	normal	0.9	0.9	0.9	no	normal	0.1	0.1	0.1	no					
1A3c; Liquid fuels	CH4	normal	0.9	0.9	0.9	no	normal	30.0	30.0	30.0	yes					
1A3c; Liquid fuels	N2O	normal	0.7	0.7	0.7	no	normal	80.0	80.0	80.0	yes					
1A3d; Biomass	CH4	normal	10.0	10.0	10.0	no	normal	59.2	59.2	59.2	yes					
1A3d; Biomass	N2O	normal	10.0	10.0	10.0	no	gamma	149.7	90.0	190.9	yes					
1A3d; Liquid fuels	CO2	normal	0.7	0.7	0.7	no	normal	0.1	0.1	0.1	no					
1A3d; Liquid fuels	CH4	normal	0.7	0.7	0.7	no	normal	30.0	30.0	30.0	yes					
1A3d; Liquid fuels	N2O	normal	0.7	0.7	0.7	no	gamma	150.0	90.0	191.4	yes					
1A3e; Gaseous fuels	CO2	normal	5.0	5.0	5.0	no	normal	0.3	0.3	0.3	no					
1A3e; Gaseous fuels	CH4	normal	5.0	5.0	5.0	no	normal	29.6	29.6	29.6	yes					
1A3e; Gaseous fuels	N2O	normal	5.0	5.0	5.0	no	normal	79.8	79.8	79.8	yes					

Table A – 2 (continued)

A Code	B Gas	E Activity data uncertainty year 2021					F Emission factor uncertainty year 2021					G Emission uncertainty year 2021				
		Distribution type	2*std. dev. %	(-)%	(+)%	Corr.	Distribution type	2*std. dev. %	(-)%	(+)%	Corr.	Distribution type	2*std. dev. %	(-)%	(+)%	Corr.
1A4a; Biomass	CH4	normal	10.0	10.0	10.0	no	normal	28.3	28.3	28.3	yes					
1A4a; Biomass	N2O	normal	10.0	10.0	10.0	no	normal	79.4	79.4	79.4	yes					
1A4a; Gaseous fuels	CO2	normal	5.0	5.0	5.0	no	normal	0.3	0.3	0.3	no					
1A4a; Gaseous fuels	CH4	normal	5.0	5.0	5.0	no	normal	29.6	29.6	29.6	yes					
1A4a; Gaseous fuels	N2O	normal	5.0	5.0	5.0	no	normal	79.8	79.8	79.8	yes					
1A4a; Liquid fuels	CO2	normal	0.7	0.7	0.7	no	normal	0.1	0.1	0.1	yes					
1A4a; Liquid fuels	CH4	normal	0.7	0.7	0.7	no	normal	30.0	30.0	30.0	yes					
1A4a; Liquid fuels	N2O	normal	0.7	0.7	0.7	no	normal	80.0	80.0	80.0	yes					
1A4b; Biomass	CH4	normal	10.0	10.0	10.0	no	normal	28.3	28.3	28.3	yes					
1A4b; Biomass	N2O	normal	10.0	10.0	10.0	no	normal	79.4	79.4	79.4	yes					
1A4b; Gaseous fuels	CO2	normal	5.0	5.0	5.0	no	normal	0.3	0.3	0.3	no					
1A4b; Gaseous fuels	CH4	normal	5.0	5.0	5.0	no	normal	29.6	29.6	29.6	yes					
1A4b; Gaseous fuels	N2O	normal	5.0	5.0	5.0	no	normal	79.8	79.8	79.8	yes					
1A4b; Liquid fuels	CO2	normal	0.7	0.7	0.7	no	normal	0.1	0.1	0.1	yes					
1A4b; Liquid fuels	CH4	normal	0.7	0.7	0.7	no	normal	30.0	30.0	30.0	yes					
1A4b; Liquid fuels	N2O	normal	0.7	0.7	0.7	no	normal	80.0	80.0	80.0	yes					
1A4b; Solid fuels	CO2	normal	5.0	5.0	5.0	no	normal	5.1	5.1	5.1	yes					
1A4b; Solid fuels	CH4	normal	5.0	5.0	5.0	no	normal	29.6	29.6	29.6	yes					
1A4b; Solid fuels	N2O	normal	5.0	5.0	5.0	no	normal	79.8	79.8	79.8	yes					
1A4c; Biomass	CH4	normal	10.0	10.0	10.0	no	normal	28.3	28.3	28.3	yes					
1A4c; Biomass	N2O	normal	10.0	10.0	10.0	no	normal	79.4	79.4	79.4	yes					
1A4c; Gaseous fuels	CO2	normal	5.0	5.0	5.0	no	normal	0.3	0.3	0.3	no					
1A4c; Gaseous fuels	CH4	normal	5.0	5.0	5.0	no	normal	29.6	29.6	29.6	yes					
1A4c; Gaseous fuels	N2O	normal	5.0	5.0	5.0	no	normal	79.8	79.8	79.8	yes					
1A4c; Liquid fuels	CO2	normal	0.7	0.7	0.7	no	normal	0.1	0.1	0.1	yes					
1A4c; Liquid fuels	CH4	normal	0.7	0.7	0.7	no	normal	30.0	30.0	30.0	yes					
1A4c; Liquid fuels	N2O	normal	0.7	0.7	0.7	no	normal	80.0	80.0	80.0	yes					
1A5; Biomass	CH4	normal	10.0	10.0	10.0	no	normal	59.2	59.2	59.2	yes					
1A5; Biomass	N2O	normal	10.0	10.0	10.0	no	gamma	149.7	90.0	190.9	yes					
1A5; Liquid fuels	CO2	normal	0.7	0.7	0.7	no	normal	0.1	0.1	0.1	no					
1A5; Liquid fuels	CH4	normal	0.7	0.7	0.7	no	normal	30.0	30.0	30.0	yes					
1A5; Liquid fuels	N2O	normal	0.7	0.7	0.7	no	gamma	150.0	90.0	191.4	yes					
1B; All fuels	Indirect CO2 from CH4											normal	29.9	29.9	29.9	no
1B; All fuels	Indirect CO2 from NMVOC											normal	22.4	22.4	22.4	no
1B2a; All fuels	CH4	normal	5.0	5.0	5.0	no	normal	29.6	29.6	29.6	yes					
1B2b; All fuels	CO2	normal	5.0	5.0	5.0	no	normal	8.7	8.7	8.7	yes					
1B2b; All fuels	CH4	normal	5.0	5.0	5.0	no	normal	29.6	29.6	29.6	yes					
1B2c; All fuels	CO2	normal	5.0	5.0	5.0	no	normal	8.7	8.7	8.7	yes					
1B2c; All fuels	CH4	normal	5.0	5.0	5.0	no	normal	29.6	29.6	29.6	yes					
1B2c; All fuels	N2O	normal	5.0	5.0	5.0	no	normal	79.8	79.8	79.8	yes					
2A	Indirect CO2 from CO											gamma	177.9	95.1	303.3	no
2A	Indirect CO2 from NMVOC											gamma	188.2	96.4	243.5	no
2A1	CO2	normal	2.0	2.0	2.0	no	normal	4.0	4.0	4.0	yes					
2A2	CO2	normal	2.0	2.0	2.0	no	normal	2.0	2.0	2.0	no					
2A3	CO2	normal	2.0	2.0	2.0	no	normal	3.0	3.0	3.0	no					
2A4	CO2	normal	2.0	2.0	2.0	no	normal	2.0	2.0	2.0	no					
2B	Indirect CO2 from CH4											normal	20.1	20.1	20.1	no
2B	Indirect CO2 from CO											normal	37.6	37.6	37.6	no
2B	Indirect CO2 from NMVOC											normal	40.0	40.0	40.0	no
2B2	N2O	normal	2.0	0.0	0.0	no	normal	7.2	0.0	0.0	no					
2B5	CO2	normal	2.0	2.0	2.0	no	normal	10.0	10.0	10.0	yes					
2B5	CH4	normal	2.0	2.0	2.0	no	normal	20.0	20.0	20.0	yes					
2B8	CO2	normal	2.0	2.0	2.0	no	normal	10.0	10.0	10.0	no					
2B10	CO2	normal	2.0	2.0	2.0	no	normal	60.0	60.0	60.0	yes					
2B10	CH4	normal	2.0	0.0	0.0	no	normal	60.0	0.0	0.0	yes					
2B10	N2O	normal	2.0	2.0	2.0	no	normal	60.0	60.0	60.0	no					
2C	Indirect CO2 from CO											gamma	191.0	96.7	262.5	no
2C	Indirect CO2 from NMVOC											gamma	99.4	72.5	112.3	no
2C1	CO2	normal	2.0	2.0	2.0	no	normal	50.0	50.0	50.0	no					
2C3	CO2	normal	5.0	0.0	0.0	no	normal	20.0	0.0	0.0	yes					
2C3	PFCs											normal	9.0	0.0	0.0	no
2C7	CO2	normal	2.0	2.0	2.0	no	normal	20.0	20.0	20.0	yes					
2D	Indirect CO2 from CO											gamma	202.1	97.6	272.5	no
2D	Indirect CO2 from NMVOC											normal	35.8	35.8	35.8	no
2D1	CO2	normal	20.0	20.0	20.0	yes	normal	50.0	50.0	50.0	yes					
2D2	CO2	normal	10.0	10.0	10.0	yes	gamma	100.0	72.8	119.2	yes					
2D3	CO2	normal	10.0	10.0	10.0	no	normal	20.0	20.0	20.0	no					
2E1	PFCs											normal	62.2	62.2	62.2	no
2E1	SF6											normal	59.1	59.1	59.1	no
2E3	NF3											gamma	108.2	76.4	130.6	no
2E5	PFCs											normal	43.9	43.9	43.9	no
2F1	HFCS											normal	19.2	19.2	19.2	no
2F1	PFCs											normal	43.5	43.5	43.5	no
2F2	HFCS											gamma	141.4	87.9	178.6	no
2F4	HFCS											normal	40.8	40.8	40.8	no
2F5	HFCS											normal	52.9	52.9	52.9	no
2G	HFCS											normal	19.7	19.7	19.7	no
2G	PFCs											normal	12.1	12.1	12.1	no
2G	SF6											normal	41.4	41.4	41.4	yes
2G	Indirect CO2 from CO											gamma	302.7	100.0	434.6	no
2G	Indirect CO2 from NMVOC											gamma	80.8	62.8	98.3	no
2G3	N2O	normal	1.0	1.0	1.0	no	normal	80.0	80.0	80.0	yes					
2G4	CO2	normal	10.0	10.0	10.0	no	normal	20.0	20.0	20.0	yes					
2G4	N2O	normal	1.0	1.0	1.0	no	normal	40.0	40.0	40.0	yes					
2H	Indirect CO2 from CO											gamma	200.0	97.5	268.9	no
2H	Indirect CO2 from NMVOC											gamma	180.4	95.5	215.2	no

Table A – 2 (continued)

A Code	B Gas	E Activity data uncertainty year 2021					F Emission factor uncertainty year 2021					G Emission uncertainty year 2021				
		Distribution type	2*std. dev. %	(-)%	(+)%	Corr.	Distribution type	2*std. dev. %	(-)%	(+)%	Corr.	Distribution type	2*std. dev. %	(-)%	(+)%	Corr.
2H3	CO2	normal	5.0	5.0	5.0	no	gamma	100.0	72.8	119.2	yes					
3A	CH4	normal	6.5	6.5	6.5	no	gamma	19.2	17.9	19.7	no					
3B1-4	CH4	normal	6.5	6.5	6.5	no	normal	54.6	54.6	54.6	no					
3B1-4	N2O	normal	24.0	24.0	24.0	no	gamma	71.0	57.0	80.6	no					
3B5	N2O	gamma	54.8	46.3	60.5	no	gamma	80.0	62.4	92.3	yes					
3Da	N2O	normal	13.4	13.4	13.4	no	gamma	78.6	61.6	90.5	no					
3Db	N2O	gamma	30.1	27.3	31.6	no	gamma	62.5	51.6	69.9	no					
3G	CO2	normal	40.0	40.0	40.0	no	normal	5.0	5.0	5.0	yes					
3H	CO2	normal	5.0	5.0	5.0	no	normal	5.0	5.0	5.0	yes					
4A1	CO2	normal	1.1	1.1	1.1	yes	normal	46.7	46.7	46.7	yes					
4A2	CO2	normal	1.5	1.5	1.5	yes	normal	46.7	46.7	46.7	yes					
4B1	CO2											normal	128.4	128.4	128.4	no
4B2	CO2											normal	152.9	152.9	152.9	no
4C1	CO2											normal	734.2	734.2	734.2	no
4C2	CO2											normal	36.0	36.0	36.0	no
4D1	CO2	normal	90.8	90.8	90.8	yes	normal	72.2	72.2	72.2	yes					
4D2	CO2											normal	20.1	20.1	20.1	no
4E1	CO2	normal	4.4	4.4	4.4	yes	normal	50.0	50.0	50.0	yes					
4E2	CO2	normal	4.6	4.6	4.6	yes	normal	50.0	50.0	50.0	yes					
4F2	CO2	normal	3.2	3.2	3.2	yes	normal	50.0	50.0	50.0	yes					
4G	CO2	normal	11.2	11.2	11.2	yes	normal	54.8	54.8	54.8	yes					
4I	CH4	normal	10.0	10.0	10.0	yes	normal	70.0	70.0	70.0	yes					
4II	N2O	normal	48.8	48.8	48.8	yes	normal	66.9	66.9	66.9	yes					
4III	N2O	normal	83.5	83.5	83.5	yes	gamma	156.2	91.4	200.8	yes					
4IV	N2O	normal	85.8	85.8	85.8	yes	gamma	177.6	95.1	233.7	yes					
4V	CH4	normal	30.0	30.0	30.0	yes	normal	70.0	70.0	70.0	yes					
4V	N2O	normal	30.0	30.0	30.0	yes	normal	70.0	70.0	70.0	yes					
5A	CH4											normal	30.0	30.0	30.0	yes
5B	CH4	normal	30.0	30.0	30.0	no	normal	30.0	30.0	30.0	yes					
5B	N2O	normal	30.0	30.0	30.0	no	normal	30.0	30.0	30.0	yes					
5C	CO2	normal	30.0	30.0	30.0	no	normal	26.5	26.5	26.5	yes					
5C	CH4	normal	50.0	50.0	50.0	no	normal	33.2	33.2	33.2	yes					
5C	N2O	normal	30.0	30.0	30.0	no	gamma	147.0	89.3	186.9	yes					
5C	Indirect CO2 from CH4											gamma	60.5	50.2	67.5	no
5C	Indirect CO2 from CO											gamma	71.8	57.5	77.4	no
5C	Indirect CO2 from NMVOC											gamma	71.8	57.5	78.9	no
5D	CH4											gamma	100.0	72.8	119.2	no
5D	N2O											gamma	50.0	42.8	105.6	no
5E	Indirect CO2 from CO											normal	28.3	28.3	28.3	no
5E	Indirect CO2 from NMVOC											normal	30.9	30.9	30.9	no
6A	CO2	normal	20.0	20.0	20.0	no	normal	34.6	34.6	34.6	yes					
6A	CH4	normal	20.0	20.0	20.0	no	normal	56.6	56.6	56.6	yes					
6A	N2O	normal	20.0	20.0	20.0	no	normal	148.7	148.7	148.7	yes					
6A	Indirect CO2 from CH4											gamma	60.2	50.0	67.1	no
6A	Indirect CO2 from CO											gamma	73.2	58.3	83.5	no
6A	Indirect CO2 from NMVOC											gamma	54.0	45.7	59.6	no

## A2.2 Detailed results of approach 1 uncertainty analysis

Table A – 3 Uncertainty analysis of greenhouse gas emissions and removals, approach 1, for 2021 and for the trend 1990–2021, including LULUCF categories and indirect CO<sub>2</sub> emissions. The uncertainties are given considering a 95 % confidence interval (from 2.5 % to 97.5 %), and expressed as the distance from edge to mean, in percentage of the mean. AD: activity data; EF: emission factor; EM: emission. d.EM stands for direct emission and indicates that input uncertainties are given for the emission but neither for activity data nor for emission factor. Columns are labelled according to Table 3-2 in the 2006 IPCC Guidelines, vol.1, chp. 3 (IPCC 2006).

Code	Gas	Emissions 1990	Emissions 2021	Emission combined uncertainty 2021		Category contribution to inventory variance 2021		Sensitivity if not corr. (type A)	Sensitivity if corr. (type B)	Contribution to inventory trend uncertainty from AD		Contribution to inventory trend uncertainty from EF		Contribution to inventory trend uncertainty from EM			
				(-)%	(+)%	(-)%	(+)%			(-)%	(+)%	(-)%	(+)%	(-)%	(+)%	(-)%	(+)%
1A1; Biomass	CH4	0.45	0.16	30	30	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		
1A1; Biomass	N2O	20.08	12.82	80	80	0.001	0.001	0.000	0.000	0.003	0.003	0.005	0.005	0.000	0.000		
1A1; Gaseous fuels	CO2	243.40	514.77	5	5	0.004	0.004	0.006	0.010	0.068	0.068	0.005	0.005	0.005	0.005		
1A1; Gaseous fuels	CH4	0.12	0.26	30	30	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		
1A1; Gaseous fuels	N2O	0.11	0.24	80	80	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		
1A1; Liquid fuels	CO2	685.81	275.92	1	1	0.000	0.000	0.005	0.005	0.005	0.005	0.000	0.000	0.000	0.000		
1A1; Liquid fuels	CH4	0.58	0.17	30	30	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		
1A1; Liquid fuels	N2O	0.98	0.20	80	80	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.000		
1A1; Other fuels	CO2	1'491.55	2'409.22	18	18	0.958	0.958	0.022	0.045	0.318	0.318	0.379	0.379	0.245	0.245		
1A1; Other fuels	N2O	21.63	7.26	80	80	0.000	0.000	0.000	0.000	0.001	0.001	0.015	0.015	0.000	0.000		
1A1; Solid fuels	CO2	49.13	NO	NO	NO	NO	NO	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000		
1A1; Solid fuels	CH4	0.15	NO	NO	NO	NO	NO	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		
1A1; Solid fuels	N2O	0.21	NO	NO	NO	NO	NO	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		
1A2; Biomass	CH4	4.16	2.41	30	30	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.001	0.000	0.000		
1A2; Biomass	N2O	4.71	17.72	80	80	0.001	0.001	0.000	0.000	0.005	0.005	0.021	0.021	0.000	0.000		
1A2; Gaseous fuels	CO2	1'091.14	2'214.76	5	5	0.065	0.065	0.025	0.041	0.292	0.292	0.020	0.020	0.086	0.086		
1A2; Gaseous fuels	CH4	0.53	1.11	30	30	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		
1A2; Gaseous fuels	N2O	0.52	1.05	80	80	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.000		
1A2; Liquid fuels	CO2	3'974.32	1'551.89	1	1	0.001	0.001	0.031	0.029	0.028	0.028	0.003	0.003	0.001	0.001		
1A2; Liquid fuels	CH4	5.14	1.11	30	30	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.002	0.000	0.000		
1A2; Liquid fuels	N2O	11.87	9.04	80	80	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.000		
1A2; Other fuels	CO2	192.37	445.46	10	10	0.012	0.012	0.005	0.008	0.059	0.059	0.050	0.050	0.006	0.006		
1A2; Other fuels	CH4	0.87	0.71	30	30	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		
1A2; Other fuels	N2O	1.97	5.27	80	80	0.000	0.000	0.000	0.000	0.001	0.001	0.011	0.011	0.000	0.000		
1A2; Solid fuels	CO2	1'274.70	341.76	7	7	0.003	0.003	0.013	0.006	0.045	0.045	0.065	0.065	0.006	0.006		
1A2; Solid fuels	CH4	0.35	0.20	30	30	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		
1A2; Solid fuels	N2O	5.46	1.43	80	80	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.004	0.000	0.000		
1A3a; Kerosene fossil	CO2	252.55	59.01	1	1	0.000	0.000	0.003	0.001	0.001	0.001	0.000	0.000	0.000	0.000		
1A3a; Kerosene fossil	CH4	0.19	0.10	60	60	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		
1A3a; Kerosene fossil	N2O	1.83	0.43	90	191	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.002	0.000	0.000		
1A3b; Biomass	CH4	NO	0.64	60	60	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.000		
1A3b; Biomass	N2O	NO	5.13	91	191	0.000	0.001	0.000	0.000	0.001	0.001	0.009	0.009	0.000	0.000		
1A3b; Diesel oil	CO2	2'631.94	7'035.43	1	1	0.021	0.021	0.091	0.131	0.164	0.164	0.013	0.013	0.027	0.027		
1A3b; Diesel oil	CH4	2.56	6.66	20	20	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.002	0.000	0.000		
1A3b; Diesel oil	N2O	5.42	90.64	22	22	0.002	0.002	0.002	0.002	0.002	0.002	0.035	0.035	0.001	0.001		
1A3b; Gaseous fuels	CO2	NO	30.19	5	5	0.000	0.000	0.001	0.001	0.004	0.004	0.000	0.000	0.000	0.000		
1A3b; Gaseous fuels	CH4	NO	0.28	30	30	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		
1A3b; Gaseous fuels	N2O	NO	0.50	80	80	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.000		
1A3b; Gasoline	CO2	11'343.26	6'345.92	1	1	0.010	0.010	0.053	0.118	0.115	0.115	0.022	0.022	0.014	0.014		
1A3b; Gasoline	CH4	128.91	14.28	37	37	0.000	0.000	0.002	0.000	0.000	0.000	0.062	0.062	0.004	0.004		
1A3b; Gasoline	N2O	143.24	15.40	50	50	0.000	0.000	0.002	0.000	0.000	0.000	0.094	0.094	0.009	0.009		
1A3b; Liquefied petroleum gas	CO2	NO	1.38	10	10	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		
1A3b; Liquefied petroleum gas	CH4	NO	0.00	30	30	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		
1A3b; Liquefied petroleum gas	N2O	NO	0.01	80	80	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		
1A3c; Biomass	CH4	NO	0.00	60	60	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		
1A3c; Biomass	N2O	NO	0.01	91	191	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		
1A3c; Liquid fuels	CO2	28.69	27.86	1	1	0.000	0.000	0.000	0.001	0.001	0.001	0.000	0.000	0.000	0.000		
1A3c; Liquid fuels	CH4	0.03	0.01	30	30	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		
1A3c; Liquid fuels	N2O	0.38	0.36	80	80	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		
1A3d; Biomass	CH4	NO	0.01	60	60	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		
1A3d; Biomass	N2O	NO	0.03	91	191	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		
1A3d; Liquid fuels	CO2	114.27	110.02	1	1	0.000	0.000	0.000	0.002	0.002	0.002	0.000	0.000	0.000	0.000		
1A3d; Liquid fuels	CH4	1.88	0.35	30	30	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.000		
1A3d; Liquid fuels	N2O	1.03	1.06	90	191	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		
1A3e; Gaseous fuels	CO2	31.42	6.71	5	5	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.000	0.000	0.000		
1A3e; Gaseous fuels	CH4	0.08	0.01	30	30	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		
1A3e; Gaseous fuels	N2O	0.01	0.00	80	80	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		

Table A – 3 (continued)

A	B	C	D	G		H		I	J	K		L		M	
				Emissions 1990	Emissions 2021	Emission combined uncertainty 2021	Category contribution to inventory variance 2021			Sensitivity if corr. (type A)	Sensitivity if not corr. (type B)	Contribution to inventory trend uncertainty from AD	Contribution to inventory trend uncertainty from EF	Contribution to inventory trend uncertainty from EM	
Code	Gas			(-)%	(+)%	(-)%	(+)%			(-)%	(+)%	(-)%	(+)%	(-)%	(+)%
1A4a; Biomass	CH4	9.43	5.82	30	30	0.000	0.000	0.000	0.000	0.002	0.002	0.001	0.001	0.000	0.000
1A4a; Biomass	N2O	3.12	12.59	80	80	0.001	0.001	0.000	0.000	0.003	0.003	0.015	0.015	0.000	0.000
1A4a; Gaseous fuels	CO2	920.00	1'348.31	5	5	0.024	0.024	0.011	0.025	0.178	0.178	0.012	0.012	0.032	0.032
1A4a; Gaseous fuels	CH4	0.76	1.44	30	30	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1A4a; Gaseous fuels	N2O	0.43	0.64	80	80	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1A4a; Liquid fuels	CO2	3'918.47	2'328.39	1	1	0.001	0.001	0.016	0.043	0.042	0.042	0.001	0.001	0.002	0.002
1A4a; Liquid fuels	CH4	17.00	9.32	30	30	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.002	0.000	0.000
1A4a; Liquid fuels	N2O	8.46	5.06	80	80	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.003	0.000	0.000
1A4b; Biomass	CH4	103.81	25.54	30	30	0.000	0.000	0.001	0.000	0.007	0.007	0.031	0.031	0.001	0.001
1A4b; Biomass	N2O	22.99	21.22	80	80	0.002	0.002	0.000	0.000	0.006	0.006	0.004	0.004	0.000	0.000
1A4b; Gaseous fuels	CO2	1'450.97	2'967.52	5	5	0.118	0.118	0.033	0.055	0.392	0.392	0.027	0.027	0.154	0.154
1A4b; Gaseous fuels	CH4	0.78	1.72	30	30	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.000
1A4b; Gaseous fuels	N2O	0.69	1.41	80	80	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.000
1A4b; Liquid fuels	CO2	10'099.07	4'878.85	1	1	0.006	0.006	0.061	0.091	0.088	0.088	0.005	0.005	0.008	0.008
1A4b; Liquid fuels	CH4	39.01	18.66	30	30	0.000	0.000	0.000	0.000	0.000	0.000	0.007	0.007	0.000	0.000
1A4b; Liquid fuels	N2O	21.81	10.56	80	80	0.000	0.000	0.000	0.000	0.000	0.000	0.011	0.011	0.000	0.000
1A4b; Solid fuels	CO2	58.40	9.27	7	7	0.000	0.000	0.001	0.000	0.001	0.001	0.004	0.004	0.000	0.000
1A4b; Solid fuels	CH4	5.29	0.84	30	30	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.002	0.000	0.000
1A4b; Solid fuels	N2O	0.25	0.04	80	80	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1A4c; Biomass	CH4	1.24	1.41	30	30	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1A4c; Biomass	N2O	0.46	1.43	80	80	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.002	0.000	0.000
1A4c; Gaseous fuels	CO2	70.06	128.70	5	5	0.000	0.000	0.001	0.002	0.017	0.017	0.001	0.001	0.000	0.000
1A4c; Gaseous fuels	CH4	0.03	0.06	30	30	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1A4c; Gaseous fuels	N2O	0.03	0.06	80	80	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1A4c; Liquid fuels	CO2	742.30	452.86	1	1	0.000	0.000	0.003	0.008	0.008	0.008	0.000	0.000	0.000	0.000
1A4c; Liquid fuels	CH4	7.52	1.27	30	30	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.003	0.000	0.000
1A4c; Liquid fuels	N2O	4.29	4.03	80	80	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.000
1A5; Biomass	CH4	NO	0.00	60	60	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1A5; Biomass	N2O	NO	0.01	91	191	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1A5; Liquid fuels	CO2	217.65	113.69	1	1	0.000	0.000	0.001	0.002	0.002	0.002	0.000	0.000	0.000	0.000
1A5; Liquid fuels	CH4	0.13	0.04	30	30	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1A5; Liquid fuels	N2O	1.64	0.89	90	191	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.000	0.000
1B; All fuels	Indirect CO2 from CH4	36.90	20.58	30	30	0.000	0.000	0.000	0.000	d.EM	d.EM	d.EM	d.EM	0.000	0.000
1B; All fuels	Indirect CO2 from NMVOC	36.96	6.12	22	22	0.000	0.000	0.000	0.000	d.EM	d.EM	d.EM	d.EM	0.000	0.000
1B2a; All fuels	CH4	3.94	0.46	30	30	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.002	0.000	0.000
1B2b; All fuels	CO2	0.38	0.18	10	10	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1B2b; All fuels	CH4	371.76	209.12	30	30	0.021	0.021	0.002	0.004	0.028	0.028	0.051	0.051	0.003	0.003
1B2c; All fuels	CO2	25.96	19.40	10	10	0.000	0.000	0.000	0.000	0.003	0.003	0.000	0.000	0.000	0.000
1B2c; All fuels	CH4	0.38	0.00	30	30	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1B2c; All fuels	N2O	0.02	0.00	80	80	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2A	Indirect CO2 from CO	0.04	0.02	95	303	0.000	0.000	0.000	0.000	d.EM	d.EM	d.EM	d.EM	0.000	0.000
2A	Indirect CO2 from NMVOC	0.10	0.07	96	243	0.000	0.000	0.000	0.000	d.EM	d.EM	d.EM	d.EM	0.000	0.000
2A1	CO2	2'580.79	1'732.24	4	4	0.032	0.032	0.007	0.032	0.091	0.091	0.027	0.027	0.009	0.009
2A2	CO2	53.35	52.69	3	3	0.000	0.000	0.000	0.001	0.003	0.003	0.003	0.003	0.000	0.000
2A3	CO2	15.25	4.88	4	4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2A4	CO2	160.16	67.73	3	3	0.000	0.000	0.001	0.001	0.004	0.004	0.004	0.004	0.000	0.000
2B	Indirect CO2 from CH4	0.39	0.67	20	20	0.000	0.000	0.000	0.000	d.EM	d.EM	d.EM	d.EM	0.000	0.000
2B	Indirect CO2 from CO	6.33	6.08	38	38	0.000	0.000	0.000	0.000	d.EM	d.EM	d.EM	d.EM	0.000	0.000
2B	Indirect CO2 from NMVOC	1.29	0.00	40	40	0.000	0.000	0.000	0.000	d.EM	d.EM	d.EM	d.EM	0.000	0.000
2B2	N2O	58.24	NO	NO	NO	NO	NO	NO	0.001	0.000	0.000	0.000	0.000	0.000	0.000
2B5	CO2	15.36	17.38	10	10	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.001	0.000	0.000
2B5	CH4	3.88	6.85	20	20	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.000
2B8	CO2	94.08	116.37	10	10	0.001	0.001	0.001	0.002	0.006	0.006	0.031	0.031	0.001	0.001
2B10	CO2	17.34	17.33	60	60	0.001	0.001	0.000	0.000	0.001	0.001	0.004	0.004	0.000	0.000
2B10	CH4	0.10	NO	NO	NO	NO	NO	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2B10	N2O	384.50	389.00	60	60	0.290	0.290	0.001	0.007	0.021	0.021	0.616	0.616	0.380	0.380
2C	Indirect CO2 from CO	1.10	0.14	97	262	0.000	0.000	0.000	0.000	d.EM	d.EM	d.EM	d.EM	0.000	0.000
2C	Indirect CO2 from NMVOC	2.25	0.29	72	112	0.000	0.000	0.000	0.000	d.EM	d.EM	d.EM	d.EM	0.000	0.000
2C1	CO2	11.91	7.29	50	50	0.000	0.000	0.000	0.000	0.000	0.000	0.010	0.010	0.000	0.000
2C3	CO2	139.26	NO	NO	NO	NO	NO	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2C3	PFCs	104.71	NO	NO	NO	NO	NO	0.002	0.000	d.EM	d.EM	d.EM	d.EM	0.000	0.000
2C7	CO2	NO	1.48	20	20	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.000
2D	Indirect CO2 from CO	0.00	0.00	98	272	0.000	0.000	0.000	0.000	d.EM	d.EM	d.EM	d.EM	0.000	0.000
2D	Indirect CO2 from NMVOC	194.04	35.44	36	36	0.001	0.001	0.002	0.001	d.EM	d.EM	d.EM	d.EM	0.001	0.001
2D1	CO2	48.24	25.34	54	54	0.001	0.001	0.000	0.000	0.005	0.005	0.013	0.013	0.000	0.000
2D2	CO2	6.32	2.29	73	120	0.000	0.000	0.000	0.000	0.001	0.001	0.004	0.006	0.000	0.000
2D3	CO2	3.65	25.07	22	22	0.000	0.000	0.000	0.000	0.007	0.007	0.013	0.013	0.000	0.000
2E1	PFCs	NO	4.33	62	62	0.000	0.000	0.000	0.000	d.EM	d.EM	d.EM	d.EM	0.000	0.000
2E1	Sf6	NO	3.59	59	59	0.000	0.000	0.000	0.000	d.EM	d.EM	d.EM	d.EM	0.000	0.000
2E3	NF3	NO	0.37	76	131	0.000	0.000	0.000	0.000	d.EM	d.EM	d.EM	d.EM	0.000	0.000
2E5	PFCs	NO	0.00	44	44	0.000	0.000	0.000	0.000	d.EM	d.EM	d.EM	d.EM	0.000	0.000
2F1	HFCs	0.02	1'195.16	19	19	0.281	0.281	0.022	0.022	d.EM	d.EM	d.EM	d.EM	0.369	0.369
2F1	PFCs	0.05	1.48	43	43	0.000	0.000	0.000	0.000	d.EM	d.EM	d.EM	d.EM	0.000	0.000
2F2	HFCs	NO	22.62	88	179	0.002	0.009	0.000	0.000	d.EM	d.EM	d.EM	d.EM	0.003	0.011
2F4	HFCs	NO	5.93	41	41	0.000	0.000	0.000	0.000	d.EM	d.EM	d.EM	d.EM	0.000	0.000
2F5	HFCs	NO	0.02	53	53	0.000	0.000	0.000	0.000	d.EM	d.EM	d.EM	d.EM	0.000	0.000
2G	HFCs	NO	17.75	20	20	0.000	0.000	0.000	0.000	d.EM	d.EM	d.EM	d.EM	0.000	0.000
2G	PFCs	NO	22.55	12	12	0.000	0.000	0.000	0.000	d.EM	d.EM	d.EM	d.EM	0.000	0.000
2G	Sf6	141.21	125.44	41	41	0.014									

Table A – 3 (continued)

A Code	B Gas	C Emissions 1990	D Emissions 2021	G Emission combined uncertainty 2021		H Category contribution to inventory variance 2021		I Sensitivi- ty if corr. (type A)	J Sensitivi- ty if not corr. (type B)	K Contribution to inventory trend uncertainty from AD		L Contribution to inventory trend uncertainty from EF		M Contribution to inventory trend uncertainty from EM			
				(-)%	(+)%	(-)%	(+)%			(-)%	(+)%	(-)%	(+)%	(-)%	(+)%	(-)%	(+)%
2H3	CO2	1.04	0.24	73	119	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.000		
3A	CH4	3'930.28	3'630.57	19	21	2.540	2.998	0.008	0.068	0.619	0.619	1.716	1.883	3.329	3.929		
3B1-4	CH4	776.12	617.96	55	55	0.614	0.614	0.000	0.012	0.105	0.105	0.891	0.891	0.804	0.804		
3B1-4	N2O	168.15	107.49	62	84	0.023	0.043	0.001	0.002	0.068	0.068	0.162	0.229	0.031	0.057		
3B5	N2O	208.60	232.26	78	110	0.173	0.349	0.001	0.004	0.284	0.371	0.074	0.109	0.086	0.149		
3Da	N2O	1'073.36	855.84	63	91	1.545	3.255	0.000	0.016	0.302	0.302	1.390	2.043	2.025	4.266		
3Db	N2O	595.71	407.55	58	77	0.301	0.520	0.001	0.008	0.294	0.340	0.555	0.752	0.394	0.681		
3G	CO2	22.25	32.79	40	40	0.001	0.001	0.000	0.001	0.035	0.035	0.001	0.001	0.001	0.001		
3H	CO2	26.66	13.26	7	7	0.000	0.000	0.000	0.000	0.002	0.002	0.001	0.001	0.000	0.000		
4A1	CO2	-1'113.28	-2'331.86	47	47	6.307	6.307	0.027	0.044	0.029	0.029	1.247	1.247	1.556	1.556		
4A2	CO2	-539.55	-627.89	47	47	0.458	0.458	0.004	0.012	0.005	0.005	0.167	0.167	0.028	0.028		
4B1	CO2	398.23	190.69	128	128	0.319	0.319	0.002	0.004	d.EM	d.EM	d.EM	d.EM	0.418	0.418		
4B2	CO2	32.71	30.60	153	153	0.012	0.012	0.000	0.001	d.EM	d.EM	d.EM	d.EM	0.015	0.015		
4C1	CO2	16.87	167.78	734	734	8.066	8.066	0.003	0.003	d.EM	d.EM	d.EM	d.EM	10.571	10.571		
4C2	CO2	94.91	263.91	36	36	0.048	0.048	0.003	0.005	d.EM	d.EM	d.EM	d.EM	0.063	0.063		
4D1	CO2	67.77	66.20	116	116	0.031	0.031	0.000	0.001	0.019	0.019	0.015	0.015	0.001	0.001		
4D2	CO2	20.81	46.99	20	20	0.000	0.000	0.001	0.001	d.EM	d.EM	d.EM	d.EM	0.001	0.001		
4E1	CO2	-44.85	-47.79	50	50	0.003	0.003	0.000	0.001	0.001	0.001	0.011	0.011	0.000	0.000		
4E2	CO2	258.24	213.21	50	50	0.061	0.061	0.000	0.004	0.000	0.000	0.004	0.004	0.000	0.000		
4F2	CO2	87.83	130.33	50	50	0.023	0.023	0.001	0.002	0.003	0.003	0.055	0.055	0.003	0.003		
4G	CO2	-1'127.21	-39.24	56	56	0.003	0.003	0.016	0.001	0.183	0.183	0.893	0.893	0.831	0.831		
4H	CH4	11.20	11.20	71	71	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.003	0.000	0.000		
4I	N2O	2.62	2.61	83	83	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.000		
4I	N2O	32.55	37.75	124	217	0.012	0.036	0.000	0.001	0.018	0.018	0.019	0.043	0.001	0.002		
4IV	N2O	7.38	7.41	128	249	0.000	0.002	0.000	0.000	0.002	0.002	0.003	0.006	0.000	0.000		
4V	CH4	20.54	2.33	76	76	0.000	0.000	0.000	0.000	0.008	0.008	0.019	0.019	0.000	0.000		
4V	N2O	9.43	0.68	76	76	0.000	0.000	0.000	0.000	0.004	0.004	0.009	0.009	0.000	0.000		
5A	CH4	862.11	289.42	30	30	0.040	0.040	0.008	0.005	d.EM	d.EM	d.EM	d.EM	0.052	0.052		
5B	CH4	13.32	32.02	42	42	0.001	0.001	0.000	0.001	0.025	0.025	0.012	0.012	0.001	0.001		
5B	N2O	4.65	8.61	42	42	0.000	0.000	0.000	0.000	0.007	0.007	0.003	0.003	0.000	0.000		
5C	CO2	40.23	8.68	40	40	0.000	0.000	0.000	0.000	0.007	0.007	0.012	0.012	0.000	0.000		
5C	CH4	9.96	5.25	60	60	0.000	0.000	0.000	0.000	0.007	0.007	0.002	0.002	0.000	0.000		
5C	N2O	64.53	48.47	94	189	0.011	0.045	0.000	0.001	0.038	0.038	0.006	0.013	0.002	0.002		
5C	Indirect CO2 from CH4	0.26	0.13	50	68	0.000	0.000	0.000	0.000	d.EM	d.EM	d.EM	d.EM	0.000	0.000		
5C	Indirect CO2 from CO	1.32	0.63	58	77	0.000	0.000	0.000	0.000	d.EM	d.EM	d.EM	d.EM	0.000	0.000		
5C	Indirect CO2 from NMVOC	0.58	0.28	57	79	0.000	0.000	0.000	0.000	d.EM	d.EM	d.EM	d.EM	0.000	0.000		
5D	CH4	209.10	217.00	73	119	0.132	0.356	0.001	0.004	d.EM	d.EM	d.EM	d.EM	0.174	0.466		
5D	N2O	1'074.44	532.68	43	106	0.277	1.681	0.006	0.010	d.EM	d.EM	d.EM	d.EM	0.363	2.203		
5E	Indirect CO2 from CO	0.00	0.00	28	28	0.000	0.000	0.000	0.000	d.EM	d.EM	d.EM	d.EM	0.000	0.000		
5E	Indirect CO2 from NMVOC	0.06	0.13	31	31	0.000	0.000	0.000	0.000	d.EM	d.EM	d.EM	d.EM	0.000	0.000		
6A	CO2	11.21	13.05	40	40	0.000	0.000	0.000	0.000	0.007	0.007	0.003	0.003	0.000	0.000		
6A	CH4	0.76	0.78	60	60	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		
6A	N2O	0.54	0.52	150	150	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		
6A	Indirect CO2 from CH4	0.05	0.06	50	67	0.000	0.000	0.000	0.000	d.EM	d.EM	d.EM	d.EM	0.000	0.000		
6A	Indirect CO2 from CO	0.87	0.98	58	83	0.000	0.000	0.000	0.000	d.EM	d.EM	d.EM	d.EM	0.000	0.000		
6A	Indirect CO2 from NMVOC	0.20	0.22	46	60	0.000	0.000	0.000	0.000	d.EM	d.EM	d.EM	d.EM	0.000	0.000		
Total						22.9	27.2							22.1	27.5		
Total		53'581.2	43'373.5	Emissions 2021 uncertainty (%):		4.8	5.2			Trend uncertainty (%):				4.7	5.2		

## A2.3 Detailed results of approach 2 uncertainty analysis

Table A – 4 Uncertainty analysis of greenhouse gas emissions and removals, approach 2, for 2021 and for the trend 1990–2021, including LULUCF categories and indirect CO<sub>2</sub> emissions. d.EM stands for direct emission and indicates that input uncertainties are given for the emission but neither for the activity data nor for the emission factor. Monte Carlo simulations were run 1'000'000 times. The reported uncertainties correspond to the borders of the narrowest 95 % confidence interval. Contributions to inventory trend (mean, uncertainties, columns I and J) are values normalised by the total inventory base year emission. Columns A to J are labelled according to Table 3-3 in the 2006 IPCC Guidelines, vol.1, chp. 3 (IPCC 2006).

IPCC category; fuel/source	Gas	Emissions		Activity data uncertainty 2021		Emission factor uncertainty 2021		Emission combined uncertainty 2021		Emission contribution to variance 2021	Contribution to trend	Contribution to uncertainty of trend	
		1990	2021	(-)%	(+)%	(-)%	(+)%	(-)%	(+)%	Fraction	%	(-)%	(+)%
		kt CO <sub>2</sub> eq.	kt CO <sub>2</sub> eq.										
1A1; Biomass	CH4	0.45	0.16	10	10	28	28	29	30	0.000	-0.001	0.000	0.000
1A1; Biomass	N2O	20.08	12.82	10	10	77	78	79	78	0.000	-0.014	0.012	0.011
1A1; Gaseous fuels	CO2	243.40	514.77	5	5	0	0	5	5	0.000	0.507	0.057	0.058
1A1; Gaseous fuels	CH4	0.12	0.26	5	5	29	29	30	29	0.000	0.000	0.000	0.000
1A1; Gaseous fuels	N2O	0.11	0.24	5	5	77	79	79	78	0.000	0.000	0.000	0.000
1A1; Liquid fuels	CO2	685.81	275.92	1	1	0	0	1	1	0.000	-0.765	0.035	0.035
1A1; Liquid fuels	CH4	0.58	0.17	1	1	30	29	29	29	0.000	-0.001	0.000	0.000
1A1; Liquid fuels	N2O	0.98	0.20	1	1	78	79	78	79	0.000	-0.001	0.001	0.001
1A1; Other fuels	CO2	1'491.55	2'409.22	5	5	16	17	17	17	0.039	1.713	0.382	0.390
1A1; Other fuels	N2O	21.63	7.26	5	5	78	78	79	79	0.000	-0.027	0.033	0.034
1A1; Solid fuels	CO2	49.13	NO	NO	NO	NO	NO	NO	NO	NO	-0.092	0.008	0.008
1A1; Solid fuels	CH4	0.15	NO	NO	NO	NO	NO	NO	NO	NO	0.000	0.000	0.000
1A1; Solid fuels	N2O	0.21	NO	NO	NO	NO	NO	NO	NO	NO	0.000	0.000	0.000
1A2; Biomass	CH4	4.16	2.41	10	10	28	28	29	29	0.000	-0.003	0.001	0.001
1A2; Biomass	N2O	4.71	17.72	10	10	77	78	78	79	0.000	0.024	0.019	0.019
1A2; Gaseous fuels	CO2	1'091.14	2'214.76	5	5	0	0	5	5	0.003	2.098	0.248	0.247
1A2; Gaseous fuels	CH4	0.53	1.11	5	5	29	29	30	29	0.000	0.001	0.000	0.000
1A2; Gaseous fuels	N2O	0.52	1.05	5	5	78	79	79	79	0.000	0.001	0.001	0.001
1A2; Liquid fuels	CO2	3'974.32	1'551.89	1	1	0	0	1	1	0.000	-4.523	0.207	0.208
1A2; Liquid fuels	CH4	5.14	1.11	1	1	29	29	29	29	0.000	-0.008	0.002	0.002
1A2; Liquid fuels	N2O	11.87	9.04	1	1	78	79	78	79	0.000	-0.005	0.004	0.004
1A2; Other fuels	CO2	192.37	445.46	5	5	9	9	10	10	0.000	0.473	0.065	0.065
1A2; Other fuels	CH4	0.87	0.71	5	5	29	29	30	29	0.000	0.000	0.000	0.000
1A2; Other fuels	N2O	1.97	5.27	5	5	79	78	79	78	0.000	0.006	0.008	0.008
1A2; Solid fuels	CO2	1'274.70	341.76	5	5	5	5	7	7	0.000	-1.742	0.165	0.164
1A2; Solid fuels	CH4	0.35	0.20	5	5	29	29	30	29	0.000	0.000	0.000	0.000
1A2; Solid fuels	N2O	5.46	1.43	5	5	78	79	79	78	0.000	-0.008	0.006	0.006
1A3a; Kerosene fossil	CO2	252.55	59.01	1	1	0	0	1	1	0.000	-0.361	0.017	0.017
1A3a; Kerosene fossil	CH4	0.19	0.10	1	1	59	59	59	58	0.000	0.000	0.000	0.000
1A3a; Kerosene fossil	N2O	1.83	0.43	1	1	99	146	99	146	0.000	-0.003	0.004	0.003
1A3b; Biomass	CH4	NO	0.64	10	10	58	58	58	59	0.000	0.001	0.001	0.001
1A3b; Biomass	N2O	NO	5.13	10	10	99	147	99	147	0.000	0.010	0.009	0.014
1A3b; Diesel oil	CO2	2'631.94	7'035.43	1	1	0	0	1	1	0.001	8.222	0.387	0.384
1A3b; Diesel oil	CH4	2.56	6.66	1	1	20	20	20	20	0.000	0.008	0.002	0.002
1A3b; Diesel oil	N2O	5.42	90.64	1	1	22	22	21	22	0.000	0.159	0.035	0.035
1A3b; Gaseous fuels	CO2	NO	30.19	5	5	0	0	5	5	0.000	0.056	0.004	0.004
1A3b; Gaseous fuels	CH4	NO	0.28	5	5	29	29	29	29	0.000	0.001	0.000	0.000
1A3b; Gaseous fuels	N2O	NO	0.50	5	5	77	79	79	78	0.000	0.001	0.001	0.001
1A3b; Gasoline	CO2	11'343.26	6'345.92	1	1	0	0	1	1	0.000	-9.331	0.438	0.445
1A3b; Gasoline	CH4	128.91	14.28	1	1	36	37	36	36	0.000	-0.214	0.079	0.077
1A3b; Gasoline	N2O	143.24	15.40	1	1	49	49	49	49	0.000	-0.239	0.116	0.118
1A3b; Liquefied petroleum gas	CO2	NO	1.38	1	1	10	10	10	10	0.000	0.003	0.000	0.000
1A3b; Liquefied petroleum gas	CH4	NO	0.00	1	1	29	29	30	29	0.000	0.000	0.000	0.000
1A3b; Liquefied petroleum gas	N2O	NO	0.01	1	1	78	79	79	78	0.000	0.000	0.000	0.000
1A3c; Biomass	CH4	NO	0.00	10	10	57	58	59	59	0.000	0.000	0.000	0.000
1A3c; Biomass	N2O	NO	0.01	10	10	99	147	99	147	0.000	0.000	0.000	0.000
1A3c; Liquid fuels	CO2	28.69	27.86	1	1	0	0	1	1	0.000	-0.002	0.001	0.001
1A3c; Liquid fuels	CH4	0.03	0.01	1	1	29	30	29	29	0.000	0.000	0.000	0.000
1A3c; Liquid fuels	N2O	0.38	0.36	1	1	78	79	78	79	0.000	0.000	0.000	0.000
1A3d; Biomass	CH4	NO	0.01	10	10	58	58	59	59	0.000	0.000	0.000	0.000
1A3d; Biomass	N2O	NO	0.03	10	10	99	147	99	147	0.000	0.000	0.000	0.000
1A3d; Liquid fuels	CO2	114.27	110.02	1	1	0	0	1	1	0.000	-0.008	0.002	0.002
1A3d; Liquid fuels	CH4	1.88	0.35	1	1	29	29	29	29	0.000	-0.003	0.001	0.001
1A3d; Liquid fuels	N2O	1.03	1.06	1	1	99	147	99	147	0.000	0.000	0.000	0.000
1A3e; Gaseous fuels	CO2	31.42	6.71	5	5	0	0	5	5	0.000	-0.046	0.004	0.004
1A3e; Gaseous fuels	CH4	0.08	0.01	5	5	29	29	29	30	0.000	0.000	0.000	0.000
1A3e; Gaseous fuels	N2O	0.01	0.00	5	5	78	78	79	78	0.000	0.000	0.000	0.000

Table A – 4 (continued)

IPCC category; fuel/source	Gas	Emissions		Activity data uncertainty 2021				Emission factor uncertainty 2021		Emission combined uncertainty 2021		Emission contribution to variance 2021	Contribution to trend	Contribution to uncertainty of trend	
		1990	2021	(-)%	(+)%	(-)%	(+)%	(-)%	(+)%	(-)%	(+)%	Fraction	%	(-)%	(+)%
		kt CO <sub>2</sub> eq.	kt CO <sub>2</sub> eq.												
1A4a; Biomass	CH <sub>4</sub>	9.43	5.82	10	10	28	28	29	29	0.000	-0.007	0.003	0.003		
1A4a; Biomass	N <sub>2</sub> O	3.12	12.59	10	10	77	79	79	79	0.000	0.018	0.014	0.014		
1A4a; Gaseous fuels	CO <sub>2</sub>	920.00	1'348.31	5	5	0	0	5	5	0.001	0.800	0.154	0.158		
1A4a; Gaseous fuels	CH <sub>4</sub>	0.76	1.44	5	5	29	29	29	29	0.000	0.001	0.000	0.000		
1A4a; Gaseous fuels	N <sub>2</sub> O	0.43	0.64	5	5	78	78	78	79	0.000	0.000	0.000	0.000		
1A4a; Liquid fuels	CO <sub>2</sub>	3'918.47	2'328.39	1	1	0	0	1	1	0.000	-2.969	0.144	0.142		
1A4a; Liquid fuels	CH <sub>4</sub>	17.00	9.32	1	1	29	29	30	29	0.000	-0.014	0.004	0.004		
1A4a; Liquid fuels	N <sub>2</sub> O	8.46	5.06	1	1	79	78	79	78	0.000	-0.006	0.005	0.005		
1A4b; Biomass	CH <sub>4</sub>	103.81	25.54	10	10	28	28	29	30	0.000	-0.146	0.046	0.045		
1A4b; Biomass	N <sub>2</sub> O	22.99	21.22	10	10	78	77	78	79	0.000	-0.003	0.007	0.006		
1A4b; Gaseous fuels	CO <sub>2</sub>	1'450.97	2'967.52	5	5	0	0	5	5	0.005	2.832	0.331	0.333		
1A4b; Gaseous fuels	CH <sub>4</sub>	0.78	1.72	5	5	29	29	29	29	0.000	0.002	0.001	0.001		
1A4b; Gaseous fuels	N <sub>2</sub> O	0.69	1.41	5	5	78	78	78	79	0.000	0.001	0.001	0.001		
1A4b; Liquid fuels	CO <sub>2</sub>	10'099.07	4'878.85	1	1	0	0	1	1	0.000	-9.747	0.452	0.452		
1A4b; Liquid fuels	CH <sub>4</sub>	39.01	18.66	1	1	29	29	29	29	0.000	-0.038	0.011	0.011		
1A4b; Liquid fuels	N <sub>2</sub> O	21.81	10.56	1	1	78	78	78	78	0.000	-0.021	0.017	0.016		
1A4b; Solid fuels	CO <sub>2</sub>	58.40	9.27	5	5	5	5	7	7	0.000	-0.092	0.008	0.008		
1A4b; Solid fuels	CH <sub>4</sub>	5.29	0.84	5	5	29	29	30	29	0.000	-0.008	0.003	0.002		
1A4b; Solid fuels	N <sub>2</sub> O	0.25	0.04	5	5	79	78	78	79	0.000	0.000	0.000	0.000		
1A4c; Biomass	CH <sub>4</sub>	1.24	1.41	10	10	28	28	29	29	0.000	0.000	0.000	0.000		
1A4c; Biomass	N <sub>2</sub> O	0.46	1.43	10	10	77	78	79	78	0.000	0.002	0.001	0.001		
1A4c; Gaseous fuels	CO <sub>2</sub>	70.06	128.70	5	5	0	0	5	5	0.000	0.109	0.014	0.014		
1A4c; Gaseous fuels	CH <sub>4</sub>	0.03	0.06	5	5	29	29	30	29	0.000	0.000	0.000	0.000		
1A4c; Gaseous fuels	N <sub>2</sub> O	0.03	0.06	5	5	79	78	78	79	0.000	0.000	0.000	0.000		
1A4c; Liquid fuels	CO <sub>2</sub>	742.30	452.86	1	1	0	0	1	1	0.000	-0.540	0.027	0.026		
1A4c; Liquid fuels	CH <sub>4</sub>	7.52	1.27	1	1	29	29	29	29	0.000	-0.012	0.003	0.003		
1A4c; Liquid fuels	N <sub>2</sub> O	4.29	4.03	1	1	79	78	78	79	0.000	0.000	0.000	0.000		
1A5; Biomass	CH <sub>4</sub>	NO	0.00	10	10	58	58	59	59	0.000	0.000	0.000	0.000		
1A5; Biomass	N <sub>2</sub> O	NO	0.01	10	10	99	146	99	147	0.000	0.000	0.000	0.000		
1A5; Liquid fuels	CO <sub>2</sub>	217.65	113.69	1	1	0	0	1	1	0.000	-0.194	0.009	0.009		
1A5; Liquid fuels	CH <sub>4</sub>	0.13	0.04	1	1	29	29	30	29	0.000	0.000	0.000	0.000		
1A5; Liquid fuels	N <sub>2</sub> O	1.64	0.89	1	1	99	147	99	147	0.000	-0.001	0.002	0.001		
1B; All fuels	Indirect CO <sub>2</sub> from CH <sub>4</sub>	36.90	20.58	d.EM	d.EM	d.EM	d.EM	29	29	0.000	-0.030	0.023	0.023		
1B; All fuels	Indirect CO <sub>2</sub> from NMVOC	36.96	6.12	d.EM	d.EM	d.EM	d.EM	22	22	0.000	-0.058	0.016	0.016		
1B2a; All fuels	CH <sub>4</sub>	3.94	0.46	5	5	29	29	30	29	0.000	-0.007	0.002	0.002		
1B2b; All fuels	CO <sub>2</sub>	0.38	0.18	5	5	9	8	10	10	0.000	0.000	0.000	0.000		
1B2b; All fuels	CH <sub>4</sub>	371.76	209.12	5	5	29	29	29	30	0.001	-0.304	0.099	0.095		
1B2c; All fuels	CO <sub>2</sub>	25.96	19.40	5	5	8	9	10	10	0.000	-0.012	0.003	0.003		
1B2c; All fuels	CH <sub>4</sub>	0.38	0.00	5	5	29	29	29	30	0.000	-0.001	0.000	0.000		
1B2c; All fuels	N <sub>2</sub> O	0.02	0.00	5	5	78	79	78	79	0.000	0.000	0.000	0.000		
2A	Indirect CO <sub>2</sub> from CO	0.04	0.02	d.EM	d.EM	d.EM	d.EM	100	176	0.000	0.000	0.000	0.000		
2A	Indirect CO <sub>2</sub> from NMVOC	0.10	0.07	d.EM	d.EM	d.EM	d.EM	100	187	0.000	0.000	0.000	0.000		
2A1	CO <sub>2</sub>	2'580.79	1'732.24	2	2	4	4	4	4	0.001	-1.584	0.146	0.144		
2A2	CO <sub>2</sub>	53.35	52.69	2	2	2	2	3	3	0.000	-0.001	0.004	0.004		
2A3	CO <sub>2</sub>	15.25	4.88	2	2	3	3	4	4	0.000	-0.019	0.001	0.001		
2A4	CO <sub>2</sub>	160.16	67.73	2	2	2	2	3	3	0.000	-0.173	0.012	0.012		
2B	Indirect CO <sub>2</sub> from CH <sub>4</sub>	0.39	0.67	d.EM	d.EM	d.EM	d.EM	19	20	0.000	0.001	0.000	0.000		
2B	Indirect CO <sub>2</sub> from CO	6.33	6.08	d.EM	d.EM	d.EM	d.EM	37	37	0.000	0.000	0.006	0.006		
2B	Indirect CO <sub>2</sub> from NMVOC	1.29	0.00	d.EM	d.EM	d.EM	d.EM	39	39	0.000	-0.002	0.001	0.001		
2B2	N <sub>2</sub> O	58.24	NO	NO	NO	NO	NO	NO	NO	NO	-0.109	0.064	0.064		
2B5	CO <sub>2</sub>	15.36	17.38	2	2	10	10	10	10	0.000	0.004	0.001	0.001		
2B5	CH <sub>4</sub>	3.88	6.85	2	2	20	20	20	20	0.000	0.006	0.002	0.002		
2B8	CO <sub>2</sub>	94.08	116.37	2	2	10	10	10	10	0.000	0.042	0.028	0.028		
2B10	CO <sub>2</sub>	17.34	17.33	2	2	59	59	59	59	0.000	0.000	0.001	0.001		
2B10	CH <sub>4</sub>	0.10	NO	NO	NO	NO	NO	NO	NO	NO	0.000	0.000	0.000		
2B10	N <sub>2</sub> O	384.50	389.00	2	2	58	59	58	59	0.012	0.009	0.605	0.598		
2C	Indirect CO <sub>2</sub> from CO	1.10	0.14	d.EM	d.EM	d.EM	d.EM	100	190	0.000	-0.002	0.004	0.003		
2C	Indirect CO <sub>2</sub> from NMVOC	2.25	0.29	d.EM	d.EM	d.EM	d.EM	82	98	0.000	-0.004	0.004	0.003		
2C1	CO <sub>2</sub>	11.91	7.29	2	2	49	49	49	49	0.000	-0.009	0.013	0.013		
2C3	CO <sub>2</sub>	139.26	NO	NO	NO	NO	NO	NO	NO	NO	-0.260	0.054	0.054		
2C3	PFCs	104.71	NO	d.EM	d.EM	d.EM	d.EM	NO	NO	NO	-0.196	0.019	0.019		
2C7	CO <sub>2</sub>	NO	1.48	2	2	20	20	20	20	0.000	0.003	0.001	0.001		
2D	Indirect CO <sub>2</sub> from CO	0.00	0.00	d.EM	d.EM	d.EM	d.EM	100	202	0.000	0.000	0.000	0.000		
2D	Indirect CO <sub>2</sub> from NMVOC	194.04	35.44	d.EM	d.EM	d.EM	d.EM	35	35	0.000	-0.296	0.144	0.146		
2D1	CO <sub>2</sub>	48.24	25.34	20	20	49	49	52	54	0.000	-0.043	0.023	0.022		
2D2	CO <sub>2</sub>	6.32	2.29	10	10	83	98	83	99	0.000	-0.008	0.007	0.006		
2D3	CO <sub>2</sub>	3.65	25.07	10	10	20	20	22	22	0.000	0.040	0.011	0.011		
2E1	PFCs	NO	4.33	d.EM	d.EM	d.EM	d.EM	61	61	0.000	0.008	0.005	0.005		
2E1	SF <sub>6</sub>	NO	3.59	d.EM	d.EM	d.EM	d.EM	58	58	0.000	0.007	0.004	0.004		
2E3	NF <sub>3</sub>	NO	0.37	d.EM	d.EM	d.EM	d.EM	86	107	0.000	0.001	0.001	0.001		
2E5	PFCs	NO	0.00	d.EM	d.EM	d.EM	d.EM	43	43	0.000	0.000	0.000	0.000		
2F1	HFCs	0.02	1'195.16	d.EM	d.EM	d.EM	d.EM	19	19	0.011	2.232	0.435	0.429		
2F1	PFCs	0.05	1.48	d.EM	d.EM	d.EM	d.EM	43	43	0.000	0.003	0.001	0.001		
2F2	HFCs	NO	22.62	d.EM	d.EM	d.EM	d.EM	98	138	0.000	0.042	0.041	0.058		
2F4	HFCs	NO	5.93	d.EM	d.EM	d.EM	d.EM	40	40	0.000	0.011	0.004	0.004		
2F5	HFCs	NO	0.02	d.EM	d.EM	d.EM	d.EM	52	51	0.000	0.000	0.000	0.000		
2G	HFCs	NO	17.75	d.EM	d.EM	d.EM	d.EM	19	19	0.000	0.033	0.007	0.007		
2G	PFCs	NO	22.55	d.EM	d.EM	d.EM	d.EM	12	12	0.000	0.042	0.005	0.005		
2G	SF <sub>6</sub>	141.21	125.44	d.EM	d.EM	d.EM	d.EM	41	40	0.001	-0.029	0.012	0.012		
2G	Indirect CO <sub>2</sub> from CO	0.01	0.01	d.EM	d.EM	d.EM	d.EM	100	303	0.000	0.000	0.000	0.000		
2G	Indirect CO <sub>2</sub> from NMVOC	125.50	40.06	d.EM	d.EM	d.EM	d.EM	70	81	0.000	-0.159	0.210	0.183		
2G3	N <sub>2</sub> O	92.49	28.12	1	1	78	78	79	78	0.000	-0.120	0.094	0.094		
2G4	CO <sub>2</sub>	6.07	31.76	10	10	20	20	22	22	0.000	0.048	0.011	0.012		
2G4	N <sub>2</sub> O	5.31	8.05	1	1	39	39	40	39	0.000	0.005	0.002	0.002		
2H	Indirect CO <sub>2</sub> from CO	1.27	0.30	d.EM	d.EM	d.EM	d.EM	100	199	0.000	-0.002	0.005	0.003		
2H	Indirect CO <sub>2</sub> from NMVOC	1.56	0.63	d.EM	d.EM	d.EM	d.EM	100	179	0.000	-0.002	0.006	0.005		

Table A – 4 (continued)

A IPCC category; fuel/source	B Gas	C		D		E		F		G		H	I	J	
		Emissions 1990	Emissions 2021	Activity data uncertainty 2021		Emission factor uncertainty 2021		Emission combined uncertainty 2021		Emission contri- bution to variance 2021	Contri- bution to trend	Contribution to uncertainty of trend			
		kt CO2 eq.	kt CO2 eq.	(-)%	(+)%	(-)%	(+)%	(-)%	(+)%	Fraction	%	(-)%	(+)%		
2H3	CO2	1.04	0.24	5	5	82	100	82	99	0.000	-0.001	0.001	0.001		
3A	CH4	3'930.28	3'630.57	6	6	19	19	19	20	0.116	-0.554	2.025	2.022		
3B1-4	CH4	776.12	617.96	6	6	54	53	54	54	0.025	-0.294	0.992	0.988		
3B1-4	N2O	168.15	107.49	23	24	63	71	66	75	0.001	-0.113	0.283	0.266		
3B5	N2O	208.60	232.26	50	54	69	79	79	99	0.011	0.044	0.344	0.357		
3Da	N2O	1'073.36	855.84	13	13	69	78	69	79	0.101	-0.398	2.135	2.030		
3Db	N2O	595.71	407.55	29	30	57	62	61	70	0.018	-0.350	0.953	0.906		
3G	CO2	22.25	32.79	39	39	5	5	40	39	0.000	0.020	0.029	0.029		
3H	CO2	26.66	13.26	5	5	5	5	7	7	0.000	-0.025	0.003	0.003		
4A1	CO2	-1'113.28	-2'331.86	1	1	46	46	45	46	0.256	-2.278	1.064	1.073		
4A2	CO2	-539.55	-627.89	2	2	46	46	46	46	0.019	-0.165	0.077	0.076		
4B1	CO2	398.23	190.69	d.EM	d.EM	d.EM	d.EM	125	127	0.013	-0.386	1.067	1.070		
4B2	CO2	32.71	30.60	d.EM	d.EM	d.EM	d.EM	149	150	0.000	-0.004	0.100	0.101		
4C1	CO2	16.87	167.78	d.EM	d.EM	d.EM	d.EM	724	720	0.327	0.294	3.268	3.260		
4C2	CO2	94.91	263.91	d.EM	d.EM	d.EM	d.EM	35	35	0.002	0.316	0.196	0.201		
4D1	CO2	67.77	66.20	89	90	71	71	104	123	0.001	-0.003	0.004	0.003		
4D2	CO2	20.81	46.99	d.EM	d.EM	d.EM	d.EM	20	20	0.000	0.049	0.020	0.020		
4E1	CO2	-44.85	-47.79	4	4	49	49	50	49	0.000	-0.005	0.003	0.003		
4E2	CO2	258.24	213.21	4	4	49	49	49	49	0.002	-0.084	0.042	0.041		
4F2	CO2	87.83	130.33	3	3	49	49	49	49	0.001	0.079	0.039	0.039		
4G	CO2	-1'127.21	-39.24	11	11	54	53	55	55	0.000	2.036	1.136	1.149		
4I1	CH4	11.20	11.20	10	10	69	68	69	70	0.000	0.000	0.000	0.000		
4I1	N2O	2.62	2.61	48	48	66	66	78	84	0.000	0.000	0.000	0.000		
4I11	N2O	32.55	37.75	82	82	100	153	104	195	0.001	0.010	0.010	0.019		
4IV	N2O	7.38	7.41	83	85	100	176	106	221	0.000	0.000	0.000	0.000		
4V	CH4	20.54	2.33	29	30	69	69	73	78	0.000	-0.034	0.026	0.025		
4V	N2O	9.43	0.68	29	30	69	68	73	77	0.000	-0.016	0.013	0.012		
5A	CH4	862.11	289.42	d.EM	d.EM	d.EM	d.EM	30	29	0.002	-1.069	0.312	0.314		
5B	CH4	13.32	32.02	29	29	29	29	40	43	0.000	0.035	0.021	0.022		
5B	N2O	4.65	8.61	29	29	29	30	40	43	0.000	0.007	0.006	0.006		
5C	CO2	40.23	8.68	29	29	26	26	38	40	0.000	-0.059	0.028	0.027		
5C	CH4	9.96	5.25	49	49	33	32	57	61	0.000	-0.009	0.011	0.011		
5C	N2O	64.53	48.47	30	29	99	144	99	148	0.001	-0.030	0.081	0.050		
5C	Indirect CO2 from CH4	0.26	0.13	d.EM	d.EM	d.EM	d.EM	55	60	0.000	0.000	0.000	0.000		
5C	Indirect CO2 from CO	1.32	0.63	d.EM	d.EM	d.EM	d.EM	64	71	0.000	-0.001	0.002	0.002		
5C	Indirect CO2 from NMVOC	0.58	0.28	d.EM	d.EM	d.EM	d.EM	63	72	0.000	-0.001	0.001	0.001		
5D	CH4	209.10	217.00	d.EM	d.EM	d.EM	d.EM	81	100	0.010	0.015	0.562	0.568		
5D	N2O	1'074.44	532.68	d.EM	d.EM	d.EM	d.EM	47	50	0.015	-1.004	1.861	1.621		
5E	Indirect CO2 from CO	0.00	0.00	d.EM	d.EM	d.EM	d.EM	28	28	0.000	0.000	0.000	0.000		
5E	Indirect CO2 from NMVOC	0.06	0.13	d.EM	d.EM	d.EM	d.EM	30	30	0.000	0.000	0.000	0.000		
6A	CO2	11.21	13.05	20	19	34	34	38	40	0.000	0.003	0.006	0.007		
6A	CH4	0.76	0.78	19	20	55	55	58	60	0.000	0.000	0.000	0.000		
6A	N2O	0.54	0.52	19	20	147	144	148	149	0.000	0.000	0.000	0.000		
6A	Indirect CO2 from CH4	0.05	0.06	d.EM	d.EM	d.EM	d.EM	55	60	0.000	0.000	0.000	0.000		
6A	Indirect CO2 from CO	0.87	0.98	d.EM	d.EM	d.EM	d.EM	65	73	0.000	0.000	0.002	0.002		
6A	Indirect CO2 from NMVOC	0.20	0.22	d.EM	d.EM	d.EM	d.EM	50	54	0.000	0.000	0.000	0.000		
Total, Monte Carlo simulations		53'581.9	43'372.9					4.8	4.9	1.0	-19.0	4.8	4.9		
Total, inventory		53'581.2	43'373.5								-19.1				

## Annex 3 Detailed description of the reference approach (including inputs to the reference approach such as the national energy balance) and the results of the comparison of national estimates of emissions with those obtained using the reference approach

### A3.1 National energy balance

The national energy balance is provided in Table A – 5. A detailed description of the reference approach and the results of the comparison is provided in chp. 3.2.1.

Table A – 5 Switzerland's energy balance 2021 (SFOE 2022) in TJ. Liechtenstein's consumption of liquid fuels is included in the numbers (see general remarks in annex A3.2 below on final Swiss energy consumption).

Tab.4 Energiebilanz der Schweiz für das Jahr 2021 (in TJ)  
Bilan énergétique de la Suisse pour 2021 (en TJ)

	Holzenergie	Kohle	Müll und Industrieabfälle	Roßöl	Erðþ-produkte	Gas	Wasserkraft	Kernbrennstoffe	Öbriqe erneuerbare Energien	Elektrizität	Fernwärme	Total	
	Energie du bois	Charbon	Ord. mén. et déchets ind.	Pétrole brut	Produits pétroliers	Gas	Energie hydraulique	Combustibles nucléaires	Autres énergies renouvelables	Bactricité	Chaleur à distance	(12)	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	
Inlandproduktion	(a) 50 750	–	59 930	–	–	–	1 422 200	–	41 610	–	–	294 490	Production indigène
+ Import	(b) 1 880	3 720	–	100 940	259 830	129 750	–	202 150	6 250	113 520	–	818 040	+ Importation
+ Export	(c) –90	–	–	–	–15 550	–	–	–	–	–104 830	–	–120 470	+ Exportation
+ Lageränderung <sup>1</sup>	(d) –	–20	–	600	23 050	–	–	–	–	–	–	23 630	+ Variation de stock <sup>1</sup>
= Bruttoverbrauch	(e) 52 540	3 700	59 930	101 540	267 330	129 750	1 422 200	202 150	47 860	8 690	–	1 015 690	= Consommation brute
+ Energieumwandlung:													+ Transformation d'énergie
- Wasserkraftwerke	(f) –	–	–	–	–	–	–1 422 200	–	–	142 200	–	0	- Centrales hydrauliques
- Kernkraftwerke	(g) –	–	–	–	–	–	–	–202 150	–	66 710	1 520	–133 920	- Centrales nucléaires
- konventionell-thermische Kraft-, Fernheiz- und Fernheizkraftwerke	(h) –3 630	–	–47 900	–	–420	–8 420	–	–	–	8 310	24 300	–27 760	- Centrales thermiques classiques, chauffage à distance, centrales chaleur-force
- Gaswerke	(i) –	–	–	–	–	0	–	–	–	–	–	0	- Usines à gaz
- Raffinerien	(j) –	–	–	–101 540	101 540	–	–	–	–	–	–	0	- Raffineries
- Diverse Erneuerbare	(k) –2 520	–	–	–	–	1 330	–	–	–14 760	13 950	–	–2 000	- Renouvelables divers
+ Eigenverbrauch des Energiesektors, Netzverluste, Verbrauch der Speicherungen	(l) –	–	–	–	–5 040	–380	–	–	–	–30 650	–2 730	–38 800	+ Consommation propre du secteur énergétique, pertes de réseaux, pompage d'accumulation
+ Nichtenergetischer Verbrauch	(m) –	–	–	–	–18 490	–	–	–	–	–	–	–18 490	+ Consommation non énergétique
= Endverbrauch	(n) 46 390	3 700	12 030	–	344 920	122 280	–	–	33 100	209 210	23 090	794 720	= Consommation finale
Haushalte	(o) 19 750	100	–	–	66 130	53 240	–	–	19 850	72 480	9 600	241 160	Ménages
Industrie	(p) 13 900	3 600	12 030	–	11 840	39 620	–	–	2 080	62 500	7 860	153 430	Industrie
Dienstleistungen	(q) 11 610	–	–	–	31 070	26 280	–	–	4 050	58 550	5 630	137 190	Services
Verkehr	(r) 0	–	–	–	233 210	660	–	–	6 570	12 200	–	252 640	Transport
Statistische Differenz inkl. Landwirtschaft	(s) 1 120	–	–	–	2 670	2 480	–	–	550	3 480	–	10 300	Différence statistique, y compris l'agriculture

<sup>1</sup> + Lagerabnahme  
– Lagerzunahme

<sup>1</sup> + diminution de stock  
– augmentation de stock

BFE, Schweizerische Gesamtenergies tati tik 2021 (Tab. 4)  
OFEN, Statistique globale suisse de l'énergie 2021 (Tabl. 4)

### A3.2 Differences between International Energy Agency (IEA) data and the reference approach

Reviewers have repeatedly asked for explanations of the apparent differences between the energy data held by the International Energy Agency (IEA) and the data reported in the Reference Approach. In order to clarify the pertaining issues, the reasons for the major differences are given below. Data for the year 2010 are used to illustrate the description, however, a recent comparison with data for 2016 produced similar results.

## General remarks

The net calorific values used by IEA differ from those used in the greenhouse gas inventory. In order to avoid differences caused by the conversion with different NCV, the comparison between IEA and the Reference Approach is made in kt.

Stock changes as reported by IEA are only including primary stocks (IEA 2005), while the reporting in the Reference Approach includes secondary and tertiary stocks. This results in a particularly large difference for gas oil, as retailers and end-consumers hold considerable amounts of heating fuel on stock. The IEA subsumes secondary and tertiary stock changes under statistical differences.

All data regarding liquid fuel consumption reported by the IEA includes fuel consumption in Liechtenstein (geographical coverage in IEA 2012). For reporting purposes under the UNFCCC, consumption of Liechtenstein is subtracted.

Data sources used for the comparison shown in Table A – 6 below are:

- Switzerland's greenhouse gas inventory 1990–2011, submission of 15. April 2013, CRF Table1.A(b), (FOEN 2013).
- Energy statistics of OECD countries (2012 Edition), (IEA 2012).

## Liquid fuels

The total amount of liquid fuel consumption as reported in the greenhouse gas inventory is 11'052 kt. There is a difference of 13 kt (0.1 %) between CRF and IEA. This difference is primarily caused by the different methodology used for aviation bunkers (see below).

## Crude oil

Crude oil in the reference approach contains additives, while IEA lists them separately (data in italics in Table A – 6. The difference between CRF and IEA is smaller than 0.1 % if the sum of additives, refinery feedstocks and crude oil is considered.

## Gasoline

The comparison is made for motor gasoline only. Aviation gasoline is included under aviation fuels. Gasoline reported by IEA includes gasoline used in Liechtenstein (LIE), which is subtracted for reporting under the UNFCCC. The difference between CRF and IEA is approximately 0.1 %, if the consumption of LIE is taken into account.

### **Aviation fuels**

The different aviation fuels are aggregated in the greenhouse gas inventory. For comparison of IEA and reference approach, all aviation fuels are summed up. The difference between IEA and reference approach if considering the apparent final consumption is 12 kt (approximately 1 % of imports). This difference is largely due to a different methodology used to estimate international bunker. Aviation bunkers have to be reported monthly to the IEA. As the tier 3 approach used for the greenhouse gas inventory is not available on a monthly basis, the international bunker fuel estimate of IEA consists of the total consumption at the two international airports in Zurich and Geneva, while all remaining fuel use is considered domestic. The reporting in the national greenhouse gas inventory is based on a much more detailed approach, where information on single flights is taken into account. Due to the different approach, the numbers are somewhat different. However, the order of magnitude is the same, and the information in the inventory is based on a higher-tier method and presumably more accurate.

### **Diesel oil and gas oil**

The IEA numbers include diesel oil and gas oil used in Liechtenstein. Furthermore, stock changes are reported differently in the CRF and by the IEA. Secondary and tertiary stock changes are subsumed under statistical differences by the IEA, while they are included in the stock change reported in the reference approach. If the statistical differences are taken into account, the difference in the apparent consumption is less than 0.1 %.

### **Residual fuel oil**

Data agree between IEA and greenhouse gas inventory. It seems as if there is a rounding error in the imported amounts, leading to an apparent difference of 1 kt. According to the foreign trade statistics, 33'693 t of residual fuel oil had been imported in 2010.

### **Bitumen**

Bitumen is a main feedstock in the greenhouse gas inventory. Data between IEA and the reference approach compare well. Again, small differences are likely due to the use of rounded values, leading to apparent differences of the order of 1–2 kt.

### **Petroleum coke**

There are considerable differences (26 kt) in the reported numbers for petroleum coke import. The reason for this apparent difference is that for IEA, all petroleum coke is reported together. In the greenhouse gas inventory submitted in 2013, however, only the petroleum coke used as a fuel was reported under petroleum coke, while calcined petroleum coke was reported together with "other oil" as feedstocks. This is largely a consequence of the treatment of fuels and feedstocks in the Swiss overall energy statistics (SFOE 2012).

### **Lubricants**

There are small differences between IEA and the reference approach, as the data reported to the IEA comprises a slightly different set of customs tariff headings for lubricants to the one used for the Swiss overall energy statistics. The substances not reported under lubricants in the reference approach are reported under other oil.

### **Liquefied petroleum gas**

The reporting of liquefied petroleum gas in the greenhouse gas inventory includes white spirit and lamp oil. As for petroleum coke, IEA numbers include fuels that are used as feedstocks, while in the reference approach, only liquefied petroleum gas, white spirit and lamp oil used as fuels are reported under liquefied petroleum gas. The difference in apparent consumption between IEA and the reference approach is 3 kt (0.03 % of total liquid fuel consumption).

### **Other oil products**

In the greenhouse gas inventory, all other oil products are reported together, while IEA has a finer degree of disaggregation. As already mentioned above, the share of petroleum coke that is used as a feedstock is reported under other oil in the greenhouse gas inventory. Therefore, the difference between IEA and the reference approach corresponds largely to the difference in apparent consumption of petroleum coke.

### **Solid fuels**

Solid fuels, mainly other bituminous coal and lignite, play only a minor role in Switzerland (246 kt) and are reported in good agreement.

### **Gaseous fuels**

In the greenhouse gas inventory, the amount of gas reported under 1B2b Fugitive emissions is subtracted from the total gas import as reported by IEA, as this gas is not used for energy purposes. Taking this into account the difference is of the order of 2 TJ.

Table A – 6 Comparison of the IEA energy statistic with the Reference Approach for the year 2010. Numbers in italics are fuels that are reported in a finer disaggregation in the IEA energy statistic than in the Reference Approach. Numbers in bold aggregate the data to the level of disaggregation used in the Reference Approach.

CRF vs. IEA (2010) Gg	Import		Export		Bunker		Stock change		Stat. Diff.	LIE	Consumption		
	IEA	CRF	IEA	CRF	IEA	CRF	IEA	CRF	IEA	CRF	IEA	CRF	
<b>Liquid Fuels</b>												<b>11'039</b>	<b>11'052</b>
<b>Sum</b>												<b>4'546</b>	<b>4'547</b>
Crude oil	4'488	4'546						1.0				4'488	4'547
Refinery feedstocks	3.0						1.0		2.0			6.0	
Additives/blending components	51						-1.0		2.0			52	
<b>Motor gasoline</b>	1'850	1'838					-9.0	-6.0	4.0	15		<b>1'830</b>	<b>1'832</b>
<b>Sum</b>												<b>0.0</b>	<b>12</b>
Aviation gasoline	7.0						-2.0		-1.0			4.0	
Kerosene type jet fuel	1'354	1'362			-1'367	-1'352		2.0	6.0			-7.0	12
Other kerosene	3.0											3.0	
<b>Gas/diesel oil</b>	3'510	3'485	-21	-39	-10	-11	38	1'072	1'020	27		<b>4'510</b>	<b>4'507</b>
<b>Fuel oil</b>	33	34	-323	-316			-17	-17	7.0			<b>-300</b>	<b>-299</b>
<b>White spirit &amp; SBP</b>	7.0								-1.0			<b>6.0</b>	
<b>Bitumen</b>	317	318	-2.0	-2.0								<b>315</b>	<b>316</b>
<b>Lubricants</b>	86	72	-38	-16					7.0			<b>55</b>	<b>56</b>
<b>Petroleum coke</b>	73	47										<b>73</b>	<b>47</b>
<b>Sum</b>												<b>10</b>	<b>34</b>
Naptha	1.0						5.0		-1.0			5.0	
Paraffin waxes	1.0											1.0	
Non-specified oil products / other oil	4.0	63		-23				-6.0				4.0	34
<b>Solid fuels</b>												<b>246</b>	<b>246</b>
Anthracite	7.0											7.0	
Other bituminous coal	123	152					36	32				159	184
Lignite	66	62					-4.0					62	62
Coke oven coke	18											18	
<b>Gaseous Fuels</b>												<b>126'014</b>	<b>126'016</b>
Natural gas (TJ, NCV)	126'014	125'627										126'014	125'627
Fugitive emissions (TJ, NCV)		389											389

### Additional information regarding reporting of waste-derived fuels

During the in-country review in 2016, the ERT identified that the apparent consumption of non-biomass fraction of waste in the CRF Table 1.A(b) was systematically smaller than the consumption reported to IEA. The difference stems from the assumptions made with regard to the fossil and renewable fractions. The SFOE, which is responsible for reporting to the IEA, allocates total wastes to 50 % fossil and 50 % renewable. For the greenhouse gas inventory, a more sophisticated method based on a detailed analysis of waste composition and measurements in the flue gas of waste incineration plants is used to estimate fossil and renewable fractions (see chp. 3.2.5.2.1).

## Annex 4 QA/QC plan

Since 2007, the National Inventory System (NIS) quality management system (QMS) is certified to comply with ISO 9001. The QMS has been audited annually and recertified according to the ISO 9001 requirements ever since. The latest audit according to ISO 9001:2015 was on 2<sup>nd</sup> June 2022 and the current certificate is valid until 2025 (Swiss Safety Center 2022).

Here we provide information on the quality assurance / quality control (QA/QC) plan for the Swiss Greenhouse gas inventory as required by UNFCCC (2019, paragraphs 34 and 35) and the IPCC Guidelines (IPCC 2006).

In the quality management system (QMS) for the Swiss greenhouse gas inventory, the QA/QC plan is represented in an internal quality manual as formerly required by the ISO 9001:2008 standard. It has been updated ever since, also under ISO 9001:2015 (FOEN 2023a). Here, all information and documents relevant to quality assurance (QA) and quality control (QC) are compiled (in German). The quality manual is reviewed annually and modified by the QA/QC officer where necessary. The process owner is reviewing the changes accordingly. The quality manual is made available via a SharePoint for all persons involved in the inventory preparation. It is available for the Expert Review Team upon request.

The quality manual (FOEN 2023a) provides information regarding:

- The scope and our quality policy and data quality objectives
- the management structure, institutional arrangements and responsibilities;
- a risk analysis, requirements, process flow charts, and results;
- scheduled time frame for the inventory preparation until submission and associated QA/QC activities including verification activities;
- archiving, internal and external audits, internal and external reviews;
- documents and a description of feedback loops allowing improvement;
- links to supporting documents and official inventory submission data.

As such the QMS is fit for purpose, in the sense that the following inventory principles are achieved:

- Timeliness
- Completeness
- Consistency (internal consistency as well as time series consistency)
- Comparability
- Accuracy
- Transparency
- Improvement

## **Annex 5 Other detailed methodological descriptions for individual source or sink categories**

### **A5.1 Sector Energy**

#### **A5.1.1 Civil aviation**

This paragraph contains further information on the emission modelling. More complete information is provided in FOCA (2006, 2006a, 2007–2022) and on request for reviewers by FOCA.

## Emission factors (1A3a)

Table A – 7 Aircraft cruise factors, used for cruise emission calculation (extract of list of 881 aircraft) GKL\_ICAO = ICAO seat categories. Mass emissions are given in kilograms or grams per nautical mile (NM).

Aircraft Cruise_Factors						
Aircraft_ICAO	GKL_ICAO	Cruise_D_Source	kg_fuel_NM	kg_NOx_NM	g_VOC_NM	g_CO_NM
AA1	0	P002FOCA	0.21	0.0098	1.79	61.7
AA5	0	P002FOCA	0.21	0.0098	1.79	61.7
AC11	0	P002FOCA	0.21	0.0098	1.79	61.7
AC14	0	P002FOCA	0.21	0.0098	1.79	61.7
AC50	0	P001FOCA	0.77	0.021	4.14	364.17
AC68	0	P001FOCA	0.77	0.0075	4.14	364.17
AC6T	1	FOCAINV95-03.2T	1.58	0.021	0.87	2.9
AC90	1	FOCAINV95-03.2T	1.58	0.021	0.87	2.9
AC95	1	FOCAINV95-03.2T	1.58	0.021	0.87	2.9
AEST	0	P001FOCA	0.77	0.021	4.14	364.17
AJET	0	FOCAEDBJ014	2.92	0.0146	8.53	63
ALO2	0	FOCAHeli	1.91	0.024	0.42	2.1
ALO3	0	FOCAHeli	1.91	0.024	0.42	2.1
AN12	0	AN26*2	5.36	0.0062	143	348
AN2	0	FOCA/91/DC3	0.82	0.0002	13.7	1000
AN22	6	FOCAINV95-03.2T*2	3.16	0.042	1.74	5.8
AN24	2	AN26	2.68	0.0031	71.7	174
AN26	1	500	2.68	0.0031	71.7	174
AN72	2	FOCAINV95-03.2J	6.4	0.1	0.83	10
AR7	0	P002FOCA	0.21	0.0098	1.79	61.7
AR7A	0	P002FOCA	0.21	0.0098	1.79	61.7
AS02	0	P002FOCA	0.21	0.0098	1.79	61.7
AS16	0	P002FOCA	0.21	0.0098	1.79	61.7
AS20	0	P002FOCA	0.21	0.0098	1.79	61.7
AS24	0	P002FOCA	0.21	0.0098	1.79	61.7
AS25	0	P002FOCA	0.21	0.0098	1.79	61.7
AS26	0	P002FOCA	0.21	0.0098	1.79	61.7
AS2T	0	FOCAEDBT758	0.95	0.005	1.8	12
AS30	0	FOCAHeli*2	3.82	0.048	0.82	4.2
AS32	1	FOCAHeli*2	3.82	0.048	0.82	4.2
AS33	0	FOCAHeli*2	3.82	0.048	0.82	4.2
AS35	0	FOCAHeli	1.91	0.024	0.42	2.1
AS50	0	FOCAHeli*2	3.82	0.048	0.82	4.2
AS55	0	FOCAHeli*2	3.82	0.048	0.82	4.2
AS65	0	FOCAHeli*2	3.82	0.048	0.82	4.2
ASK1	0	P002FOCA	0.21	0.0098	1.79	61.7
ASTA	0	FOCAINV95-03.B	3.016	0.046	0.3	2.8
ASTR	0	FOCAINV95-03.B	3.016	0.046	0.3	2.8
ASTRA	0	FOCAINV95-03.B	3.016	0.046	0.3	2.8
AT42	1	FOCAINV95-03.2T	1.58	0.021	0.87	2.9
AT43	1	500	1.6	0.013	0	15

### Activity data (1A3a)

LTO-cycle times (minutes). ICAO standard cycle times were originally designed for emissions certification, not for emissions modelling. Today, they do generally not match real world aircraft LTO operations. Swiss FOCA has therefore adjusted some of the ICAO standard cycle times for different aircraft categories. For jets, the mean time for taxi-in and taxi-out at Swiss airports has been determined 20 minutes instead of the standard 26 minutes (Aerocert 2012, FOCA 2007b, ZRH 2017).

Table A – 8 For jets, business jets, turboprops, piston engines and helicopters, the times in mode are shown and are based on ICAO, US EPA and Swiss FOCA data. "Type" is a classification variable. J = Jet, T = Turboprop, P = Piston, H = Helicopter, HP = Helicopter with Piston Engine, B = Business jet, SJ = Supersonic Jet, E = Electric Aircraft. The number in "Type" stands for the number of engines. For Jet Aircraft, the cycle times and associated thrust settings still lead to an overestimation of LTO emissions (FOCA 2007b).

LTO Cycle				
Type	Time_Take_Off	Time_Climbout	Time_Approach	Time_Taxi
1J	0.7	2.2	4	20
1T	0.5	2.5	4.5	13
1P	0.3	2.5	3	12
1H	0	3	5.5	5
2B	0.4	0.5	1.6	13
3B	0.4	0.5	1.6	13
2T	0.5	2.5	4.5	13
4T	0.5	2.5	4.5	13
2J	0.7	2.2	4	20
3J	0.7	2.2	4	20
4J	0.7	2.2	4	20
2P	0.3	2.5	3	12
3P	0.3	2.5	3	12
4P	0.3	2.5	3	12
2H	0	3	5.5	5
4SJ	1.2	2	2.3	20
3H	0	3	5.5	5
4H	0	3	5.5	5
4B	0.4	0.5	1.6	13
1HP	0	4	5.5	5
2HP	0	4	5.5	5
3HP	0	4	5.5	5
4HP	0	4	5.5	5
1B	0.4	0.5	1.6	13
1E	0.7	10	5	13
4E	0.3	10	5	13
6J	0.7	2.2	4	20

Table A – 9 Aircraft-Engine Combinations and associated codes for SWISS FOCA emissions database. (Extract from list of more than 40'000 individual aircraft)

Aircraft Engine Combinations							
Engine Name	Aircraft Name	Aircraft Registr.	No. Eng.	Code	Type	Aircr. ICAO	Source
V2527-A5	AIRBUS A320-232	ECHXA	2	J220	2J	A320	1IA003
CF34-3B1	BOMBARDIER CRJ200ER (CL-600-2B19)	ECHXM	2	J090	2J	CRJ2	1GE034
CFM56-3C1	BOEING 737-4K5	ECHXT	2	J022	2J	B734	1CM007
TPE331-11U-611G	FAIRCHILD (SWEARIN-GEN) SA227AC METR	ECHXY	2	T310	2T	SW4	FOI
CFM56-5B4/P	AIRBUS A320-214	ECHYC	2	J067	2J	A320	3CM026
CFM56-5B4/P	AIRBUS A320-214	ECHYD	2	J067	2J	A320	3CM026
CF34-3B1	BOMBARDIER CRJ200ER (CL-600-2B19)	ECHYG	2	J090	2J	CRJ2	1GE034
CFEC-FE738-1-1B	DASSAULT FALCON 2000	ECHYI	2	B130	2B	F2TH	FOI-Honeywell
GA TPE331-11U-612G		ECHZH	2	T310	2T	FA3	FOI
CF34-3B1	BOMBARDIER CRJ200ER (CL-600-2B19)	ECHZR	2	J090	2J	CRJ2	1GE034
CFM56-7B27B1	BOEING 737-86Q (WINGLETS)	ECHZS	2	J075	2J	B738	3CM034
CFM56-5B4/P	AIRBUS A320-214	ECHZU	2	J067	2J	A320	3CM026
CF34-3B1	BOMBARDIER CRJ200ER (CL-600-2B19)	ECIAA	2	J090	2J	CRJ2	1GE034
FJ44-1A	CESSNA 525 CITATIONJET	ECIAB	2	B001	2B	C525	FOCA
CFM56-5B4/P	AIRBUS A320-214	ECIAG	2	J067	2J	A320	3CM026
V2527-A5	AIRBUS A320-232	ECIAZ	2	J220	2J	A320	1IA003
BRBR700-710A2-20	BOMBARDIER BD-700-1A10 GLOBAL EX-PRE	ECIBD	2	J854	2J	GLEX	4BR009
PT6A-60A	BEECH-CRAFT KING AIR 350 (RAYTHEON B)	ECIBK	2	T738	2T	B350	FOI
CF34-3B1	BOMBARDIER CRJ200ER (CL-600-2B19)	ECIBM	2	J090	2J	CRJ2	1GE034
CFM56-7B27B1	BOEING 737-81Q (WINGLETS)	ECICD	2	J075	2J	B738	3CM034
CFM56-5B4/P	AIRBUS A320-214	ECICK	2	J067	2J	A320	3CM026

## Emissions (1A3a)

The output of the FOCA emission modelling consists of tables with the following structure:

Table A – 10 Extract of the output file of FOCA emission and fuel consumption modelling (example for 2004). Emissions and fuel consumption in tonnes.

Airport	Distance	Type Traffic	Movements	Type	Aircraft ICAO	Engine Name	Fuel (LTO) tons	Emissions (LTO) in tons					
	Km		No.					CO <sub>2</sub>	H <sub>2</sub> O	SO <sub>2</sub>	NO <sub>x</sub>	VOC	CO
LSGG	181501.69	Taxi	165	2B	C550	JT15D-4	5673.492	17871.5	6978.395	5.673	26.04	139	359.2
LSGG	164165.197	Taxi	77	2J	B752	RB211-535E4	47470.5	149532.1	58388.72	47.47	554.91	0	361.47
LSGG	133166.837	Taxi	118	2B	F2TH	CFE738-1-1B	6164.2728	19417.46	7582.056	6.164	87.539	40.59	185.53
LSGG	117228.943	Taxi	99	3B	F900	TFE731-60-1C	5668.542	17855.91	6972.307	5.669	46.937	28.13	163.44
LSGG	114258.902	Taxi	134	2B	LJ45	TFE731-20R	4725.108	14884.09	5811.883	4.725	31.31	53.62	169.01
LSGG	112510.267	Taxi	100	2B	F2TH	CFE738-1-1B	5223.96	16455.47	6425.471	5.224	74.186	34.4	157.23
LSGG	107945.477	Taxi	96	2B	C560	JT15D-5D	3795.3216	11955.26	4668.246	3.795	16.959	271.6	287.98
LSGG	181501.69	Taxi	165	2B	C550	JT15D-4	307732.68	969357.9	378511.2	307.7	4513	29.43	274.71
LSGG	164165.197	Taxi	77	2J	B752	RB211-535E4	673698.47	2122150	828649.1	673.7	7986.4	647.8	1038.2
LSGG	133166.837	Taxi	118	2B	F2TH	CFE738-1-1B	225781.85	711212.8	277711.7	225.8	3311.2	21.59	201.55
LSGG	117228.943	Taxi	99	3B	F900	TFE731-60-1C	298139.18	939138.4	366711.2	298.1	4372.3	28.52	266.14
LSGG	114258.902	Taxi	134	2B	LJ45	TFE731-20R	193723.81	610230	238280.3	193.7	2841	18.53	172.93
LSGG	106761.289	Taxi	100	2B	F2TH	CFE738-1-1B	181011.75	570187	222644.4	181	2654.6	17.31	161.58
LSGG	103217.159	Taxi	96	2B	C560	JT15D-5D	175002.74	551258.6	215253.4	175	2566.5	16.74	156.22

## A5.1.2 Road transportation

### Base emission factors (1A3b)

The derivation of the emission factors for road transport is described in detail in INFRAS (2019a), Matzer et al. (2019) and Notter et al. (2022). The emission factors are contained in the “Handbook Emission Factors for Road Transport (HBEFA)” (version 4.2), which is available publicly as a database application (INFRAS 2022). Some important features of the emission factor methodologies are summarised in the following paragraphs.

HBEFA differentiates emission factors by emission category, vehicle types and traffic situations.

The following **emission categories** are accounted for:

- a) Hot emissions – the emissions caused by vehicles on the road with hot engines;
- b) Cold start (excess) emissions – the excess emissions caused by vehicles after cold start when the engine is still cold (note that these emissions can be negative in some cases, when the cold engine produces less emissions than in the hot state)
- c) Evaporation emissions – evaporation of hydrocarbons (i.e. methane, NMVOC) from the fuel tank of gasoline vehicles. Three sub-processes are distinguished:
  - Soak emissions: evaporation after stopping when the engine is still hot;
  - Diurnal emissions: evaporation caused by the daily temperature variation;
  - Running losses: evaporation during driving.

The hot emissions are generally the most relevant emission category; results show that for CO<sub>2</sub> the hot exhaust emissions contribute about 98 % of the total in the year 2019. Only 2 % stem from cold start excess emissions. For CH<sub>4</sub>, however, the picture is different. Hot exhaust emissions contribute about two thirds to the total, cold start emissions about one third. For N<sub>2</sub>O, the cold start emission factors are based on the EMEP guidebook (EMEP/EEA 2019). According to these emission factors, the share of cold start emissions amounts to roughly 7 % of total emissions in the year 2019.

Regarding **vehicle types**, HBEFA distinguishes six vehicle categories at the highest aggregation level (i.e. passenger cars, light commercial vehicles, urban buses, coaches, heavy goods vehicles and motorcycles). Each vehicle category is further differentiated by technology (in turn related to fuel type), emission standard, and (optionally) size class. The following table illustrates the segmentation of passenger cars. Similar “segmentations” hold for the other vehicle categories, too.

Table A – 11 Vehicle segmentation of passenger cars for different fuel types (according to HBEFA 4.2, INFRAS 2022).

Technology	Vehicle sub-segment	Technology	Vehicle sub-segments
Gasoline	<ECE	Bifuel CNG/Gasoline	Euro-2
	AGV82 (CH)		Euro-3
	ECE-15'00		Euro-4
	ECE-15'01/02		Euro-5
	ECE-15'03		Euro-6
	PreEuro 3WCat <1987		Euro-2
	PreEuro 3WCat 1987-90	Bifuel LPG/Gasoline	Euro-3
	Euro-1		Euro-4
	Euro-2		Euro-5
	Euro-3		Euro-6
	Euro-4	Flex-fuel E85	Euro-3
	Euro-5		Euro-4
	Euro-6ab		Euro-5
	Euro-6c		Euro-6
Euro-6d-temp	PHEV	Euro-4	
Euro-6d		Euro-5	
		Euro-6d	
Diesel	conv	Electricity	BEV
	1986-1988	FuelCell	FuelCell
	Euro-1		
	Euro-2		
	Euro-3		
	Euro-4		
	Euro-5		
	Euro-5 EA189 before software update		
	Euro-5 EA189 after software update		
	Euro-6ab		
	Euro-6c		
	Euro-6d-temp		
	Euro-6d		

**Traffic situations** are relevant for hot emissions. They are defined by a scheme (see table below) taking into account 4 parameters: area type (urban/rural areas), 10 road types, speed limits and 5 levels of service (i.e. traffic density classes). This leads to the definition of 365 different traffic situations in total. Each traffic situation implies a typical driving behaviour. The traffic situations have been defined based on driving behaviour studies in Germany and in Switzerland (see Ericsson et al. 2019, INFRAS 2015b).

Table A – 12 Traffic situation-scheme in HBEFA 4.2 (INFRAS 2022). Every traffic situation is characterised by a typical driving pattern (i.e. a speed-time curve). Legend: Orange colour = urban, blue colour = rural, green colour = motorway.

Area	Road type	Levels of service	Speed Limit [km/h]														
			30	40	50	60	70	80	90	100	110	120	130	>130			
Rural	Motorway-Nat.	5 levels of service															
	Semi-Motorway	5 levels of service															
	TrunkRoad/Primary-Nat.	5 levels of service															
	Distributor/Secondary	5 levels of service															
	Distributor/Secondary(sinuous)	5 levels of service															
	Local/Collector	5 levels of service															
	Local/Collector(sinuous)	5 levels of service															
	Access-residential	5 levels of service															
Urban	Motorway-Nat.	5 levels of service															
	Motorway-City	5 levels of service															
	TrunkRoad/Primary-Nat.	5 levels of service															
	TrunkRoad/Primary-City	5 levels of service															
	Distributor/Secondary	5 levels of service															
	Local/Collector	5 levels of service															
	Access-residential	5 levels of service															

Traffic situations are defined independently of vehicle categories (LDV, HDV, 2-wheelers). But for the same traffic situation, each vehicle category is assigned its own “driving pattern” which is expressed as a speed curve (i.e. speed time series).

(Hot) emission factors for these driving patterns are developed by first creating engine maps (i.e. emissions by torque and engine speed) based on measurements performed both on laboratory test benches and on the road using Portable Emission Measurement Systems (PEMS); the PHEM model (Passenger car and Heavy duty Emission model) is then used to simulate emissions for the HBEFA driving patterns by using the emission maps as input. This process is described in detail in Matzer et al. (2019). Hot emission factors are differentiated for 7 gradient classes (flat, +/-2 %, +/-4 %, +/-6 %) within each traffic situation. The driving pattern is adapted automatically in PHEM if it cannot be realised at a given gradient (e.g. a fully loaded truck might not be able to accelerate as quickly on an upward slope as on a flat or downhill road).

For **cold start and evaporation emission factors**, not the driving pattern is determining but ambient conditions. These include climatic parameters (diurnal temperature and humidity profiles for all seasons) but also diurnal profiles of traffic volumes, trip length and parking time distributions. The methodology for the development of cold start emission factors is described in INFRAS (2004, 2019a). The methodology for the evaporation emission factors is adopted from EMEP/EEA guidebook (EMEP/EEA 2016); its implementation in HBEFA is described in INFRAS (2019a).

**Cold start excess emissions for N<sub>2</sub>O** are estimated on the basis of the Tier 3 emission factors for cold-start and hot-start urban conditions published in Tables 3-56 ff. in the EMEP/EEA guidebook (EMEP/EEA 2019). Based on these emission factors, two N<sub>2</sub>O emission calculations are carried out for Switzerland – one hypothetical calculation assuming all starts are hot starts, and a second calculation using the actual cold start share in Switzerland. The difference between the two emission values are the cold start excess emissions. These are divided by the number of cold starts in order to obtain the cold start excess emission factors in g/start.

### Activity data (1A3b)

Activity data for the emission model include (see also chp. 3.2.9.2.2.):

- a) mileage (vehicle kilometres) for hot emissions and evaporation running losses.
- b) the number of starts for cold start excess emissions.
- c) the number of stops for evaporation soak emissions.
- d) the number of vehicles for evaporation diurnal emissions.

Mileage must be differentiated by vehicle types, traffic situations, and gradients in order to be able to link it to the hot emission factors differentiated by the same parameters. To do so, three steps must be carried out:

1. Vehicle turnover: The vehicle fleet is built up for each year accounting for stock changes. This vehicle turnover is modelled

- a) for historical periods (ex-post) on the basis of vehicle stock and age distributions, and

b) for future periods on the basis of new registrations and by applying survival probabilities.

Trends in traffic volume per vehicle category and segment, including structural changes (size distributions, shares of diesel vehicles) are then combined to draw the continual substitution of older technologies by new ones constantly altering the fleet composition or mileage by emission concepts (Euro classes) in all vehicle categories, see also the following Figure A-1 (INFRAS 2017).

2. The total mileage is an input dataset by the Federal Statistical Office (FSO 2022f, 2022g).

3. Assignment of the traffic situations to the mileage for all vehicle categories: This step requires the use of a traffic model: Each road network link carries the information on modelled traffic volume and can be characterized with the parameters defining traffic situations (described above) and gradients, which allows the assignment sought.

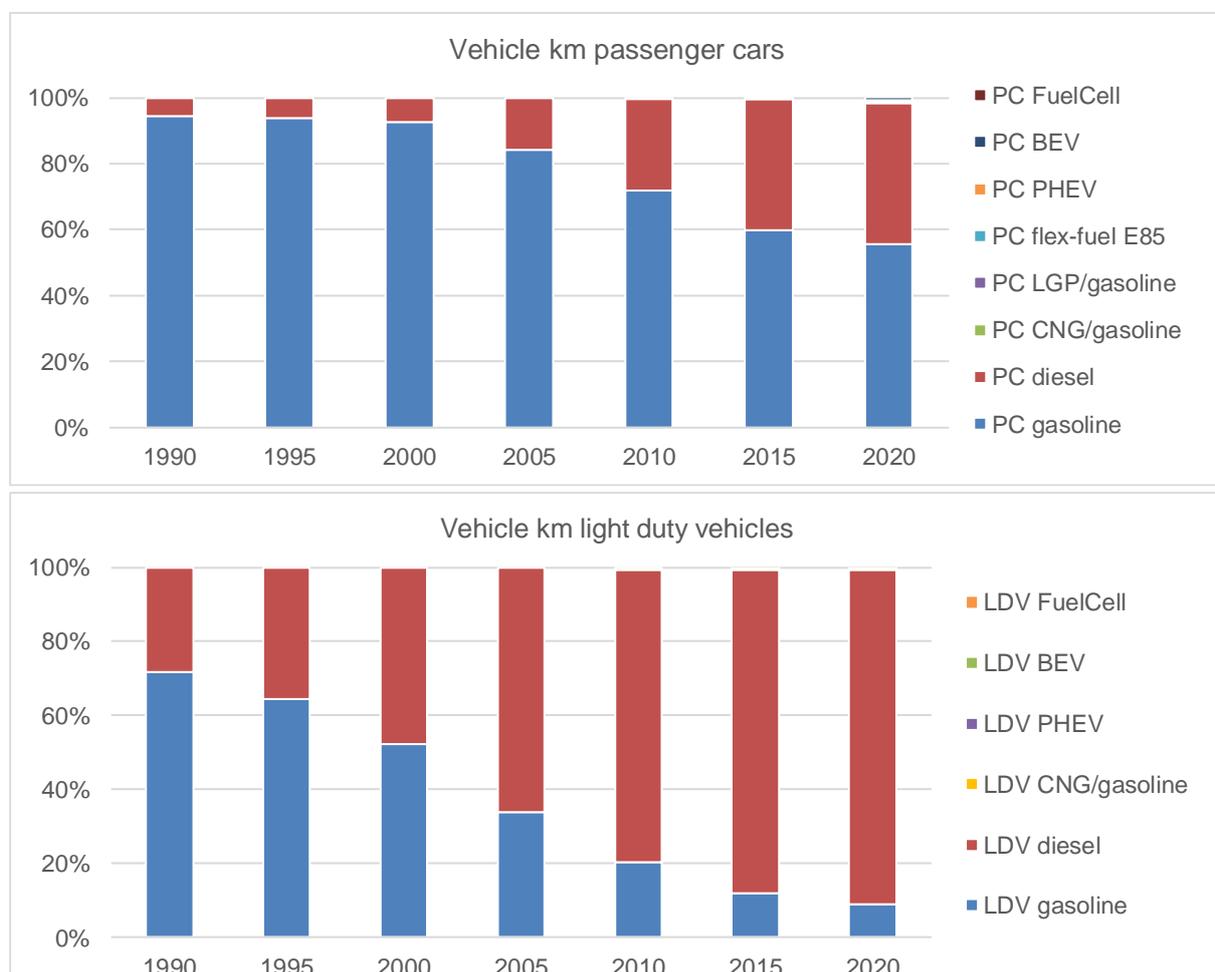


Figure A – 1 Vehicle kilometres per fleet composition for passenger cars (PC, above) and light duty vehicles (LDV, below). Data source: INFRAS (2022).

### Aggregated emission factors (1A3b)

From the base emission factors differentiated by vehicle type, traffic situations and gradients, aggregated emissions can be derived by using the activity data described above – i.e. taking into account the fleet composition, which varies from year to year, and the distribution of vehicle kilometres across traffic situations (temporally dynamic as well, derived from traffic

models – see section on activity data below).

Average emission factors by vehicle and emission category for Switzerland are shown in the next table.

Table A – 13 Mean emission factors of passenger cars (PC), light duty vehicles (LDV), heavy duty vehicles (HDV), coaches and urban buses (Bus) and Motorcycles (MC) in grams per kilometre (from HBEFA 4.2). Cold start excess emissions are given in g/start.

Pollutant	Year	PC	LDV	HDV	Bus	MC	PC	LDV
		Emission factors in gram per vehicle kilometre					Cold starts in gram per start	
CH <sub>4</sub>	1990	0.031	0.054	0.036	0.045	0.183	0.675	0.725
CH <sub>4</sub>	1995	0.017	0.038	0.029	0.041	0.125	0.423	0.496
CH <sub>4</sub>	2000	0.013	0.026	0.019	0.032	0.152	0.282	0.288
CH <sub>4</sub>	2005	0.010	0.015	0.012	0.019	0.141	0.186	0.149
CH <sub>4</sub>	2010	0.006	0.007	0.004	0.045	0.129	0.120	0.070
CH <sub>4</sub>	2015	0.004	0.004	0.004	0.020	0.093	0.073	0.035
CH <sub>4</sub>	2020	0.006	0.005	0.001	0.012	0.076	0.051	0.022
CO	1990	6.9	24.2	3.8	5.1	12.2	41.2	60.8
CO	1995	3.0	17.9	3.3	4.9	12.5	29.4	46.9
CO	2000	1.6	12.1	2.4	4.1	12.2	22.0	31.3
CO	2005	1.1	6.5	2.0	2.9	10.9	15.7	17.5
CO	2010	0.8	2.9	2.0	1.8	8.8	10.4	8.7
CO	2015	0.5	1.0	1.9	1.6	5.5	6.6	4.7
CO	2020	0.4	0.6	0.8	0.9	3.2	5.2	3.2
CO <sub>2</sub> (fossil)	1990	233	299	829	1097	110	108	140
CO <sub>2</sub> (fossil)	1995	238	297	857	1117	122	102	134
CO <sub>2</sub> (fossil)	2000	242	293	855	1126	109	99	126
CO <sub>2</sub> (fossil)	2005	231	284	897	1123	117	101	115
CO <sub>2</sub> (fossil)	2010	219	272	874	1072	111	104	105
CO <sub>2</sub> (fossil)	2015	197	265	840	1008	116	91	98
CO <sub>2</sub> (fossil)	2020	178	242	788	952	112	80	93
VOC	1990	0.86	1.57	1.49	1.88	3.01	7.16	6.84
VOC	1995	0.37	0.97	1.19	1.71	2.32	5.75	5.59
VOC	2000	0.17	0.48	0.78	1.35	2.40	4.69	4.14
VOC	2005	0.09	0.19	0.47	0.78	1.56	3.32	2.50
VOC	2010	0.03	0.06	0.16	0.27	1.01	2.21	1.32
VOC	2015	0.01	0.02	0.11	0.11	0.62	1.35	0.67
VOC	2020	0.01	0.01	0.04	0.05	0.43	0.95	0.42
N <sub>2</sub> O	1990	0.0096	0.0054	0.0087	0.0107	0.0016	0.0175	0.0018
N <sub>2</sub> O	1995	0.0132	0.0073	0.0092	0.0107	0.0018	0.0372	0.0180
N <sub>2</sub> O	2000	0.0116	0.0091	0.0094	0.0102	0.0018	0.0419	0.0316
N <sub>2</sub> O	2005	0.0050	0.0075	0.0080	0.0080	0.0019	0.0028	0.0360
N <sub>2</sub> O	2010	0.0031	0.0057	0.0298	0.0168	0.0019	0.0108	0.0380
N <sub>2</sub> O	2015	0.0032	0.0057	0.0427	0.0302	0.0019	0.0096	0.0244
N <sub>2</sub> O	2020	0.0044	0.0079	0.0460	0.0371	0.0019	0.0066	0.0081
NM VOC	1990	0.82	1.52	1.45	1.84	2.83	6.48	6.11
NM VOC	1995	0.35	0.93	1.16	1.67	2.19	5.33	5.10
NM VOC	2000	0.16	0.45	0.76	1.31	2.24	4.40	3.86
NM VOC	2005	0.08	0.18	0.45	0.76	1.42	3.14	2.35
NM VOC	2010	0.03	0.05	0.16	0.23	0.88	2.09	1.25
NM VOC	2015	0.01	0.02	0.11	0.09	0.53	1.27	0.63
NM VOC	2020	0.00	0.01	0.04	0.04	0.36	0.90	0.39
NO <sub>x</sub>	1990	0.98	2.38	12.47	17.21	0.15	0.56	0.03
NO <sub>x</sub>	1995	0.58	1.90	11.76	16.62	0.20	1.20	0.53
NO <sub>x</sub>	2000	0.46	1.48	10.36	15.23	0.19	1.20	0.57
NO <sub>x</sub>	2005	0.44	1.36	8.74	12.57	0.21	0.75	0.24
NO <sub>x</sub>	2010	0.42	1.53	5.44	8.73	0.24	0.36	0.02
NO <sub>x</sub>	2015	0.44	1.53	3.63	5.95	0.19	0.28	-0.07
NO <sub>x</sub>	2020	0.31	1.02	1.57	3.40	0.12	0.22	0.04
SO <sub>2</sub>	1990	0.0386	0.1073	0.7371	0.9748	0.0140	0.0176	0.0435
SO <sub>2</sub>	1995	0.0306	0.0469	0.1855	0.2418	0.0156	0.0134	0.0208
SO <sub>2</sub>	2000	0.0224	0.0380	0.1479	0.1946	0.0098	0.0094	0.0159
SO <sub>2</sub>	2005	0.0012	0.0016	0.0056	0.0070	0.0006	0.0005	0.0007
SO <sub>2</sub>	2010	0.0010	0.0014	0.0048	0.0059	0.0005	0.0005	0.0005
SO <sub>2</sub>	2015	0.0008	0.0012	0.0040	0.0049	0.0004	0.0004	0.0004
SO <sub>3</sub>	2020	0.0007	0.0011	0.0037	0.0045	0.0004	0.0003	0.0004

### **Modelling total emissions (1A3b)**

In order to calculate total emissions, the activity data is multiplied with the respective emission factors resulting in total emissions.

These results correspond to territorial emissions; they do not yet contain the emissions from fuel tourism and statistical differences. Emissions from fuel tourism and statistical differences are calculated by assigning the fuel consumption to categories 1A3bi, 1A3bii, and 1A3biii (as described in chp. 3.2.9.2.2), and using mean emission factors averaged over all vehicle categories.

#### **A5.1.3 Non-road vehicles and machinery: supplementary activity data**

The following table shows some aggregated information on stock numbers and annual operation hours of non-road vehicles and machinery. Detailed information is available in the report FOEN (2015j) and most disaggregated information is available by query from the online non-road database INFRAS (2015a):

<https://www.bafu.admin.ch/bafu/en/home/topics/air/state/non-road-datenbank.html>

Table A – 14 Overview over stock and operating hours of non-road vehicles and machinery (FOEN 2015j): Upper table: Number of vehicles; middle table Specific operating hours per year; lower table: Total operating hours per year (in million hours)

Category	1980	1990	2000	2010	2020	2030
	number of vehicles					
Construction machinery	63'364	58'816	52'729	57'102	60'384	62'726
Industrial machinery	26'714	43'244	70'671	69'786	69'757	70'083
Agricultural machinery	292'773	324'567	337'869	318'876	309'825	305'235
Forestry machinery	11'815	13'844	13'055	11'857	10'831	10'170
Garden-care / hobby appliances	1'198'841	1'539'624	1'944'373	2'322'737	2'464'323	2'499'627
Navigation machinery	94'866	103'383	93'912	95'055	97'522	99'104
Railway machinery	529	1'300	1'255	697	640	640
Military machinery	13'092	13'373	14'272	13'083	12'853	12'856
<b>Total</b>	<b>1'701'994</b>	<b>2'098'151</b>	<b>2'528'136</b>	<b>2'889'193</b>	<b>3'026'135</b>	<b>3'060'441</b>

Category	1980	1990	2000	2010	2020	2030
	Specific operating hours per year					
Construction machinery	247	322	406	417	424	429
Industrial machinery	666	670	684	680	675	671
Agricultural machinery	136	119	112	103	99	95
Forestry machinery	203	199	203	193	188	182
Garden-care / hobby appliances	12	17	20	64	77	81
Navigation machinery	39	38	38	36	35	35
Railway machinery	877	613	617	783	719	719
Military machinery	64	64	63	73	74	74

Category	1980	1990	2000	2010	2020	2030
	million operating hours per year					
Construction machinery	16	19	21	24	26	27
Industrial machinery	18	29	48	48	47	47
Agricultural machinery	40	39	38	33	31	29
Forestry machinery	2.4	2.8	2.6	2.3	2.0	1.9
Garden-care / hobby appliances	15	26	39	150	191	201
Navigation machinery	3.7	3.9	3.5	3.4	3.4	3.4
Railway machinery	0.50	0.80	0.80	0.50	0.50	0.50
Military machinery	0.80	0.90	0.90	0.90	0.90	0.90
<b>Total</b>	<b>95</b>	<b>121</b>	<b>155</b>	<b>261</b>	<b>301</b>	<b>311</b>

#### A5.1.4 Sulphur dioxide (SO<sub>2</sub>)

Table A – 15 shows sulphur contents and SO<sub>2</sub> emission factors per fuel type. Explanations:

- For liquid and solid fuels the SO<sub>2</sub> emission factors are determined by the sulphur content. The upper table depicts the maximum values as defined in the Federal Ordinance on Air Pollution Control OAPC (Swiss Confederation 1985).
- The middle table contains the effective sulphur contents. They are based on measurements: Summary and annual reports of Avenegy Suisse (formerly Erdöl-Vereinigung EV), reports by the Federal Office for Customs and Border Security (FOCBS) since 2000, as well as their measurement project 'Schwerpunktaktion Brenn- und Treibstoffe'. For diesel oil and gasoline, the measurement project 'Tankstellensurvey', arranged by the FOEN, is a central data source.
- The lower table shows the emission factors in kg/TJ. They are calculated from the effective sulphur content S, the net calorific value NCV and the quotient of the molar masses of S and SO<sub>2</sub>.

- $EF_{SO_2} = \frac{M_{SO_2}}{M_S} * \frac{S}{NCV} = 2 \frac{S}{NCV}$
- Gas oil: starting from 1990 and for each fifth subsequent year up to and including 2015 the values for the SO<sub>2</sub> emission factors are based on five-year averages (e.g. the value for 1995 is based on an average of the years 1993–1997). 1990 is the exception: for this year, the value is based on an average of the three years 1990–1992. The values for all other years are linear interpolations between the years 2015 and 2025 (value 2025: 2 g/GJ). Furthermore, 2006 saw the introduction to the market of low-sulphur eco-grade gas oil with a maximum legal sulphur limit of 50 ppm. From this year onwards, FOCBS measurements include both standard Euro- and eco-grade gas oil. For each year, the two grades are weighted by the respective total annual fuel consumption. Additionally, since 2018, heating gas is also classified as gas oil.
- (Bituminous) coal: The legal limit of sulphur content depends on the size of the heat capacity of the combustion system. The value of 1 % sulphur content (350 kg SO<sub>2</sub>/TJ; see Table A – 15) holds for heat capacity below 1 MW (see OAPC Annex 3, §513 (Swiss Confederation 1985)). For larger capacities, the value is 3 % (OAPC Annex 5, §2, Swiss Confederation 1985). For industrial combustion plants, the limit for the exhaust emissions actually sets the corresponding maximum sulphur content to 1.4 % (500 kg SO<sub>2</sub>/TJ).
- Residual fuel oil: OAPC Annex 5, §11, lit.2 sets 2.8 % for the legal limit (denoted as class B in the upper table). Simultaneously, OAPC dispenses from emission control measurements if residual fuel oil of class A is used with sulphur content of maximum 1 % (see OAPC Annex 3, §421, lit.2, Swiss Confederation 1985), which holds for most combustion plants. The emission factors are based on five-year averages in the case of 1995, 2000 and 2015. 1990 is based on an average of the years 1990–1992 because no non-interpolated data is available for 1988 and 1989. Similarly, because the emission factors of the years 2006–2008 are not available, the average of 2005 is based on the years 2003–2005 and that of 2010 on 2009–2012. The values for all other years are linear interpolations between the years 2015 and 2035 (value 2035: 500 g/GJ).
- Natural gas: OAPC Annex 5, §42 sets 190 ppm as the legal limit for natural gas.

Table A – 15 Sulphur content (legal limits and effective) and SO<sub>2</sub> (SO<sub>x</sub>) emission factors. Legal limits that did not change in a specific year are printed in grey colour.

Year	Maximum legal limit of sulphur content						
	Diesel oil ppm	Gasoline ppm	Gas oil (Euro) ppm	Natural gas ppm	Res. fuel oil Class A, %	Res. fuel oil Class B, %	Coal %
1990	1400	200	2000	190	1.0	2.8	1-3
1991	1300	200	2000	190	1.0	2.8	1-3
1992	1200	200	2000	190	1.0	2.8	1-3
1993	1000	200	2000	190	1.0	2.8	1-3
1994	500	200	2000	190	1.0	2.8	1-3
2000	350	150	2000	190	1.0	2.8	1-3
2005	50	50	2000	190	1.0	2.8	1-3
2008	50	50	1000	190	1.0	2.8	1-3
2009	10	50	1000	190	1.0	2.8	1-3
2010-2021	10	10	1000	190	1.0	2.8	1-3

Year	Effective sulphur content				
	Diesel oil ppm	Gasoline ppm	Gas oil (Euro) ppm	Gas oil (Oeko) ppm	Res. fuel oil %
1990	1400	200	1600	NO	0.97
1991	1300	200	1300	NO	0.89
1992	1200	200	1200	NO	0.86
1993	1000	200	1000	NO	0.87
1994	434	200	1350	NO	0.77
1995	341	200	1170	NO	0.78
1996	372	200	1160	NO	0.78
1997	353	200	1250	NO	0.70
1998	402	200	926	NO	0.83
1999	443	200	650	NO	0.62
2000	272	142	680	NO	0.66
2001	250	121	830	NO	0.82
2002	235	101	798	NO	0.82
2003	200	81	700	NO	0.79
2004	10	8.0	700	NO	0.76
2005	10	8.0	800	NO	0.78
2006	10	8.0	740	NO	0.74
2007	10	8.0	680	NO	0.71
2008	10	8.0	620	NO	0.67
2009	7.6	5.3	549	NO	0.92
2010	6.7	4.7	519	NO	0.88
2011	6.6	5.0	417	NO	0.90
2012	7.0	5.3	503	NO	0.91
2013	7.1	4.8	224	NO	0.90
2014	6.8	4.8	516	14	1.11
2015	7.7	4.5	516	14	1.93
2016	7.0	4.6	246	10	1.92
2017	7.7	5.2	248	19	0.98
2018	7.2	4.4	486	5	0.91
2019	No measurements in the year 2019				
2020	6.2	Not measured	319	18	0.55
2021	Not measured	Not measured	337	19	0.56

Year	SO <sub>x</sub> emission factor used for Switzerland's emission inventory								
	Diesel oil (average in 1A3b)	Gasoline (average in 1A3b)	Gas oil (boilers and engines in 1A1a, 1A2, 1A4) *	Natural gas (boilers and engines in 1A1, 1A2, 1A4, 1A3e)	Natural gas (for 1A3b only)	Res. fuel oil (boilers in 1A1a, 1A2) *	Lignite (boilers in 1A2g)	Bituminous coal (boilers in 1A4b)	Kerosene (average)
kg/TJ									
1990	65	9.4	64			440			23.2
1991	61	9.4	62			428			23.2
1992	56	9.4	61			416			23.2
1993	47	9.4	59			404			23.3
1994	20	9.4	58			392			23.3
1995	16	9.4	56			380			23.3
1996	17	9.4	52			376			23.3
1997	16	9.4	48			372			23.3
1998	19	9.4	45			368			23.2
1999	21	9.4	41			364			23.2
2000	13	6.6	37			360			23.2
2001	12	5.7	36		0.27	364			23.2
2002	11	4.8	35		0.27	368			23.2
2003	9.3	3.8	35		0.27	372			23.2
2004	0.47	0.38	34		0.27	376			23.2
2005	0.46	0.37	33		0.27	380			23.2
2006	0.44	0.36	31		0.27	392			23.1
2007	0.43	0.35	30		0.27	404			23.2
2008	0.42	0.34	28		0.27	416			23.2
2009	0.41	0.33	27		0.27	428			23.2
2010	0.40	0.32	25		0.28	440			23.2
2011	0.39	0.31	22		0.27	480			23.2
2012	0.38	0.30	19		0.27	520			23.2
2013	0.37	0.29	17		0.28	560			23.1
2014	0.36	0.28	14		0.28	600			23.1
2015	0.35	0.27	11		0.28	640			23.1
2016	0.34	0.26	10		0.28	633			23.1
2017	0.33	0.26	9.2		0.28	626			23.1
2018	0.33	0.26	8.3		0.28	619			23.2
2019	0.33	0.26	7.4		0.28	612			23.2
2020	0.33	0.26	6.5		0.27	605			23.1
2021	0.33	0.26	5.6		0.27	598			23.1

\* blue cells = interpolation

## A5.2 Industrial processes and product use (illustrative example of mobile air conditioning)

The use of HFCs as substitutes of ODSs in 2F1 refrigeration and air conditioning is the main factor for the increase of HFC emissions from 1990 to 2015. Refrigerants contained in installed equipment lead to a considerable stock with annual losses of between 0.5 % to 20 % depending on the equipment type (see Table 4-48). Emissions are calculated for the production, operation, service and disposal of equipment. The following illustrative example shows the calculations for the example of mobile air conditioning (HFC-134a use as refrigerant). The example is calculated bottom-up, based on vehicle statistics and information on air conditioning equipment. There is no production of air conditioning equipment for cars in Switzerland, equipment is imported already charged.

Table A – 16 Applied model parameters and assumption for mobile air conditioning of cars.

<b>Characteristic values</b>			
Initial charge in kg HFC per unit AC	1994	0.81	kg
	2002	0.70	kg
	2014	0.55	kg
	Extrapolation of other years		
Lifetime		15	years
<b>Production</b>			
Import of precharged equipment		100	%
<b>Operation</b>			
Annual losses		8.5	%
Recharge of losses (7.2% of 8.5%)		85	%
Additional service losses over lifetime		10	%
<b>Disposal</b>			
Export rate		31-72	%
Share with total loss of refrigerant		40	%
Disposal loss of professional recovery		15	%

Since 1991 HFC-134a has been used to replace ODS in the mobile air conditioning sector leading to a considerable stock of about 1'860 t of HFC-134a in registered cars at present (peak value of stock 2'418 t of HFC-134a in 2014). A phase-out of HFC-134a and replacement with HFO-1234yf is under way, due to regulations in the European Union and their implementation in Switzerland. AC-refrigerants exceeding a GWP of 150 are not allowed for new car models since 2011. Since 2017, no new cars with AC-refrigerant exceeding a GWP of 150 are allowed. Due to safety concerns with alternative use of HFO-1234yf (GWP 4), there has been a delay in the replacement of HFC-134a.

Interviews were carried out 2014, 2017 and 2018 with garages in Switzerland to follow the development of HFC-134a replacement. The first interviews held in 2014 showed that only few of the imported brands switched to HFO-1234yf (GWP 4). In 2014, garages confirmed a minor portion below 5 % of equipment with HFO-1234yf. In 2017 feedback of garages on the sold vehicles of the former year varied widely depending on the models sold and origin of cars. In interviews carried out in 2018, garages confirmed complete phase-out of HFC-134a in new vehicles sold in 2017 (excluding sold vehicles from former years in stock and second-hand vehicles). Most of them switched to HFO-1234yf, few models apply CO<sub>2</sub> (R744). A

complete replacement of HFC-134a was assumed for all new vehicles models sold since 2020.

Table A – 17 Bottom-up calculations to identify the number of air conditioning equipment and amount of HFC-134a

Year	New registered vehicles	Vehicles in use	Disposed vehicles	New equipment: number of air conditioning units with HFC-134a in new registered cars			Equipment stock: Number of air conditioning units with HFC-134a in use		Equipment disposal	Initial equipment charge
				Portion of vehicles with AC [%]	HFC-134a as refrigerant [%]	AC units with HFC-134 [units]	Portion of vehicles with HFC-134a [%]	AC units with HFC-134 [units]		
1989	335'094	2'895'842		5	0	0	0	0	0	0.85
1990	327'456	2'985'399	237'899	6	0	0	0	0	0	0.84
1991	314'824	3'057'800	242'423	7	10	2'204	0	2'204	0	0.83
1992	296'009	3'091'230	262'579	9	30	7'992	0	10'196	0	0.83
1993	262'814	3'109'524	244'520	14	66	24'284	1	34'480	0	0.82
1994	270'009	3'165'043	214'490	19	90	46'172	3	80'652	0	0.81
1995	272'897	3'229'169	208'771	24	100	65'495	5	146'147	0	0.78
1996	269'529	3'268'073	230'625	38	100	102'421	8	248'568	0	0.77
1997	272'441	3'323'421	217'093	52	100	141'669	12	390'237	0	0.76
1998	297'336	3'383'275	237'482	68	100	202'188	18	592'426	0	0.75
1999	317'985	3'467'275	233'985	75	100	238'489	24	830'914	0	0.73
2000	315'398	3'545'247	237'426	77	100	242'856	30	1'073'771	0	0.72
2001	317'126	3'629'713	232'660	85	100	269'557	37	1'343'328	0	0.71
2002	295'109	3'704'822	220'000	87	100	256'745	43	1'600'073	0	0.70
2003	271'541	3'754'000	222'363	89	100	241'671	49	1'841'744	0	0.69
2004	269'211	3'811'351	211'860	91	100	244'982	55	2'086'726	0	0.68
2005	259'426	3'863'807	206'970	92	100	238'672	60	2'325'398	0	0.66
2006	269'421	3'899'917	233'311	96	100	258'644	66	2'581'839	2'204	0.65
2007	284'674	3'955'787	228'804	96	100	273'287	72	2'847'133	7'992	0.64
2008	288'525	4'030'965	213'347	96	100	276'984	77	3'099'833	24'284	0.63
2009	266'018	4'051'569	245'414	96	100	255'377	82	3'309'039	46'172	0.61
2010	294'239	4'119'370	226'438	96	100	282'469	86	3'526'013	65'495	0.60
2011	327'896	4'209'300	237'966	96	100	314'780	90	3'738'372	102'421	0.59
2012	328'139	4'254'725	282'714	96	100	315'013	92	3'911'717	141'669	0.58
2013	310'154	4'320'885	243'994	96	92	273'928	92	3'983'456	202'188	0.56
2014	304'083	4'384'490	240'478	96	85	248'132	91	3'993'099	238'489	0.55
2015	327'143	4'458'069	253'564	96	77	241'510	90	3'991'753	242'856	0.55
2016	319'331	4'524'029	253'371	96	69	211'525	87	3'933'720	269'557	0.55
2017	315'032	4'570'823	268'238	96	30	90'729	82	3'767'705	256'745	0.55
2018	300'887	4'602'688	269'022	97	10	29'186	77	3'555'219	241'671	0.55
2019	312'902	4'623'952	291'638	97	6	18'211	72	3'328'448	244'982	0.55
2020	238'664	4'658'335	204'281	97	0	0	66	3'089'776	238'672	0.55
2021	242'263	4'688'235	212'363	97	0	0		2'831'132	258'644	0.55

Table A – 18 Results and structure of emission calculations of HFC-134a from mobile air conditioning of cars for 1990 to 2021.

HFC-134a	Activity			Emissions				Recharge	Disposal
	Input with vehicles	Stock	Retiring vehicles (incl. Export)	Production	Stock incl. Recharge	Disposal	Total	import in bulk	recovered for disposal
	[t]	[t]	[t]	[t]	[t]	[t]	[t]	[t]	[t]
1990	0	0	0	NO	0	0	0	0	0
1991	2	2	0	NO	0	0	0	0	0
1992	7	8	0	NO	1	0	1	0	0
1993	20	28	0	NO	3	0	3	1	0
1994	37	65	0	NO	6	0	6	2	0
1995	51	115	0	NO	11	0	11	5	0
1996	79	193	0	NO	18	0	18	9	0
1997	107	297	0	NO	27	0	27	15	0
1998	151	444	0	NO	41	0	41	23	0
1999	175	612	0	NO	56	0	56	35	0
2000	175	779	0	NO	71	0	71	48	0
2001	191	960	0	NO	88	0	88	61	0
2002	180	1'126	0	NO	103	0	103	75	0
2003	166	1'277	0	NO	117	0	117	88	0
2004	165	1'425	0	NO	131	0	131	100	0
2005	158	1'563	0	NO	143	0	143	111	0
2006	168	1'709	1	NO	157	0	157	122	1
2007	174	1'856	4	NO	170	1	171	133	2
2008	173	1'992	12	NO	183	3	186	145	6
2009	156	2'096	25	NO	192	8	200	155	13
2010	169	0	0	NO	0	0	211	163	16
2011	185	0	0	NO	0	0	226	163	26
2012	181	0	0	NO	0	0	236	172	41
2013	155	0	0	NO	0	0	245	180	46
2014	136	0	0	NO	0	0	248	185	49
2015	133	0	0	NO	0	0	248	188	52
2016	117	0	0	NO	0	0	247	188	57
2017	50	0	0	NO	0	0	240	188	60
2018	16	0	0	NO	0	0	228	186	61
2019	10	0	0	NO	0	0	217	166	66
2020	0	0	0	NO	0	0	196	154	46
2021	0	0	0	NO	0	0	186	147	49

## A5.3 Agriculture

### A5.3.1 Additional data for estimating CH<sub>4</sub> emission from 3A Enteric fermentation

Table A – 19 Data for estimating enteric fermentation emission factors for cattle (Table according to outline in IPCC 1997c, p 4.31–4.33).

Type	Age <sup>a</sup>	Weight <sup>a</sup> kg	Weight Gain <sup>a</sup> kg*day <sup>-1</sup>	Feeding Situation / Further Specification <sup>a</sup>	Milk <sup>b</sup> kg*day <sup>-1</sup>	Work hrs*day <sup>-1</sup>	Pregnant <sup>a</sup> % 305 days of lactation	Digestibility of Feed <sup>d</sup> %	Y <sub>m</sub> <sup>d</sup> %	Em. Factor kg*head <sup>-1</sup> *year <sup>-1</sup> <sup>e</sup>
Mature Dairy Cattle	NA	685	0		13.2-19.8 <sup>c</sup>	0		72	6.90	115.5 - 141.0
Other Mature Cattle	NA	650	0		6.85	0		62	6.50	106.8
Fattening Calves	0-98 days	124	1.43	Rations of unskimmed milk and supplementary milk feed when life weight exceeds 100 kg. Rations are apportioned on two servings per day.	0	0	0	95	0.00	0.0
Pre-Weaned Calves	0-300 days	195	0.88	*Natura beef* production, milk from mother cow and additional feed.	0	0	0	65	4.00	15.8
Breeding Calves	0-105 days	85	0.67	Feeding plan for a dismission with 14 to 15 weeks. Milk, feed concentrate (100kg in total), hay (80 kg in total).	0	0	0	73	3.99	29.0
Breeding Cattle (4-12 months)	4-12 month	210	0.80	Premature race (Milk-race)	0	0	0	65	6.30	
Breeding Cattle (> 1 year)	12-28/30 month	450	0.80	Premature race (Milk-race)	0	0	0	65	6.30	59.3
Fattening Calves (0-4 months)	0-132 days	115	0.83	Diet based on milk or milk-powder and feed concentrate, hay and/or silage	0	0	0	73	5.54	
Fattening Cattle (4-12 months)	4-12 month	361	1.37	Feeding recommendations for fattening steers, concentrate based	0	0	0	65	6.30	41.9

<sup>a</sup> Data source: RAP 1999 and calculations according to Soliva 2006.

<sup>b</sup> Milk production in kg/day is calculated by dividing the average annual milk production per head by 365 days.

<sup>c</sup> data source: Swiss farmers union (MISTA 2022).

<sup>d</sup> data source: IPCC 2019 and Zeitz et al. 2012.

<sup>e</sup> For better comparability emission factors of young cattle were converted to kg\*head<sup>-1</sup>\*year<sup>-1</sup> although the time span of most of the individual categories is less than 365 days.

### A5.3.2 Additional data for estimating CH<sub>4</sub> and N<sub>2</sub>O emission from 3B Manure management

Table A – 20 Data for estimating manure management CH<sub>4</sub> emission factors (Table according to outline in IPCC 1997c, Tables B-1 to B-7).

Type	Weight kg <sup>a</sup>	Digestibility of Feed % <sup>b</sup>	Energy Intake MJ <sup>c</sup> day <sup>-1</sup>	Feed Intake kg <sup>c</sup> day <sup>-1</sup>	% Ash Dry Basis <sup>b</sup>	VS kg <sup>c</sup> head <sup>-1</sup> day <sup>-1</sup>	B <sub>0</sub> m <sup>3</sup> CH <sub>4</sub> *kgVS <sup>-1</sup> b
Mature Dairy Cattle	685.0830833	72	255 - 312	15.34 <sup>c</sup>	8.8 - 9.1	3.51 - 4.3	0.24
Other Mature Cattle	650	62	251	13.70 <sup>c</sup>	8	4.75	0.18
Fattening Calves	124	95	47	2.02 <sup>a</sup>	8	0.12	0.18
Pre-Weaned Calves	195	65	60	2.99 <sup>a</sup>	8	0.67	0.18
Breeding Calves	85	73	44	2.19 <sup>a</sup>	8	0.37	0.18
Breeding Cattle (4-12 months)	210	65	90	4.88 <sup>a</sup>	8	1.57	0.18
Breeding Cattle (> 1 year)	450	65	144	7.78 <sup>a</sup>	8	2.51	0.18
Fattening Calves (0-4 months)	115	73	57	3.00 <sup>a</sup>	8	0.67	0.18
Fattening Cattle (4-12 months)	361	65	126	6.84 <sup>a</sup>	8	2.20	0.18
Sheep	NA	65	21 - 24	1.08-1.24 <sup>c</sup>	8	0.40	0.19
Swine	NA	75	24 - 27	NA	6	0.31	0.45
Buffalo	NA	65	129 - 163	7.00-8.82 <sup>c</sup>	8	2.76	0.10
Camels	NA	65 <sup>d</sup>	31 - 38	1.68-2.05 <sup>c</sup>	8	0.55	0.26
Deer	NA	65	51 - 60	2.74-3.24 <sup>c</sup>	8	1.04	0.19
Goats	NA	65	25 - 28	1.34-1.40 <sup>c</sup>	8	0.43	0.18
Horses	NA	70	107 - 109	7.73-7.89 <sup>c</sup>	4	1.69	0.3
Mules and Asses	NA	70	38 - 40	2.76-2.83 <sup>c</sup>	4	0.60	0.33
Poultry	NA	NA	1 - 1.4 <sup>c</sup>	NA	NA	0.01	0.37 <sup>#</sup>
Rabbits	NA	NA	1.2	NA	NA	0.10	0.32
Livestock NCAC	NA	NA	NA	NA	NA	0.62	0.25

<sup>a</sup> RAP 1999

<sup>b</sup> IPCC 2006 and IPCC 2019

<sup>c</sup> Richner and Sinaj 2017

<sup>d</sup> Llamas and alpacas: same value as for sheep

<sup>e</sup> metabolizable energy (ME)

<sup>#</sup> weighted average

### A5.3.3 Additional data for estimating N<sub>2</sub>O emissions from 3D Agricultural soils

Table A – 21 Additional data for estimating N<sub>2</sub>O emission from crop residues (based on SBV (2021), Richner and Sinaj (2017) and FAL/RAC (2001)).

2021		Total crop production	Nitrogen incorporated with crop residues F <sub>(CR)</sub>	N <sub>2</sub> O emissions from crop residues
		t DM	t N	t N <sub>2</sub> O
<b>1. Cereals</b>	Wheat	369'910	1'550	24.35
	Barley	144'260	735	11.56
	Maize	83'484	786	12.35
	Oats	6'255	39	0.61
	Rye	6'756	29	0.45
	Other:			
	Triticale	32'085	157	2.47
	Spelt	17'343	159	2.49
	Mix of Fodder Cereals	688	4	0.06
	Mix of Bread Cereals	157	1	0.01
	Millet	146	4	0.06
<b>2. Pulse</b>	Dry Beans	1'311	52	0.82
	Peas (Eiweisserbsen)	5'667	167	2.62
	Soybeans	4'957	204	3.21
	Leguminous Vegetables	2'346	245	3.84
	Lupines	519	21	0.32
<b>3. Tuber and Root</b>	Potatoes	73'486	268	4.22
	Other:			
	Fodder Beet	4'912	35	0.56
	Sugar Beet	242'466	1'730	27.19
<b>5. Other</b>	Fruit	40'330	377	5.92
	Grass	5'359'328'251	24'547	385.75
	Green Corn	138'838	132	2.07
	Non-Leguminous Vegetables	46'694	552	8.67
	Rape	69'327	1'188	18.68
	Renewable Energy Crops	758	13	0.20
	Silage Corn	816'691	481	7.56
	Sunflowers	9'471	201	3.15
	Tobacco	588	15	0.24
	Berries	2'834	50	0.78
	Vine	15'458	271	4.25
	Oil Squash	11	0	0.00
	Oil Hemp	23	1	0.02
	Oil Flax	356	3	0.05
	Hops	45	0	0.00
Medicinal Plants and Herbs	296	24	0.38	
<b>Total Non-leguminous</b>		2'123'667	8'804	138.35
<b>Total Leguminous</b>		14'800	688	10.81
<b>Total excluding grass</b>		2'138'467	9'492	149.16
<b>Total including grass</b>		5'361'466'719	34'040	534.91

Table A – 22 Additional data for estimating N<sub>2</sub>O emission from crop residues (fractions, based on Richner and Sinaj (2017) and FAL/RAC (2001)).

2021		Residue/ Crop ratio	Dry matter fraction of residue	Nitrogen content of residues
		kg/kg	kg/kg	kg/kg
<b>1. Cereals</b>	Wheat	1.15	0.85	0.0037
	Barley	1.00	0.85	0.0051
	Maize	1.10	0.85	0.0086
	Oats	1.27	0.85	0.0049
	Rye	1.17	0.85	0.0036
	Other :			
	Triticale	1.25	0.85	0.0039
	Spelt	1.56	0.85	0.0059
	Mix of Fodder Cereals	1.00	0.85	0.0051
	Mix of Bread Cereals	1.15	0.85	0.0037
	Millet	1.29	0.85	0.0196
	<b>2. Pulse</b>	Dry Beans	1.13	0.85
Peas (Eiweisserbsen)		1.25	0.85	0.0235
Soybeans		1.00	0.85	0.0412
Other:				
Leguminous Vegetables		3.87	0.16	0.0328
Lupines		1.00	0.85	0.0412
<b>3. Tuber and Root</b>	Potatoes	0.47	0.13	0.0127
	Other :			
	Fodder Beet	0.37	0.15	0.0233
	Sugar Beet	0.53	0.15	0.0220
<b>5. Other</b>	Fruit	NA	0.17	0.0040
	Grass	0.24	NA	0.0205
	Green Corn	0.05	0.32	0.0190
	Non-Leguminous Vegetables	0.46	0.13	0.0230
	Rape	2.57	0.85	0.0071
	Renewable Energy Crops	2.57	0.85	0.0071
	Silage Corn	0.05	0.32	0.0118
	Sunflowers	2.00	0.60	0.0150
	Tobacco	1.18	NA	0.0221
	Berries	NA	0.20	0.0060
	Vine	NA	0.20	0.0060
	Oil Squash	0.46	0.13	0.0230
	Oil Hemp	4.62	0.85	0.0106
	Oil Flax	1.25	0.85	0.0071
	Hops	NA	1.00	NA
	Medicinal Plants and Herbs	2.50	NA	0.0330

### A5.3.4 Estimation of the distribution of nitrogen and volatile solids to manure management systems for cattle animals

The fraction of animal manure handled using different manure management systems (MS) as well as the percentages of urine and dung deposited on pasture, range and paddock was separately assessed for each cattle category.

In a first step the share of manure deposited on pasture, range and paddock is calculated assuming that the amount of deposited manure is proportional to the time spent grazing. The estimated grazing time is based on expert judgement and values from the literature (1990, 1995) and on extensive farm surveys (2002, 2007, 2010, 2015 and 2019) (Kupper et al. 2022). The approach is consistent for nitrogen and volatile solids.

Subsequently, the remaining manure is distributed to the different manure management systems. Data for manure management system distribution for cattle are different for VS and nitrogen. This is because cattle stables often have simultaneously both liquid and solid manure storage systems. As volatile solids are excreted mainly in dung and nitrogen mainly in urine, the proportion of VS stored as solid manure is higher compared to the proportion of N.

Estimation of the distribution of nitrogen is conducted within the Swiss ammonium model AGRAMMON and follows a nitrogen mass balance approach. Further details are provided in Kupper et al. (2022).

The distribution of VS was estimated using data on stable systems, manure accumulation and manure properties from Richner and Sinaj (2017; chapter 4, table 4 and 6). For this purpose five different stable systems are distinguished. For tie stall and loose housing systems with slurry production only (“Vollgülle”) it is assumed that all manure goes to liquid systems. For loose housing systems with deep litter 100 % of the manure is allocated to “deep litter”. For tie stall and loose housing systems with simultaneous production of liquid slurry and solid manure (dung) the distribution to the respective storage systems is conducted as exemplified for mature dairy cattle in Table A – 23. The final shares of volatile solids in the different manure management systems is then calculated based on the frequency of the 5 different stable systems as assessed based on expert judgement and values from the literature (1990, 1995) and on extensive farm surveys (2002, 2007, 2010, 2015 and 2019) (Kupper et al. 2022) (Table A – 24).

Table A – 23 Production of slurry and dung and manure management system distribution for nitrogen and volatile solids for mature dairy cattle in stable systems with simultaneous production of slurry and dung (according to Richner and Sinaj 2017).

	slurry*	dung	Richner and Sinaj 2017, chapter 4
Production per year	11 m <sup>3</sup> *year <sup>-1</sup>	8.9 t*year <sup>-1</sup>	table 4
Content of nitrogen	4.5 kg*m <sup>-3</sup>	4.5 kg*t <sup>-1</sup>	table 6
Total amount of nitrogen produced	49.5 kg*year <sup>-1</sup>	40.1 kg*year <sup>-1</sup>	
<b>Distribution of nitrogen</b>	<b>55.3%</b>	<b>44.7%</b>	
Content of volatile solids	40 kg*m <sup>-3</sup>	150 kg*t <sup>-1</sup>	table 6
Total amount of volatile solids produced	440 kg*year <sup>-1</sup>	1335 kg*year <sup>-1</sup>	
<b>Distribution of volatile solids</b>	<b>24.8%</b>	<b>75.2%</b>	

\* all values are for undiluted slurry

Table A – 24 Distribution of nitrogen and volatile solids to different storage systems in different stable systems for mature dairy cattle.

	Distribution of nitrogen <sup>*</sup>		Distribution of volatile solids		Frequency of stable system 2019	Distribution of nitrogen <sup>*</sup>		Distribution of volatile solids	
	Liquid Slurry / Digesters	Solid manure / Deep litter	Liquid Slurry / Digesters	Solid manure / Deep litter		Liquid Slurry / Digesters	Solid manure / Deep litter	Liquid Slurry / Digesters	Solid manure / Deep litter
Tie stall with slurry ("Vollgülle")	100.0	0.0	100.0	0.0	12.8%	80.4%	19.6%	67.7%	32.3%
Tie stall with liquid slurry and solid manure	55.3	44.7	24.8	75.2	29.5%				
Loose housing system with slurry ("Vollgülle")	100.0	0.0	100.0	0.0	44.6%				
Loose housing system with liquid slurry and solid manure	55.3	44.7	24.8	75.2	12.0%				
Loose housing system with deep litter	0.0	100.0	0.0	100.0	1.1%				

<sup>\*</sup> all values for nitrogen are only indicative here as the exact distribution is assessed in a more detailed mass balance approach within the AGRAMMON-model

In order to assess the quality of the final result the distribution of volatile solids was calculated alternatively by multiplying the distribution of nitrogen from the AGRAMMON-model with average VS/N ratios for slurry and solid manure. The resulting values differ only slightly from the estimated distribution of volatile solids.

## A5.4 Land use, land-use change and forestry (LULUCF)

### A5.4.1 Category 4(III) – Direct N<sub>2</sub>O emissions

#### A5.4.1.1 Description

Table A – 25 Key categories in category 4(III) Direct N<sub>2</sub>O from disturbance. Combined KCA results, level for 2021 and trend for 1990–2021, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC category	Gas	Identification criteria
4III	Direct N <sub>2</sub> O from disturbance	N <sub>2</sub> O	L2

This chapter presents the method for calculating direct N<sub>2</sub>O emissions from nitrogen (N) mineralisation in mineral soil (category 4(III)). The source of nitrogen is N mineralisation associated with loss of soil organic matter resulting from change of land use or management of mineral soil. As the approaches applied are not Tier 3, no N<sub>2</sub>O immobilisation is reported (see footnote 1 in CRF Table4(III)).

Direct N<sub>2</sub>O emissions on Cropland remaining cropland (no category registered in CRF Table4(III)) and on Grassland remaining grassland (category 4(III)C1) were included in the Agriculture sector. In Switzerland, grassland is considered to be under agricultural management, see chp. 5.5.1 (category 3Da5). On productive forest land, small annual carbon stock changes in mineral soil are reported that were calculated with the Yasso07 model (chp. 6.4.2.3.5). These changes were deliberately not considered for the calculation of N<sub>2</sub>O emissions in category 4(III) as they are not associated with a land-use change or any change in management. Accordingly, N<sub>2</sub>O emissions for category 4A.1 in CRF Table4(III) are reported as “NO”.

#### A5.4.1.2 Methodological issues

For  $\Delta C_s = 0$  or  $\Delta C_s > 0$  (carbon gain), there are no N<sub>2</sub>O emissions provoked by the specific change of land use or management.

For  $\Delta C_s < 0$ , direct N<sub>2</sub>O emissions were calculated according to IPCC (2019, Volume 4, chp. 11, equation 11.1):

$$\text{Emission(N}_2\text{O)} = - \Delta C_s * 1 / (\text{C:N}) * \text{EF}_1 * 44/28 \quad (\text{kt N}_2\text{O})$$

where:

- $\Delta C_s$ : soil carbon stock change induced by change of land use or management (calculated according to the methodology described in chp. 6.1.3.2) (kt C)
- C:N: C to N ratio of the soil before the land-use change
- $\text{EF}_1$ : default emission factor = 0.01 kg N<sub>2</sub>O-N (kg N)<sup>-1</sup> (IPCC 2019, Volume 4, Table 11.1).

The value of the C:N ratio is related to the land-use category before the change. For Forest land, the default value of C:N = 15 was used (IPCC 2019, Volume 4, equation 11.8). For Cropland and Grassland the ratio is 9.8 according to Leifeld et al. (2007). This value was

also used for mineral soil in unproductive wetland (CC42) and unsealed settlement areas (CC52, CC53, CC54).

### **A5.4.1.3 Uncertainties and time-series consistency**

#### **Uncertainties**

##### *Activity data*

The uncertainty of the activity data corresponds to the uncertainty of the amount of mineralised N. It was calculated as the combined uncertainty of:

- Uncertainty of the carbon stock losses in mineral soil: Land converted to settlements (category 4E2) is the main source in category 4(III). Therefore, the uncertainty of the area converted to settlements (4.6 %; Table 6-5) and the uncertainty of the CO<sub>2</sub> emission factor (50.0 %) were combined to estimate the uncertainty of the carbon stock loss: 50.2 %.
- Uncertainty of the C:N ratio: The uncertainty of the C:N ratio for Forest land was used. With a value of 15 and a 95 %-range between 10 and 30 (IPCC 2019, Volume 4, equation 11.8) the mean uncertainty results in 66.7 %.

The resulting uncertainty of activity data is 83.5 %, calculated as  $(50.2^2+66.7^2)^{0.5}$ .

##### *Emission factor*

A relative uncertainty for the emission factor was taken from IPCC (2006, Volume 4, Table 11.1). Since the uncertainty envelopes are skewed and no negative values occur, a gamma distribution was chosen (see Annex A2.1):

- Uncertainty EF<sub>1</sub>: gamma distribution, 2 standard deviations of 156 %, which corresponds to a 95 % confidence interval (from 2.5 % to 97.5 %) of -91.4 %, +200.8 %

#### **Time-series consistency**

Time series for categories 4(III) N<sub>2</sub>O emissions from nitrogen mineralisation are all considered consistent; they were calculated based on consistent methods and homogenous databases.

### **A5.4.1.4 Category-specific QA/QC and verification**

The general QA/QC measures are described in chp. 1.5.

No category-specific QA/QC activities were carried out.

### **A5.4.1.5 Category-specific recalculations**

- 4(III): Activity data (areas) 2013–2020 were updated (see chp. 6.3.1.5).
- 4(III): Activity data (loss of soil organic matter) were recalculated due to various recalculations of carbon stocks in mineral soil. In the case of a land-use change, the recalculated carbon stocks in mineral soil of Forest land, Cropland, Grassland, Wetlands and Settlements (see chp. 6.4.5, chp. 6.5.5, chp.6.6.5, chp.6.7.5, and chp.6.8.5) led to

recalculations of soil carbon stock changes (deltaCs) following the stock-difference approach (see Table 6-3) and – in a next step – of resulting direct N<sub>2</sub>O emissions.

#### **A5.4.1.6 Category-specific planned improvements**

No category-specific improvements are planned.

### **A5.4.2 Category 4(IV) – Indirect N<sub>2</sub>O emissions**

#### **A5.4.2.1 Description**

Category 4(IV) is not a key category.

This chapter presents the method for calculating indirect N<sub>2</sub>O emissions from managed soils (category 4(IV)). The source of nitrogen is N mineralisation associated with loss of soil organic matter resulting from change of land use or management of mineral soil.

Indirect N<sub>2</sub>O emissions due to atmospheric deposition (category 4(IV)1; all land uses) and nitrogen leaching and run-off on agricultural land (category 4(IV)2; Cropland remaining cropland and Grassland remaining grassland) were included in the Agriculture sector, see chp. 5.5.1 (category 3Db). On productive forest land, small annual carbon stock changes in mineral soil are reported that were calculated with the Yasso07 model (chp. 6.4.2.3.5). These changes were deliberately not considered for the calculation of N<sub>2</sub>O emissions in category 4(IV) as they are not associated with a land use change or any change in management.

#### **A5.4.2.2 Methodological issues**

For deltaCs = 0 or deltaCs >0 (carbon gain), there are no N<sub>2</sub>O emissions provoked by the specific change of land-use or management.

For deltaCs <0, indirect N<sub>2</sub>O emissions were calculated according to IPCC (2019, Volume 4, equation 11.10):

$$\text{Emission(N}_2\text{O)} = - \text{deltaCs} * \text{Fra}_{\text{CLEACH-(H)}} / (\text{C:N}) * \text{EF}_5 * 44/28 \quad (\text{kt N}_2\text{O})$$

where:

- deltaCs: soil carbon stock change induced by change of land use or management (calculated according to the methodology described in chp. 6.1.3.2) (kt C)
- Fra<sub>CLEACH-(H)</sub>: fraction of mineralised N lost by leaching or run-off; see Table 5-27
- C:N ratio as for direct N<sub>2</sub>O emissions (see chp. A5.4.1.2)
- EF<sub>5</sub>: default emission factor = 0.011 kg N<sub>2</sub>O-N (kg N)<sup>-1</sup> (IPCC 2019, Volume 4, Table 11.3).

For calculating deltaCs, the same land-use changes were taken into account as for the direct N<sub>2</sub>O emissions (see chp. A5.4.1; i.e. excluding 4A1, 4B1 and 4C1).

### **A5.4.2.3 Uncertainties and time-series consistency**

#### **Uncertainties**

##### *Activity data*

The uncertainty of the activity data for category 4(IV)2 is 85.8 %. It is the combined uncertainty of the amount of leached N, which was calculated from the amount of mineralised N (uncertainty 83.5 %, see chp. A5.4.1) and  $Frac_{LEACH}$  (uncertainty 20 %, adopted from ART 2008a) (see Table 6-5).

##### *Emission factors*

A relative uncertainty for the emission factor was taken from IPCC (2006, Volume 4, Table 11.3). Since the uncertainty envelopes are skewed and no negative values occur, a gamma distribution was chosen (see Annex A2.1):

- Uncertainty  $EF_5$ : gamma distribution, 2 standard deviations of 178 %, which corresponds to a 95 % confidence interval (from 2.5 % to 97.5 %) of -95.1 %, +233.7 %

#### **Time-series consistency**

Time series for category 4(IV)  $N_2O$  emissions from managed soils are all considered consistent; they were calculated based on consistent methods and homogenous databases.

### **A5.4.2.4 Category-specific QA/QC and verification**

The general QA/QC measures are described in chp. 1.5.

No category-specific QA/QC activities were carried out.

### **A5.4.2.5 Category-specific recalculations**

- 4(IV): Activity data (areas) 2013–2020 were updated (see chp. 6.3.1.5).
- 4(IV)2: Activity data (loss of soil organic matter) were recalculated due to various recalculations of carbon stocks in mineral soil. In the case of a land-use change, the recalculated carbon stocks in mineral soil of Forest land, Cropland, Grassland, Wetlands and Settlements (see chp. 6.4.5, chp. 6.5.5, chp.6.6.5, chp.6.7.5, and chp.6.8.5) led to recalculations of soil carbon stock changes ( $\Delta C_s$ ) following the stock-difference approach (see Table 6-3) and – in a next step – of resulting indirect  $N_2O$  emissions.
- 4(IV): The  $N_2O$  emission factor ( $EF_5$ ) for indirect emissions was changed from 0.0075 to 0.011  $kg N_2O-N (kg N)^{-1}$  according to IPCC (2019).

### **A5.4.2.6 Category-specific planned improvements**

No category-specific improvements are planned.

## Annex 6 Additional information on verification activities

### A6.1 Independent verification of the National Greenhouse Gas Inventory for F-gases

#### *Introduction*

Since 2000, the Swiss Federal Laboratories for Materials Science and Technology (Empa) performs continuous measurements of halogenated greenhouse gases at the high-Alpine site of Jungfraujoch (3'580 m a.s.l.). These measurements are used for estimating emissions of fluorinated greenhouse gases (HFCs, SF<sub>6</sub>) from Switzerland and neighbouring countries. The information can be used for an independent assessment of Swiss inventory data of these greenhouse gases. The independent emission estimate is not used directly for deriving data for the inventory. Data is used, however, to identify either consistency in support of the inventory or discrepancies, which could lead to a reassessment for identifying sources for disagreement and options for improvements.

For the independent assessment of fluorinated greenhouse gas emissions from Switzerland the so-called tracer-ratio method is applied, where Swiss pollution events of HFCs and SF<sub>6</sub>, arriving at Jungfraujoch, are scaled to concurrent pollution events of carbon monoxide (CO) and then multiplied by the Swiss CO emission inventory (see Figure A – 2 for a graphical illustration of the method). Similar approaches are also used for the independent verification of greenhouse gas emissions in the United Kingdom (UK MetOffice – using atmospheric observations from Mace Head (Ireland) combined with atmospheric transport models), in Australia (CSIRO – using the tracer-ratio method with measurements from Cape Grim, Tasmania) and in the US (NOAA – using a combination of airborne and ground-based samples).

#### *Method description*

For estimates of annual Swiss HFC and SF<sub>6</sub> emissions, only observations at the high-Alpine station Jungfraujoch are taken from air masses that are predominantly influenced by emissions from Switzerland. The number of events which can be used each year depends on the meteorological conditions and lies between 7-15 days per year (mostly in the summer). The process to select these periods is shown in Figure A – 2 and is shortly described here. First, the footprints from the COSMO-model are screened for periods when the Jungfraujoch site is under the influence of air masses which were within the Swiss boundary layer for the last 48 hours. Second, for these periods, mixing ratios of halogenated greenhouse gases are compared with those of CO. Periods which show a concurrent increase are selected for the independent assessment of Swiss emissions, as this is taken as an indication of thorough mixing of Swiss emissions during the transport to Jungfraujoch. Third, the emissions are calculated for each case/day using the formula given in Figure A – 2. The resulting emissions are only used for the annual emission estimate if they are within three standard deviations of the average (Grubbs test). This criterion is met by approximately 90 % of the selected data. Finally, annual emissions are estimated as the median of these individual cases. These annual estimates are merged to a 3-year annual average centred over a 3-year period (e.g. the estimate for the 2015 emissions is calculated by using data from 2014–2016). Since 2009, the uncertainty of the estimates for HFCs has been assessed by using the range of the 25 % to 75 % percentiles of the estimates from single pollution events. For estimates between 2001–2008 the average of the 2009–2011 uncertainties has been taken. For SF<sub>6</sub>, with comparably low emissions and a higher degree of uncertainty, an overall uncertainty of

50 % is estimated, based on the long-term average of the 25 % to 75 % percentiles. An additional systematic error could occur if the Swiss emissions of CO are over/underestimated by the inventory. This would linearly impact the emissions of the fluorinated greenhouse gases. Uncertainties may vary from year to year due to the limited amount of data for performing the analysis. Therefore, even subsequent years of lower or higher uncertainty do not signify a change towards lower or higher uncertainty but are just a result of this.

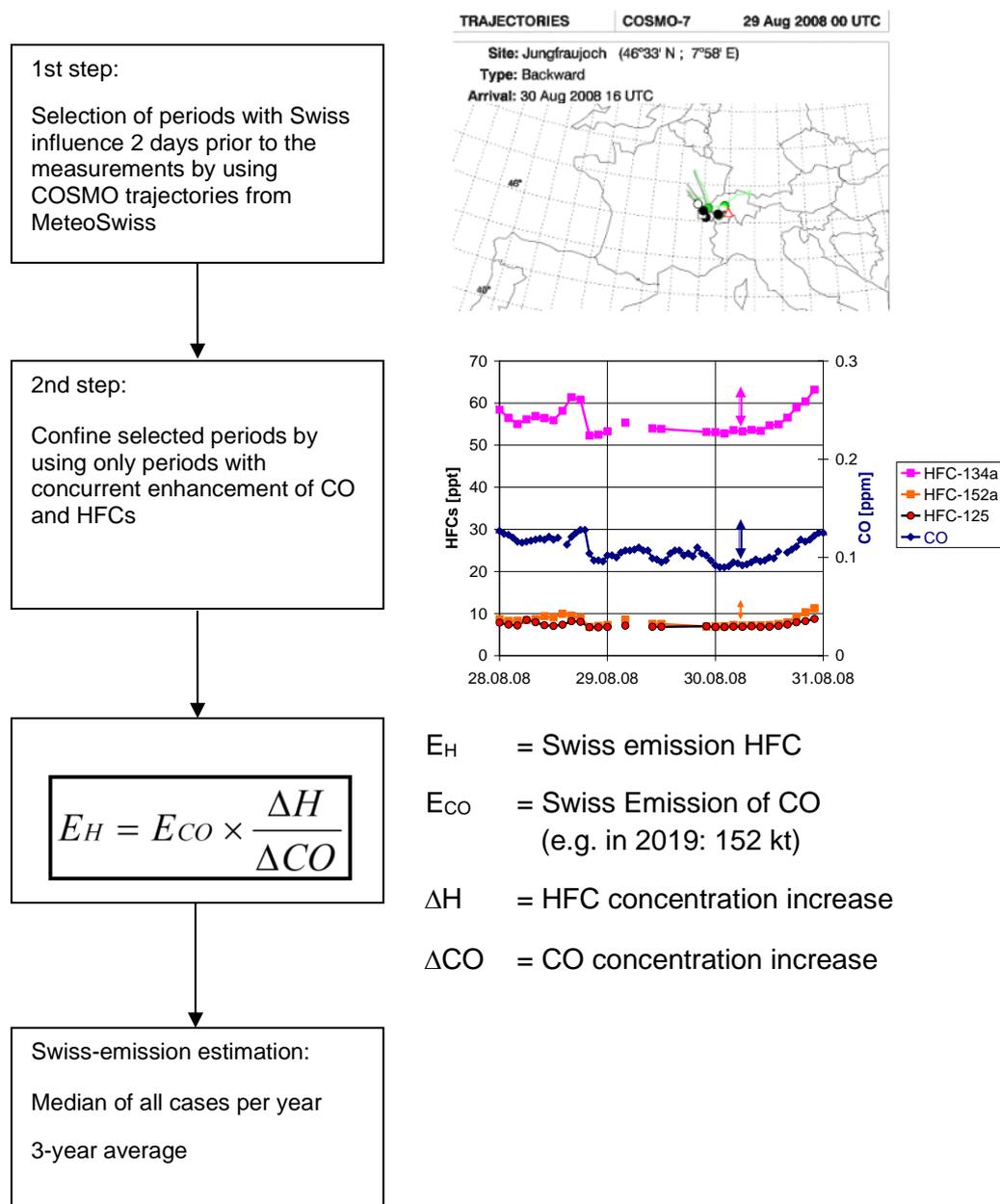


Figure A – 2 Description of the procedure to estimate annual emissions of halogenated greenhouse gases from Switzerland by using continuous measurements of HFCs at Jungfraujoch (Switzerland). Swiss emission of CO ( $E_{CO}$ ) values are taken from FOEN (2021b), see chp. 3.2.4.1 concerning system boundaries.

### Results and discussion

In the following, Swiss emissions of five HFCs (HFC-134a, HFC-125, HFC-152a, HFC-143a, HFC-32) and of  $SF_6$  are estimated based on data from Jungfraujoch and are compared to the

emission estimate of the Swiss greenhouse gas inventory. Further emission estimates of other fluorinated greenhouse gases will be added in future National Inventory Documents (NID) upon availability.

#### HFC-134a

HFC-134a is the most important anthropogenic HFC. One of its main sources is the diffuse emission from its usage as cooling agent in mobile air conditioners (MACs). Further relevant applications are the usage in cooling mixtures in the industrial and commercial refrigeration as well as in stationary air conditioners and heat pumps and as propellant. The stock of HFC-134a in MACs and the related emissions have been steadily increasing until 2016 but are declining in most recent years due to the replacement of HFC-134a in this application by HFO-1234yf. Furthermore, in recent years, HFC-134a is also replaced in other cooling applications, which leads to a steady decline of its emissions.

After a common increase of estimated emissions from 2001 until 2007 both the estimate from Jungfrauoch and the inventory showed a stabilization of the emissions. This could be related to the decreasing HFCs used in propellants and to optimizations in the industrial and commercial refrigeration. In the inventory increasing tendencies are found again from 2008 until 2018, whereas the measurement-based estimate shows no clear trend and fluctuates around 300 tonnes/year. Overall, the agreement between the two methods was excellent from 2001 – 2006; while a discrepancy of ca. 25 % to 40 % is observed between 2012 and 2018 (Figure A – 3). Interestingly, also emission estimates for HFC-134a for the United Kingdom of Great Britain and Northern Ireland show a similar discrepancy in the comparison between measurement-based emission estimates (comparable to those performed here) and the UK inventory (Brown et al. 2019). Since 2019 both estimates show consistent declining numbers, which is more pronounced for the inventory-based emissions.

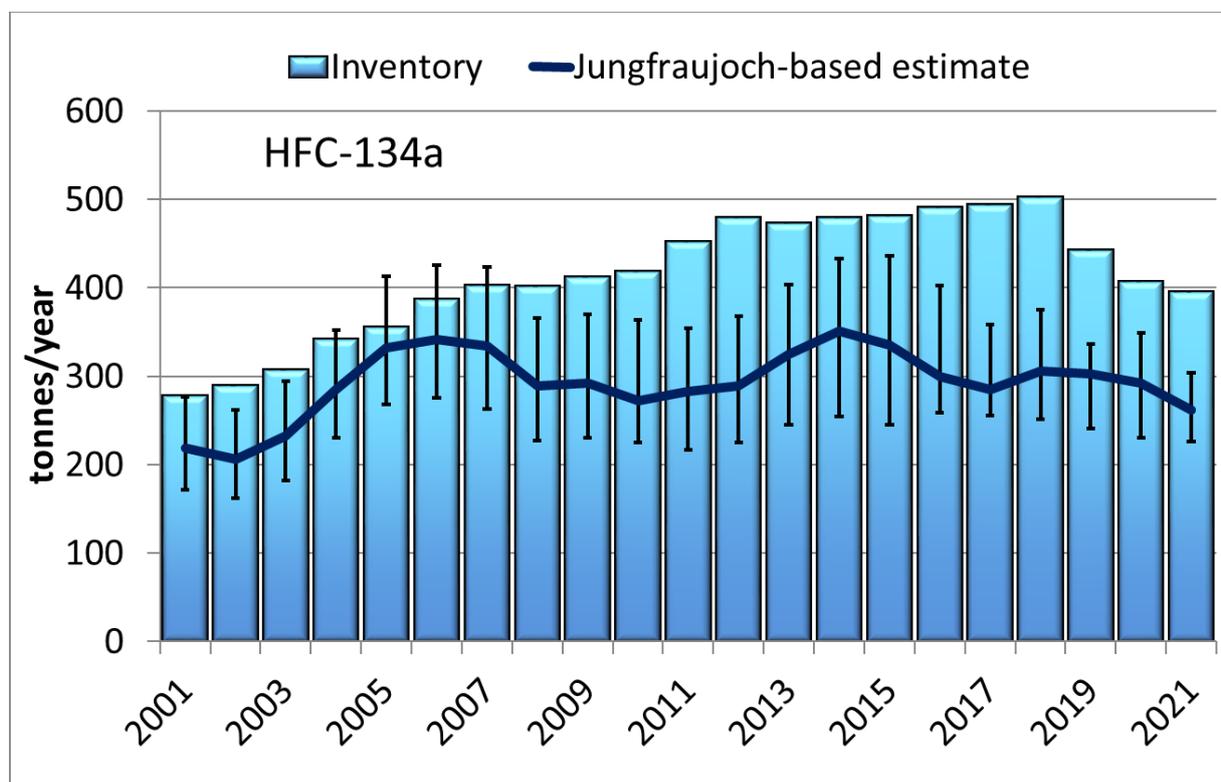


Figure A – 3 Comparison of HFC-134a emissions from Switzerland: Inventory and estimates from measurements at Jungfrauoch.

### HFC-125

HFC-125 is mainly used in cooling mixtures in air conditioners and commercial refrigeration equipment. Estimated emissions from Jungfrauoch measurement data tend to be slightly but consistently lower than in the inventory (Figure A – 4). Emission estimates from Jungfrauoch show a decrease of emissions since 2016 and a stabilization thereafter. Due to efforts to eliminate high-GWP HFCs from refrigeration applications and the related elimination of HFC-125 containing blends, the emissions based on the inventory became stable in recent years and are expected to decrease in the near future. Potentially the timing between the two approaches is different due to differences in the real-world usage of HFC-125 and the model approach in the inventory.

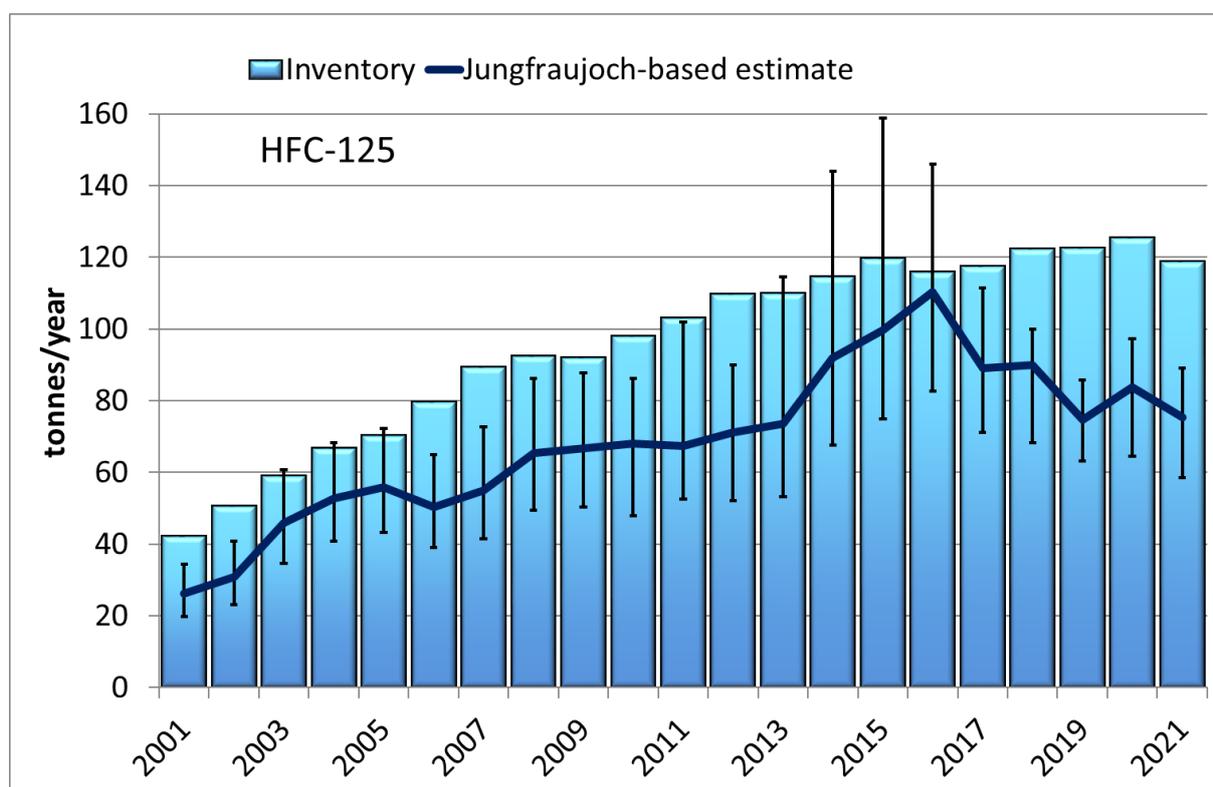


Figure A – 4 Comparison of HFC-125 emissions from Switzerland: Inventory and estimates from measurements at Jungfrauoch.

### HFC-152a

HFC-152a is mainly used as a blowing agent in open-cell polyurethane (PU) foams, in closed cell PU sprays and closed-cell extruded polystyrene (XPS) foams. In open cell foams, 100 % of emissions are related to the blowing process. In closed cell foams, part of the blowing agent remains in the product and emissions occur over its lifetime, with a rate depending on the cell- and molecular-structure of the blowing agent. Unlike for other blowing agents, experts assume that within the first year of the lifetime of the foam 95 % to 100 % of HFC-152a is emitted. The emissions of the first year are commonly allocated to the country of production (according to UNFCCC good practice guidance). These assumptions and allocation are also applied for the model used in the Swiss inventory for estimating HFC-152a emissions under the source category 2F2 (Foam Blowing).

HFC-152a emissions from foams in the inventory are mainly related to the production and consumption of PU spray. Most of other foam products are imported, and consequently these

emissions are allocated to the country of origin. The reported decrease in the inventory since 2003 reflects the replacement of HFC-152a in PU spray.

Up to the year 2002, estimated emissions from Jungfrauoch measurement data are lower than reported in the inventory and from then onwards they are higher. This can be explained by the UNFCCC practice to allocate HFC-152a emissions of the first year to the country of production of foams (which is except for PU spray mainly outside Switzerland). However, in reality a fraction of these first-year emissions occur during the usage of the products (e.g. for insulation) in Switzerland and are, therefore, reflected in the measurements but, by definition, not in the inventory. Nonetheless, it is important to apply the UNFCCC approach in the inventory as otherwise double counting may occur when allocating the total emissions to the country of origin and the country of product use. Emissions estimated from Jungfrauoch show a consistent decrease related to the partial phase-out of HFC-152a from the foam-blowing applications (Figure A – 5).

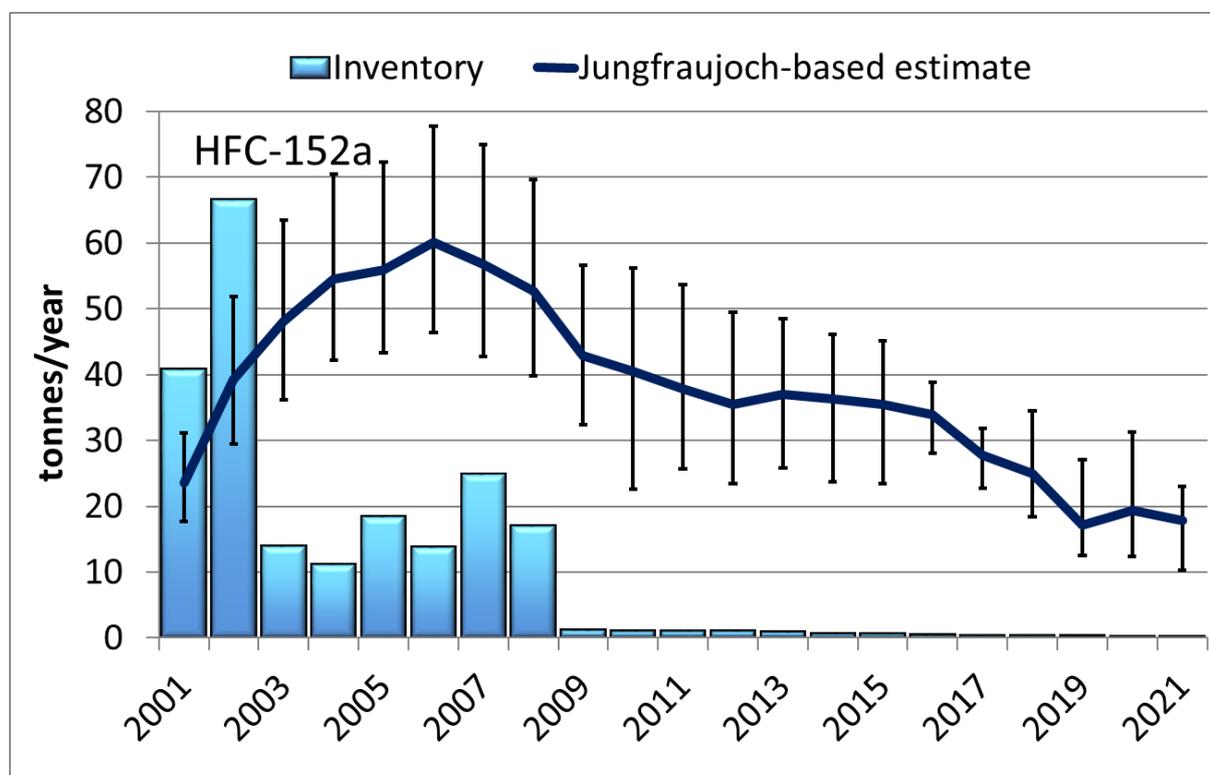


Figure A – 5 Comparison of HFC-152a emissions from Switzerland: Inventory and estimates from measurements at Jungfrauoch.

#### *HFC-143a and HFC-32*

HFC-143a (Figure A – 6) and HFC-32 (Figure A – 7) are mainly used in cooling agent mixtures in commercial refrigeration and stationary air conditioners (together with HFC-134a and/or HFC-125). Until 2013, HFC-143a emissions estimated from Jungfrauoch measurement data were slightly lower than those from the inventory. From 2014–2016, there was a very good agreement between the two methods and a slight decrease in emissions in most recent years, which is seen by both methods. Since 2017 a downward trend is seen by both methods, with a more pronounced tendency by the Jungfrauoch-based method. A further decline is expected in the future because of regulations of HFCs with a high GWP for refrigeration applications and the related elimination of HFC-143a containing blends.

For HFC-32 the measurement-based estimates of HFC-32 have been consistently lower (by about 40 %) than the data from the inventory between 2010 and 2018. In contrast to HFC-125 and HFC-143a, emissions of HFC-32 increased until 2018. This could be due to the fact that HFC-32 has a lower GWP than the other two compounds and is therefore preferably used in new air-conditioner applications. Since 2016, however, stable emissions are estimated by the measurement-based method estimates, whereas the inventory-based method sees a steady increase of emissions. Emissions of HFC-32 are in fact expected to increase, as its low GWP allows its use also in the future for cooling applications. The different behaviour of the two estimates could be of transient nature, as real-world emissions are hold back and will only occur in the future.

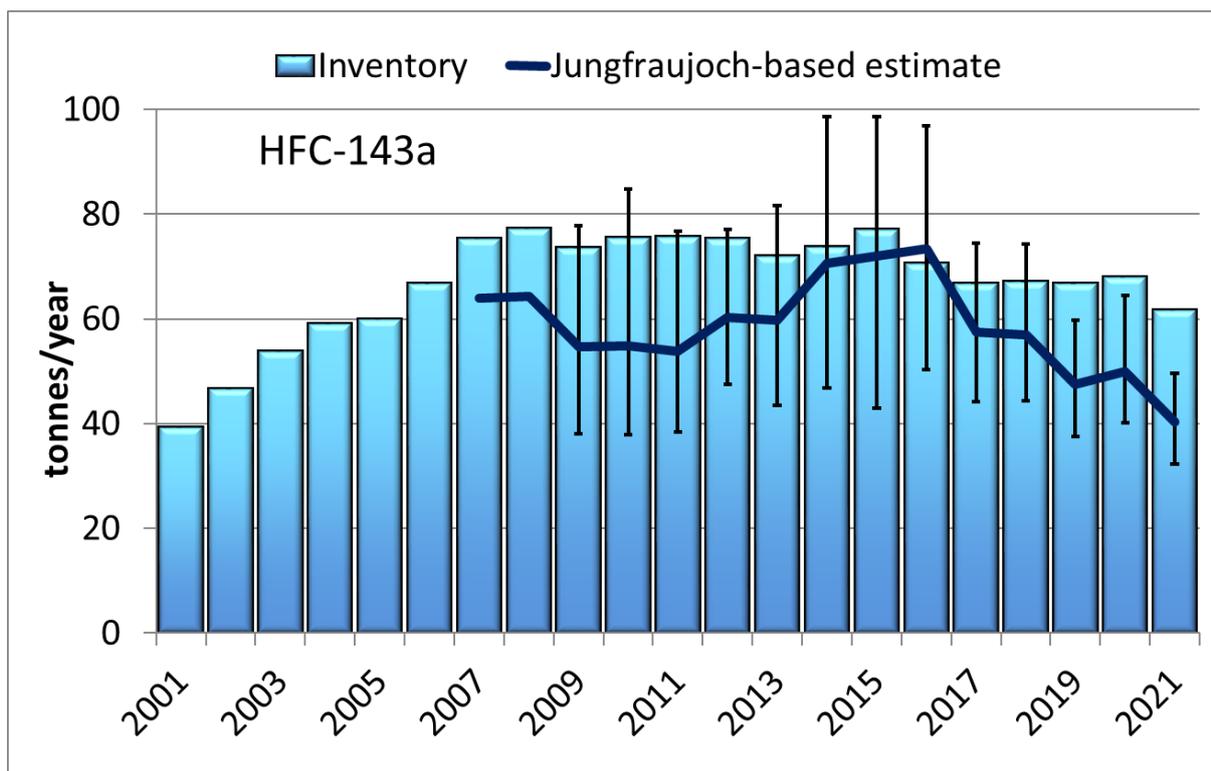


Figure A – 6 Comparison of HFC-143a emissions from Switzerland: Inventory and estimates from measurements at Jungfrauoch.

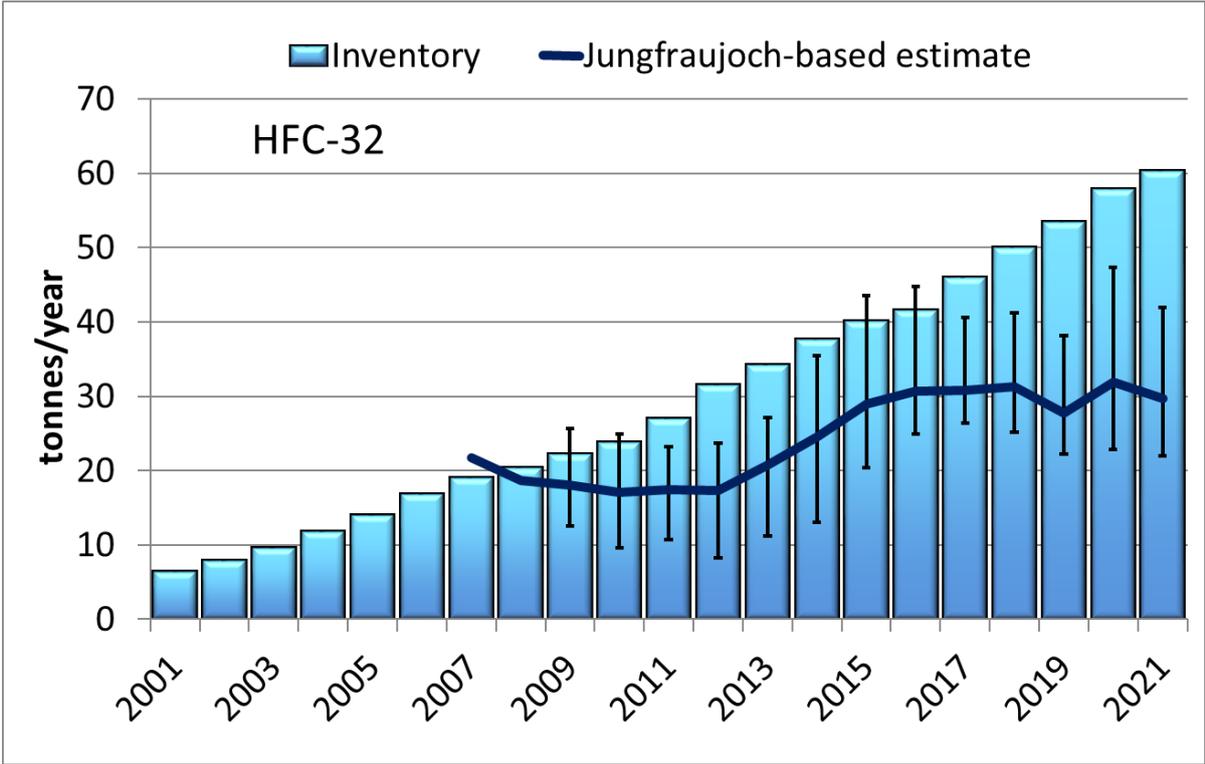


Figure A – 7 Comparison of HFC-32 emissions from Switzerland: Inventory and estimates from measurements at Jungfrauoch.

### *Sulfur hexafluoride (SF<sub>6</sub>)*

Until 2010, emissions of SF<sub>6</sub> in Switzerland were mainly due to its use as an insulator of electrical equipment, as for example in gas insulated switchgears and in gas circuit breakers. Since then, emissions from decommissioning of insulating windows are dominant. Additional minor emissions arise from magnesium smelters, industrial particle accelerators and various other applications. Generally, emission estimates for both methods show a remarkable similarity in the trend. Increasing SF<sub>6</sub> emissions were estimated between 2010 and 2015 and could be the result of the increased disposal of insulating windows (all SF<sub>6</sub> released) during this period. Since then, emissions from the inventory are constantly falling, whereas the Jungfrauoch-based estimate shows more or less stable emissions (Figure A – 8).

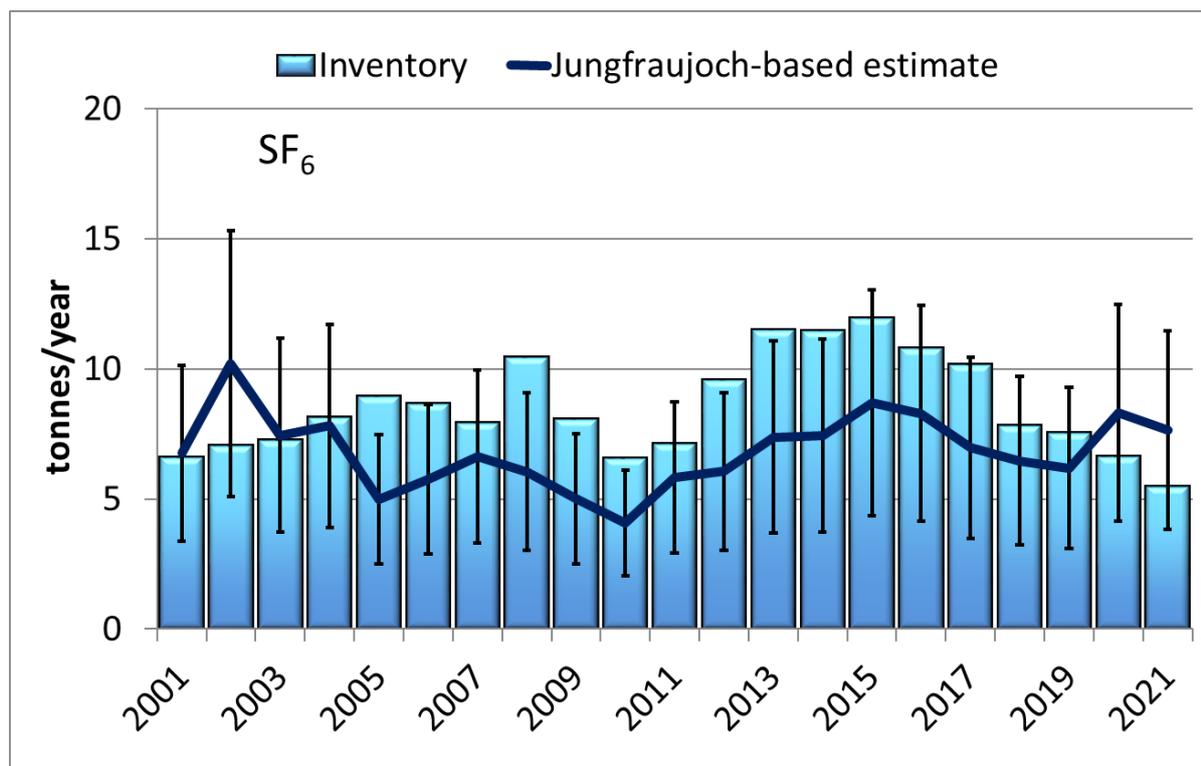


Figure A – 8 Comparison of SF<sub>6</sub> emissions from Switzerland: Inventory and estimates from measurements at Jungfrauoch.

### *Perfluorinated carbons (PFCs)*

Perfluorinated carbons are mainly used and emitted in the electronics industry. Since 2014, all PFCs contained in the NID have been measured at Jungfrauoch, which enables an independent verification of the inventory. Emissions of single PFCs are very small. Therefore, only results for the whole group are reported. Emission estimates for both methods show small emissions of some tonnes per year, which are increasing in recent years (Figure A – 9).

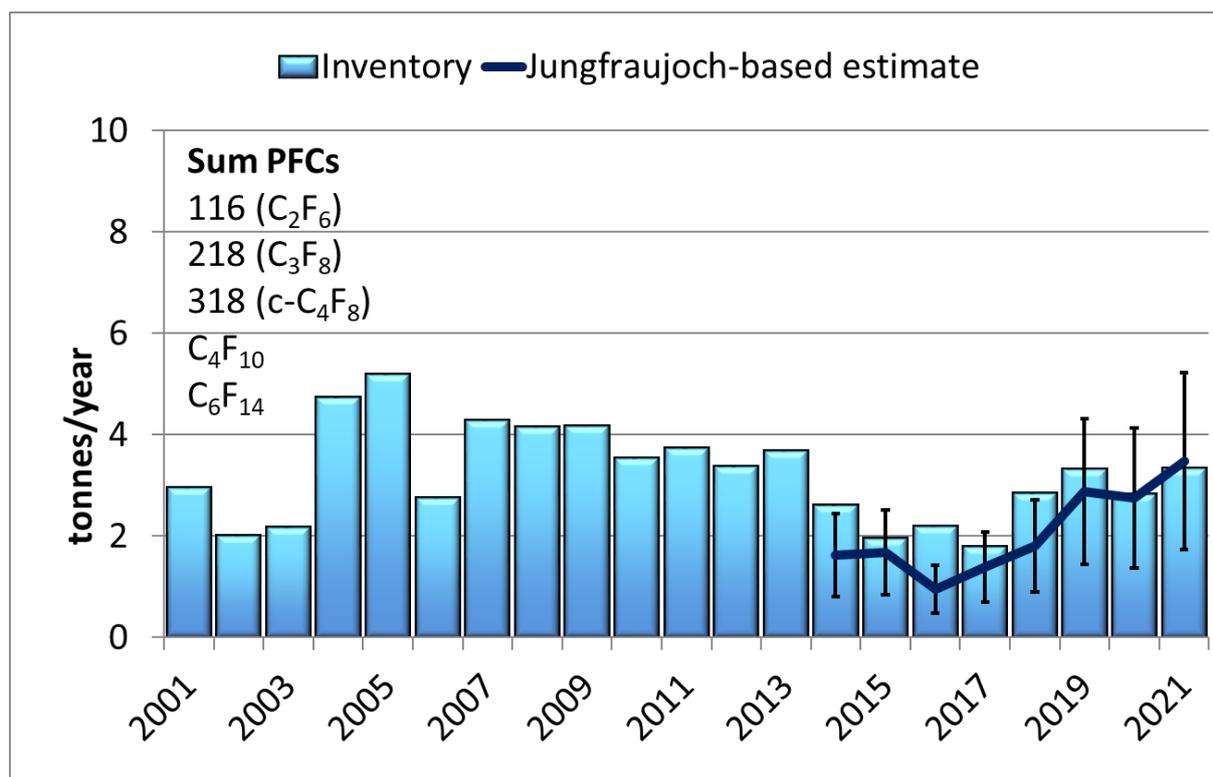


Figure A – 9 Comparison of PFC emissions from Switzerland: Inventory and estimates from measurements at Jungfraujoch.

## A6.2 Independent verification of methane and nitrous oxide emissions by inverse modelling

### Introduction

In 2013 the Swiss Federal Laboratories for Material Science and Technology (Empa), ETH Zurich and the University of Bern established a greenhouse gas (GHG) observing network in Switzerland as part of the CarboCount-CH SNF-Sinergia project ([www.carbocount.ch](http://www.carbocount.ch)). The network consisted of four sites that continuously measure the atmospheric concentration of carbon dioxide (CO<sub>2</sub>) and methane (CH<sub>4</sub>). The sites were chosen to cover most of the densely populated and agriculturally used Swiss Plateau (see Figure A – 10). Atmospheric transport simulations confirm that the measurements at these sites are sensitive to emissions from a large part of Switzerland (Oney et al. 2015). The aim of CarboCount-CH was to better understand and quantify the anthropogenic emissions and biosphere-atmosphere exchange of the abovementioned GHGs by inverse modelling. Currently (March 2023), 3 of the 4 sites (Beromünster, Lägern-Hochwacht, Gimmiz) are still operational, whereas the measurements at Frübüel were closed down in 2016. Additional GHG measurements were carried out in the summer of 2017 in north-eastern Switzerland (Gäbris, GBR, Appenzell) as part of a FOEN-funded validation study to analyse the sensitivity of inverse modelling results to additional measurements in an area poorly covered by the network. Further continuous GHG observations with sensitivity to emissions over Switzerland are available from the high altitude site Jungfraujoch (Empa) and Schauinsland (Germany, UBA, mountain top). High precision measurements of N<sub>2</sub>O commenced in March 2017 at the tall tower site Beromünster and additional N<sub>2</sub>O observations are available from Jungfraujoch and Schauinsland.

Here, the results of inverse modelling to validate total Swiss CH<sub>4</sub> and N<sub>2</sub>O emissions are reported. A previous analysis for CH<sub>4</sub> had been carried out for the measurement period

March 2013 to February 2014, the first year with data available from all four CarboCount-CH sites, which showed good agreement between the NID reporting and the top-down inverse modelling (Henne et al. 2016). That study also raised further questions regarding the spatial and temporal distribution of the emissions and the sensitivity to boundary conditions (i.e., CH<sub>4</sub> baseline concentrations) required for the regional inversion. Additional sensitivity tests concerning the use of additional measurements in north-eastern Switzerland and the use of baseline concentrations from global scale models were reported in a previous NIR (FOEN 2018). Here, results for CH<sub>4</sub> are given for the period 2013 to 2021, whereas for N<sub>2</sub>O inverse modelling results are given for 2017 to 2021.

### Methods

The inversion approach applied here was described in detail in Henne et al. (2016). It is based on source sensitivities that were calculated for each of the mentioned measurement sites with the Lagrangian atmospheric transport model FLEXPART. Source sensitivities give the sensitivity of an atmospheric concentration observation to the emissions released at a distant source and as such can be given as concentration units divided by a mass flux (e.g. ppb kg<sup>-1</sup> s). FLEXPART was driven with high resolution meteorological input data from the numerical weather prediction model COSMO (7 km by 7 km horizontal resolution) provided by the Swiss national weather service (MeteoSwiss) until 2020-10-29 (decommissioning of COSMO-7 forecasts and respective compute hardware). For FLEXPART simulations after 2020-10-29, COSMO-7 analysis fields were calculated by Empa following the previous MeteoSwiss setup as closely as possible. For each site, 3-hourly source sensitivities were calculated by running the model in time-inverted mode, releasing in each 3-hour time interval 50'000 air parcels and following them 4 days backward in time.

When convoluting source sensitivities with gridded surface emission fluxes, atmospheric concentrations at the location of the observations can be obtained. These simulated concentrations can be compared with the measurements, and through “inverse modelling” an optimized (*a posteriori*) emission distribution can be estimated that minimizes the differences between simulated and observed concentrations while also considering the uncertainties of the initial (*a priori*) emission distribution. In addition to the emission distribution, the applied inversion system also optimizes a baseline concentration for each site, which is required to subtract the non-regional contribution from the total observed concentration

In contrast to the previously reported approach (Henne et al. 2016), which contained a large number of sensitivity inversions to investigate the structural uncertainty of the inversion system, only a reduced set of sensitivity inversions was used here, varying some key aspects of the transport model and the inversion system (particle release height, absolute *a priori* emissions, and seasonality).

As *a priori* emissions for Switzerland, the MAIOLICA CH<sub>4</sub> inventory was used (Hiller et al. 2014), which disaggregates the emissions reported by the Swiss National Inventory Report (NIR) onto a regular spatial grid. For emissions outside of Switzerland the European TNO/MACC-2 inventory was employed (Kuenen et al. 2014). The total anthropogenic emissions of the MAIOLICA inventory was 176 kt yr<sup>-1</sup>, which corresponds to the Swiss CH<sub>4</sub> emissions in 2012 as reported by the NIR in 2014 (FOEN 2014). The MAIOLICA inventory also includes a small contribution from natural sources of 3 kt yr<sup>-1</sup> (<2 %). For the application to more recent years the Swiss national total emissions were scaled to those included in the NIR in 2016 (FOEN 2016).

The same inversion technique as for CH<sub>4</sub> was also applied to N<sub>2</sub>O for the period March 2017 to December 2021. In addition to the grid-resolved inversion used for CH<sub>4</sub>, an additional sector-based inversion system was set-up for N<sub>2</sub>O, allowing for the distinction between emissions from different source sectors, but at a reduced spatial resolution (Henne et al. 2019). *A priori* emissions for the N<sub>2</sub>O inversion were developed with a spatial resolution of 500 m by 500 m and for 26 emission sectors based on EMIS/NID total national emission estimates and an evaluation of indirect emissions from (semi-)natural ecosystems (Bühlmann et al. 2015).

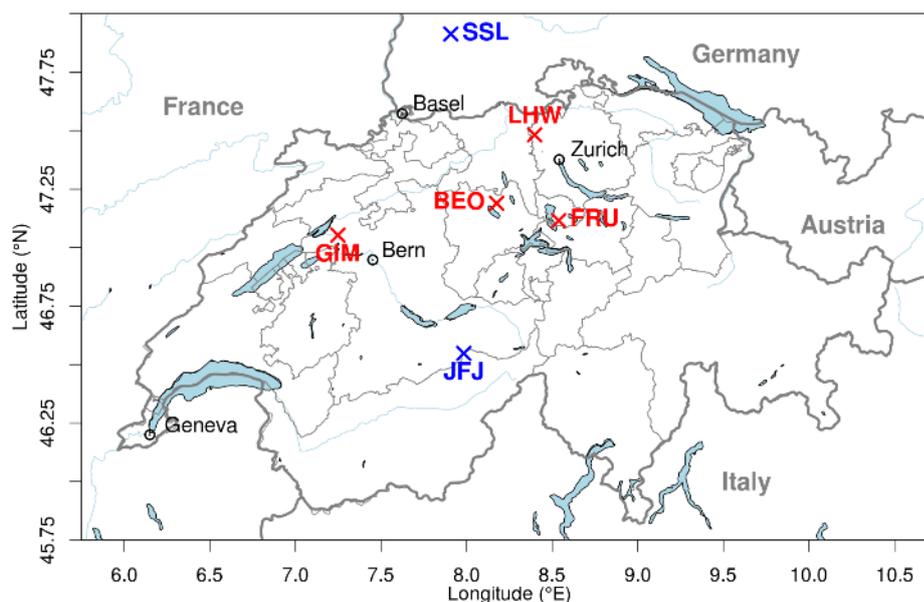


Figure A – 10 Map of Switzerland illustrating the location of CarboCount-CH sites (red), supplementary sites (blue), cantonal and national borders (grey) as well as major cities (black). The sites are: Beromünster (tall tower, BEO), Lägern Hochwacht (mountain top, tower, LHW), Gimmiz (flat, tower, GIM), Fruehbuehl (mountain, near surface, FRU), Schauinsland (mountain top, SSL), and Jungfrauoch (high Alpine, JFJ).

### *Methane emissions*

The inversion results are presented in the following in terms of national total emissions and spatial distribution. The inversion system was not set-up to optimize emissions by category separately, but to estimate the spatial distribution of total emissions. Nevertheless, through the spatial and temporal information the results can provide qualitative insights into the contribution from specific source categories that dominate in a given region or period. Further details and discussion on the inversion performance and results can be found in Henne et al. (2017).

The overall mean inverse estimate of total Swiss CH<sub>4</sub> emissions for the period 2013 to 2021 was  $198 \pm 15$  kt yr<sup>-1</sup> (1- $\sigma$  confidence interval around the mean). This number represents the average and standard deviation over the reference and all sensitivity inversions for all years. It is slightly larger than NID values (incl. emissions from LULUCF) reported in the latest submission (2023) for the same period of 189 kt yr<sup>-1</sup> (CRF Table10s3) but well within the 1- $\sigma$  uncertainty range of  $\sim \pm 15$  kt yr<sup>-1</sup> for the reporting year 2021. Since inverse modelling estimates integrate all fluxes (sources and sinks) between the land surface and the atmosphere, they need to be compared to inventory emissions including those from LULUCF.

For the period 2013 to 2021, the NID suggests a CH<sub>4</sub> emission (incl. LULUCF) reduction of 11.2 kt (from 194 to 183 kt yr<sup>-1</sup> between 2013 and 2021), whereas the inversion estimates

showed large inter-annual variability (range: 175 to 220 kt yr<sup>-1</sup>; standard deviation of 15.0 kt yr<sup>-1</sup> for individual years) with considerably lower emissions in some years (2018, 2019) (Figure A – 11). This variability may mostly reflect the uncertainty of the inverse modelling system itself rather than a real temporal variability in the emissions. Due to this variability it is currently not possible to determine or validate the reported tendency. Additional years of observations and inverse modelling are required for this purpose.

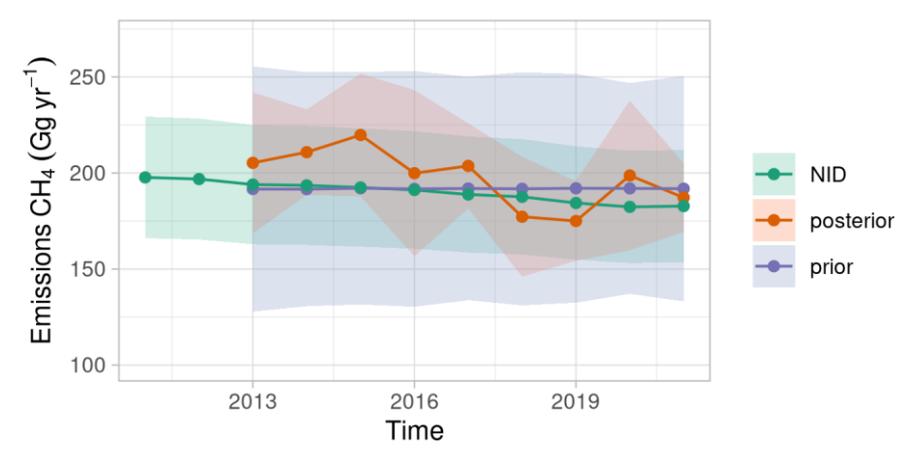


Figure A – 11 Time series of total Swiss CH<sub>4</sub> emissions as reported in the latest NID (green), used as *a priori* information in the inverse modelling (purple), and as estimated by the inverse modelling (*a posteriori*, orange). The uncertainty ribbons give the 95 % confidence ( $2\sigma$ ) level of each estimate.

In Figure A – 12 the spatial distribution of the *a priori* emissions is shown, whereas the absolute differences between *a posteriori* minus *a priori* emissions for individual years are shown in Figure A – 13. An irregular inversion grid was used that exhibits high spatial resolution close to the observations and gets coarser with distance to these. In the *a priori* emissions the dominating role of agricultural emissions in the rural areas of the Cantons Lucerne and Thurgau/Appenzell is clearly seen. In contrast, the densely populated areas of Zurich, Basel and Geneva do not show up as emission hot-spots, consistent with the small contribution of emissions from natural gas distribution and wastewater treatment reported in the NID.

The *a posteriori* results for the nine analysed years (2013 to 2021) in terms of annual totals and spatial distribution were rather similar providing evidence for the robustness of the method. The *a posteriori* emissions were smaller than *a priori* emissions in the agricultural areas of Canton Lucerne, but were increased in the north-eastern part of Switzerland (Cantons Appenzell and Saint Gallen). Smaller differences were seen in other parts of the country.

Previously, an alternative sensitivity inversion was performed that used *a priori* emissions from the EDGAR inventory (v4.2 FT2010, EC JRC 2009). In EDGAR, the Swiss country total amounts to 228 kt yr<sup>-1</sup>, mostly due to about 25 kt yr<sup>-1</sup> larger emissions from the natural gas distribution network (IPCC category 1B2: fugitive emissions from oil and gas). *A posteriori* emissions in this sensitivity inversion were very similar to those of the reference inversion, which in turn required large reductions from the *a priori* distribution especially in densely populated areas. From this Henne et al. (2016) concluded that the natural gas emissions as given in the NID (8 kt yr<sup>-1</sup>) are in much better agreement with the atmospheric observations than the emissions in the EDGAR inventory (32 kt yr<sup>-1</sup>).

When allowing the inversion to derive seasonal mean instead of annual mean emissions, a clear seasonal cycle with reduced winter time and increased spring to summer emissions was detected for all years (Figure A – 14). This is in line with the temperature-dependent seasonality expected from manure handling and storage (lower emissions at lower temperatures) and the productivity-dependent seasonality of milk cows (spring maximum in productivity and calving date). However, considerable variability in the seasonality was observed for different years, sometimes showing a secondary summer minimum (2018) and in other years a summer maximum (2019). In 2021 exceptionally high emissions were observed in fall. In how far these variations could be traced to climate variability needs yet to be analysed.

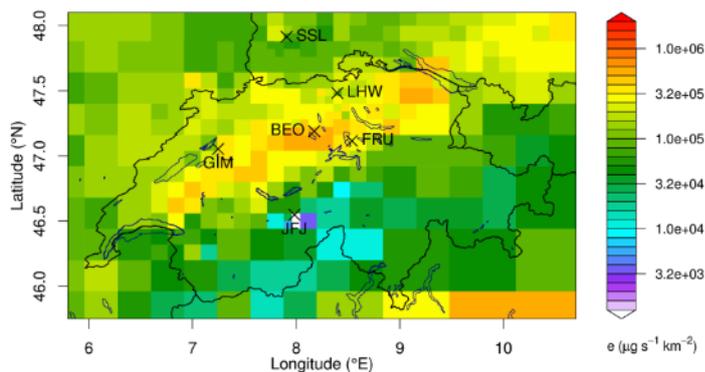


Figure A – 12 Spatial distribution of *a priori* CH<sub>4</sub> emissions. Within Switzerland the distribution follows that derived by Hiller et al. (2014), scaled to the bottom-up estimates of the NIR 2016 (FOEN 2016), outside Switzerland the bottom-up inventory of TNO/MACC (Kuenen et al. 2014) was used.

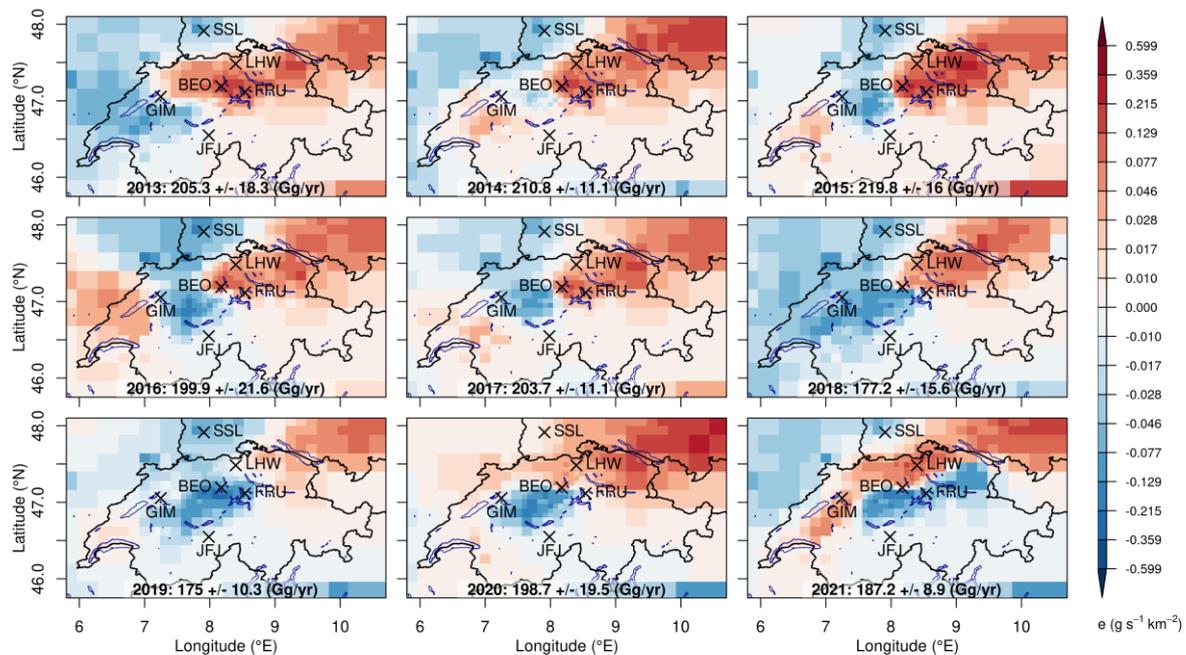


Figure A – 13 Absolute difference between *a posteriori* and *a priori* mean annual CH<sub>4</sub> emissions (each being the mean over 8 sensitivity runs). The numbers given in the plots refer to the total *a posteriori* Swiss emissions and their uncertainty (1 $\sigma$  level) for the given year.

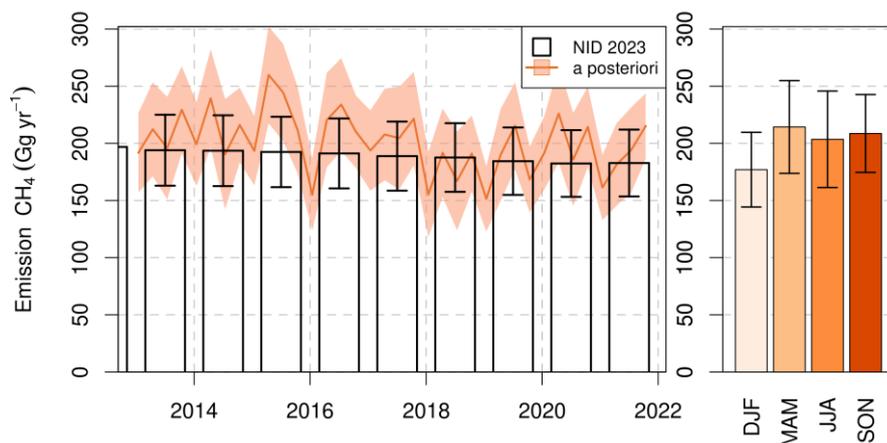


Figure A – 14 Seasonality of Swiss CH<sub>4</sub> emissions. Left panel: NID values and their uncertainties are given as black bars and error bars. *A posteriori* emissions are given as orange line and uncertainty ribbons. Average *a posteriori* emissions by season are given on the right panel (DJF: December, January, February; MAM: March, April, May; JJA: June, July, August; SON: September, October, November). All uncertainties refer to 2- $\sigma$  confidence intervals.

### Nitrous oxide emissions

With the N<sub>2</sub>O observations established at the Beromünster tall tower site in 2017, it was possible to estimate Swiss N<sub>2</sub>O emissions by inverse methods at the country scale for the period March 2017 to April 2018 (Henne et al. 2019). Inversely estimated Swiss N<sub>2</sub>O emissions were slightly larger than reported N<sub>2</sub>O emission. However, due to the large uncertainties connected to these numbers, the inverse estimates are not significantly different from the NID estimates. The relative uncertainty of the inverse modelling estimate was smaller than that of the NID estimate. The uncertainty range of the inverse method was calculated from the spread across 14 sensitivity inversions. These comprised the application of two different inversion approaches: one focussing on the spatial distribution (grid inversion), the other on the temporal evolution and emissions by sector (sector inversion). The largest contributors to the *a posteriori* spread were the definition and uncertainty of a baseline of the atmospheric concentrations required by the model approach and systematic differences between grid and sector inversions.

The inverse modelling methodology described in Henne et al. (2019) was extended to the period 2017 to 2021. A slightly different set of 14 sensitivity inversions (per year) was selected, using both inversion approaches and varying important factors of the inversion setup: baseline, a priori emissions, receptor height above model ground.

The best inverse estimate of Swiss annual N<sub>2</sub>O emissions for the years 2017 to 2021 was 10.8±3.1 Gg yr<sup>-1</sup>. This compares to 11.5 (8.3 to 14.9) Gg yr<sup>-1</sup> given for the same period in this NID (incl. emissions from LULUCF; 2- $\sigma$  confidence range; compare Figure A – 15). With recent updates in the present NID, inverse estimates and NID estimates agree very closely. The small downward trend, as present in the NID for the most recent years, can be seen in the inverse estimate as well, but is not significant given the short time period and uncertainties.

The inversion model assigned the by far largest share of N<sub>2</sub>O emissions to agricultural soils (central and eastern Swiss Plateau) and to a smaller degree to indirect emissions from (semi-)natural ecosystems (southern Switzerland) and agricultural soils (northern Switzerland) (compare Figure A – 16 for spatial distributions of emissions; Figure A – 17 for emissions by sector). The general increase from agricultural lands and (semi)natural

ecosystems may partly be explained by solely natural N<sub>2</sub>O emissions, which were not taken into account in the applied *a priori* inventory, since they are not part of the NID (only indirect emissions from (semi)natural ecosystems were considered). However, the inverse estimates for individual sectors are not completely in line with the NID. NID estimates are generally larger for the non-agricultural sectors and smaller for agriculture. Reductions in the uncertainty of these estimates were largest for the sectors 'direct agriculture', 'industry and use', and 'indirect (semi-)natural'. Lower than *a priori* emissions were assigned to other types of anthropogenic emission sectors, mainly industry and use. However, the changes in this and other smaller sectors were associated with larger uncertainties and considerable negative covariance towards the major emission sectors. Hence, it cannot be concluded that they are significant. However, some further support for reduced industry and use emissions is provided by the grid inversions, which also estimated that emissions in urban areas are potentially overestimated in the NID.

All inversions suggested a pronounced seasonality in the emissions with a mean amplitude over all inversions of around  $\pm 40\%$  of the annual total (Figure A –18). Largest emissions were estimated in summer, smallest in winter. However, there was considerable spread in the seasonal amplitude as well, with the tendency of inversions with smaller annual total emissions to predict smaller summertime emissions and correspondingly smaller seasonal amplitudes. Seasonality was dominated by emissions from soils. The strong seasonality obtained here for Switzerland compares well with other recent inverse estimates of N<sub>2</sub>O emissions in Europe. Some of these studies also highlight a similarly pronounced seasonality (Ganesan et al. 2015, Brown et al. 2019).

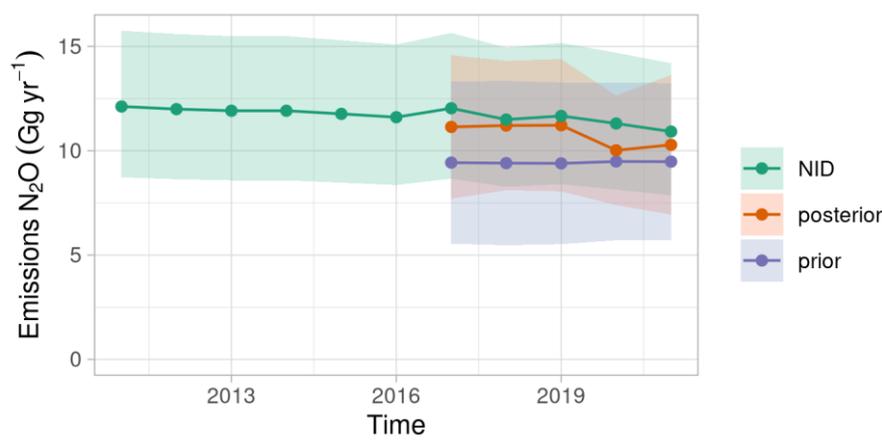


Figure A – 15 Time series of inversely estimated and NID reported Swiss N<sub>2</sub>O emissions. (NID reported and inversely estimated annual values and their uncertainties are given by lines, symbols and uncertainty ribbons. All uncertainty indicators refer to 2- $\sigma$  levels.

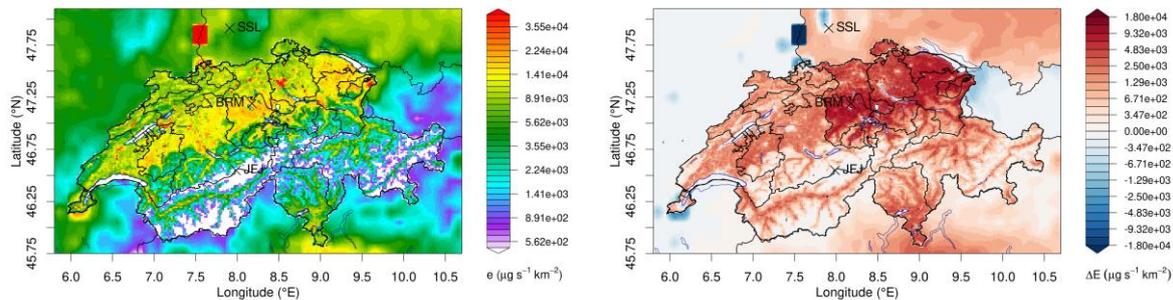


Figure A – 16 (Left) mean *a priori* and (right) *a posteriori* minus *a priori* N<sub>2</sub>O emission distribution over all sensitivity inversions (sector inversion only) for the period 2017 March to 2021 November.

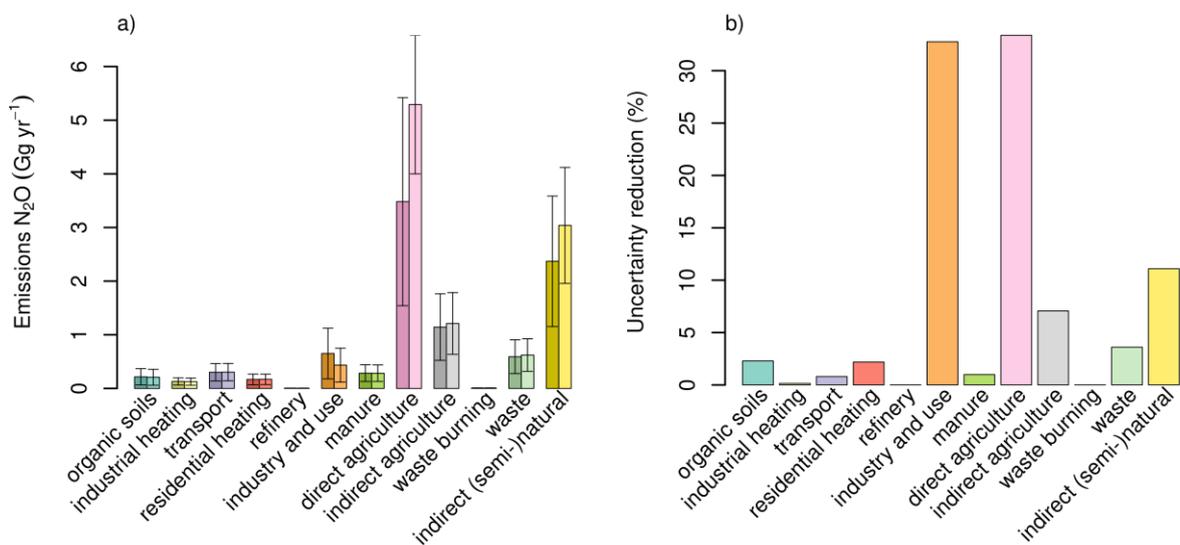


Figure A – 17 (Left) contributions to Swiss N<sub>2</sub>O emissions: *a priori* darker colours, *a posteriori* lighter colours. (right) reduction of uncertainty estimate from a *a priori* assumption to inverse a *a posteriori* estimate. Results present the average for the period 2017 March to 2021 November. Uncertainty bars represent 2- $\sigma$  confidence intervals.

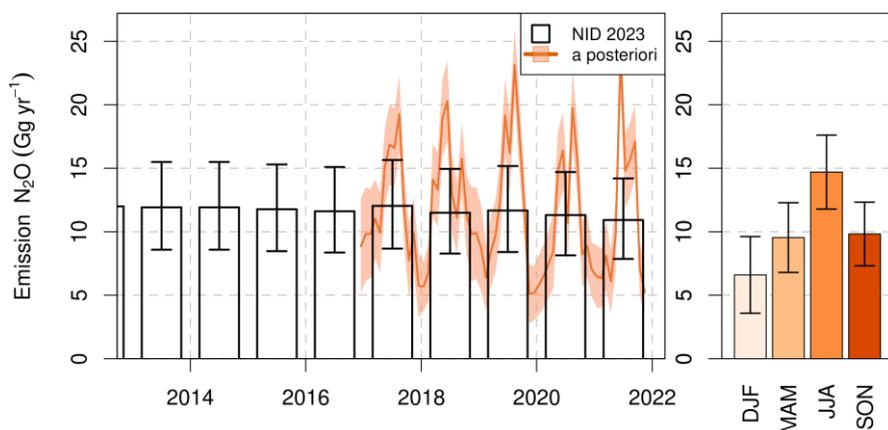


Figure A – 18 Seasonality of Swiss N<sub>2</sub>O emissions. Left panel: NID values and their uncertainties are given as black bars and error bars. Monthly *a posteriori* emissions are given as orange line and uncertainty ribbons. Average *a posteriori* emissions by season are given on the right panel (DJF: December, January, February; MAM: March, April, May; JJA: June, July, August; SON: September, October, November). All uncertainties refer to 2- $\sigma$  confidence intervals.

## Annex 7 Information on the CRF reporter

For the submission at hand the CRF reporter v6.0.10\_AR5 provided by UNFCCC in late January 2023 has been used. The CRF reporter still seems to generate errors in the numerical output of some reporting tables. A non-exhaustive list of issues and errors identified so far is provided in Table A – 26. In some instances where numbers are not identical in the reporting tables (CRF) and in the NID, a remark was added in the NID. This aspect should be taken into consideration when comparing information in the NID with the reporting tables.

Table A – 26 Identified issues or errors in the output of some reporting tables (CRF).

Reporting table CRF	Problem	Solution
Table1A(d)	The column "Reported under..." should include the NFR code in the Text.	Actually, there is no possibility to change it, because a drop-down-menu determines the text.
Table2(I)s1-s2	In all empty cells should be written „NO“, but the effort would be very big to generate in the navigation tree of the CRF web application for every cell a new node and then to adapt all the import files to these changes.	Because the effort would be quite big, and there is no real benefit, we passed on it.
Table2(II)	In all empty cells should be written „NO“, but the effort would be very big to generate in the navigation tree of the CRF web application for every cell a new nod and then to adapt all the import files to these changes.	Because the effort would be quite big, and there is no real benefit, we indicate in the documentation box: „2.B.9, 2.C, 2.E, 2.F.1-2.F6, 2.G: "NO" for all empty cells“.
Table2(II)B-Hs1	In Line 50 of the reporting table the emissions are indicated as kt CO <sub>2</sub> eq instead of t.	Problem in the CRF web application.
Table3.B(a)s2	NFR codes 3B4g and 3B4hi: cells I55 and L103 are still empty despite of correctly imported values.	Problem in the CRF web application.
Table3.B(b)	The IEF for "indirect emissions from atmospheric deposition" (cell R37): Wrong molecular weight. The IEF is displayed in kg N <sub>2</sub> O per kg N handled instead of kg N <sub>2</sub> O-N per kg N handled.	Problem in the CRF web application.
Table3s1; Table3.As1; Table3.As2; Table3.B(a)s1; Table3.B(a)s2; Table3.B(b)	All cells for "Cattle, Option A" should be filled with "IE" but this Option A cannot be selected together with Option B.	Problem in the CRF web application. Solved with comment in documentation boxes of tables Table3.As1,

		Table3.B(a)s1, Table3.B(b)
Table4	N <sub>2</sub> O from 4(IV) (indirect emissions) are included in the total sum in Table 4 without being displayed in any subcategory in Table 4. The sum is correct (with indirect emissions).	Inaccuracy in the CRF web application. The total in the table is not equal to the sum of the subcategories shown in the table.
Table4	There are several empty cells in the CH <sub>4</sub> and N <sub>2</sub> O columns, where numbers and/or notation keys are not inserted.	Problem in the CRF web application.
Table4(V)	"Values" and "IEF" in lines 8 to 10 are missing.	Problem in the CRF web application.
Table5 Table5.C	The entry "5.C.1.1.b.iii Sewage Sludge:" in the last line of the documentation box is redundant.	Problem in the CRF web application.
Summary3s1 Summary3s2	Empty cells in "Method applied" and "Emission factor" for several sectors and gases: There should be indicated "NO" instead of empty cells.	Inaccuracy in the CRF web application. „NO“ is not imported and there is no possibility to change it, because „NO“ or „NA“ are not in the drop-down menu.
Summary3s1 Summary3s2	Some method and emission factor information are not imported into the web application.	Problem in the CRF web application.
Table8s4	PFC emissions from 2G2 are also displayed under 2G4.	Problem in the CRF web application.
Table8s4	For HFCs and PFCs values for previous submission are calculated with GWP from AR4. (From a helpdesk e-mail (ANAIS-4180): "The current behaviour for the previous submission data in the recalculation tables is that single gases – CH <sub>4</sub> , N <sub>2</sub> O, SF <sub>6</sub> and NF <sub>3</sub> – will appear with AR5 GWPs while, while gas groups – HFCs and PFCs – will appear with AR4 GWPs.")	Known behaviour of the CRF web application. Occurrence only in this submission.
Table9	For some entries "no gas" is documented for the first column "GHG" with no additional information.	Problem in the CRF web application.
Table9	For "allocation used by Party" 4.D an additional ' has to be added in front of 4.D in the web app. Else in the reporting tables is written 4.00 instead of 4.D	Problem in the CRF web application.
Table10s1	For CO <sub>2</sub> eq in sector 4 LULUCF,	Inaccuracy in the CRF web

	the total is not equal to the sum of the displayed CO <sub>2</sub> eq emissions in the categories 4A+4B+4C+4D+4E+4F (rows 40 to 47) but includes also indirect N <sub>2</sub> O from 4(IV) in CO <sub>2</sub> eq. The sum is correct (with indirect emissions).	application.
Table10s2	Empty cell for CO <sub>2</sub> captured in the year 2005.	Problem in the CRF web application.
Table10s4	For N <sub>2</sub> O in sector 4 LULUCF, the total is not equal to the sum of the displayed N <sub>2</sub> O emissions in the categories 4A+4B+4C+4D+4E+4F (rows 39 to 46) but includes also indirect N <sub>2</sub> O from 4(IV). The sum is correct (with indirect emissions).	Inaccuracy in the CRF web application.
All	Documentation box entries are not consistent. Sometimes all entries are in a single cell, sometimes there are several lines with entries, some of them empty.	Inaccuracy in the CRF web application.

## **Annex 8 Common reporting tables**

Reporting tables in the common reporting format (CRF) as created by the CRF Reporter v6.0.10\_AR5 (January 2023) and making use of GWP values from the 5. Assessment Report of the IPCC (Myhre 2013) have been submitted for the years 1990–2021.

## **Annex 9 Additional information under Article 7 of the Kyoto Protocol**

### **A9.1 Information on changes in the national system**

No changes compared to Switzerland's National Inventory Report (NIR) 2022 (FOEN 2022).

### **A9.2 Information on changes in the national registry**

No changes compared to Switzerland's National Inventory Report (NIR) 2022 (FOEN 2022).

In September 2022, a new version of the registry software was deployed to the PRODUCTION environment to adapt the emissions trading registry to national legislation. However, this new registry version does not impact the ITL connection or the Annex H CP2 conformance in any way.

### **A9.3 Information on minimization of activities under Article 3, paragraph 14, of the Kyoto Protocol**

For the latest information see chp. 4.13 Economic and social consequences of response measures (minimising adverse effects) in Switzerland's Eighth National Communication and Fifth Biennial Report submitted to the UNFCCC on 16 September 2022 (FOEN 2022j).

### **A9.4 Activities under Article 3, paragraphs 3 and 4, of the Kyoto Protocol**

Not applicable. See Switzerland's National Inventory Report (NIR) 2022 for the latest relevant information (FOEN 2022).

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# References to EMIS database comments

Table A – 27 Assignments of NFR Codes to titles of EMIS (Swiss Emission Information System) database comments. These internal documents will be made available to reviewers on request.

NFR Code CRF [UNECE]	EMIS Title	NFR Code CRF [UNECE]	EMIS Title
1 A	Energiemodell***	2 D 3 a [2 D 3 g]	Gummi-Verarbeitung**
1 A	Holzfeuerungen	2 D 3 a [2 D 3 g]	Klebband-Produktion
1 A 2	Sektorgliederung Industrie	2 D 3 a [2 D 3 g]	Klebstoff-Produktion**
1 A 1 a	Kehrichtverbrennungsanlagen	2 D 3 a [2 D 3 g]	Lösungsmittel-Umschlag und -Lager
1 A 1 a	Sondermüllverbrennungsanlagen	2 D 3 a [2 D 3 g]	Pharmazeutische Produktion**
1 A 1 a & 5 A	Kehrichtdeponien	2 D 3 a [2 D 3 g]	Polyester-Verarbeitung
1 A 1 b	Heizkessel Raffinerien* (ab 2016)	2 D 3 a [2 D 3 g]	Polystyrol-Verarbeitung**
1 A 1 c	Holzkohle Produktion	2 D 3 a [2 D 3 g]	Polyurethan-Verarbeitung
1 A 2 a & 2 C 1	Eisengiessereien Kupolöfen	2 D 3 a [2 D 3 g]	PVC-Verarbeitung
1 A 2 a	Stahl-Produktion Wärmeöfen**	2 D 3 a [2 D 3 g]	Gerben von Ledermaterialien
1 A 2 b	Buntmetallgiessereien übriger Betrieb**	2 D 3 b	Strassenbelagsarbeiten**
1 A 2 b & 2 C 3	Aluminium Produktion	2 D 3 c	Dachpappe**
1 A 2 c & 2 B 8 b [2 B 10 a]	Ethen-Produktion*	2 D 3 d	Urea (AdBlue) Einsatz Strassenverkehr
1 A 2 d & 2 A 4 d	Zellulose-Produktion Feuerung*	2 G 3 a	Lachgasanwendung Spitäler**
1 A 2 f	Kalkproduktion, Feuerung*	2 G 3 b	Lachgasanwendung Haushalt**
1 A 2 f	Mischgut Produktion	2 G 4 [2 D 3 a]	Pharma-Produkte im Haushalt
1 A 2 f	Zementwerke Feuerung	2 G 4 [2 D 3 a]	Reinigungs- und Lösemittel; Haushalte
1 A 2 f & 2 A 3	Glas übrige Produktion*	2 G 4 [2 D 3 a]	Spraydosen Haushalte**
1 A 2 f & 2 A 3	Glaswolle Produktion Rohprodukt*	2 G 4 [2 D 3 h]	Verpackungsdruckereien**
1 A 2 f & 2 A 3	Hohlglas Produktion*	2 G 4 [2 D 3 h]	Druckereien uebrige**
1 A 2 f & 2 A 4 a	Feinkeramik Produktion*	2 G 4 [2 D 3 i]	Entfernung von Farben und Lacken**
1 A 2 f & 2 A 4 a	Zegeleien**	2 G 4 [2 D 3 i]	Entwachsung von Fahrzeugen
1 A 2 f & 2 A 4 d	Steinwolle Produktion*	2 G 4 [2 D 3 i]	Kosmetika-Produktion**
1 A 2 g iv	Faserplatten Produktion* (ab 2020)	2 G 4 [2 D 3 i]	Lösungsmittel-Emissionen IG nicht zugeordnet
1A2gvii, 1A3c, 1A3e, 1A4ai/bii/cii, 1A5b (without military aviation)	Non-Road	2 G 4 [2 D 3 i]	Öl- und Fettgewinnung
1 A 2 g viii & 5 B 2	Vergärung IG (industriell-gewerblich)	2 G 4 [2 D 3 i]	Papier- und Karton-Produktion**
1 A 3 a & 1 A 5	Flugverkehr	2 G 4 [2 D 3 i]	Parfum- und Aromen-Produktion**
1 A 3 b i-viii	Strassenverkehr	2 G 4 [2 D 3 i]	Tabakwaren Produktion**
1 A 3 c	Schiennenverkehr	2 G 4 [2 D 3 i]	Textilien-Produktion**
1 A 3 e	Gastransport Kompressorstation	2 G 4 [2 D 3 i]	Wissenschaftliche Laboratorien
1 A 4 b i	Holzkohle-Verbrauch	2 G 4 [2 G]	Korrosionsschutz im Freien
1 A 4 b i	Lagerfeuer	2 G 4 [2 G]	Betonzusatzmittel-Anwendung
1 A 4 c i	Gewächshäuser**	2 G 4 [2 G]	Coffeursalons
1 A 4 c i	Graströcknung**	2 G 4 [2 G]	Fahrzeug-Unterbodenschutz**
1 A 4 c i & 5 B 2	Vergärung LW (landwirtschaftlich)	2 G 4 [2 G]	Feuerwerke
1 B 2 a iii	Raffinerie, Pipelinetransport	2 G 4 [2 G]	Flaechenenteisung Flughafeen
1 B 2 a iv	Raffinerie, Leckverluste*	2 G 4 [2 G]	Flugzeug-Enteisung
1 B 2 a iv	H2-Produktion*	2 G 4 [2 G]	Frostschutzmittel Automobil
1 B 2 a iv	Raffinerie, Clausanlage*	2 G 4 [2 G]	Gas-Anwendung
1 B 2 a v	Benzinumschlag Tanklager	2 G 4 [2 G]	Gesundheitswesen übrige**
1 B 2 a v	Benzinumschlag Tankstellen	2 G 4 [2 G]	Glaswolle Imprägnierung*
1 B 2 b ii & 1 B 2 c ii 2	Gasproduktion & Gasproduktion, Flaring	2 G 4 [2 G]	Holzschutzmittel-Anwendung
1 B 2 b iv-vi	Netzverluste Erdgas	2 G 4 [2 G]	Klebstoff-Anwendung**
1 B 2 c ii 1	Raffinerie, Abtackelung	2 G 4 [2 G]	Kosmetik-Institute
2 A 1	Zementwerke Rohmaterial	2 G 4 [2 G]	Kühlschmiermittel-Verwendung
2 A 1	Zementwerke übriger Betrieb	2 G 4 [2 G]	Medizinische Praxen**
2 A 2	Kalkproduktion, Rohmaterial*	2 G 4 [2 G]	Pflanzenschutzmittel-Verwendung
2 A 2	Kalkproduktion, übriger Betrieb*	2 G 4 [2 G]	Reinigung Gebäude IGD**
2 A 4 d	Kehrichtverbrennungsanlagen Karbonat**	2 G 4 [2 G]	Schmierstoff-Verwendung
2 A 4 d	Karbonatanwendung weitere	2 G 4 [2 G]	Spraydosen IndustrieGewerbe
2 A 5 a	Gips-Produktion übriger Betrieb*	2 G 4 [2 G]	Tabakwaren Konsum
2 A 5 a	Kieswerke	2 G 4 [2 G]	Steinwolle-Imprägnierung*
2 B 1	Ammoniak-Produktion*	2 H 1	Faserplatten Produktion* (ab 2020)
2 B 10 [2 B 10 a]	Ammoniumnitrat-Produktion*	2 H 1	Zellulose Produktion übriger Betrieb*
2 B 10 [2 B 10 a]	Chlorgas-Produktion*	2 H 1	Spanplatten Produktion*
2 B 10 [2 B 10 a]	Essigsäure-Produktion* (ab 2013)	2 H 2	Bierbrauereien
2 B 10 [2 B 10 a]	Formaldehyd-Produktion	2 H 2	Branntwein Produktion
2 B 10 [2 B 10 a]	PVC-Produktion	2 H 2	Brot Produktion
2 B 10 [2 B 10 a]	Salzsäure-Produktion*	2 H 2	Fleischräuchereien
2 B 10 [2 B 10 a]	Schwefelsäure-Produktion*	2 H 2	Kaffeeöstereien
2 B 10	Kalksteingrube*	2 H 2	Müllereien
2 B 10	Niacin-Produktion*	2 H 2	Wein Produktion
2 B 2	Salpetersäure Produktion*	2 H 2	Zucker Produktion
2 B 5	Graphit und Siliziumkarbid Produktion*	2 H 3	Sprengen und Schiessen
2 C - 2 G	Synthetische Gase	2 I	Holzbearbeitung
2 C 1	Eisengiessereien Elektroschmelzöfen	2K, 1A1a, 2C1, 5A, 5C1, 5E & 6Ad	Emissions due to former PCB usage
2 C 1	Eisengiessereien übriger Betrieb	2 L	NH3 aus Kühlanlagen
2 C 1 & 1 A 2 a	Stahl-Produktion Elektroschmelzöfen**	3	Landwirtschaft
2 C 1	Stahl-Produktion übriger Betrieb**	3 B	Tierhaltung
2 C 1	Stahl-Produktion Walzwerke**	3 C	Reisanbau
2 C 7 a	Buntmetallgiessereien Elektroöfen**	3 D e	Landwirtschaftsflächen
2 C 7 c	Verzinkereien	4 V A 1 [11 B]	Waldburände
2 C 7 c	Batterie-Recycling*	5 B 1	Kompostierung
2 D 1	Schmiermittel-Anwendung	5 B 2	Biogasaufbereitung (Methanverlust)
2 D 1	Schmiermittel-Verbrauch B2T	5 C 1 [5 C 1 a]	Abfallverbrennung illegal
2 D 2	Paraffinwachs-Anwendung	5 C 1 [5 C 1 b i]	Kabelabbrand
2 D 3 a [2 D 3 d]	Farben-Anwendung Bau	5 C 1 [5 C 1 b iii]	Spitalabfallverbrennung
2 D 3 a [2 D 3 d]	Farben-Anwendung andere	5 C 1 [5 C 1 b iv]	Klärschlammverbrennung
2 D 3 a [2 D 3 d]	Farben-Anwendung Haushalte**	5 C 1 [5 C 1 b v]	Krematorien
2 D 3 a [2 D 3 d]	Farben-Anwendung Holz	5 C 2 / 4 V A 1 (Forstwirtschaft)	Abfallverbrennung Land- und Forstwirtschaft und Private
2 D 3 a [2 D 3 d]	Farben-Anwendung Autoreparatur**	5 D 1 [5 D]	Kläranlagen kommunal (Luftschadstoffe)
2 D 3 a [2 D 3 e]	Elektronik-Reinigung**	5 D 2 [5 D]	Kläranlagen industriell (Luftschadstoffe)
2 D 3 a [2 D 3 e]	Metallreinigung**	5 D 1 / 5 D 2 [5 D]	Abwasserbehandlung GHG
2 D 3 a [2 D 3 e]	Reinigung Industrie übrige**	5 E	Shredder Anlagen
2 D 3 a [2 D 3 f]	Chemische Reinigung**	6 A d	Brand- und Feuerschäden Immobilien
2 D 3 a [2 D 3 g]	Druckfarben Produktion**	6 A d	Brand- und Feuerschäden Motorfahrzeuge
2 D 3 a [2 D 3 g]	Farben-Produktion**	[11 C]	NMVOE Emissionen Wald
2 D 3 a [2 D 3 g]	Feinchemikalien-Produktion**	1, 2, 5, 6 - indirect	Indirekte Emissionen

\* confidential process

\*\* confidential EMIS comment

\*\*\* work in progress

Cursive: process not relevant for the years after 1990.