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Methodology to derive generic inventories

Make everything as simple as possible, but not simpler.

(Albert Einstein)

Contents

Executive summary

The present project aims to answer a central question, which is currently of great concern in the LCA world: "Is it possible to extrapolate LCIA data available for a given situation to another situation, where data are missing?"
Any person who already performed a LCA knows the time requirements for LCI data gathering and for LCIA calculation. Interest in having a methodology to derive LCIA data from a given country to another one or to derive LCIA data from a given product to another one is thus very important. We try to give a first answer to this question with the present project.

The developed methodology is thought for the impact assessment of the *agricultural production of bio-based material* and for their post-production treatments *until the farm gate*. We do not consider transport, further industrial processing, packaging, distribution or retail in this project. Only commercial production is considered, subsistence farming is not the purpose of the study. Case studies take place in five groups of vegetable species, peas and beans, root vegetables, herbs and spices, cocoa and cereals, in order to test the practicability and the performance of the methodology.

Two extrapolation methods are proposed in this project, having different degrees of refinement. Both extrapolation methods rely on a set of assumptions described in details in the present report and enable a very quick extrapolation of LCIA data. The basic method corresponds to a yield correction. The more sophisticated one is described as a "modular inventory" in the present document.

The modular inventory starts from the hypothesis that an inventory for crop production can be split into several modules, corresponding to the management axes (soil cultivation, fertilisation or crop protection for instance) that can be varied independently to a certain extent. For each module, one input parameter is required. Less than ten inputs have to be quantified instead of several dozens or even hundreds in case of a classical inventory of agricultural products. If the values of the input parameters are not known in a given situation, estimators can be used instead of an accurate value. The estimators have been developed in the frame of this project too, based on the FAOSTAT database. They are available for any country.

The application of the modular inventory for geographical extrapolation shows a very important time saving and relative user friendliness. The comfort of use should be improved by programming a conventional IT tool before a large application of the system.

Two additional questions are continually encountered in the course of this study:
"What is the loss of accuracy by extrapolating LCIA data instead of establishing a new specific LCIA for the current situation?"
"What are the limits for the application of the developed methodology? In which cases, is it meaningful to extrapolate LCIA data and in which cases is a new inventory necessary?"

The developed methodology has been applied to a set of crops, in which some are present in the ecoinvent database too. It enables us to compare the results obtained by applying the modular inventory with the corresponding ecoinvent datasets. The results show a relatively good accordance with the ecoinvent LCIA data for ozone formation and energy demand, a lower one for the global warming potential. The modular inventory extrapolation seems to perform relatively well for these impact categories. The results of the modular inventory extrapolation are significantly correlated to the ecoinvent LCIA data for energy demand and acidification. The modular inventory can thus determine these impact categories but should be improved in order to assess them better. For eutrophication, the modular inventory extrapolation in its current form badly assesses the impacts. For ecotoxicity and human toxicity impacts, a reliable assessment is not feasible without having detailed data on pesticide use.

The results are promising, but further improvement, refinement, extension and validation is necessary, before the methodology can be widely used.

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Abbreviations and acronyms

ART	Agroscope Reckenholz-Tänikon Research Station
BR	Brazil
CED	Cumulative Energy Demand
CH	Switzerland
D.M.	Dry matter
Eq (or eq)	Equivalent
F.M.	Fresh matter
FS	File System
ha	Hectare
IP	Integrated Production
IPCC	Intergovernmental Panel on Climate Change
kg	Kilogram
L	Litre
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LU	Livestock Unit
MJ	Mega joules
MY	Myanmar
SALCA	Swiss Agricultural Life Cycle Assessment
USA or US	United States of America

1 Introduction

LCA has become a common approach for assessing the environmental impact of products, of activities or of companies. The trade intensification across the whole world, the diversification of the production paths and the increasing mobility of humans make a follow-up of the product life cycles tedious. A large number of good quality datasets as well as rapid assessment procedures are required to make LCA practicable. These two requirements are not always met. We can currently observe that a lot of LCAs are carried out with inventories developed for situations that do not match the considered case on the one hand and on the other hand that the methods used to compute emissions are sometimes very different. Both of these weaknesses are related to the lack of specific input data and to the absence of a simple, standardised and transposable methodology to estimate emissions. This project makes a step towards overcoming these obstacles.

The present document constitutes the final report of the ART-project CH-2008-0779 commissioned by Unilever. The general topic is the variability of bio-based materials and its handling in the LCA approach. The concept of bio-based materials includes food products, but also cosmetics, drugs or bio-fuels for instance. The goal is to develop a methodology to derive generic inventories for these materials. In order to set up the procedure to derive generic datasets, we use concrete case studies, arranged in five different crop groups: herbs and spices, peas and beans, root vegetables, cereals and cocoa. The present work deals solely with the agricultural stage of the whole production chain of bio-based products. We limit our research to the farm gate and do not consider transport, industrial processing, packaging, distribution, use or waste treatment.

Two types of extrapolation have been approached in this project: geographical extrapolation with a high degree of detail and case studies and a short insight in product extrapolation. For product extrapolation, a basic extrapolation method by yield correction is theoretically proposed. For geographical extrapolation, the same yield correction approach can also be used. Better estimates are thought to be achieved by a second method, more sophisticated, called “modular inventory” extrapolation in the present document. The “modular inventory” methodology constitutes the core part of this project.

This introduction describes the context of the project and the impact categories considered. The second chapter explains the possible types of extrapolation and details the basic extrapolation using a yield correction. Chapter 3 presents the idea of the modular inventory, the procedure to use it and a simplified procedure using estimators. It is the theoretical part of the project. The concrete implementation of the modular inventory, its use and its practicability are described in chapter 4. Two new inventories have been developed, one for pepper and one for cocoa, and are documented in chapter 5. Both methods, the extrapolation by yield correction and the modular inventory extrapolation, are applied to selected crops (case studies) (chapter 6). In chapter 7, plausibility checks and verification are performed. An analysis of the relations between key parameters and LCIA results is done in chapter 8, by the means of a multivariate analysis on two databases and a sensitivity analysis of the modular inventory, using realistic variability of the inputs. The last chapter (chapter 9) is a discussion and conclusion of the project. The limitations of the developed methods are discussed, conclusions are drawn and some possible ways to improve the methods are presented. The aspects, for which a deeper investigation would be worthwhile, from our point of view, are outlined.

1.1 Considered impact categories

Several impact categories have been analysed in this project:

- Demand for non-renewable energy resources [MJ-eq] (oil, coal and lignite, natural gas and uranium), using the upper heating or gross calorific value for fossil fuels according to (Frischknecht *et al.*, 2004).
- Global warming potential over 100 years [kg CO_2-eq] (IPCC, 2006).

- Ozone formation potential [kg ethylene-eq] (so-called "summer smog" according to the EDIP97 method) (Hauschild & Wenzel, 1998).
- Eutrophication potential [kg N-eq] (impact of the losses of N and P to aquatic and terrestrial ecosystems, according to the EDIP97 method) (Hauschild & Wenzel, 1998)
- Acidification potential [kg SO_2-eq] (impact of acidifying substances released into ecosystems, according to the EDIP97 method(Hauschild & Wenzel, 1998)
- Terrestrial ecotoxicity potential [kg 1,4-DCB-eq] (impact of toxic pollutants on terrestrial ecosystems, according to the CML01 method) (Guinée *et al.*, 2001)
- Aquatic ecotoxicity potential [kg 1,4-DCB-eq] (impact of toxic pollutants on aquatic ecosystems, according to the CML01 method) (Guinée *et al.*, 2001)
- Human toxicity potential [kg 1,4-DCB-eq] (impact of toxic pollutants on human health, according to the CML01 method) (Guinée *et al.*, 2001)
- Water use expressed as the total amount of water abstracted from water bodies ("blue water" according to (Milà i Canals *et al.*, 2009) [m^3]
- Land use expressed as the total land occupation as described in (Guinée *et al.*, 2001) (CML01) [m^2 year]

For the ecotoxicity and human toxicity assessment methods, new and additional characterisation factors have bee calculated by ART for about 400 pesticide active ingredients. They have been used in the LCA calculations by SALCA. As these factors are not included in ecoinvent, the results for these three categories cannot be compared.

2 Methodological development for the extrapolation of LCIA data

2.1 TYPES OF EXTRAPOLATION

The need of LCIA data for various situations, and the related time and effort required for the inventory data collection, explains the interest for having recourse to LCIA data extrapolation. Extrapolation is intended as a mathematical operation in which new data points are created *outside* a set of known data points. This process is generally performed by observing the behaviour of a variable against an explanatory variable inside the set of known data points and by assuming that this behaviour is the same outside the set of known data points.

We can distinguish two types of situations in which extrapolations are useful:

1. LCIA data for a crop Y are not available and it would be difficult to create a new inventory and to calculate the LCIA for this crop (due to lack of data, time or money limitations). Some LCIA data are however available for a "similar" crop X in the same producing country (or region). A way to derive the expected LCIA data for the crop Y would be to use the LCIA data of the crop X and to extrapolate them to the specific situation of the crop Y. This operation of determining the environmental impacts of a new crop (outside the set of known data points) based on the environmental impacts of an already known crop will be called *product extrapolation*.

2. LCIA data for the considered crop are already available for its production in one or several countries A but not yet for its production in a specific country B. The LCIA data for the production of the crop in the new geographical situation of the country B could be derived from the LCIA data for the production of the crop in the country(ies) A, where there are already some LCIA data. Determining the environmental impacts of the production of a given crop in a new geographical context (outside the set of known data points) based on the environmental impacts of this crop production in a (some) already characterised country(ies) will be called *geographical extrapolation*.

A purely statistical approach for extrapolation is not applicable in our case, due to the complexity of the relationships between crop management, site parameters (soil, climate, topography), yield and environmental impacts. The proposed methodology is based on simplification and modelling of know relationships and mechanisms of crop production and their environmental impacts. Two different degrees of complexity are proposed for the extrapolation: a basic one using a yield correction and a more sophisticated one using the theory of the modular inventory.

In this project, we focus more on geographical extrapolation than on product extrapolation.

2.2 THREE LEVELS OF CROP IMPACT ASSESSMENT

As mentioned above, we can distinguish different levels of complexity (or of refinement) in estimating LCIA data new situations (new geographical situation or new product situation). We mainly distinguish three levels in this project:

Level 1: Simple extrapolation by yield correction

A statistical analysis of the datasets from ecoinvent and SALCA (presented in AI) shows that a correlation exists between the inverse of the yield and several environmental impacts. A possibility for a simple approximation is therefore to calculate the average or the median of the impacts per area unit from existing inventories, that are considered to be somewhat similar (section 8.4), and to apply a yield correction. The method will be developed for both geographical and product extrapolation and illustrated below (sections 2.3 and 2.4).

Level 2: Extrapolation using the modular crop inventories

This method is designed as an intermediate way enabling to define more specific crop inventories, without the necessity for defining a very detailed inventory for each situation, as for level 3. The procedure is explained in more detail in chapter 3. This is the core part of the project. Its application has been restricted to the geographical extrapolation until now.

Level 3: Detailed crop inventories followed by the emissions calculation and the impact assessment

This third procedure is the classical method to define inventories of crops and then to assess the related environmental impacts (as e.g. applied in the ecoinvent or SALCA databases, which are the state-of-the-art for crop LCI/LCIA). This is relatively time consuming and requires a lot of specific data. All good practitioners apply this procedure and there is no need of further explanations. The datasets defined at this level will however serve for validation purposes (chapter 7), as well as starting point (known data point) for the extrapolation using the modular crop inventories (chapter 6).

The succession of the complexity levels for getting new LCIA data implies (from level 1 to level 3): an increased level of detail, an increased workload and time required and a decrease of uncertainties and inaccuracy.

We describe the application of the procedure corresponding to the lowest degree of complexity, the extrapolation by yield correction, in the two next sections.

2.3 PRODUCT EXTRAPOLATION BY YIELD CORRECTION

Analysing the datasets of ecoinvent (statistical analysis in AI), we note that some impacts are more related to the cultivated area, while others are more related to the yield (Table 2-1).

Table 2-1 Coefficient of variation[1] of impacts per kg and per ha for 14 wheat, barley and rye datasets from ecoinvent.

	Energy	GWP	Ozone	Acidi	Eutro	TET_EDIP	AET_EDIP	HTP_CML	AET_CML	TET_CML
CV per kg	31%	26%	33%	30%	43%	169%	35%	27%	249%	299%
CV per ha	24%	30%	20%	44%	43%	141%	21%	35%	197%	254%

The best estimation can therefore be achieved by taking both into account, impacts per area unit and impacts per product unit. The following model is therefore proposed:

$$E_p^c = e_p \times \frac{E_a^{c'}}{Y^{c'}} + (1 - e_p) \times \frac{E_a^{c'}}{Y^c}$$

Where:

E_p^c = Environmental impact per product unit of the considered crop *c* [impact kg $^{-1}$]

$E_a^{c'}$ = Environmental impact per area unit of similar crops *c'* (median of the crop inventories considered as similar according to the criteria in section 8.4) [impact ha $^{-1}$]

$Y^{c'}$ = Median yield of the similar crops *c'* (corresponding to $Ea^{c'}$) [kg ha $^{-1}$]

Y^c = Yield of the considered crop *c* [kg ha $^{-1}$]

e_p = Fraction of the environmental impacts related to the yield

1 The coefficient of variation is defined as the ratio between the standard deviation and the arithmetic mean.

If $e_p = 1$, it means that the impacts per area unit are proportional to the yield, in other words the impacts per kg are constant. In such a case, the median of the impacts per kg of a group of similar products can directly be used as an estimate of the impacts per kg of considered product. However, a different and more robust weighting is introduced by first calculating the median of the impacts per ha and then dividing them by the median yield. This second approach is preferred.
If $e_p = 0$, it means that the impacts per area unit do not vary with the yield; they are constant per area unit. Higher yield will consequently lead to lower impacts per kg.
The truth lies in many cases in between. The application of the model can lead to a better estimation of this parameter (e_p), which depends on the crop and the impact considered.

We illustrate the method with the cereal datasets from ecoinvent. We use 14 datasets for wheat, barley and rye, excluding the 3 datasets from organic production. The median D.M. yield is 4593 kg/ha, the median energy demand is 15512 MJ/ha. The median gave better and more robust results than the mean. In particular toxicity values are strongly biased and the median gives a better estimate than used the arithmetic mean.

e_p was estimated to be 0.7 from the cereal datasets, which means that 70% of the impacts are mainly related to the yield (or production intensity) and 30% to the cultivated area. This value was determined by calculating the absolute deviations between the extrapolated and the original values. With e_p=0.7, the deviations were the lowest. In principle, different values could also be used for different impact categories. However, this would require quite large datasets to obtain reliable figures. The impacts have revealed to be not very sensitive to small changes in e_p; values of 0.6 or 0.8 would lead to similar results.
Cereals are known to respond strongly to the production intensity; using more fertilisers and pesticides leads to an increase of yield. This would imply relatively high values for e_p. We assume that the value of e_p could be lower for crops having a lower yield response to inputs, like e.g. apple. However, we have not enough data to confirm or to reject such a hypothesis.

As a default value, in case of lack of more precise data, we propose to use $e_p = 0.5$ (half of the impacts constant per area unit and half proportional to the yield).

We test the method for wheat. The energy use for the dataset wheat is 3.23 MJ/kg D.M. according to ecoinvent, the yield is 6375 kg D.M./ha. As mentioned above the median of the yield D.M. is 4593 kg/ha for the cereals in ecoinvent and the median of the energy demand is 15512 MJ/ha for this group.

The estimated energy use will thus be:

$$0.7 * \frac{15512}{4593} + 0.3 * \frac{15512}{6375} = 3.09 \text{ MJ/kg D.M.}$$

Whereas the value reported in ecoinvent is 3.23 MJ/kg DM.

2.4 GEOGRAPHICAL EXTRAPOLATION BY YIELD CORRECTION

In a similar way than for product extrapolation, geographical extrapolation of LCIA data can be performed using a yield correction.

A possible model is:

$$E_p^l = e_p \times \frac{E_a^{l'}}{Y^{l'}} + (1 - e_p) \times \frac{E_a^{l'}}{Y^l}$$

Where:

E_p^l = Environmental impact per product unit in the considered country *l* [impact kg $^{-1}$]

$E_a^{l'}$ = Environmental impact per area unit in another country(ies) *l'* (one available producing country or median of the crop inventories for the available producing countries) [impact ha $^{-1}$]

$Y^{l'}$ = Yield of the crop in the country or median yield of the crop in the country(ies) *l'* (corresponding to $Ea^{c'}$) [kg ha $^{-1}$]

Y^l = Yield of the crop in the considered country *l* [kg ha^{-1}]

e_p = Fraction of the environmental impacts related to the yield

The determination of the coefficient e_p should be easier than for product extrapolation, since the crop is already known and its impacts already characterised in one or several countries. It is expected that this method would lead to better results by using the median of several countries instead of one single country or by using a neighbour country with a similar yield.

3 Modular inventory extrapolation: theoretical approach

The extrapolation of LCIA data using the modular inventory is an intermediate approach (in complexity and in accuracy) between the extrapolation of LCIA data by yield correction (described in sections 2.3 and 2.4) and a classical LCIA procedure (following an inventory creation and an emission calculation).

3.1 PRINCIPLES

The procedure is based on the idea that crop management can be described by few “management axes”. Nemecek & Gaillard (2007) have shown that e.g. the Swiss crop production datasets could be described by three management axes:

1. *Resource management*, which is largely driven by the use of machinery and other infrastructures and determines environmental impacts like energy demand, global warming potential and ozone formation potential.
2. *Nutrient management*: this axis is determined by the use of fertilisers and closely related to the environmental impacts eutrophication and acidification.
3. *Pollutant management*, which is related to the use of pesticides and determines the impacts ecotoxicity and human toxicity.

In addition to these three axes, irrigation has to be considered (water management), which was of no importance in the Swiss datasets.

Within a certain group, the management is not completely independent and similarity should be detected among the inputs used for crop production. For each crop or crop group, a *base system* has to be defined. The base system is typically a detailed existing crop inventory (at level 3) for a given country or larger geographical area. The extrapolations are done starting from the base system.

For the different management issues, modules are defined and impacts calculated for each of them. By summing the individual impacts, we obtain the total impact of the whole system. The following issues have to be considered:

1. Machinery use
2. Fertilisation
3. Plant protection
4. Irrigation
5. Drying
6. Yield

The modules are defined as follows:

1. For the machinery use, we distinguish the fixed part, the part dedicated to tillage and the variable part.
    - *The fixed machinery*: it corresponds to the machinery used for the indispensable operations for the crop production. It is assumed to be constant for a given crop across the world. This module includes sowing and harvest, and base fertilisation (and eventually other operations which have to be performed inevitably wherever the crop is grown). In addition to machinery operations it includes also inputs considered as fixed, like seed[2].
    - *The tillage machinery*. It corresponds to the ploughing operations. Till and no-till have to be distinguished.

[2] In fact the quantity of seed is not constant, but can vary within certain limits. As the seed input rarely plays a dominating role in crop LCAs, we can assume it as constant for the purpose of the project.

- *The variable machinery*. This part of the machinery use is related to all incidental field operations. It is related to the management intensity (machinery use for mechanical weeding for instance) and to the level of mechanisation in the considered country (this factor is related to the size of the agricultural enterprise or to the cost of the labour force above all).

2. For fertilisation, distinction is made between the nitrogen, the phosphorus and the potassium fertilisation. The machinery used for topdressing is taken into account. The basic rule for fertilisation is that the nutrient removal by the crop should be compensated by the fertilisation. The mineral and the organic fertilisers have different behaviour and should be considered separately. In the present work, we take only mineral fertilisers into account.

    - *Nitrogen fertilisation*. We consider the nitrogen amount applied in form of mineral fertilisers, as well as the different nitrogen fertiliser types. The split of the application is taken into account and the machinery used for topdressing is counted in this module.
    - *Phosphorus fertilisation*. The amount and the types of phosphorus mineral fertilisers are considered. It is assumed that the whole amount of phosphorus is applied as base fertilisation.
    - *Potassium fertilisation*. The amount and the types of potassium mineral fertilisers are considered. It is assumed that the whole amount of potassium is applied as base fertilisation.

3. For plant protection, herbicides, insecticides and fungicides are taken into account, as well as the machinery used their application. Biological control cannot be considered in the present work. It would be possible to further subdivide the pesticides into the main categories herbicides, fungicides, insecticides and other pesticides. We abstained from this, since the database on pesticide use of the global scale is too thin and too unreliable.

    - *Pesticides*. The amount of pesticides, the types of pesticides and the machinery used to apply them are used.

4. For irrigation, the origin of the water and its transportation are beyond the level of detail that can be considered. The irrigation module contains the infrastructure for the pump and water pipes, energy for pumping (electricity) and installation of the equipment (Diesel) and the water extracted from water bodies.

    - *Irrigation*. The presence/absence of irrigation is determined as well as the amount of water used for irrigation.

5. For drying, sun drying is not considered since the related impacts are negligible. In order to determine the quantity of water to be evaporated, we need to know the water content before and after drying.

    - *Drying*. It contains the quantity of water to be evaporated.

6. For the yield, no module is created. The yield is used in order to calculate the global input parameter estimator (section 3.3) and the impacts per kg of product.

A synthetic view of the module categories, of the modules, of the required inputs and of the units for impact calculation are summarised in

Table **3-1**. Once the base system is defined, we need nine parameters to adapt it to the specific situation of a given country.

Table 3-1 Categories and modules, impact units and needed input parameters for the modules.

Category	Module	Impacts	Input parameter
Machinery	Fixed operations	Per ha (area unit)	-
Machinery	Tillage	Per ha (area unit)	% of no-till area
Machinery	Variable operations	Per ha (area unit)	Mechanisation index
Fertilisation	N fertilisation, including N-emissions	Per kg N applied (input mass unit)	kg N applied
Fertilisation	P fertilisation, including P-emissions	Per kg P_2O_5 applied (input mass unit)	kg P_2O_5 applied
Fertilisation	K fertilisation	Per kg K_2O applied (input mass unit)	kg K_2O applied
Plant protection	Pesticide application	Per kg pesticide (active ingredient) applied (input mass unit)	kg active ingredient
Irrigation	Irrigation	Per m^3 of irrigation water supplied (input volume unit)	m^3 water used
Product drying	Product drying	Per kg of evaporated water (mass unit)	kg water evaporated
Impact per kg	-		yield per area unit

3.2 PROCEDURE

The modular inventory can be used in several situations: for the determination of the environmental impacts in a given country or in several countries or even for an “average world” production, having some detailed data for the country of interest or having no data (that is typically the case at the global scale or in some Third World countries), having a unique inventory for this crop or several.

In this project, we will focus on global application, where no detailed data are available. This is done by the “global input parameter estimator”, which is described in the next section.

3.2.1 Definition of a base system

The base system is based on an average yield for a given country, on an adequate fertilisation (i.e. nutrient uptake replaced through fertilisation), and on an average crop management. Inventories for organic production or for an extreme intensive production are not adapted to serve as base system. A way to create the base system is the following:

- Take an existing inventory for the considered crop in a representative country
- Recalculate the fertiliser amounts based on the crop needs.
- Replace the actual fertiliser type share by the world fertiliser type share (AII)
- Subdivide the whole inventory into modules as described above and allocate all your inventory data to the correct module. Each module is calculated per one unit as specified in Table 3-1 in the column “Impacts”.
- If the country is not representative for some inputs (e.g. irrigation in Switzerland is not a good starting point for potato irrigation in other countries since potatoes are generally not irrigated in Switzerland) or if some inputs are missing, take these inputs from other inventories (other country). It is possible to combine information from different countries, but care must be taken to ensure consistency.

This step is depicted by “STATE 0” in Fig. 3-1.

3.2.2 Definition of the scope of the base system

We have to answer the question of which situations (crops, spatial scale, etc.) can be described by the base system and its variations.

We recommend using the modular inventory only in situations where the creation of a specific inventory and the calculation of the related impacts are not possible, or at large scales, or for a rapid screening of the environmental burdens of a large set of products. We do not recommend applying it for an accurate environmental assessment of a specific product in a particular geographic situation or for the comparison of the environmental impacts of two products or of the production in two different countries.

For a detailed and accurate assessment, the conventional LCA method should be preferred.

3.2.3 Calculation of the environmental impacts for the base system

The environmental impacts have to be calculated for the base system. This can be done using any emission model or any emission factor and any LCA software containing any impact assessment method. The whole extrapolation method is thus independent of prior methodological choices and of any tool, except Excel.

In this project, we used the SALCA models as emission models, TEAM as LCA software and the methods for impact assessment specified in section 1.1.

Environmental impacts are thus calculated using the adapted inventory for the base system and applying the SALCA models. The computations are operated with the TEAM software and the results saved in Excel format. The results are then expressed in a unitary form for each module (
Table 3-1).
We used the SALCAcrop tool based on the TEAM software to calculate the environmental impacts. The modular approach itself however it more general and should work also e.g. with ecoinvent unit process data or other models of environmental impacts of crops.

3.2.4 Definition of the nine required input parameters for all countries of interest

There are two possibilities:

i. Table 3-1 have to be provided directly.

ii. No detailed data available for the current situation. The nine inputs are derived using global estimators. These global estimators and the procedure to derive the inputs from them are described in section 3.3.

3.2.5 Determination of the modular inventory for all countries of interest

The values of the nine input parameters (or of the estimators) are used in order to adapt the base system inventory to the other countries of interest.

3.2.6 Calculation of the environmental impacts for all countries of interest

The environmental impacts are calculated for each country of interest, using the environmental impacts calculated with the LCA software for the base system (unit impacts) and the nine inputs for the country.

3.2.7 Calculation of the median of the environmental impacts and quantification of their variability

This step can only be done if the impacts have been calculated for several countries. Typical situations, for which the determination of the median and of the variability is meaningful, are for the determination of:

- The environmental impacts related to the global production of a crop (world scale)
- The environmental impacts related to the regional/continental production of a crop

The variability can be determined by several characteristic numbers: standard deviation, coefficient of variation or quantiles. We recommend using quantiles since they are less sensitive to extreme values which could result from errors. Furthermore they allow expressing the skewness of the distribution. In most cases the distributions of most parameters are skewed to the right (positive skewness), with a majority of relatively low values and a long right tail. In this report, we consider the following 10^{th} and the 90^{th} quantiles ($q_{10\%}$ and $q_{90\%}$). Very small or high quantiles are recommended only in case of good quality input data, since the risk of errors is higher on both tails.

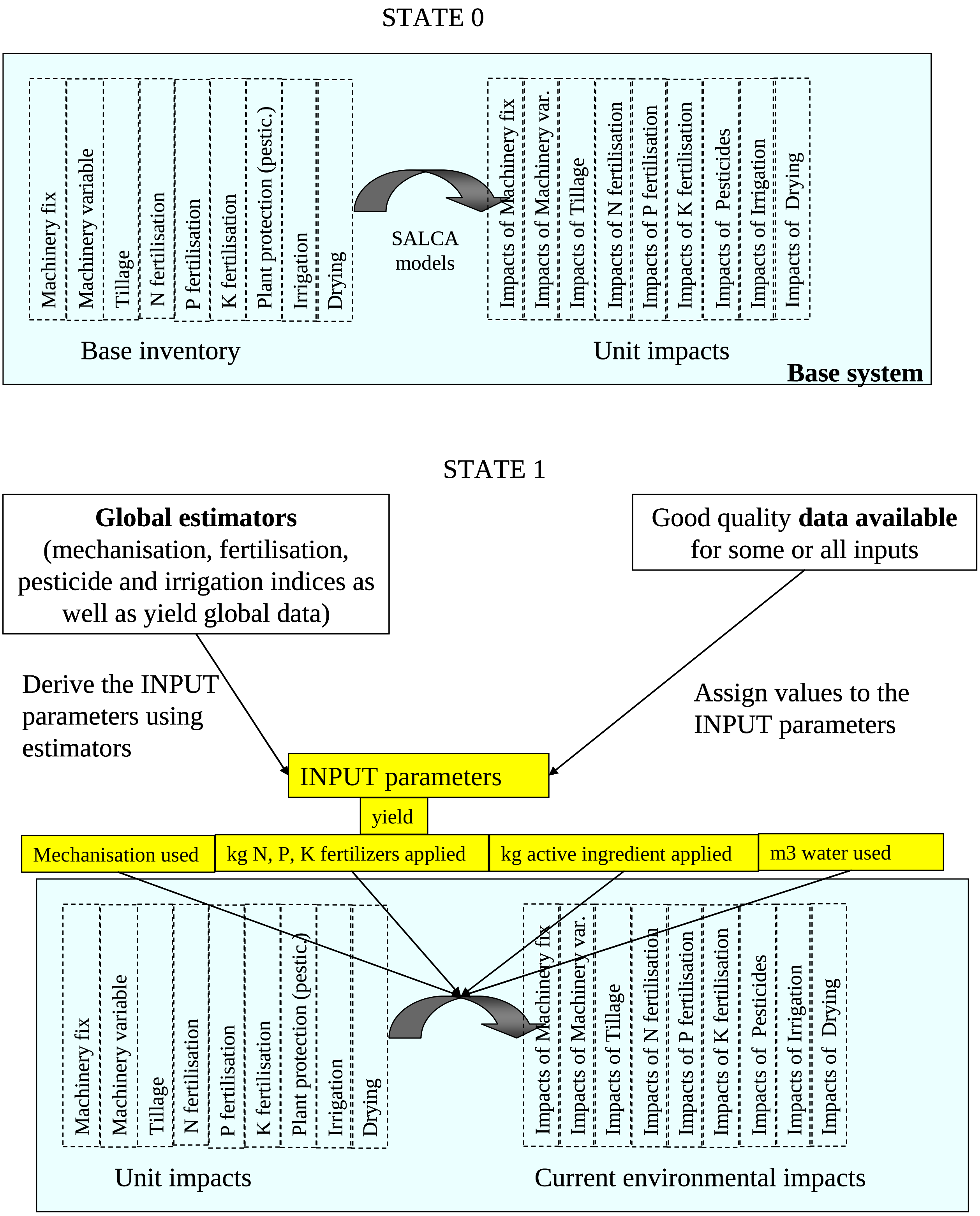


Fig. 3-1 Base system, inventory construction and environmental impacts calculation

3.3 GLOBAL INPUT PARAMETER ESTIMATOR

Input parameters are required for (almost) each module described above in order to compute environmental impacts and thus to characterise the eco-profile of a given crop product at the farm gate (the only exception is the module “Machinery fix”). If they are not available, we can use the global input parameter estimators instead of them.

Superscripts for a variable always refer to the crop and subscript to the considered country in this chapter.

The inputs are estimated by using the same inputs for a “base system” country, i.e. for a representative country where data are available, and by extrapolating them. This spatial extrapolation is useful when data are missing for the considered country.

Doing this extrapolation, we assume that a higher or lower use of inputs is due to two effects:

1. the overall production intensity level in a country (or the specific use intensity of the considered input)

2. the yield

In many cases these will run in parallel, i.e. where the production is generally intensive, the yields will also be high. The hypothesis is that both effects are parallel and of similar magnitude. This means that taking the square root allows to isolate one of these effects, and therefore a potential double-counting can be avoided. The effect of the yield will be taken directly into account by the yield ratio. We think that this procedure will give more reliable data than taking the (quite unspecific) input use indices alone.

3.3.1 Yield

Yield is an important factor since several emissions are related to the production intensity, i.e. to the yield. A higher yield is often correlated with a higher fertilisation for instance and inversely correlated with the land consumption.

Source:

- FAOSTAT, taking averages of the last 5 years (minimum 3 years to smooth the yearly variation), for the global scale or for smaller scale if no more detailed data available
- National Office of Statistics or National Office of Agriculture or Product Associations (CIP: International Potato Centre for example) for a country level typically or for a departmental level
- Departmental Office of Statistics, Departmental Office of Agriculture, local associations, producers collectives, etc. for a regional level
- Farm surveys at a field level

For the current concrete studied cases, yield data for the period 2003-2007 are considered since they are the most recent data available at the global scale (FAOSTAT). It is thought that the data should be updated in time interval of about five years.

3.3.2 Machinery

Machinery use is important for environmental impacts such as energy use, GWP and ozone formation.

For a given crop, certain field operations have to be carried out in any case, whereas others are optional, being performed for yield improvement, for product quality enhancement or for easiness of cultivation. In case of commercial production of a given crop, certain machines are thus encountered in any producing country or situation. Other machines are related to the country agricultural traditions, to the expected yield, etc.

The machinery used is thus divided in different modules (chapter 3.1):

Fixed machinery

This part is only related to the product (crop) not to the geographical situation (country). It is referred as $machFix^c$ in the present report. If, for a given crop, lime or other fertilisers than N, P, K are systematically applied (i.e. in any country) or if soil improvements are systematically performed (i.e. in any country), they are summarised under the fixed part of machinery.
Global estimator = 1 (no input required for the estimator)

Tillage machinery

The type of soil cultivation as well as its frequency and intensity vary greatly between two crops, two countries (or farms!) or two production modes.

Ploughing (or conventional tillage) is performed by farmers in order to incorporate fertilizers and crop residues, to prepare the seedbed and to control weeds by turning over the upper layer of the soil. Such operations disturb the soil profile and enhance the risk of soil erosion and lead to water loss by removing the soil cover. This observation has led many farmers to adopt less disturbing tillage methods or zero tillage (no-till).

No systematic data are available about the importance of no-till systems for each crop specifically at the global scale. If no-till farming is suited for any crop, its application however performs much better and easier for certain crops than for others. Soya is one of the most frequent crops cultivated in no-till systems whereas tubers are rarely cultivated in this way. From a geographical point of view, South America is the undisputed leader in no-till practice and the area under no-till reaches about 100 millions ha worldwide (AIII).

As a rough approximation, it is assumed that the tillage of one hectare of any crop in any country requires the same machinery. This is of course not exactly what happens in reality but for *commercial* production and at the global scale, this approximation should be sufficient. The variable representing the machinery used for the tillage of one hectare is referred as $machTill$ in the present report.

The machinery used for tillage has to be corrected by a factor taking into account that a part of the area is under no-till. We should thus have data about no-till for each crop in each country. These data being not available, we assume a constant percentage of 7% under no-till for all countries and all crops (AIII). It implies that 93% of the global agricultural area is tilled. This proportion factor is referred as $till$ in the present report. This rough approximation should be revised when working at a more detailed level.
Global estimator = 0.93 (no input required for the estimator)

Variable machinery

The other field operations are additional operations beside sowing, ploughing and harvest aiming to improve the yield, the product properties, the soil or other field properties. They vary from one country to the other for a given crop. They are related to the size of a typical exploitation in a country, to the agricultural traditions of the country as well as its current economic development, to the yield and to other parameters (soil, climate conditions, etc.).

The machinery used for these additional field operations are assumed to be correlated with the yield and with a country index in the present project. We compute it as follows:

$$machVar_i^c = machVar_b^c \times \frac{Y_i^c}{Y_b^c} \times \sqrt{\frac{mach_i}{mach_b}}$$

Where:

$machVar_i^c$ = Additional machinery used for the cultivation of the considered crop *c* in the considered country *i* [-]

$machVar_b^c$ = Additional machinery used for the cultivation of the considered crop *c* in the "base system" country [-]

Y_i^c = Yield of the considered crop *c* in the considered country *i* [kg ha^{-1} (growing season)$^{-1}$]

Y_b^c = Yield of the considered crop *c* in the "base system" country *i* [kg ha^{-1} (growing season)$^{-1}$]

$mach_i$ = Machinery index for the considered country *i* [-]

$mach_b$ = Machinery index for the "base system" country [-]

The machinery index is obtained by using the number of tractors and the number of combine harvesters-threshers in use per hectare (FAOSTAT) and by comparing it with the world average value.

This index is presented for each country in Appendix 0, representing the mechanization level of a given country. It is related to the yield and to the agricultural traditions essentially. We assume that the ratio between the yields of two countries has the same magnitude order than the ratio of the "agricultural traditions" between these two countries, i.e. the ratio of the machinery use for a given yield between these two countries. This assumption allows us to take the root of the index in order to avoid the double counting of the yield effect.

Two corrections are thus applied to get the additional machinery use for a given country from the additional machinery of a "base system" country:

1. A yield correction

2. A mechanization level correction for the country, reflecting both the yield and the mechanization practices. The root is taken, assuming the same order of magnitude for both the yield ratio and the mechanization practices ratio.

Input data for the global estimator:

1. Additional machinery used in a "base system" country (see split of the "base system" inventory)
2. Yields of both the considered country and the "base system" country (FAOSTAT)
3. Machinery indices of both the considered country and the "base system" country (0)

3.3.3 Fertilisation data

Fertilisers usually are major contributors to eutrophication occurring during the production of a crop product. For some bio-based materials (e.g. some biofuels), the fertilisers applied during the crop cultivation are the main contributors to eutrophication caused by the crop product during its entire life cycle.

Fertilisation is relatively well documented and data easy to access for some countries and some crops. On the contrary, fertilisation data are very scarce in other countries and for other crops.

Principles

- The starting point is the yield. The farmer is supposed to apply fertilisers according to the crop's needs. According to the agronomic principles and recommendations, the nutrients removed from the field should be replaced. A simple way would thus be to calculate the amount of nutrients removed from the field and to calculate the respective amount of fertilisers.
- Two fractions of the nutrients have to be distinguished: nutrients exported in the main products and nutrients taken up by the other parts of the plant (e.g. stems, leaves, roots). For N we consider the amount of nutrients in the whole plant, whereas for P and K only the part removed by the harvested products is replaced. P and K in the crop residues are available for the following crops and therefore the fertilisation can be adapted. From a LCA perspective, therefore only the part of P and K in the harvested

products is counted. For N the situation is different: the availability to the following crops depends on factors like C/N-ratio, soil temperature and humidity, etc. Furthermore the losses due to ammonia volatilisation, nitrate leaching, nitrous oxide emissions and denitrification can be quite substantial. Therefore the fertiliser requirement is calculated from the amount of N in the whole plant.

- The data about fertiliser use provided by FAO however suggest (example potato) that the amount of fertilisers effectively applied is higher than this in some cases and lower in some others. This implies that excessive use or insufficient use of fertilisers is quite widespread.
- The amount needed depends on many other factors: soil type, soil nutrient status, precedent crop, etc.

Procedure

The approach adopted for the variable part of the machinery can be used for the fertilizers too. The fertilizer use is assumed to be correlated with the yield and with a country index (0) in the present project:

$$fertN_i^c = fertN_b^c \times \frac{Y_i^c}{Y_b^c} \times \sqrt{\frac{Nferti_i}{Nferti_b}}$$

$$fertP_i^c = fertP_b^c \times \frac{Y_i^c}{Y_b^c} \times \sqrt{\frac{Pferti_i}{Pferti_b}}$$

$$fertK_i^c = fertK_b^c \times \frac{Y_i^c}{Y_b^c} \times \sqrt{\frac{Kferti_i}{Kferti_b}}$$

Where:

$fertN_i^c =$ Nitrogen fertilisation applied to the cultivation of the considered crop *c* in the considered country *i* [kg N ha^{-1} (growing season)$^{-1}$]

$fertN_b^c =$ Nitrogen fertilisation applied to the cultivation of the considered crop *c* in the “base system” country [kg N ha^{-1} (growing season)$^{-1}$]

$fertP_i^c =$ Phosphorus fertilisation applied to the cultivation of the considered crop in the considered country *i* [kg P_2O_5 ha^{-1} (growing season)$^{-1}$]

$fertP_b^c =$ Phosphorus fertilisation applied to the cultivation of the considered crop *c* in the “base system” country [kg P_2O_5 ha^{-1} (growing season)$^{-1}$]

$fertK_i^c =$ Potassium fertilisation applied to the cultivation of the considered crop *c* in the considered country *i* [kg K_2O ha^{-1} (growing season)$^{-1}$]

$fertK_b^c =$ Potassium fertilisation applied to the cultivation of the considered crop *c* in the “base system” country [kg K_2O ha^{-1} (growing season)$^{-1}$]

$Y_i^c =$ Yield of the considered crop in the considered country *i* [kg ha^{-1} (growing season)$^{-1}$]

$Y_b^c =$ Yield of the considered crop in the “base system” country [kg ha^{-1} (growing season)$^{-1}$]

$Nferti_i =$ Nitrogen fertilisation index for the considered country *i* [-]

$Nferti_b =$ Nitrogen fertilisation index for the “base system” country [-]

$Pferti_i =$ Phosphorus fertilisation index for the considered country *i* [-]

$Pferti_b =$ Phosphorus fertilisation index for the “base system” country [-]

$Kferti_i =$ Potassium fertilisation index for the considered country *i* [-]

$Kferti_b =$ Potassium fertilisation index for the “base system” country [-]

The N, P, K fertilisation indices are presented for each country in 0.

Two corrections are thus applied for the fertilisation of the considered crop in the considered country starting from the fertilisation in the “base system” country:

1. A yield correction
2. A country correction. The root is taken in order to avoid the double counting of the yield, which is reflected in the country correction. The yield ratio between the two countries is assumed to be of the same magnitude order than the ratio of the fertilizer practice which is also reflected in the country correction.

The number of passes for fertiliser spreading is supposed to grow linearly with the applied fertiliser quantity, which is a simplification.

Input data for the global estimator:

1. Nitrogen/Phosphorus/Potassium fertilisation for the considered crop in a “base system” country
2. Yield of the considered crop in the considered country
3. Yield of the considered crop in a “base system” country
4. Nitrogen/Phosphorus/Potassium fertilisation index in the considered country
5. Nitrogen/Phosphorus/Potassium fertilisation index in a “base system” country
6. Number of passes for nitrogen/phosphorus/potassium fertiliser spreading on the considered crop in a “base system” country
7. Nitrogen/Phosphorus/Potassium fertilisers share (from International Fertilizer Industry Association (IFA), www.fertilizers.org)

We assume that no organic fertilisers are applied. On the global scale this is a reasonable assumption for cash crop production, where mainly mineral fertilisers are used.

Alternative procedure or validation procedure

For some specific crops (potato, cocoa, pulses), data are available for the fertilisation applied in a quite long list of country (Fertibase of the FAO). These values could be used directly for computing the emissions related to fertilizer application.
However, care must be taken, since some of the data are of poor quality. A validation is therefore needed before using these data, and this step can be difficult to do for people who are not agricultural experts.

3.3.4 Plant protection data

No good pesticide consumption statistics exist worldwide with the exception of some countries (like USA or England for instance). Even if the amount of herbicides, fungicides and insecticides is known, this tells us very little about the active ingredients actually applied.

Therefore only a very rough assessment is possible and this part of the model remains the most uncertain one.

The procedure is analogous to the procedure adopted for the variable part of machinery and for fertilisers. For each pesticide present for the considered crop in a “base system” country, we compute the use of this pesticide in the considered country as followed:

$$pestZ_i^c = pestZ_b^c \times \frac{Y_i^c}{Y_b^c} \sqrt{\frac{pest_i}{pest_b}}$$

Where:

$pestZ_i^c$ = Quantity of the pesticide Z applied on the considered crop *c* in the considered country *i* [kg active ingredient ha^{-1} (growing season)$^{-1}$]
$pestZ_b^c$ = Quantity of the pesticide Z applied on the considered crop *c* in a "base system" country [kg active ingredient ha^{-1} (growing season)$^{-1}$]
Y_i^c = Yield of the considered crop in the considered country *i* [kg ha^{-1} (growing season)$^{-1}$]
Y_b^c = Yield of the considered crop in the "base system" country [kg ha^{-1} (growing season)$^{-1}$]
$pest_i$ = Pesticide use index for the considered country *i* [-]
$pest_b$ = Pesticide use index for a "base system" country [-]

The pesticide use index for each country is presented in 0.

Two corrections are applied for the transformation of the pesticide use from one country to another one:

1. A country correction. The square root is taken in order to avoid the double counting of the yield effect, which is reflected in the country correction. The yield ratio between the two countries is assumed to be of the same magnitude order than the ratio of the pesticide use practice which is also reflected in the country correction.

2. A yield correction

The number of passes for pesticide spreading is supposed to grow linearly with the applied pesticide quantity. It will be included directly in the calculation.

Input data for the global estimator:
- Type and quantity of the pesticides applied on the considered crop in a "base system" country (e.g. from ecoinvent)
- Yield of the considered crop in the considered country
- Yield of the considered crop in a "base system" country
- Pesticide use index for the considered country
- Pesticide use index for a "base system" country
- Number of passes for pesticide spreading on the considered crop in a "base system" country

Limitations:
- The pesticide use indices can be considered only as a rough approximation. They reflect the general intensity of pesticides use in the country, but they are influenced also by the crops grown in that country. Horticultural crops are much more frequently treated, which can considerably bias the results.
- Air treatments are not considered. All treatments are assumed to be done by a tractor and a field sprayer.
- Several active ingredients, which are forbidden in most of the industrial countries, are still widely used in some regions, especially in the developing countries. Starting for a specific inventory developed for an industrial country and correcting it for a developing country will lead to neglect some very toxic pesticides that are indeed applied in the developing country. Therefore the ecotoxicity impacts are likely to be underestimated in such cases.
- Starting from an existing inventory and correcting them by a pesticide use factor leads to an adjustment of the quantities only and not of the pesticides used.
- A good estimation of toxicity values will be out of reach of this project. To achieve this, a detailed knowledge of the active ingredients used in necessary.

3.3.5 Irrigation

Irrigation is a key feature for the estimation of the use of the resources energy and water. It is a parameter which can relatively well be estimated at a regional level and in certain countries, at a national level. At a global scale, the characterization of the irrigation of a given crop remains an unsolved problem.

The best approach, in our point of view, with the current knowledge and data is presented in 0.

Used approach

The adopted approach is simple and requires a limited set of data. It makes a comparison of the areas equipped for irrigation between the country of interest and a "base system" country. The base system country is chosen for its data availability and its representativeness (large country showing different climate conditions and different management practices).

The extrapolation is mathematically described as followed:

$$w_i^c = w_b^c \times \frac{irr_i}{irr_b}$$

Where:

w_i^c = Irrigation water supplied to the crop *c* in the country of interest *i* [$m^3\,ha^{-1}$ (growing season)$^{-1}$]

w_r^c = Irrigation water supplied to the crop *c* in the "base system" country [$m^3\,ha^{-1}$ (growing season)$^{-1}$]

irr_i = Irrigation equipment index in the country of interest *i* [-]

irr_b = Irrigation equipment index in the "base system" country [-]

The irrigation equipment indices are computed based on FAO data (FAOSTAT) by using the two following variables:

- total area equipped for irrigation
- arable land and permanent crops

An index is then created by comparing the percentage of agricultural area which is equipped for irrigation in a given country with the average world value. The irrigation equipment index is given for each country in 0.

This approach is based on the hypothesis that the irrigation supplied to a given crop in a given country is similar to the irrigation supplied to the same crop in another country adapted by a country correction factor. Several parameters are included in the irrigation equipment index: the climatic conditions occurring in the country, the type of cultivated crops and their respective proportion, the development degree of the country and so on.

No correction is applied for the yield in this case, since the quantity of water for irrigation rather depends on the climatic factors than on the yield. This approach gives a rough estimation but, as explained before, it is not possible to have a systematic and precise approach at the global scale for computing the irrigation of a given crop.

The procedure requires that irrigation data for the considered crop are available at least in one representative country.

3.3.6 Product drying

Only drying with use of fossil fuels or biofuels is relevant for LCA. Drying by solar radiation or wind will not be considered (except if machinery operations are involved).

The need for drying depends on the

- crop resp. harvested plant organ and
- on the climatic conditions before, during and after harvest.

For drying we assume a very rough approximation from the share of the irrigated area. Irrigation is needed in dry areas, while crop drying (occurring directly after harvest) on the contrary is needed in the wet areas.

We thus compute drying as followed in a first step:

$$dry_i^c = dry_b^c \times \frac{1 - irr_i}{1 - irr_b}$$

Where:

$dry_i^c =$ Water to evaporate for the considered crop *c* in the considered country *i* [kg water evaporated ha^{-1} (growing season)$^{-1}$] (it corresponds to the difference in water content before and after drying in the crop times the crop mass)
$dry_b^c =$ Water to evaporate for the considered crop *c* in a "base system" country *i* [kg water evaporated ha^{-1} (growing season)$^{-1}$]
$irr_i =$ Irrigation equipment index in the country of interest *i* [-]
$irr_b =$ Irrigation equipment index in the "base system" country [-]

The index for each country is given in 0.

An alternative approach would be to compute the amount of water (kg) to be evaporated by considering the yield and the % humidity before and after drying.
The humidity after drying is quite constant and is determined by the product.
The humidity before drying can be estimated from the amount of precipitation during harvest time (say the 3 months around harvest).

3.4 CALCULATION OF ENVIRONMENTAL IMPACTS FOR A SPECIFIC COUNTRY

In this chapter, any variable written with upper case relates to its environmental impacts whereas when written in lower case it refers to the input variable.

The procedure is as follows:

- Use the global input parameter estimator to derive input parameters.
- Multiply the unit impacts of each module by the corresponding estimator (or more accurate input) and sum all the calculated impacts.
- Finally, the sum is divided by the average yield of the considered country.

The environmental impacts (E_i^c) of the considered crop product *c* in the considered country *i* are given by:

$$E_i^c = \frac{Mach_i^c + Fert_i^c + Pest_i^c + Irr_i^c + Dry_i^c}{Y_i^c}$$

Where the different modules are:

$E_i^c =$ Environmental impacts of the crop *c* in the country of interest *i*
$Mach_i^c =$ Environmental impacts related to the machinery used for the crop *c* in the country of interest *i*
$Fert_i^c =$ Environmental impacts related to the fertilizers applied for the crop *c* in the country of interest *i*
$Pest_i^c =$ Environmental impacts related to the pesticides applied for the crop *c* in the country of interest *i*
$Irr_i^c =$ Environmental impacts related to the irrigation supplied for the crop *c* in the country of interest *i*
$Dry_i^c =$ Environmental impacts related to the drying performed for the crop *c* in the country of interest *i*

Y_i^c = Yield of the crop *c* in the country of interest *i*

Furthermore the environmental impacts within the fertilizer module have to be described in more details.

For fertilizers, the environmental impacts are the sum of the environmental impacts of nitrogen application, of phosphorus application and of potassium application:

$$Fert_i^c = FertN_i^c + FertP_i^c + FertK_i^c$$

Where:

$Fert_i^c$ = Environmental impacts related to the fertilizers applied for the crop *c* in the country of interest *i*
$FertN_i^c$ = Environmental impacts related to the nitrogen fertilizers applied for the crop *c* in the country of interest *i*
$FertP_i^c$ = Environmental impacts related to the phosphorus fertilizers applied for the crop *c* in the country of interest *i*
$FertK_i^c$ = Environmental impacts related to the potassium fertilizers applied for the crop *c* in the country of interest *i*

3.5 CALCULATION OF GENERIC MEANS

Generic means can be derived from the country specific environmental impacts:

- Define a subset of countries to be analysed (e.g. South Asia) or take all countries to derive global averages.
- The generic mean is derived as an average of the selected environmental impacts per kg weighted by the production volumes of each country.
- Alternatively the generic median can be calculated as the 50th percentile of the cumulative distribution.
- The variability of the country specific environmental impacts is used to derive a range of values and/or a standard deviation.

Two types of statistical measures can be used to describe the distribution:

- *Weighted average and standard deviation*: this may be easier to handle. The problem is that the distributions are quite skewed to the left (asymmetric). Therefore this measure may be misleading.
- *Median and percentiles for the extreme values*. The percentiles can be chosen according to the needs. We propose to use the 10th and 90th percentiles to indicate the range. We strongly discourage from using minimum and maximum values, since the extreme values can be due to data errors. The 10th and 90th percentiles should be quite robust.

4 Modular inventory extrapolation: the File System and its use

4.1 DESCRIPTION OF THE FILE SYSTEM

A File System (FS) has been created in Excel. It is possible to use it with any LCA software or emission model. We did the calculation of the modular LCIA with Excel and SALCA macros on one hand, and the tool SALCAcrop based on the TEAM software and including the ecoinvent database on the other hand.

The FS is made up of:

1. ***One common folder***. This folder is not crop-specific and contains mainly one file with the values for all **agricultural indices** for the 218 countries, which have an agricultural area defined as an arable land or/and as a permanent crop area according to the FAOSTAT data. This folder contains also all the files needed to create these agricultural indices (0). When the data for the creation of an agricultural index are missing for a country, the mean values for the index is used (usually 1).

2. ***One specific folder per crop***. This specific folder contains first a folder entitled "PI_CP_RAW". This folder contains:

   - The production inventory: this production inventory can be an already existing inventory, a new one or a modified one. ("PIbase_syst_crop.xls")
   - The control panel: it is created by using the SALCAcrop tool and used in TEAM for the impact calculation. ("CPbase_syst_crop.xls")
   - The raw results issuing from TEAM. ("RAWbase_syst_crop.xls")
   - An LCIA summary of the results created with the SALCA macros. ("LCIAbase_syst_crop.xls")

   These files are then used for the creation of several other files:

   - An LCIA file. The impacts related to the direct emissions (and to the seeds, as well as land occupation) have to be shared adequately over the different modules. This operation is done in this file. For this purpose direct N-emissions are assigned to the N-fertiliser module, P-emissions to the P-fertiliser module and heavy metal emissions to the "machinery fix" module. ("crop_LCIA.xls"). When using other models than SALCA and other LCA software than TEAM, the user should provide a file with the name "crop_LCIA.xls" and having the same structure than the proposed file.
   - An input-impact file. This file contains the calculations of the inputs for each producing country (global input parameter estimator), based on the inputs in the "base system" country and on the agricultural indices, as well as the calculation of the impacts for each producing country using the global input parameter estimator computed previously and the impacts per input unit obtained from the LCIA file. ("crop_world.xls")
   - 4 files: one for the median and quantiles of all inputs per ha and one for the same per kg, one for the median and quantiles of all impacts per ha and one for the same per kg ("crop_inputs_per_ha.xls", "crop_inputs_per_kg.xls", "crop_impacts_per_ha.xls", "crop_impacts_per_kg.xls"). The determination of the median and of the quantiles is done as follows (for each input or for each impact):
     - Country sorting in the order of increasing input (or impact)
     - Calculation of the corresponding cumulative production
     - Rank attribution to each cumulative production (i.e. to each country)

- Setting limits for the cumulative production: 10%, 25%, 50%, 75%, 90% for instance
- Calculation of how many countries have a lower or equal cumulated production than these limits (lower boundary) and add one (upper boundary)
- Calculation of the corresponding cumulated productions
- Identification of the corresponding input (or impact)
- For each limit: linear interpolation between the lower and the upper boundary. We now have the inputs (or impacts) corresponding to a cumulated production of 10%, 25%, 50%, 75%, 90% for instance (other limits are available too).

A schematic representation of the FS is depicted in Fig. 4-1.

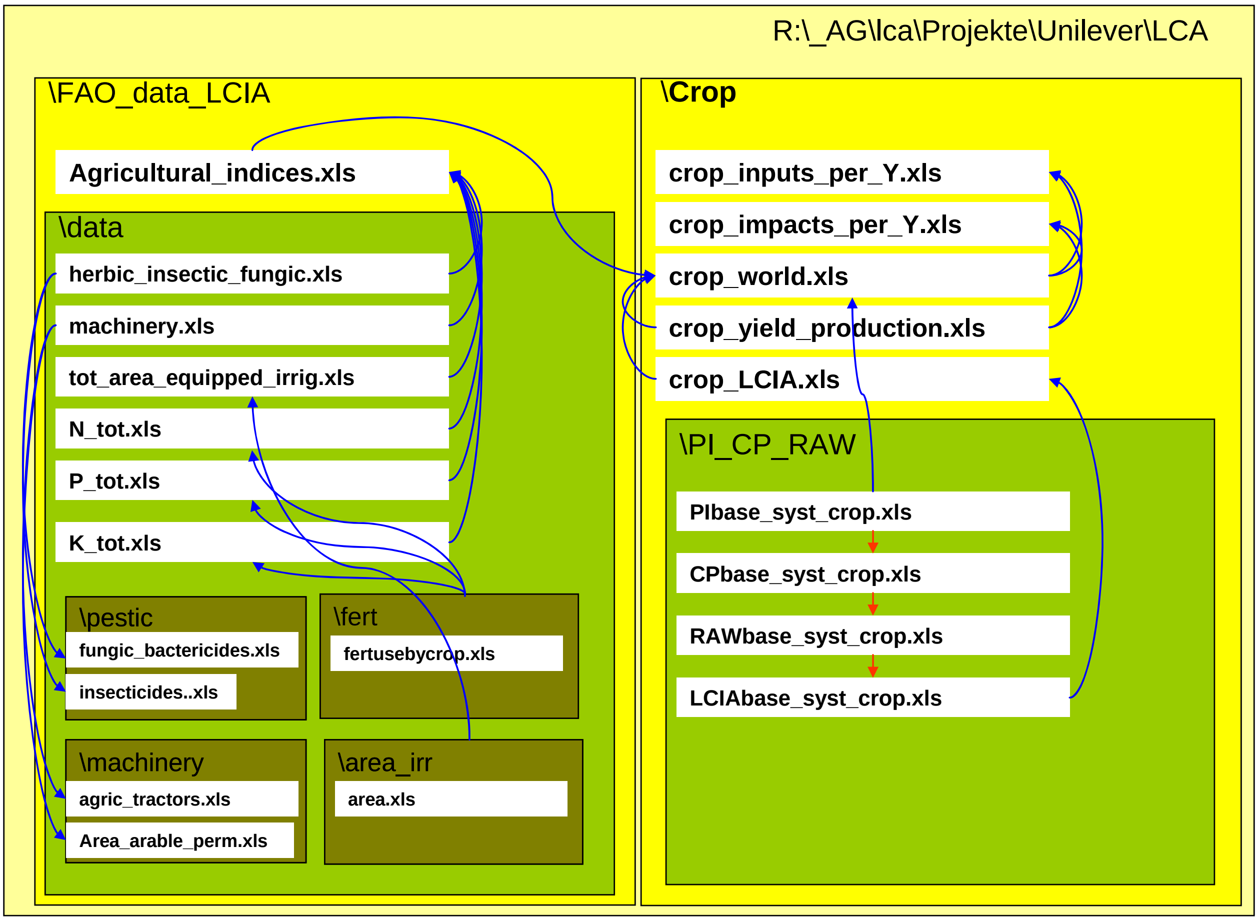


Fig. 4-1. File System for the modular inventory. The coloured rectangles are folders, the white ones are files, and the blue arrows are the symbolic links between the files, red arrows show the order of the calculations within the SALCAcrop tool. Crop corresponds to the studied crop and Y is either kg or ha.

4.2 USE OF THE FILE SYSTEM

The FS has been developed for the calculation of the inputs and of the impacts of several crops in all producing countries (producing countries list according to the FAO data) and for the calculation of the corresponding median and some quantiles. Since several crops had to be handled and since some other could be added in the future, a special attention has been addressed to the development of a coherent and highly automated FS.

The FS has however been designed as a research tool and, in spite of our efforts, some operations have still to be done manually. The FS has to be used for each new crop and, for a broad use of the FS, some automation improvements should be done and the tool should be designed in a more user friendly way.

A short manual for the use of the FS in its current form is provided in AVI.

4.3 PRACTICABILITY AND TIME SAVING

With the short manual, the package should be usable in a quite convenient way.
For a geographical extrapolation, the FS designers currently need about two hours[3] for a crop, for which a base inventory has already been defined (base system):

- Inventory adaptation in the modular form (Excel sheet): 30 to 45 minutes (PI and CP files)
- Impact calculations (in Team): 15 minutes (RAW file)
- LCIA summary file creation (in Excel with SALCA macro): 5 minutes (LCIA file)
- Copy of the temp_LCIA.xls file and links update (in Excel): 5 minutes
- Copy of the temp_yield_production.xls file, download of the FAOSTAT data and fill in the file (Excel and Internet download): 30 minutes
- Copy of the temp_world.xls file and links update: 15 minutes
- Copy of the temp_impacts_per_ha.xls, temp_inputs_per_ha.xls, the temp_impacts_per_kg.xls, temp_inputs_per_kg.xls (Excel): 10 minutes

At the end of this procedure, the user has these data:

- Quantity of each input used for each producing country (per ha and per kg of product):
  - Fixed machinery use [-]
  - Tillage machinery use [-]
  - Variable machinery use [-]
  - N fertilisers [kg N]
  - P fertilisers [kg P_2O_5]
  - K fertilisers [kg K_2O]
  - Pesticides [kg active ingredient]
  - Irrigation water [m^3]
- Median of each input used for the whole world (as well as different quantiles)
- Impacts per input units for different impact categories:
  - Non renewable energy demand [MJ-eq] (Frischknecht *et al.*, 2004)
  - GWP 100 years [CO_2-eq] (IPCC, 2006)
  - Photochemical ozone formation [kg ethylene-eq] (Guinée *et al.*, 2001)
  - Nutrient enrichment [kg N-eq] (Hauschild & Wenzel, 1998)
  - Acidification [kg SO_2-eq] (Hauschild & Wenzel, 1998)
  - Human toxicity 100 years [kg 1,4-DCB-eq] (Guinée *et al.*, 2001)
  - Aquatic ecotoxicity 100 years [kg 1,4-DCB-eq] (Guinée *et al.*, 2001)
  - Terrestrial ecotoxicity 100 years [kg 1,4-DCB-eq] (Guinée *et al.*, 2001)
- Impacts of the production in each producing country (all of the above impact categories)
- Median of each impact category for the whole world (as well as a lot of different quantiles)

The procedure therefore allows a considerable time saving for a rough estimation of environmental impacts in a series of countries. Time saving is particularly high, if the number of producing countries to consider is high as well. The proposed modular crop model is quite unaffected by the number of producing countries.

Some improvements for the user friendliness of the system and for the consequent use time could be done later by programming a fully automated tool.

[3] These durations of course depend on the performance of the computer.

5 New inventories

No usable inventory for the purpose of the modular inventory extrapolation for spice and for cocoa could be found. We thus had to create a new inventory for these crops (or for one crop in this group in case of spices) as “base system” inventory, in order to then have the possibility to apply the modular inventory extrapolation.
These inventories are created using the production inventory corresponding to the SALCAcrop tool. We try to have a similar quality to the ecoinvent or to the SALCA inventories. The inventory, as well as the emission calculations, is very detailed and sophisticated. Since these crops are “exotic” crops, for which our expert knowledge is very limited, and the produced inventories are “first generation” inventories, the estimated impacts for these crops should be used with caution.
Experts should be consulted in the producing countries in order to certify that the data used for the inventory creation are correct (or at least plausible). We contacted several experts, but unfortunately no one was willing to give advice and to help us in the production inventory creation and to validate the production data during the period of the timeframe of this project. Error detection and inventory refinement should be done with the collaboration of experts in further steps in order to get the same confidence and to ensure the same quality as for the datasets in the ecoinvent or in the SALCA databases.

The new inventories presented here have been created using literature values. Confidence about such the accuracy and representativeness of such data is generally lower than for survey data, for statistical figures or for experimental measurements.

We had an original group encompassing herbs and spices. Our method relies on the FAOSTAT database (FAO, 2009) for the estimators. There is no data about herbs in this database. We thus had to consider spices solely. Furthermore, herbs and spices are often very different concerning the edible part, the taxonomy and the management of the crop. It is not a homogeneous group. For the spice group, we choose to create an inventory for pepper, since this spice is the most important one regarding its importance on the world market, the world import value during 2000 and 2004 rising to 601 mio. of US $ (UNCTAD/WTO, 2006).

5.1 COCOA

Cocoa (*Theobroma cocoa*) is a perennial deciduous tree, growing in tropical regions. The main crop requirements are a temperature ranging between 10 and 38 °C, an annual rainfall amount of 900 to 7600 mm and a soil of at least medium depth with a pH between 4 and 8, low salinity and well drained (FAO, 2008).

The inventory refers to this functional unit: “**1 ha of cocoa beans production in Ghana during an “average year of life”, at farm”**. It thus refers to an average production under the Ghanaian conditions, with an assumed yield of about 239 kg of dried beans per ha and year during the fully productive period.

The included processes are: soil cultivation, sowing, weed control, fertilisation, pest and pathogen control, harvest and beans drying, as well as inputs of fertilisers, pesticides, seeds, machinery. Direct field emissions are included too.

5.1.1 General crop data

Teal (Teal, 2006) reports a yield of 231.66 kg of dried beans per ha and year for the cultivation period 2001/2002 and of 277.99 kg of dried beans per ha and year for the cultivation period 2003/2004 in Ghana, whereas Vigneri (2007) reports a value of 207 kg of dried beans per ha and year in the same country. Assiedu (1991) reports a typical yield of 1 to 1.5 tonnes of fresh beans per ha and year, without specifying to which world producing region this value refers to. Others authors give values for other producing countries (Sonwa for Cameroon for instance (Sonwa, 2008)). We decided to average the values given in Teal (Teal, 2006) and in Vigneri (Vigneri, 2007), since they are the only one referring to the Ghanaian production in a univocal way. Furthermore, the data in these studies originate from a quite large survey and should thus be more representative than a single literature value. We assume a yield of 239 kg of dried beans per ha and year during the fully productive years.

Vigneri (Vigneri, 2007) also indicates that the commercial lifespan of a cocoa tree is about 25 to 30 years, that there is an unproductive period of 3 to 5 years and that the trees reach a full productivity only after 10 years. We thus assume a lifespan of 30 years, an unproductive period of 5 years, a period with low productivity of 10 years and a period of normal productivity of 15 years. We assume that in the period of low productivity, only the half of the normal production is provided by the tree. Doing that and balancing over the full life span of the trees and then dividing by the total number of years in order to get the yield per "average year", we get:

$$Y_a = \frac{239*15 + 239*10*0.5}{30} = 159.26 \text{ [kg of dried beans/ha/year]}$$

A yield of 159.26 kg of dried beans per ha and per "average year of life" is considered.

The cocoa plantations are established by seedlings planting (http://www.dacnet.nic.in/cashewcocoa/ctech.htm).

5.1.2 Use of fertilisers

Use of mineral fertilisers is very low in the Ghanaian cocoa production. Abenyega *et al.* (2001) reports that 98% of the Ghanaian cocoa producers do not use any mineral fertiliser, Vigneri (Vigneri, 2007) reports percentage between 53% and 91% of cocoa producers using no mineral fertiliser at all (depending on the production year) and Teal *et al.* (2006) that between 52% and 90% of the cocoa producers do not use any mineral fertiliser. We see that the application of mineral fertilisation is particularly low in the cocoa production in Ghana. The crop management is more similar to a forest management than to a conventional field crop.

Concerning the applied amounts per ha among the producers who apply mineral fertilisers, Vigneri (2007) reports a mean use between 0.09 and 5.24 bags of 50 kg for different cultivation years, whereas Teal *et al.* (2006) report an average (among the producers using fertilisers) of 0.54 and 5.14 bags of 50 kg for the periods 2001/2002 and 2003/2004 respectively.
By using these data (percentage of farmers using no mineral fertilisers and quantity applied by the producers who apply mineral fertilisers), we assume an average use of mineral fertilisers corresponding to 42 kg per ha and years.

The authors of the two studies mentioned above do not explain which fertilisers are contained in the bags of 50 kg. We thus look at the cocoa nutrient removal in order to determine the part of N, P_2O_5 and K_2O fertilisers. The removed amount of nutrient during a 75 years cocoa production is estimated to be equal to 655400 tonnes of N, 100300 tonnes of P_2O_5 and 173500 tonnes of K_2O (Afrifa, 2006), that means that 71% of the nutrient removal is nitrogen, 11% is P_2O_5 and 9% is K_2O. Assuming that fertilisation should correspond to the crop needs (removal), we assume, with a global fertiliser share (see AII), that 71% of a 50 kg bag is nitrogen compounds, 11% is phosphorus compounds and 9% is potassium compounds.

Fertiliser application is split into 2 doses each year: one third of the conventional amount is applied during the first year, two third during the second and the third years and full dose is given from the fourth year onwards. We can finally calculate the assumed N, P_2O_5 and K_2O fertilisation amounts for the whole life span and then divide them by the total number of years in order to balance an "average year of life".

We get these amounts: 28 kg N, 4 kg P_2O_5 and 7 kg K_2O per ha and "average year of life".

5.1.3 Pest and disease management

It is always very difficult to be confident with the literature values found about pesticides.

Vigneri (2007) and Teal *et al.*(2006) report values between 5% and 58% of cocoa growers not using pesticides, whereas Abenyega *et al.* (2001) reports that 66% of the cocoa growers do not use insecticides and 77% do not use fungicides. Vigneri (2007) and Teal *et al.*(2006) mention values ranging 0.86 and 11.81 litres of insecticides per ha and years (for the growers who apply insecticides), without indicating if these quantities are active ingredient or chemicals (diluted). Abenyega *et al.* (2001) mentions 1.12 insecticide spraying per year (hand spraying with backbag) and 0.7 fungicides spraying per year (hand spraying with backbag) in average. Using these data, we consider an average of 3.1 litres of insecticides per ha and year and 2.1 litres of fungicides per ha and year.

The chemicals found in the literature for cocoa production in Ghana (Mull, 2005) and in Cameroon (Sonwa, 2008) are:

- Insecticides:
    - Cocostar
    - Unden 20
    - Thionex
    - Azinphos methyl
    - Cypercal
    - Durbsan
    - Aldrin

- Fungicides:
    - Ridomil
    - Nordox Super 75
    - Kocide
    - Cacaobre

Some of these chemicals (and their related active ingredients) are not available in our production inventory designed for the use of the SALCA models. Their quantities were thus equally distributed to the other active ingredients. The pesticides considered finally and amounts (given in grams of active ingredient per ha and “average year of life”):

- Azinphos methyl: 777 g/ha/year
- Bifenthrin: 388 g/ha/year
- Copper: 517 g/ha/year
- Cypermethrin: 88 g/ha/year
- Metalaxyl: 517 g/ha/year
- Pirimiphos methyl: 388 g/ha/year

5.1.4 Irrigation

No irrigation has been mentioned in the literature studied and therefore the amount of irrigation water has been set to 0.

5.1.5 Field operations

Very few field operations are mentioned in the previously cited literature and all are done manually (weeding with machetes for instance). We considered only the following field operations in the inventors: fertiliser broadcasting, pesticide application and tree planting (at the beginning of the 30-year period).

5.1.6 Harvesting

Harvest (as well as transportation of the beans) is done manually (Abenyega, 2001).

5.1.7 Post harvesting operations

Assiedu (1991) mentions these post-harvesting operations:

- Pod opening and bean extraction (manually with a knife)
- Fermentation (beans under banana leaves) (we assume no impacts for this process)
- Drying: generally sun drying

The environmental impacts of cocoa beans production in Ghana as calculated using this created production inventory are:

Table 5-1 Impacts per ha and year for the Ghanaian cocoa production (average yield of 159 kg/ha/year).

	impacts per ha
non-renewable energy resources [MJ-eq]	4376.9
GWP 100a [kg CO2-eq]	698.2
photochemical ozone formation [kg ethylene-Eq]	0.102
nutrient enrichment [kg N-eq]	87.3
Acidification [kg SO2-Eq]	9.4
Land use [m2 year]	10074.71
Water use [m3]	1.53
Aquatic ecotoxicity 100a [kg 1,4-DCB-Eq]	2386.7
Terrestrial ecotoxicity 100a [kg 1,4-DCB-Eq]	76.7
Human toxicity 100a [kg 1,4-DCB-Eq]	232.6

5.2 PEPPER

Pepper (*Piper nigrum*) is a perennial vine, growing in tropical regions close to the equator (from 15° South to 20° North). The main crop requirements are a temperature in the range of 10 to 40 °C, abundant rainfall amounting to 2000 to 5500 mm and a slightly acid soil, with low salinity, enough deep and well drained (FAO, 2008).

The inventory refers to this functional unit: **"1 ha of black pepper production in India during an average year of life, at farm"**. It thus refers to an average production under the Indian conditions, with an assumed yield of about 3471 kg of fresh berries per ha and year during the productive period.

India is the second most important producer during the years 2003 to 2007 considering the quantity produced (FAO, 2009).

The included processes are: soil cultivation, sowing, weed control, fertilisation, pest and pathogen control, harvest and beans drying, as well as inputs of fertilisers, pesticides, seeds, machinery. Direct field emissions are included too.

5.2.1 General crop data

Ravindran (2000) reports a typical yield of one kg of dry berries per vine, an approximate density of 1350 pepper vines per ha, a moisture at harvest of about 65% and a moisture for sale of 10%. By using these data, we get a yield of about 3471 kg of fresh berries per ha and year during the productive years. The inventory should however not refer to a specific year inside the productive period but to an "average year of life". We thus calculate the produced amount of pepper berries during the whole life span and then divide it by the total number of years of the commercial life span of the trees.

Ravindran (Ravindran, 2000) indicates that the commercial life span of the pepper vines in India is about 20 years and that the vines start bearing only after 4 to 5 years. We thus assume a productive period of 15 years and an unproductive period of 5 years. We obtain an average yield of:

$$Y_a = \frac{3471*15}{20} = 2603.6 \text{ [kg fresh berries/ha/year]}$$

A yield of 2603.6 kg of fresh berries per ha and per "average year of life" is considered.

Ravindran (2000) shows that there are many possible propagation methods (by seeds, by cuttings, etc.) but that the propagation by cuttings is the most frequent one. Cuttings are operated on vines by pruning and then grown in a nursery. After a few months, the seedlings are planted in the field.

Pepper can be grown as a monocrop, as a mixed crop with arecanut, coffee or coconut for instance, as a pure crop on a plantation scale. In India, the most important part of the production is furnished by small holders (Ravindran, 2000).

5.2.2 Pedo-climatic conditions

Ravindran (Ravindran, 2000) reports that in India 70% of the production is grown on alfisols, having a pH ranging between 5.3 and 6.3, low organic matter and nutrients, low water retention capacity, prone to phosphorus fixation. A typical pedon corresponding to an alfisol (USDA, 1999) has this textural composition: 28% clay, silt 12.3% and sand 59.7%. By using the textural triangle (http://www.pedosphere.com/resources/bulkdensity/worktable_us.cfm), we assume a sandy clay loam texture with a bulk density of 1.4 g/cm^3. We use these data to slightly adapt the production inventory to the local conditions (by setting the clay content to 28% instead of the default value of 15% and by setting the pH value to 5.8 instead of the default value of 6.7).

5.2.3 Use of fertilisers

The use of fertilisers in the Indian pepper production is not high enough to cover the needs of the crop in most of the cases (Ravindran, 2000). We thus assume that in average only 20 % of the fertilisation recommendations is applied to the pepper crop. The general recommendations for pepper fertilisation are given in Ravindran (Ravindran, 2000) 100 g N per vine and year, 40 g P_2O_5 per vine and year and 140 g K_2O per vine and year, that is (by assuming the density of 1350 pepper vines per ha mentioned above) 135 kg N per ha and year, 54 kg P_2O_5 per ha and year and 189 kg K_2O per ha and year. During the first year, only one third of the dose is applied, during the second year about two third of the dose and, from third year onwards, the full dose is applied (Ravindran, 2000). By considering these facts and by balancing during the whole period and then by dividing by the number of years in the life span, we obtain a fertilisation of about 26 kg N, 10 kg P_2O_5 and 36 kg K_2O per ha and "average year of life".

We assume that there is no nitrogen return to the soil by leaves loss.
As previously mentioned, we do not consider organic fertilisers in this project. Manure and organic refuses are however quite often applied in the pepper production (rotten cattle manure, husk, neem cake[4], castor, cotton, fish refuses, bones, etc.).

5.2.4 Pest and disease management

There are very few data about pesticide use in the pepper production in India. Ravindran (2000) only mentions one application per year of Carbofuran (3 g) at a rate of 30 g per ha. We thus assume that only 90 g of Carbofuran are applied per ha and year once in a year on a pepper plantation in India. This approximation has to be considered with caution: pesticide application is often very variable from a grower to another one, above all in emerging countries. We should improve this aspect with help of an expert in order to get a better toxicity assessment.

5.2.5 Irrigation

According to Ravindran (2000), all producing countries grow pepper under rainfed conditions except Thailand, where the crop is irrigated. We thus consider no irrigation in our inventory.

[4] Neem cake is a by-product of the cold pressing of neem fruits and kernels. Neem is a tree growing in tropical and subtropical regions.

5.2.6 Field operations

Field operations are much reduced: pruning and thinning usually not occurs in India (in contrary to Indonesia for instance). The only real field operation is a light hoeing between the pepper lines two times a year (once in May-June, once in October-November) (Ravindran, 2000). We assume that the space between the pepper line only corresponds to approximately half of the area (0.5 ha).

5.2.7 Harvesting

According to Ravindran (Ravindran, 2000), harvest and threshing are usually done by hand in India. We thus consider no environmental impacts related to these harvest activities.

5.2.8 Post harvest operations

Post-harvest operations are the following one in case of black pepper (Ravindran, 2000):

- Drying: generally sun drying in India
- Washing (not considered in the present inventory)
- Blanching one minute in boiling water (not considered in the present inventory)
- Garbling and grading: usually done by hand by the exporters outside the farm gate in India (not considered in the present inventory)

The environmental impacts of pepper production in India as calculated using this created production inventory are:

Table 5-2 Impacts per ha and year of the Indian pepper production.

	impacts per ha
non-renewable energy resources [MJ-eq]	4764.6
GWP 100a [kg CO2-eq]	797.5
photochemical ozone formation [kg ethylene-Eq]	0.122
nutrient enrichment [kg N-eq]	107.8
Acidification [kg SO2-Eq]	9.3
Land use [m2 year]	14302.55
Water use [m3]	2.68
Aquatic ecotoxicity 100a [kg 1,4-DCB-Eq]	26.8
Terrestrial ecotoxicity 100a [kg 1,4-DCB-Eq]	2.3
Human toxicity 100a [kg 1,4-DCB-Eq]	721.1

6 Application of the modular inventory method

We apply the modular inventory extrapolation and the yield correction extrapolation to several crops belonging to:

1. Root vegetables
2. Peas and beans
3. Cereals
4. Cocoa
5. Spices

The modular inventory is used here for geographical extrapolation solely (although it could be used for product extrapolation too, after a few adaptations). The yield correction is applied in both contexts: geographical and product extrapolation.

6.1 GEOGRAPHICAL EXTRAPOLATION WITH THE MODULAR INVENTORY

We present the results *per ha* and *per kg* in this section. The results *per kg* are available in the excel files delivered with the report. Only some results are presented in this report since the number and size of the tables is huge:

- Impacts per input unit for each module. These values are required in a situation, where more precise figures on input quantities are available. These impacts per input unit have to be multiplied by the corresponding input amount (or by the corresponding estimators) and then all these impacts need to be summed up.
- Median and some quantiles of the inputs used in the cultivation of one ha. These figures give an idea about the intensity of cultivation worldwide and its variability. The median can be used for the determination of the impacts caused by the cultivation of one ha at the world scale.
- Median and some quantiles of the impacts caused by the cultivation of one ha. These figures give an idea about the environmental burdens caused by the cultivation of one ha worldwide.

The impacts per input unit are given in those units (see also Table 3-1):

- Fixed machinery: per ha
- Tillage machinery: per ha
- Variable machinery: per ha
- N fertilisation: per kg N applied
- P fertilisation: per kg P_2O_5 applied
- K fertilisation: per K_2O applied
- Pesticides: per kg active ingredient applied
- Irrigation: per m^3 irrigation water applied
- Drying: per kg water evaporated

6.1.1 Root vegetables: potato

The modular inventory is applied to potato in order to get the environmental impacts of potato production in any producing country.

The base system corresponds to the ecoinvent inventory for potatoes IP at farm in Switzerland with a few adaptations:

- Fertiliser share: we decide to use the share of different fertilisers in the total world consumption (i.e. no country specific adaptation is applied, see AII).
- Organic fertilisers: are not considered here, all fertilisers are assumed to be mineral fertilisers.

- Fertiliser quantity applied corresponding to the needs (in the ecoinvent inventory, the quantity applied corresponds to the Swiss recommendations and not exactly to the needs).
- Irrigation: no irrigation is considered in the ecoinvent inventory. We know that, in some producing countries, potatoes are grown under irrigation. If we do not consider any irrigation in the base system inventory, no irrigation can be considered in all the other producing countries. In order to avoid this imprecision, we use the irrigation value of Turkey (Ünlü, 2006). That means that the extrapolation of the impacts per m^3 of irrigation water will be done, starting from Turkey, whereas the extrapolation of the impacts per input units for the other inputs will start from Switzerland.

The base system inventory is then split into the nine modules. Emissions are calculated using the SALCA methods and impacts are assessed using the methods described in the section 1.1. We get the following impacts per input units:

Table 6-1 Impacts per unit for each module (potato cultivation).

Impacts	*Modules*								
	MachFix	MachTill	MachVar	Nfert	Pfert	Kfert	Pestic	Irrigat	Drying
non-renewable Energy [MJ-eq]	13604.50	1818.25	4621.45	70.91	31.26	10.69	341.5	9.988	0
GWP 100a [kg CO2-eq]	1074.68	118.49	272.66	13.45	2	0.614	15.127	0.247	0
photochemic O3 formation [kg ethylene-eq]	0.65	0.08	0.23	0.001	6E-04	2E-04	0.0092	2E-04	0
Nutrient enrichment [kg N-eq]	12.65	0.34	0.60	0.917	0.126	7E-04	0.023	2E-04	0
Acidification [kg SO2-eq]	9.38	0.95	1.80	0.282	0.039	0.003	0.099	9E-04	0
Land use [m2 year]	12665.65	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Water use [m3]	4.61	0.28	1.44	0.01	0.13	0.01	0.06	1.00	0
Aquatic ecotoxicity 100a [kg 1,4-DCB-eq]	56.92	0.13	0.45	0.015	0.404	0.007	114.99	4E-04	0
Terrestrial ecotoxicity 100a [kg 1,4-DCB-eq]	0.99	0.01	0.05	7E-04	0.009	3E-04	80.696	1E-04	0
Human toxicity 100a [kg 1,4-DCB-eq]	460.52	38.32	209.11	1.216	0.97	0.337	337.68	0.181	0

The first column (MachFix) contains the environmental impacts that are in any case caused by the cultivation of one hectare of potato (see section 3.1). If no other input is used for the potato cultivation, the impacts will be the ones in the first column. This first column cannot be varied; it is always multiplied by a factor 1.
The second column (MachTill) contains the impacts related to the tillage operations of one hectare of potato. In this project, we assume that the proportion of the area that is tilled is constant and equal to 93%. That means that the impacts in the second column are multiplied by 0.93.
The third column (MachVar) contains the impacts related to the field operations that are not essential for the potato cultivation. The importance of these impacts varies from a country to another one. We thus have to multiply these unit impacts by a machinery index which depicts the specific machinery use of the country of interest.
The fourth column (Nfert) contains the impacts per kg of nitrogen applied (in form of mineral fertiliser). These unit impacts have to be multiplied by the quantity of nitrogen applied to the potato field.
The fifth column (Pfert) contains the impacts per kg of P_2O_5 applied (in form of mineral fertiliser). These unit impacts have to be multiplied by the quantity of P_2O_5 applied to the potato field.
The sixth column (Kfert) contains the impacts per kg of K_2O applied (in form of mineral fertiliser). These unit impacts have to be multiplied by the quantity of K_2O applied to the potato field.
The seventh column (Pestic) contains the impacts per kg of pesticides applied (active ingredient). These unit impacts have to be multiplied by the quantity of active ingredient applied to the potato field.
The eighth column (Irrigat) contains the impacts per m^3 of irrigation water used. The unit impacts have to be multiplied by the number of m^3 used for the irrigation of the potato field.
The ninth column (Drying) contains the impacts per kg of water evaporated during the drying process. The units have to be multiplied by the quantity of water evaporated during the drying process. In the case of potato, where no drying is necessary, the amount is 0.

Note that some of these unit modules are the same for all crops (e.g. MachTill and Irrigat), since the impacts per ha of tillage and per m^3 of irrigation are considered constant over the world. The impacts for drying are also the same per kg of water evaporated, however for the crops not needing any drying these impacts are set to 0. For the other unit modules the impacts depend on the crop or contain direct emissions that vary with the crop.

For each country where an extrapolation is desired, we could multiply the above impacts per input units (modules) by the proper input quantity and then sum the impacts of all modules. But as we do not know the quantity of the inputs used in each producing country in many cases, the global input parameter estimators can be used (section 3.3). We use them for the extrapolation of the impacts in all producing countries and obtain the results presented in the excel file "potato_world.xls", delivered with this report. This file contains the quantity of each input used per ha and per kg of product as well as the impacts per ha and per kg of product.

We finally calculate the median and different quantiles for each input and for each impact, considering the production of each producing country. We obtain these results *per ha* for the world:

Table 6-2 Key figures for the inputs used in the cultivation of one hectare of potato in the world.

QUANTILES	***INPUTS***						
	MachVar	Nfert	Pfert	Kfert	Pestic	Irrigat	Drying
2.5%	0.02	10.12	3.41	4.17		47.93	0
10.0%	0.05	10.79	4.11	14.55		149.25	0
25.0%	0.07	25.95	9.73	19.35	0.80	243.85	0
median	0.10	60.70	24.51	59.29	1.85	1018.01	0
75.0%	0.28	72.75	26.78	92.16	4.68	2243.53	0
90.0%	0.58	159.20	50.46	180.97	8.91	3026.42	0
97.5%	0.85	206.17	64.70	249.25	18.11	4605.59	0

Table 6-3 Key figures for the impacts caused by the cultivation of one hectare of potato in the world.

QUANTILES		2.5%	10.0%	25.0%	median	75.0%	90.0%	97.5%
IMPACTS	Energy [MJ-eq]	18958.19	19229.16	23019.20	41020.71	45013.10	52136.47	93882.60
	GWP [kg CO2-eq]	1430.59	1435.20	2079.26	2728.62	2875.21	3994.89	5310.31
	O3 form. [kg ethylene-eq]	0.81	0.81	0.91	1.26	1.26	1.41	2.13
	Nutr. enrich. [kg N-eq]	22.78	23.61	38.58	72.08	83.51	159.82	211.19
	Acidific. [kg SO2-eq]	13.92	13.97	20.29	30.26	34.27	58.55	74.50
	Land use [m2 year]	12665.65	12665.65	12665.65	12665.65	12665.65	12665.65	12665.65
	Water use [m3]	57.86	157.54	271.63	1030.69	2261.75	3050.27	4632.53
	Aquat. Ecotox.[kg 1,4-DCB-eq]	74.53	74.57	151.44	276.79	559.24	1104.61	2162.49
	Terr. Ecotox. [kg 1,4-DCB-eq]			65.35	151.00	378.75	720.80	1463.23
	Human tox.[kg 1,4-DCB-eq]	848.10	851.41	1071.86	1440.63	2493.12	4003.79	7438.79

These figures have the following meaning: only 2.5% of the potato world production is produced with 10.12 kg N/ha (nitrogen fertilisers) or less. 50% of the potato world production is produced with 1018.01 m^3 of irrigation water per ha or more. 2.5% of the potato world production is produced using 18.11 kg of active ingredient per ha or more. 2.5% of the potato world production causes 18'958 MJ-eq or less. 50% of the potato world production is related to a nutrient enrichment of 72.08 kg N-eq or more.

The results given *per kg* are:

Table 6-4 Key figures for the inputs used in the cultivation of one kg of potato in the world.

QUANTILES	*INPUTS*								
	MachFix	MachTill	MachVar	Nfert	Pfert	Kfert	Pestic	Irrigat	Drying
2.5%	2.33E-05	2.17E-05	2.73E-06	9.01E-04	2.96E-04	6.14E-04		2.74E-03	0
10.0%	2.37E-05	2.20E-05	4.10E-06	9.06E-04	3.44E-04	1.17E-03		5.80E-03	0
25.0%	3.90E-05	3.62E-05	4.92E-06	1.78E-03	6.93E-04	1.21E-03	6.40E-05	1.93E-02	0
median	6.48E-05	6.03E-05	6.09E-06	2.92E-03	1.10E-03	3.78E-03	1.12E-04	4.50E-02	0
75.0%	7.08E-05	6.59E-05	8.98E-06	4.69E-03	1.62E-03	4.16E-03	1.55E-04	1.50E-01	0
90.0%	8.16E-05	7.58E-05	1.62E-05	4.86E-03	1.77E-03	5.23E-03	2.33E-04	1.55E-01	0
97.5%	9.64E-05	8.97E-05	2.15E-05	6.91E-03	1.81E-03	7.87E-03	4.33E-04	2.87E-01	0

Table 6-5 Key figures for the impacts caused by the cultivation of one kg of potato in the world.

QUANTILES		2.5%	10.0%	25.0%	median	75.0%	90.0%	97.5%
IMPACTS	Energy [MJ-eq]	9.11E-01	9.77E-01	1.27E+00	1.72E+00	3.00E+00	3.05E+00	4.15E+00
	GWP [kg CO2-eq]	7.38E-02	8.58E-02	1.11E-01	1.23E-01	1.91E-01	1.92E-01	2.05E-01
	O3 form. [kg ethylene-eq]	2.84E-05	3.13E-05	4.75E-05	6.59E-05	8.50E-05	8.53E-05	1.07E-04
	Nutr. enrich. [kg N-eq]	1.85E-03	1.92E-03	2.41E-03	3.44E-03	5.54E-03	5.61E-03	7.52E-03
	Acidific. [kg SO2-eq]	9.44E-04	1.14E-03	1.23E-03	1.49E-03	2.27E-03	2.30E-03	2.82E-03
	Land use [m2 year]	2.95E-01	3.00E-01	4.93E-01	8.21E-01	8.97E-01	1.03E+00	1.22E+00
	Water use [m3]	3.28E-03	6.41E-03	1.98E-02	4.57E-02	1.52E-01	1.56E-01	2.89E-01
	Aquat. Ecotox.[kg 1,4-DCB-eq]			1.18E-02	1.65E-02	2.30E-02	3.06E-02	5.24E-02
	Terr. Ecotox. [kg 1,4-DCB-eq]			5.41E-03	9.15E-03	1.26E-02	1.89E-02	3.50E-02
	Human tox.[kg 1,4-DCB-eq]	6.91E-02	6.96E-02	7.26E-02	8.34E-02	1.01E-01	1.40E-01	2.00E-01

The results are briefly discussed here by example of potato.
We can see a large variability of the results, which applied both to the inputs and the impacts. In the model, the inputs and the impacts have the same variability by definition. We can always observe a positively skewed distribution with a long right tail. This means that a majority of the production is at low and medium intensity and a small fraction of the world's production is managed at high or very high intensity.

6.1.2 Root vegetables: carrot

The modular inventory is applied to carrot production in order obtain the environmental impacts of carrot production in any producing country.

The base system corresponds to an inventory created for the carrot production IP at farm in Switzerland (Nemecek, 2005) with some few adaptations:

- Fertiliser share: we decide to use the share of different fertilisers in the total world consumption (i.e. no country specific adaptation and no crop adaptation is applied, see AII).
- Organic fertilisers: are not considered here, all fertilisers are assumed to be mineral fertilisers.
- Fertiliser quantity applied corresponding to the needs (in the original inventory, the quantity applied corresponds to the Swiss recommendations and not exactly to the needs).

The same procedure as described for potato (see above) is applied. We obtain these results per input unit:

Table 6-6 Impacts per unit for each module (carrot cultivation).

Impacts	MachFix	MachTill	MachVar	Nfert	Pfert	Kfert	Pestic	Irrigat	Drying
non-renewable Energy [MJ-eq]	17373.01	1818.25	2436.80	76.88	31.26	10.69	352.41	9.988	0
GWP 100a [kg CO2-eq]	1119.71	118.49	154.34	16.3	2	0.614	15.807	0.247	0
photochemic O3 formation [kg ethylene-eq]	0.78	0.08	0.13	0.001	6E-04	2E-04	0.0101	2E-04	0
Nutrient enrichment [kg N-eq]	3.36	0.34	0.38	1.149	0.122	7E-04	0.0265	2E-04	0
Acidification [kg SO2-eq]	9.06	0.95	1.12	0.286	0.039	0.003	0.1203	9E-04	0
Land use [m2 year]	12040.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Water use [m3]	2.83	0.28	0.59	0.01	0.13	0.01	0.08	1.00	0
Aquatic ecotoxicity 100a [kg 1,4-DCB-eq]	1.28	0.13	0.23	0.003	0.21	3E-05	50.187	4E-04	0
Terrestrial ecotoxicity 100a [kg 1,4-DCB-eq]	0.01	0.01	0.03	0.00	0.00	0.00	2.7021	1E-04	0
Human toxicity 100a [kg 1,4-DCB-eq]	255.61	38.32	108.61	1.298	0.484	0.33	75.595	0.181	0

(The column group MachFix–Drying is headed "Modules".)

And for the inputs and impacts *per ha*:

Table 6-7 Key figures for the inputs used in the cultivation of one hectare of carrot in the world.

QUANTILES	INPUTS						
	MachVar	Nfert	Pfert	Kfert	Pestic	Irrigat	Drying
2.5%	0.05	8.53	2.66	4.89		77.53	0.00
10.0%	0.08	13.61	3.80	16.76		289.50	0.00
25.0%	0.09	42.26	12.15	40.88		664.71	0.00
median	0.10	66.66	17.80	61.13	2.19	2875.59	0.00
75.0%	0.35	76.04	25.86	127.57	6.30	3664.18	0.00
90.0%	0.88	120.10	29.94	166.75	12.52	4886.25	0.00
97.5%	1.07	221.70	49.07	288.82	19.91	8732.69	0.00

Table 6-8 Key figures for the impacts caused by the cultivation of one hectare of carrot in the world.

QUANTILES		2.5%	10.0%	25.0%	median	75.0%	90.0%	97.5%
IMPACTS	Energy [MJ-eq]	23996.12	27474.81	37705.87	54520.66	61680.74	82614.07	118510.59
	GWP [kg CO2-eq]	1580.73	1681.88	2413.00	3307.45	3398.20	4408.18	6310.90
	O3 form. [kg ethylene-eq]	0.97	1.02	1.22	1.62	1.63	2.18	2.66
	Nutr. enrich. [kg N-eq]	14.33	19.97	53.80	83.86	95.26	146.14	265.29
	Acidific. [kg SO2-eq]	13.78	14.68	24.45	33.65	40.10	49.31	79.68
	Land use [m2 year]	12040.60	12040.60	12040.60	12040.60	12040.60	12040.60	12040.60
	Water use [m3]	85.22	304.94	678.42	2893.17	3686.80	4939.55	8778.78
	Aquat. Ecotox.[kg 1,4-DCB-eq]	7.17	7.66	8.63	112.68	323.44	637.04	1019.00
	Terr. Ecotox. [kg 1,4-DCB-eq]				5.84	15.63	32.16	51.11
	Human tox.[kg 1,4-DCB-eq]	478.95	537.03	926.31	1091.16	1353.29	2256.79	2816.05

And for the inputs and impacts *per kg*:

Table 6-9 Key figures for the inputs used in the cultivation of one kg of carrot in the world

QUANTILES	INPUTS								
	MachFix	MachTill	MachVar	Nfert	Pfert	Kfert	Pestic	Irrigat	Drying
2.5%	1.63E-05	1.51E-05	3.43E-06	6.67E-04	1.69E-04	6.19E-04		2.77E-03	0
10.0%	2.15E-05	2.00E-05	3.98E-06	7.87E-04	1.89E-04	9.72E-04		8.01E-03	0
25.0%	2.79E-05	2.59E-05	4.78E-06	2.01E-03	5.57E-04	1.99E-03		3.22E-02	0
median	4.90E-05	4.56E-05	5.72E-06	2.40E-03	6.66E-04	3.28E-03	1.27E-04	9.30E-02	0
75.0%	5.35E-05	4.98E-05	9.98E-06	3.54E-03	9.41E-04	3.36E-03	1.73E-04	1.98E-01	0
90.0%	5.77E-05	5.37E-05	1.68E-05	3.62E-03	9.73E-04	4.65E-03	3.03E-04	2.04E-01	0
97.5%	8.60E-05	7.99E-05	2.57E-05	4.49E-03	1.36E-03	6.43E-03	4.04E-04	3.56E-01	0

Table 6-10 Key figures for the impacts caused by the cultivation of one kg of carrot in the world.

QUANTILES		2.5%	10.0%	25.0%	median	75.0%	90.0%	97.5%
IMPACTS	Energy [MJ-eq]	7.77E-01	9.83E-01	1.21E+00	2.21E+00	3.24E+00	3.38E+00	4.61E+00
	GWP [kg CO2-eq]	6.55E-02	7.73E-02	8.81E-02	1.32E-01	1.79E-01	1.79E-01	2.00E-01
	O3 form. [kg ethylene-eq]	2.55E-05	3.43E-05	4.09E-05	6.68E-05	8.77E-05	8.78E-05	1.10E-04
	Nutr. enrich. [kg N-eq]	8.22E-04	1.34E-03	2.55E-03	2.99E-03	4.54E-03	4.54E-03	5.42E-03
	Acidific. [kg SO2-eq]	6.38E-04	7.71E-04	1.02E-03	1.31E-03	1.80E-03	1.81E-03	2.10E-03
	Land use [m2 year]	1.96E-01	2.59E-01	3.36E-01	5.90E-01	6.44E-01	6.95E-01	1.03E+00
	Water use [m3]	3.07E-03	8.24E-03	3.26E-02	9.36E-02	1.99E-01	2.05E-01	3.58E-01
	Aquat. Ecotox.[kg 1,4-DCB-eq]				6.64E-03	8.69E-03	1.53E-02	2.05E-02
	Terr. Ecotox. [kg 1,4-DCB-eq]				3.00E-04	4.31E-04	7.70E-04	1.05E-03
	Human tox.[kg 1,4-DCB-eq]	2.28E-02	2.40E-02	3.28E-02	5.45E-02	5.82E-02	7.02E-02	9.36E-02

The detailed results for each country are given in the excel file “carrot_world.xls” delivered with this report.

6.1.3 Peas and beans: protein pea

The base system corresponds to the ecoinvent inventory for protein pea IP at farm in Switzerland with some few adaptations:

- Fertiliser share: we decide to use the share of different fertilisers in the total world consumption (i.e. no country specific adaptation is applied, see AII).
- Organic fertilisers: are not considered here and the amount of organic fertilisers is replaced with mineral fertilisers (in the ecoinvent inventory, there are no mineral fertilisers applied).
- Irrigation: no irrigation is considered in the ecoinvent inventory. We know that, in some producing countries, peas are grown under irrigation. If we do not consider any irrigation in the base system inventory, no irrigation can be considered in all the other producing countries. In order to avoid this imprecision, we use the irrigation value of New Zealand (Martin, 1996). That means that the extrapolation of the impacts per m^3 of irrigation water will be done, starting from New Zealand, whereas the extrapolation of the impacts per input units for the other inputs will start from Switzerland.

The same procedure as described for potato is applied. We obtain these results per input unit:

Table 6-11 Impacts per unit for each module (protein pea cultivation).

Impacts	Modules								
	MachFix	MachTill	MachVar	Nfert	Pfert	Kfert	Pestic	Irrigat	Drying
non-renewable Energy [MJ-eq]	4979.60	1818.25	1136.11	65.46	31.26	10.69	339.94	9.988	18.23
GWP 100a [kg CO2-eq]	496.32	118.49	72.10	89.26	2	0.614	14.779	0.247	0.76
photochemic O3 formation [kg ethylene-eq]	0.23	0.08	0.06	9E-04	6E-04	2E-04	0.0097	2E-04	0.00
Nutrient enrichment [kg N-eq]	5.04	0.34	0.19	2.683	0.128	7E-04	0.0245	2E-04	0.00
Acidification [kg SO2-eq]	3.14	0.95	0.54	0.317	0.039	0.003	0.099	9E-04	0.00
Land use [m2 year]	10682.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Water use [m3]	1.20	0.28	0.28	0.01	0.13	0.01	0.07	1.00	0.01
Aquatic ecotoxicity 100a [kg 1,4-DCB-eq]	6.74	0.13	0.11	0.021	0.438	0.011	20.295	4E-04	0.00
Terrestrial ecotoxicity 100a [kg 1,4-DCB-eq]	0.26	0.01	0.01	0.00	0.00	0.00	0.8782	1E-04	0.00
Human toxicity 100a [kg 1,4-DCB-eq]	93.01	38.32	43.12	1.13	0.923	0.336	16.684	0.181	0.12

And these figures *per ha*:

Table 6-12 Key figures for the inputs used in the cultivation of one ha of protein pea in the world.

QUANTILES	INPUTS						
	MachVar	Nfert	Pfert	Kfert	Pestic	Irrigat	Drying
2.5%	0.01	0.27	3.62	0.52		12.26	91.97
10.0%	0.06	0.52	4.21	4.00		14.66	93.14
25.0%	0.07	0.85	8.51	4.86	0.25	19.45	121.93
median	0.14	1.63	13.33	9.27	0.80	66.93	137.86
75.0%	0.19	2.45	20.10	19.91	1.06	210.09	143.26
90.0%	0.56	5.57	43.52	47.11	3.13	457.30	143.30
97.5%	0.61	6.18	44.20	49.20	3.46	476.08	143.33

Table 6-13 Key figures for the impacts caused by the cultivation of one ha of protein pea in the world.

QUANTILES		2.5%	10.0%	25.0%	median	75.0%	90.0%	97.5%
IMPACTS	Energy [MJ-eq]	9743.85	10009.83	10534.50	11285.49	13955.56	14947.71	14953.10
	GWP [kg CO2-eq]	755.69	788.46	889.85	921.28	1060.28	1488.64	1515.38
	O3 form. [kg ethylene-eq]	0.34	0.35	0.36	0.38	0.43	0.47	0.47
	Nutr. enrich. [kg N-eq]	6.60	7.33	8.63	11.49	14.88	26.26	27.93
	Acidific. [kg SO2-eq]	4.56	4.72	5.46	5.53	6.29	8.93	8.96
	Land use [m2 year]	10682.01	10682.01	10682.01	10682.01	10682.01	10682.01	10682.01
	Water use [m3]	22.81	23.21	24.01	70.48	214.63	462.19	482.52
	Aquat. Ecotox.[kg 1,4-DCB-eq]	9.96	14.12	15.76	29.00	36.82	90.08	97.28
	Terr. Ecotox. [kg 1,4-DCB-eq]				1.00	1.20	3.07	3.37
	Human tox.[kg 1,4-DCB-eq]	156.16	165.15	184.13	204.19	252.40	317.26	324.19

And these figures *per kg*:

Table 6-14 Key figures for the inputs used in the cultivation of one kg of protein pea in the world.

QUANTILES	INPUTS								
	MachFix	MachTill	MachVar	Nfert	Pfert	Kfert	Pestic	Irrigat	Drying
2.5%	2.26E-04	2.10E-04	9.42E-06	3.14E-04	2.55E-03	5.50E-04		6.98E-03	2.65E-02
10.0%	2.33E-04	2.17E-04	4.25E-05	3.40E-04	2.77E-03	2.76E-03		7.74E-03	2.90E-02
25.0%	4.66E-04	4.34E-04	5.17E-05	7.12E-04	5.88E-03	3.96E-03	1.69E-04	9.26E-03	6.00E-02
median	4.77E-04	4.43E-04	6.81E-05	9.51E-04	8.40E-03	4.67E-03		3.89E-02	6.71E-02
75.0%	7.51E-04	6.98E-04	9.31E-05	1.46E-03	1.02E-02	9.52E-03	4.68E-04	1.36E-01	8.75E-02
90.0%	8.86E-04	8.24E-04	1.41E-04	1.78E-03	1.38E-02	1.15E-02	7.61E-04	3.64E-01	9.29E-02
97.5%	1.59E-03	1.48E-03	1.68E-04	1.87E-03	1.45E-02	1.30E-02	8.36E-04	3.83E-01	1.67E-01

Table 6-15 Key figures for the impacts caused by the cultivation of one kg of protein pea in the world.

QUANTILES		2.5%	10.0%	25.0%	median	75.0%	90.0%	97.5%
IMPACTS	Energy [MJ-eq]			4.93E+00	5.64E+00	1.03E+01	1.19E+01	1.84E+01
	GWP [kg CO2-eq]	3.47E-01	3.55E-01	4.29E-01	4.73E-01	8.02E-01	8.25E-01	1.25E+00
	O3 form. [kg ethylene-eq]			1.70E-04	1.86E-04	3.25E-04	3.63E-04	5.85E-04
	Nutr. enrich. [kg N-eq]	4.69E-03	4.81E-03	5.42E-03	6.56E-03	8.17E-03	1.10E-02	1.19E-02
	Acidific. [kg SO2-eq]	2.09E-03	2.10E-03	2.58E-03	2.81E-03	4.56E-03	4.87E-03	7.49E-03
	Land use [m2 year]	2.41E+00	2.49E+00	4.98E+00	5.09E+00	8.02E+00	9.47E+00	1.70E+01
	Water use [m3]	1.04E-02	1.07E-02	1.13E-02	4.15E-02	1.32E-01	3.69E-01	3.87E-01
	Aquat. Ecotox.[kg 1,4-DCB-eq]				1.39E-02	1.83E-02	2.33E-02	2.46E-02
	Terr. Ecotox. [kg 1,4-DCB-eq]				4.80E-04	6.14E-04	8.12E-04	8.54E-04
	Human tox.[kg 1,4-DCB-eq]	7.65E-02	7.65E-02	8.72E-02	1.03E-01	1.81E-01	2.11E-01	3.13E-01

The detailed results are delivered in an additional excel file "pea_world.xls".

6.1.4 Cereals: wheat

The base system corresponds to the ecoinvent inventory for wheat grains IP at farm in Switzerland with some few adaptations:

- Fertiliser share: we decide to use the share of different fertilisers in the total world consumption (i.e. no country specific adaptation is applied, see AII).
- Organic fertilisers: are not considered here, all fertilisers are assumed to be mineral fertilisers.
- Fertiliser quantity applied corresponding to the needs (in the ecoinvent inventory, the quantity applied corresponds to the Swiss recommendations and not exactly to the needs).
- Straw production is not considered (in contrast to the ecoinvent inventory). The part of the inventory concerning the straw production has been removed.
- Irrigation: no irrigation is considered in the ecoinvent inventory. We know that, in some producing countries, wheat is grown under irrigation. If we do not consider any irrigation in the base system inventory, no irrigation can be considered in all the other producing countries. In order to avoid this imprecision, we use the irrigation value of China (Binder, 2007). That means that the extrapolation of the impacts per m^3 of irrigation water will be done, starting from China, whereas the extrapolation of the impacts per input units for the other inputs will start from Switzerland.

The same procedure as described for potato is applied. We obtain these results per input unit:

Table 6-16 Impacts per unit for each module (wheat cultivation).

	Modules								
Impacts	MachFix	MachTill	MachVar	Nfert	Pfert	Kfert	Pestic	Irrigat	Drying
non-renewable Energy [MJ-eq]	3572.28	1818.25	2355.07	75.86	31.26	10.69	457.88	9.988	18.23
GWP 100a [kg CO2-eq]	295.64	118.49	151.37	13.84	2.00	0.614	21.766	0.247	0.76
photochemic O3 formation [kg ethylene-eq]	0.18	0.08	0.11	0.001	6E-04	2E-04	0.0165	2E-04	0.00
Nutrient enrichment [kg N-eq]	3.34	0.34	0.41	0.964	0.123	7E-04	0.0429	2E-04	0.00
Acidification [kg SO2-eq]	2.51	0.95	1.16	0.284	0.039	0.003	0.1511	9E-04	0.00
Land use [m2 year]	10553.78	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Water use [m3]	0.83	0.28	0.48	0.01	0.13	0.01	0.10	1.00	0.01
Aquatic ecotoxicity 100a [kg 1,4-DCB-eq]	23.97	0.13	0.20	0.02	0.459	0.01	351.57	4E-04	0.00
Terrestrial ecotoxicity 100a [kg 1,4-DCB-eq]	0.62	0.01	0.02	0.00	0.00	0.00	8.7924	1E-04	0.00
Human toxicity 100a [kg 1,4-DCB-eq]	76.20	38.32	70.54	1.293	0.965	0.337	79.904	0.181	0.12

And these figures *per ha*:

Table 6-17 Key figures for the inputs used for the cultivation of one ha of wheat in the world.

QUANTILES	INPUTS						
	MachVar	Nfert	Pfert	Kfert	Pestic	Irrigat	Drying
2.5%	0.02	6.48	2.77	0.22		25.18	12.34
10.0%	0.05	12.41	4.63	1.76		106.10	43.05
25.0%	0.11	35.80	15.23	2.46	0.20	148.98	52.08
median	0.13	60.32	21.87	7.77	0.52	470.27	68.36
75.0%	0.16	153.34	53.96	15.09	0.89	1026.10	77.03
90.0%	0.60	184.22	57.61	28.53	2.48	1387.13	78.18
97.5%	0.78	272.52	75.35	33.69	3.56	2467.04	80.48

Table 6-18 Key figures for the impacts caused by the cultivation of one ha of wheat in the world.

QUANTILES		2.5%	10.0%	25.0%	median	75.0%	90.0%	97.5%
IMPACTS	Energy [MJ-eq]	7872.76	8987.06	12452.37	20653.27	30245.06	30561.16	37870.82
	GWP [kg CO2-eq]	609.07	649.01	1009.87	1502.39	2958.32	3391.28	4662.55
	O3 form. [kg ethylene-eq]	0.30	0.32	0.39	0.53	0.71	0.76	0.88
	Nutr. enrich. [kg N-eq]	10.29	16.23	39.13	65.68	158.57	188.62	275.88
	Acidific. [kg SO2-eq]	6.38	7.36	14.62	22.17	49.86	59.66	85.57
	Land use [m2 year]	10553.78	10553.78	10553.78	10553.78	10553.78	10553.78	10553.78
	Water use [m3]	29.67	107.72	153.46	474.77	1034.38	1401.19	2486.99
	Aquat. Ecotox.[kg 1,4-DCB-eq]	58.50	58.53	96.19	209.63	349.85	923.83	1309.63
	Terr. Ecotox. [kg 1,4-DCB-eq]				5.49	8.84	23.23	32.90
	Human tox.[kg 1,4-DCB-eq]	174.30	205.05	285.41	415.81	573.23	814.08	948.85

And these figures *per kg*:

Table 6-19 Key figures for the inputs used for the cultivation of one kg of wheat in the world.

QUANTILES	INPUTS								
	MachFix	MachTill	MachVar	Nfert	Pfert	Kfert	Pestic	Irrigat	Drying
2.5%	1.27E-04	1.18E-04	1.85E-05	4.48E-03	2.21E-03	2.09E-04		7.34E-03	3.44E-03
10.0%	1.45E-04	1.35E-04	2.62E-05	6.53E-03	2.41E-03	6.87E-04		1.77E-02	9.80E-03
25.0%	2.26E-04	2.10E-04	3.20E-05	1.42E-02	6.50E-03	1.24E-03	1.08E-04	5.78E-02	1.10E-02
median	3.60E-04	3.34E-04	4.13E-05	2.11E-02	7.60E-03	2.23E-03	2.35E-04	1.64E-01	2.07E-02
75.0%	4.11E-04	3.82E-04	5.82E-05	2.78E-02	8.84E-03	3.55E-03	3.17E-04	3.53E-01	2.97E-02
90.0%	5.21E-04	4.84E-04	9.96E-05	3.48E-02	1.20E-02	4.25E-03	4.25E-04	4.58E-01	4.05E-02
97.5%	8.35E-04	7.77E-04	1.14E-04	3.59E-02	1.24E-02	5.06E-03	5.20E-04	9.25E-01	5.23E-02

Table 6-20 Key figures for the impacts caused by the cultivation of one kg of wheat in the world.

QUANTILES		2.5%	10.0%	25.0%	median	75.0%	90.0%	97.5%
IMPACTS	Energy [MJ-eq]	3.84E+00	4.19E+00	4.32E+00	6.06E+00	7.56E+00	1.03E+01	1.38E+01
	GWP [kg CO2-eq]	3.35E-01	3.43E-01	4.72E-01	5.44E-01	6.28E-01	6.78E-01	8.01E-01
	O3 form. [kg ethylene-eq]	1.04E-04	1.12E-04	1.42E-04	1.63E-04	2.02E-04	2.64E-04	3.35E-04
	Nutr. enrich. [kg N-eq]	8.26E-03	8.55E-03	1.60E-02	2.27E-02	2.94E-02	3.65E-02	3.66E-02
	Acidific. [kg SO2-eq]	3.70E-03	4.27E-03	6.03E-03	8.01E-03	9.92E-03	1.16E-02	1.16E-02
	Land use [m2 year]	1.34E+00	1.53E+00	2.39E+00	3.80E+00	4.34E+00	5.49E+00	8.81E+00
	Water use [m3]	8.42E-03	1.87E-02	5.97E-02	1.67E-01	3.56E-01	4.62E-01	9.32E-01
	Aquat. Ecotox.[kg 1,4-DCB-eq]				9.34E-02	1.20E-01	1.68E-01	1.91E-01
	Terr. Ecotox. [kg 1,4-DCB-eq]				2.38E-03	3.11E-03	4.34E-03	4.79E-03
	Human tox.[kg 1,4-DCB-eq]	8.89E-02	9.16E-02	1.10E-01	1.32E-01	1.57E-01	2.09E-01	2.70E-01

The detailed results are in the excel file “wheat_world.xls”.

6.1.5 Cereals: Barley

The base system corresponds to the ecoinvent inventory for barley grains IP at farm in Switzerland with some few adaptations:

- Fertiliser share: we decide to use the share of different fertilisers in the total world consumption (i.e. no country specific adaptation is applied, see AII).
- Organic fertilisers: are not considered here, all fertilisers are assumed to be mineral fertilisers.

- Fertiliser quantity applied corresponding to the needs (in the ecoinvent inventory, the quantity applied corresponds to the Swiss recommendations and not exactly to the needs).
- Straw production is not considered (in contrast to the ecoinvent inventory).
- Irrigation: no irrigation is considered in the ecoinvent inventory. We know that, in some producing countries, barley is grown under irrigation. If we do not consider any irrigation in the base system inventory, no irrigation can be considered in all the other producing countries. In order to avoid this imprecision, we use the irrigation value of Poland (Karczmarczyk, 2002). That means that the extrapolation of the impacts per m^3 of irrigation water will be done, starting from Poland, whereas the extrapolation of the impacts per input units for the other inputs will start from Switzerland.

The same procedure as described for potato is applied. We obtain these results per input unit:

Table 6-21 Impacts per unit for each module (barley).

	Modules								
Impacts	MachFix	MachTill	MachVar	Nfert	Pfert	Kfert	Pestic	Irrigat	Drying
non-renewable Energy [MJ-eq]	3229.08	1818.25	2374.71	77.3	31.26	10.69	459.06	9.988	15.64
GWP 100a [kg CO2-eq]	233.72	118.49	152.61	13.87	2.00	0.614	21.217	0.247	0.59
photochemic O3 formation [kg ethylene-eq]	0.17	0.08	0.11	0.001	6E-04	2E-04	0.0153	2E-04	0.00
Nutrient enrichment [kg N-eq]	2.42	0.34	0.41	0.956	0.119	7E-04	0.0396	2E-04	0.00
Acidification [kg SO2-eq]	2.16	0.95	1.16	0.285	0.039	0.003	0.1455	9E-04	0.00
Land use [m2 year]	9833.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Water use [m3]	0.68	0.28	0.49	0.01	0.13	0.01	0.10	1.00	0.01
Aquatic ecotoxicity 100a [kg 1,4-DCB-eq]	30.58	0.13	0.20	0.02	0.446	0.01	298.28	4E-04	0.00
Terrestrial ecotoxicity 100a [kg 1,4-DCB-eq]	0.80	0.01	0.02	0.00	0.00	0.00	7.5673	1E-04	0.00
Human toxicity 100a [kg 1,4-DCB-eq]	65.30	38.32	70.93	1.315	0.975	0.337	56.912	0.181	0.11

And these figures *per ha*:

Table 6-22 Key figures for the inputs used in the cultivation of one ha of barley in the world.

QUANTILES	***INPUTS***						
	MachVar	Nfert	Pfert	Kfert	Pestic	Irrigat	Drying
2.5%	0.019	5.916	3.634	0.286	0.044	2.912	45.740
10.0%	0.041	9.119	4.451	2.385	0.154	5.077	64.600
25.0%	0.066	15.300	6.287	2.463	0.310	14.404	69.392
median	0.150	37.935	18.210	6.105	0.555	24.018	80.744
75.0%	0.371	89.752	36.164	19.099	1.064		83.053
90.0%	0.553	138.959	54.170	32.615	2.300	95.686	84.837
97.5%	0.572	163.733	60.179	37.202	2.553	186.952	85.598

Table 6-23 Key figures for the impacts caused by the cultivation of one ha of barley in the world.

QUANTILES		2.5%	10.0%	25.0%	median	75.0%	90.0%	97.5%
IMPACTS	Energy [MJ-eq]	6147.12	6521.35	7185.64	10002.71	15378.59	21304.19	23376.10
	GWP [kg CO2-eq]	453.11	518.54	587.47	987.49	1803.15	2600.86	2903.51
	O3 form. [kg ethylene-eq]	0.27	0.28	0.29	0.35	0.47	0.59	0.64
	Nutr. enrich. [kg N-eq]	8.94	12.26	18.23	41.25	91.31	142.16	162.81
	Acidific. [kg SO2-eq]	5.00	6.09	7.65	14.98	30.30	45.92	52.15
	Land use [m2 year]	9833.81	9833.81	9833.81	9833.81	9833.81	9833.81	9833.81
	Water use [m3]	2.80	4.82	7.77	17.41	38.31	64.10	128.81
	Aquat. Ecotox.[kg 1,4-DCB-eq]	52.12	78.23	121.71	236.93	374.21	773.52	820.25
	Terr. Ecotox. [kg 1,4-DCB-eq]				6.07	9.57	19.73	20.91
	Human tox.[kg 1,4-DCB-eq]	128.25	136.07	157.63	220.41	361.81	508.83	573.38

And these figures *per kg:*

Table 6-24 Key figures for the inputs used in the cultivation of one kg of barley in the world.

QUANTILES	INPUTS								
	MachFix	MachTill	MachVar	Nfert	Pfert	Kfert	Pestic	Irrigat	Drying
2.5%	1.62E-04	1.50E-04	1.75E-05	4.96E-03	2.17E-03	2.69E-04	4.01E-05	8.91E-04	1.20E-02
10.0%	1.69E-04	1.57E-04	2.42E-05	5.12E-03	2.38E-03	1.27E-03	8.23E-05	1.68E-03	1.31E-02
25.0%	2.37E-04	2.20E-04	3.17E-05	8.94E-03	4.50E-03	1.32E-03	1.42E-04	2.76E-03	1.42E-02
median	3.48E-04	3.24E-04	5.22E-05	1.60E-02	7.28E-03	2.70E-03	1.94E-04	8.44E-03	2.75E-02
75.0%	5.36E-04	4.99E-04	8.09E-05	2.00E-02	8.20E-03	4.86E-03	2.61E-04	2.92E-02	4.17E-02
90.0%	5.84E-04	5.43E-04	9.66E-05	2.45E-02	9.90E-03	5.35E-03	3.75E-04	3.99E-02	4.80E-02
97.5%	1.12E-03	1.05E-03	1.24E-04	2.85E-02	1.25E-02	6.62E-03	4.26E-04	1.04E-01	6.95E-02

Table 6-25 Key figures for the impacts caused by the cultivation of one kg of barley in the world.

QUANTILES		2.5%	10.0%	25.0%	median	75.0%	90.0%	97.5%
IMPACTS	Energy [MJ-eq]	2.97E+00	3.07E+00	3.57E+00	3.69E+00	4.07E+00	4.52E+00	7.36E+00
	GWP [kg CO2-eq]	2.75E-01	2.83E-01	3.08E-01	3.94E-01	4.15E-01	5.13E-01	5.80E-01
	O3 form. [kg ethylene-eq]	9.11E-05	9.60E-05	1.09E-04	1.27E-04	1.52E-04	1.67E-04	2.99E-04
	Nutr. enrich. [kg N-eq]	6.58E-03	6.72E-03	1.10E-02	1.74E-02	2.23E-02	2.53E-02	2.90E-02
	Acidific. [kg SO2-eq]	2.83E-03	3.24E-03	4.56E-03	6.17E-03	7.33E-03	8.13E-03	9.53E-03
	Land use [m2 year]	1.59E+00	1.66E+00	2.33E+00	3.42E+00	5.27E+00	5.74E+00	1.11E+01
	Water use [m3]	2.66E-03	3.11E-03	4.37E-03	1.01E-02	3.13E-02	4.04E-02	1.06E-01
	Aquat. Ecotox.[kg 1,4-DCB-eq]	4.03E-02	4.26E-02	6.16E-02	7.44E-02	9.22E-02	1.34E-01	1.38E-01
	Terr. Ecotox. [kg 1,4-DCB-eq]	1.06E-03	1.10E-03	1.60E-03	1.91E-03	2.36E-03	3.43E-03	3.51E-03
	Human tox.[kg 1,4-DCB-eq]	6.84E-02	7.19E-02	7.50E-02	8.45E-02	9.10E-02	1.02E-01	1.51E-01

6.1.6 Cereals: rye

The base system corresponds to the ecoinvent inventory for rye grains IP at farm in Switzerland with some few adaptations:

- Fertiliser share: we decide to use the share of different fertilisers in the total world consumption (i.e. no country specific adaptation is applied, see AII).
- Organic fertilisers: are not considered here, all fertilisers are assumed to be mineral fertilisers.
- Fertiliser quantity applied corresponding to the needs (in the ecoinvent inventory, the quantity applied corresponds to the Swiss recommendations and not exactly to the needs).
- Straw production is not considered (in contrary to the ecoinvent inventory).
- Irrigation: no irrigation is considered in the ecoinvent inventory. We know that, in some producing countries, rye is grown under irrigation. If we do not consider any irrigation in the base system inventory, no irrigation can be considered in all the other producing countries. In order to avoid this imprecision, we use the irrigation value of Germany (Richter, 1999). That means that the extrapolation of the impacts per m^3 of irrigation water will be done, starting from Germany, whereas the extrapolation of the impacts per input units for the other inputs will start from Switzerland.

The same procedure as described for potato is applied. We obtain these results per input unit:

Table 6-26 Impacts per unit for each module (rye)

Impacts	Modules								
	MachFix	MachTill	MachVar	Nfert	Pfert	Kfert	Pestic	Irrigat	Drying
non-renewable Energy [MJ-eq]	3440.30	1818.25	2409.49	73.37	31.26	10.69	458.39	9.988	18.23
GWP 100a [kg CO2-eq]	246.39	118.49	154.80	15.15	2.00	0.614	21.183	0.247	0.76
photochemic O3 formation [kg ethylene-eq]	0.18	0.08	0.11	0.001	6E-04	2E-04	0.0153	2E-04	0.00
Nutrient enrichment [kg N-eq]	2.34	0.34	0.41	1.295	0.119	7E-04	0.0395	2E-04	0.00
Acidification [kg SO2-eq]	2.27	0.95	1.18	0.284	0.039	0.003	0.1452	9E-04	0.00
Land use [m2 year]	10440.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Water use [m3]	0.74	0.28	0.50	0.01	0.13	0.01	0.10	1.00	0.01
Aquatic ecotoxicity 100a [kg 1,4-DCB-eq]	35.40	0.13	0.21	0.02	0.443	0.01	297.93	4E-04	0.00
Terrestrial ecotoxicity 100a [kg 1,4-DCB-eq]	0.93	0.01	0.02	0.00	0.00	0.00	7.5638	1E-04	0.00
Human toxicity 100a [kg 1,4-DCB-eq]	69.28	38.32	71.61	1.254	0.954	0.337	56.92	0.181	0.12

And these figures *per ha*:

Table 6-27 Key figures for the inputs used in the cultivation of one ha of rye in the world.

QUANTILES	INPUTS						
	MachVar	Nfert	Pfert	Kfert	Pestic	Irrigat	Drying
2.5%	0.04	8.19	3.69	2.30		4.11	60.65
10.0%	0.04	8.43	4.00	2.32	0.14	4.18	82.18
25.0%	0.06	12.36	4.64	2.38	0.15	5.81	91.38
median	0.15	37.53	18.51	12.41	0.36	19.24	91.71
75.0%	0.27	80.12	32.74	16.13	0.78	22.46	93.70
90.0%	0.51	129.26	42.67	27.19	1.50	73.55	94.51
97.5%	0.51	131.09	43.06	27.41	1.52	196.19	94.54

Table 6-28 Key figures for the impacts caused by the cultivation of one ha rye in the world.

QUANTILES		2.5%	10.0%	25.0%	median	75.0%	90.0%	97.5%
IMPACTS	Energy [MJ-eq]	7936.92	7959.78	8504.48	11210.73	15064.39	19957.22	20198.89
	GWP [kg CO2-eq]	582.45	583.79	649.91	1048.81	1855.73	2513.01	2613.66
	O3 form. [kg ethylene-eq]	0.29	0.29	0.31	0.36	0.44	0.55	0.55
	Nutr. enrich. [kg N-eq]	13.63	14.02	19.58	51.65	112.40	176.71	178.21
	Acidific. [kg SO2-eq]	5.90	5.98	7.24	14.50	28.55	40.82	42.75
	Land use [m2 year]	10440.48	10440.48	10440.48	10440.48	10440.48	10440.48	10440.48
	Water use [m3]	8.65	8.75	11.17	22.61	31.65	82.83	201.73
	Aquat. Ecotox.[kg 1,4-DCB-eq]		80.16	82.12	150.13	279.60	499.68	510.75
	Terr. Ecotox. [kg 1,4-DCB-eq]				3.89	7.18	12.79	13.07
	Human tox.[kg 1,4-DCB-eq]	145.73	146.26	167.54	225.76	321.37	446.90	457.33

And these figures *per kg*:

Table 6-29 Key figures for the inputs used in the cultivation of one kg of rye in the world.

QUANTILES	INPUTS								
	MachFix	MachTill	MachVar	Nfert	Pfert	Kfert	Pestic	Irrigat	Drying
2.5%	1.92E-04	1.79E-04	2.57E-05	3.89E-03	2.49E-03	1.22E-03		1.45E-03	1.73E-02
10.0%	1.94E-04	1.81E-04	2.59E-05	4.43E-03	2.67E-03	1.41E-03	2.63E-05	1.58E-03	1.77E-02
25.0%	2.56E-04	2.38E-04	3.07E-05	6.71E-03	2.75E-03	1.43E-03	8.35E-05	2.89E-03	2.27E-02
median	4.27E-04	3.97E-04	6.60E-05	1.63E-02	8.45E-03	5.15E-03	1.51E-04	5.77E-03	4.03E-02
75.0%	5.80E-04	5.39E-04	1.02E-04	2.32E-02	8.71E-03	5.39E-03	2.54E-04	1.26E-02	5.03E-02
90.0%	6.02E-04	5.60E-04	1.11E-04	2.53E-02	9.16E-03	6.36E-03	3.00E-04	2.69E-02	5.40E-02
97.5%	6.09E-04	5.67E-04	1.14E-04	2.88E-02	1.36E-02	7.26E-03	3.01E-04	8.47E-02	5.56E-02

Table 6-30 Key figures for the impacts caused by the cultivation of one kg rye in the world.

QUANTILES		2.5%	10.0%	25.0%	median	75.0%	90.0%	97.5%
	Energy [MJ-eq]	3.58E+00	3.98E+00	4.15E+00	4.82E+00	4.87E+00	5.29E+00	6.26E+00
	GWP [kg CO2-eq]	3.48E-01	3.52E-01	3.66E-01	4.74E-01	5.20E-01	5.21E-01	6.67E-01
	O3 form. [kg ethylene-eq]	1.03E-04	1.08E-04	1.36E-04	1.57E-04	1.79E-04	1.80E-04	1.99E-04
IMPACTS	Nutr. enrich. [kg N-eq]	7.62E-03	8.11E-03	1.09E-02	2.36E-02	3.27E-02	3.47E-02	4.05E-02
	Acidific. [kg SO2-eq]			3.89E-03	6.64E-03	8.51E-03	8.54E-03	1.01E-02
	Land use [m2 year]	2.01E+00	2.03E+00	2.67E+00	4.45E+00	6.05E+00	6.29E+00	6.36E+00
	Water use [m3]	3.36E-03	3.52E-03	5.01E-03	7.55E-03	1.34E-02	2.90E-02	8.73E-02
	Aquat. Ecotox.[kg 1,4-DCB-eq]		3.02E-02	4.79E-02	6.46E-02	9.66E-02	1.00E-01	1.09E-01
	Terr. Ecotox. [kg 1,4-DCB-eq]		8.06E-04	1.25E-03	1.67E-03	2.52E-03	2.57E-03	2.82E-03
	Human tox.[kg 1,4-DCB-eq]	7.74E-02	8.93E-02	8.97E-02	9.06E-02	9.75E-02	1.10E-01	1.27E-01

6.1.7 Cocoa

The base system corresponds to the inventory developed in the frame of this project for the Ghanaian production (section 5.1).

The same procedure as described for potato is applied. We obtain these results per input unit:

Table 6-31 Impacts per input for each module (cocoa cultivation).

	Modules								
Impacts	MachFix	MachTill	MachVar	Nfert	Pfert	Kfert	Pestic	Irrigat	Drying
non-renewable Energy [MJ-eq]	977.91	0.00	0.00	79.5	31.26	10.69	347.54	0	0.00
GWP 100a [kg CO2-eq]	67.59	0.00	0.00	20.3	2.00	0.614	15.764	0	0.00
photochemic O3 formation [kg ethylene-eq]	0.03	0.00	0.00	0.002	6E-04	2E-04	0.0095	0	0.00
Nutrient enrichment [kg N-eq]	0.32	0.00	0.00	2.983	0.544	7E-04	0.0252	0	0.00
Acidification [kg SO2-eq]	0.68	0.00	0.00	0.289	0.039	0.003	0.1202	0	0.00
Land use [m2 year]	10074.71	0.00	0.00	0.00	0.00	0.00	0.00	0	0.00
Water use [m3]	0.33	0.00	0.00	0.01	0.13	0.01	0.08	0	0.00
Aquatic ecotoxicity 100a [kg 1,4-DCB-eq]	0.29	0.00	0.00	0.032	0.757	0.015	889.67	0	0.00
Terrestrial ecotoxicity 100a [kg 1,4-DCB-eq]	0.03	0.00	0.00	0.00	0.00	0.00	28.76	0	0.00
Human toxicity 100a [kg 1,4-DCB-eq]	17.15	0.00	0.00	1.349	0.935	0.336	63.748	0	0.00

And these figures *per ha*:

Table 6-32 Key figures for the inputs used in the cultivation of one ha of cocoa in the world.

QUANTILES	INPUTS						
	MachVar	Nfert	Pfert	Kfert	Pestic	Irrigat	Drying
2.5%	0.944	24.372	4.214	5.286	2.535	0.000	0.000
10.0%	0.971	26.350	4.295	5.394	2.606	0.000	0.000
25.0%	2.788	41.846	6.739	7.435	11.341	0.000	0.000
median	2.815	82.918	17.930	17.326	23.303	0.000	0.000
75.0%	6.690	107.087	32.410	18.614	26.175	0.000	0.000
90.0%	13.016	509.409	66.633	54.456	41.374	0.000	0.000
97.5%	13.118	585.490	69.997	55.097	45.499	0.000	0.000

Table 6-33 Key figures for the impacts caused by the cultivation of one ha of cocoa in the world

QUANTILES		2.5%	10.0%	25.0%	median	75.0%	90.0%	97.5%
IMPACTS	Energy [MJ-eq]	3772.00	4076.48	10281.54	17390.91	17779.52	60443.62	66455.94
	GWP [kg CO2-eq]	603.59	650.79	1167.65	2189.45	2520.32	11178.61	12823.97
	O3 form. [kg ethylene-eq]	0.09	0.10	0.24	0.43	0.43	1.34	1.42
	Nutr. enrich. [kg N-eq]	75.21	81.23	128.79	261.51	344.50	1553.52	1785.00
	Acidific. [kg SO2-eq]	8.14	8.76	15.61	29.05	34.47	155.25	178.27
	Land use [m2 year]	10074.71	10074.71	10074.71	10074.71	10074.71	10074.71	10074.71
	Water use [m3]	1.52	1.53	3.05	6.15	6.84	19.43	20.82
	Aquat. Ecotox.[kg 1,4-DCB-eq]	2260.79	2323.32	10115.09	20744.06	23303.37	36873.78	40552.22
	Terr. Ecotox. [kg 1,4-DCB-eq]				669.30	751.56	1185.29	1303.53
	Human tox.[kg 1,4-DCB-eq]	231.40	232.02	874.86	1823.12	1864.40	3375.30	3794.67

And these figures *per kg*:

Table 6-34 Key figures for the inputs used in the cultivation of one kg of cocoa in the world.

QUANTILES	INPUTS								
	MachFix	MachTill	MachVar	Nfert	Pfert	Kfert	Pestic	Irrigat	Drying
2.5%			1.72E-03	6.62E-02	1.13E-02	1.27E-02	6.18E-03	0	0
10.0%			2.16E-03	7.02E-02	1.14E-02	1.30E-02	6.61E-03	0	0
25.0%	1.39E-03	1.29E-03	2.99E-03	1.08E-01	1.64E-02	1.94E-02	3.47E-02	0	0
median	1.40E-03	1.30E-03	3.88E-03	1.13E-01	2.50E-02	2.16E-02	3.73E-02	0	0
75.0%	2.48E-03	2.30E-03	1.21E-02	3.41E-01	5.69E-02	4.27E-02	3.76E-02	0	0
90.0%	2.65E-03	2.46E-03	1.55E-02	4.95E-01	6.76E-02	5.24E-02	3.77E-02	0	0
97.5%	3.44E-03	3.20E-03	1.60E-02	4.97E-01	1.03E-01	8.74E-02	5.88E-02	0	0

Table 6-35 Key figures for the impacts caused by the cultivation of one kg of cocoa in the world

QUANTILES		2.5%	10.0%	25.0%	median	75.0%	90.0%	97.5%
IMPACTS	Energy [MJ-eq]	1.08E+01	1.12E+01	2.27E+01	2.49E+01	4.70E+01	5.58E+01	6.14E+01
	GWP [kg CO2-eq]	1.69E+00	1.76E+00	2.81E+00	3.08E+00	8.01E+00	1.09E+01	1.12E+01
	O3 form. [kg ethylene-eq]	2.54E-04	2.61E-04	5.57E-04	5.90E-04	1.03E-03	1.18E-03	1.36E-03
	Nutr. enrich. [kg N-eq]	2.05E-01	2.17E-01	3.34E-01	3.63E-01	1.07E+00	1.51E+00	1.52E+00
	Acidific. [kg SO2-eq]	2.17E-02	2.32E-02	3.63E-02	3.95E-02	1.10E-01	1.51E-01	1.52E-01
	Land use [m2 year]			1.40E+01	1.41E+01	2.50E+01	2.67E+01	3.46E+01
	Water use [m3]	3.77E-03	3.89E-03	7.52E-03	8.02E-03	1.73E-02	1.95E-02	2.22E-02
	Aquat. Ecotox.[kg 1,4-DCB-eq]	5.51E+00	5.89E+00	3.10E+01	3.36E+01	3.36E+01	3.36E+01	5.24E+01
	Terr. Ecotox. [kg 1,4-DCB-eq]	1.77E-01	1.89E-01	9.93E-01	1.08E+00	1.08E+00	1.08E+00	1.69E+00
	Human tox.[kg 1,4-DCB-eq]	5.22E-01	5.67E-01	2.58E+00	2.62E+00	2.92E+00	3.16E+00	4.39E+00

6.1.8 Spice: pepper

The base system corresponds to the inventory developed in the frame of this project for the Indian production (section 5.2).

The same procedure as described for potato is applied. We obtain these results per input unit:

Table 6-36 Impacts per input unit for each module (pepper cultivation).

Impacts	Modules								
	MachFix	MachTill	MachVar	Nfert	Pfert	Kfert	Pestic	Irrigat	Drying
non-renewable Energy [MJ-eq]	1056.54	0.00	325.75	96.48	31.26	10.69	1691.9	0	0.00
GWP 100a [kg CO2-eq]	77.27	0.00	20.49	25.16	2.00	0.614	97.597	0	0.00
photochemic O3 formation [kg ethylene-eq]	0.02	0.00	0.02	0.002	6E-04	2E-04	0.0871	0	0.00
Nutrient enrichment [kg N-eq]	0.44	0.00	0.05	4.102	0.197	7E-04	0.2365	0	0.00
Acidification [kg SO2-eq]	0.85	0.00	0.15	0.3	0.039	0.003	0.7141	0	0.00
Land use [m2 year]	14302.55	0.00	0.00	0.00	0.00	0.00	0.00	0	0.00
Water use [m3]	0.48	0.00	0.09	0.01	0.13	0.01	0.53	0	0.00
Aquatic ecotoxicity 100a [kg 1,4-DCB-eq]	0.50	0.00	0.03	0.021	0.43	0.011	173.97	0	0.00
Terrestrial ecotoxicity 100a [kg 1,4-DCB-eq]	0.05	0.00	0.00	0.00	0.00	0.00	20.22	0	0.00
Human toxicity 100a [kg 1,4-DCB-eq]	19.86	0.00	14.50	1.613	0.945	0.337	5196.5	0	0.00

And these figures *per ha*:

Table 6-37 Key figures for the inputs used in the cultivation of one ha of pepper in the world.

QUANTILES	INPUTS						
	MachVar	Nfert	Pfert	Kfert	Pestic	Irrigat	Drying
2.5%	0.59	7.23	2.99	30.87		0.00	0.00
10.0%	0.96	25.39	9.76	33.44	0.11	0.00	0.00
25.0%	1.51	49.68	15.86	105.69	0.12	0.00	0.00
median	3.47	86.38	33.89	139.09	0.72	0.00	0.00
75.0%	6.87	145.29	82.50	375.34	1.66	0.00	0.00
90.0%	8.35	188.94	94.75	527.82	1.92	0.00	0.00
97.5%	13.35	219.73	105.90	578.14	2.62	0.00	0.00

Table 6-38 Key figures for the impacts caused by the cultivation of one ha of pepper in the world.

QUANTILES		2.5%	10.0%	25.0%	median	75.0%	90.0%	97.5%
IMPACTS	Energy [MJ-eq]	2705.30	4676.53	8360.28	19742.82	28157.95	32158.50	36174.46
	GWP [kg CO2-eq]	299.40	787.72	1477.62	3308.38	4708.48	5622.20	6368.85
	O3 form. [kg ethylene-eq]	0.09	0.11	0.23	0.54	0.79	0.92	1.05
	Nutr. enrich. [kg N-eq]	30.72	105.99	207.90	360.28	607.94	792.74	919.07
	Acidific. [kg SO2-eq]	3.34	9.26	17.19	30.91	54.49	65.63	73.90
	Land use [m2 year]	14302.55	14302.55	14302.55	14302.55	14302.55	14302.55	14302.55
	Water use [m3]	1.34	2.42	4.54	11.43	18.98	21.42	23.95
	Aquat. Ecotox.[kg 1,4-DCB-eq]	24.25	25.30	42.29	138.93	337.58	382.14	499.63
	Terr. Ecotox. [kg 1,4-DCB-eq]				14.17	31.84	37.27	51.67
	Human tox.[kg 1,4-DCB-eq]	603.83	657.40	717.29	3976.69	9191.72	10646.22	14324.08

And these figures *per kg*:

Table 6-39 Key figures for the inputs used in the cultivation of one kg of pepper in the world.

QUANTILES	INPUTS								
	MachFix	MachTill	MachVar	Nfert	Pfert	Kfert	Pestic	Irrigat	Drying
2.5%	2.45E-04	2.27E-04	6.70E-04	1.11E-02	4.87E-03	2.48E-02		0	0
10.0%	3.54E-04	3.29E-04	2.33E-03	4.95E-02	2.05E-02	1.08E-01	3.33E-04	0	0
25.0%	5.69E-04	5.29E-04	2.44E-03	7.13E-02	2.32E-02	1.09E-01	3.63E-04	0	0
median	6.80E-04	6.33E-04	2.81E-03	7.81E-02	3.11E-02	1.59E-01	7.17E-04	0	0
75.0%	1.61E-03	1.49E-03	3.70E-03	8.79E-02	4.12E-02	2.09E-01	7.27E-04	0	0
90.0%	2.75E-03	2.56E-03	4.97E-03	1.10E-01	4.65E-02	2.28E-01	1.15E-03	0	0
97.5%	2.97E-03	2.76E-03	5.20E-03	1.22E-01	4.99E-02	2.72E-01	1.15E-03	0	0

Table 6-40 Key figures for the impacts caused by the cultivation of one kg of pepper in the world.

QUANTILES		2.5%	10.0%	25.0%	median	75.0%	90.0%	97.5%
IMPACTS	Energy [MJ-eq]	3.89E+00	1.09E+01	1.24E+01	1.29E+01	1.52E+01	1.81E+01	1.86E+01
	GWP [kg CO2-eq]	4.75E-01	1.62E+00	2.13E+00	2.39E+00	2.63E+00	3.13E+00	3.54E+00
	O3 form. [kg ethylene-eq]	1.18E-04	3.21E-04	3.27E-04	3.69E-04	4.19E-04	5.04E-04	5.32E-04
	Nutr. enrich. [kg N-eq]	4.74E-02	2.08E-01	3.00E-01	3.28E-01	3.67E-01	4.62E-01	5.10E-01
	Acidific. [kg SO2-eq]	4.93E-03	1.85E-02	2.50E-02	2.75E-02	3.02E-02	3.62E-02	4.08E-02
	Land use [m2 year]	3.50E+00	5.07E+00	8.14E+00	9.73E+00	2.30E+01	3.94E+01	4.25E+01
	Water use [m3]	2.06E-03	5.98E-03	6.27E-03	8.13E-03	9.13E-03	1.10E-02	1.11E-02
	Aquat. Ecotox.[kg 1,4-DCB-eq]	2.75E-02	6.67E-02	8.03E-02	1.40E-01	1.42E-01	2.19E-01	2.25E-01
	Terr. Ecotox. [kg 1,4-DCB-eq]		6.56E-03	6.93E-03	1.43E-02	1.44E-02	2.15E-02	2.23E-02
	Human tox.[kg 1,4-DCB-eq]		1.92E+00	2.17E+00	3.90E+00	4.07E+00	6.27E+00	6.36E+00

6.2 GEOGRAPHICAL EXTRAPOLATION WITH THE YIELD CORRECTION

The yield correction extrapolation can be applied to the existing environmental impacts of the crop production in a given country to obtain the environmental impacts in a new specific country. As starting point for the extrapolation by yield correction, one can use values found in the literature or ecoinvent datasets for instance.

We present the results obtained for barley starting with ecoinvent datasets.

6.2.1 Ecoinvent datasets as starting point

We extrapolate the environmental impacts of barley production from the four countries available in the ecoinvent database successively to the same four countries. We could also extrapolate them to other countries; the only requirement being the knowledge of the yield in the country where we want to get data. If the yield in this country is not known accurately, we can use the FAOSTAT database for instance.

The obtained results are (*per ha*):

Table 6-41 Results of the geographical extrapolation by yield correction, using the ecoinvent datasets as starting point, for barley in four European countries. The results are given per ha.

- With the Swiss dataset as starting point:

FROM SWITZERLAND	*Switzerland*	*France*	*Spain*	*Germany*
Energy [MJ-eq]	20235.1	20025.8	12362.0	19386.2
GWP [kg CO2-eq]	3196.6	3163.5	1952.8	3062.4
O3 form. [kg ethylene-eq]	0.6	0.6	0.4	0.6
Nutr. enrich. [kg N-eq]	121.5	120.2	74.2	116.4
Acidific. [kg SO2-eq]	29.1	28.8	17.8	27.9
Aquat. Ecotox.[kg 1,4-DCB-eq]	267.9	265.1	163.7	256.7
Terr. Ecotox. [kg 1,4-DCB-eq]	9.0	8.9	5.5	8.6
Human tox.[kg 1,4-DCB-eq]	1739.7	1721.7	1062.8	1666.7

- With the French dataset as starting point:

FROM FRANCE	*Switzerland*	*France*	*Spain*	*Germany*
Energy [MJ-eq]	21303.9	21082.5	12978.1	20406.1
GWP [kg CO2-eq]	3820.6	3780.9	2327.4	3659.6
O3 form. [kg ethylene-eq]	0.6	0.6	0.3	0.5
Nutr. enrich. [kg N-eq]	106.7	105.6	65.0	102.2
Acidific. [kg SO2-eq]	44.9	44.4	27.3	43.0
Aquat. Ecotox.[kg 1,4-DCB-eq]	1202.4	1189.9	732.5	1151.7
Terr. Ecotox. [kg 1,4-DCB-eq]	458.1	453.4	279.1	438.8
Human tox.[kg 1,4-DCB-eq]	1306.2	1292.6	795.7	1251.1

- With the Spanish dataset as starting point:

FROM SPAIN	Switzerland	France	Spain	Germany
Energy [MJ-eq]	27637.1	27294.0	14732.2	26245.6
GWP [kg CO2-eq]	4843.1	4783.0	2581.7	4599.3
O3 form. [kg ethylene-eq]	0.9	0.9	0.5	0.8
Nutr. enrich. [kg N-eq]	147.5	145.7	78.6	140.1
Acidific. [kg SO2-eq]	24.4	24.1	13.0	23.2
Aquat. Ecotox.[kg 1,4-DCB-eq]	196.6	194.2	104.8	186.7
Terr. Ecotox. [kg 1,4-DCB-eq]	3.3	3.3	1.8	3.1
Human tox.[kg 1,4-DCB-eq]	1336.4	1319.8	712.4	1269.1

- With the German dataset as starting point:

FROM GERMANY	Switzerland	France	Spain	Germany
Energy [MJ-eq]	25304.9	25038.4	15279.1	24223.9
GWP [kg CO2-eq]	3826.9	3786.6	2310.7	3663.5
O3 form. [kg ethylene-eq]	0.8	0.7	0.5	0.7
Nutr. enrich. [kg N-eq]	51.0	50.5	30.8	48.8
Acidific. [kg SO2-eq]	21.6	21.3	13.0	20.6
Aquat. Ecotox.[kg 1,4-DCB-eq]	153.1	151.5	92.4	146.5
Terr. Ecotox. [kg 1,4-DCB-eq]	1.2	1.2	0.7	1.1
Human tox.[kg 1,4-DCB-eq]	1146.6	1134.5	692.3	1097.6

The extrapolation works in some situations for the energy demand, GWP, ozone formation and acidification, sometimes also for eutrophication. Where the extensive production in Spain is taken as a basis, the deviations are larger. The production in Germany, France and Switzerland is similar to a certain extent, while the Spanish production is quite different. In this case, the extrapolation is done starting from the inventory of a single country. We recommend pooling all available data that are similar to the situation according to expert knowledge and to calculate the median as a basis (as described in 2.3 and 2.4).
For the toxicity impacts, the extrapolation does not work, since the impact depends much more on the pesticides applied than on the yield (or the overall intensity).

6.3 PRODUCT EXTRAPOLATION WITH THE YIELD CORRECTION

The yield correction extrapolation can be applied to the existing environmental impacts of a given crop production in a given country to obtain the environmental impacts of the production of a new crop in the same country. As starting point for the extrapolation by yield correction, one can use values found in the literature or ecoinvent datasets for instance.

We present the results obtained for barley, starting with ecoinvent datasets.

6.3.1 Ecoinvent datasets as starting point

We extrapolate the environmental impacts of barley production using the environmental impacts of wheat or rye production in the same country.

Table 6-42 Results of the product extrapolation by yield correction, using the ecoinvent datasets for wheat or rye, for barley in four European countries.

- With the wheat dataset as starting point:

FROM WHEAT	Switzerland	France	Spain	Germany
Energy [MJ-eq]	24126.9	22525.4	19113.0	22701.9
GWP [kg CO2-eq]	4327.4	3952.6	2266.3	3588.9
O3 form. [kg ethylene-eq]	0.7	0.6	0.6	0.6
Nutr. enrich. [kg N-eq]	108.3	94.2	25.7	46.6
Acidific. [kg SO2-eq]	31.3	44.9	13.7	19.8
Aquat. Ecotox.[kg 1,4-DCB-eq]	363.0	1552.0	136.7	138.0
Terr. Ecotox. [kg 1,4-DCB-eq]	12.3	631.5	1.8	1.8
Human tox.[kg 1,4-DCB-eq]	2507.0	1258.6	868.9	981.7

- With the rye dataset as starting point:

FROM RYE	Switzerland	France	Spain	Germany
Energy [MJ-eq]	20064.2	18715.2	20464.3	16772.4
GWP [kg CO2-eq]	2992.8	2238.6	2447.8	2006.2
O3 form. [kg ethylene-eq]	0.6	0.5	0.5	0.4
Nutr. enrich. [kg N-eq]	103.1	28.6	31.2	25.6
Acidific. [kg SO2-eq]	27.6	16.9	18.5	15.2
Aquat. Ecotox.[kg 1,4-DCB-eq]	275.1	7660.3	8376.2	6865.1
Terr. Ecotox. [kg 1,4-DCB-eq]	10.1	3366.1	3680.7	3016.7
Human tox.[kg 1,4-DCB-eq]	1777.4	1373.1	1501.5	1230.6

The extrapolation works better from wheat to barley, since wheat inventories are available in the respective countries. Again the extrapolation does not work for the toxicity impacts.

7 Plausibility and verification of the results

7.1 PLAUSIBILITY

The modular inventory contains several assumptions and simplifications compared to a classical LCA which has to be assessed regarding their plausibility. The main simplifications are:

1. The decomposition of the base system inventory in a modular inventory (with nine modules) and the assumption of linear relationships between input quantity and certain field emissions.
2. The estimators derived using the FAOSTAT data.
3. The use of these estimators instead of the specific input quantities.
4. Impact of tillage & irrigation assumed to be constant

We test the plausibility of these simplifications and try to quantify their effect on the results in the next sections.

7.1.1 The decomposition of the base system inventory

The underlying idea of the modular inventory is the possible decomposition of the LCI (and subsequently) LCA of food production in a few modules, corresponding to the major axes of the production management. This assumption enables a simplified LCIA calculation by reducing the needed amount of input data.

The quality of this simplified assessment has to be tested. A comparison between the base system inventory and its modular version has to be undertaken. The base system inventory in its unified form is the reference since it corresponds to a complete and detailed LCIA calculated with the state-of-the-art tools (SALCA). Its modular form is a simplification and cannot thus be considered as the "truth".

By doing this comparison for barley, we notice that there are some small differences between the two LCIA results related to:

- Direct field emissions
- Land occupation
- Seed

Direct field emissions appear in the inventory in its unified form but not in its modular form. This is related to the structure of the LCIA tools and does not constitute a problem. They simply have to be distributed in the proper module:

- For GWP: direct field emissions correspond to the emissions of nitrous oxide. They are thus related to the use of nitrogen fertilizers and have to be counted in the N fertilisation module.
- For eutrophication: direct field emissions are phosphorus and nitrogen emissions (in diverse forms). They are thus related to the use of nitrogen fertilizers and of phosphorus fertilizers. They have to be distributed in the N fertilisation module and in the P fertilisation module properly.
- For acidification: direct field emissions are emissions of nitrous oxides and of ammonia. They are thus related to the use of nitrogen fertilizers and counted in the N fertilisation module.

Land occupation is calculated in the unified inventory using the yield and the produced amount. We decide to count land occupation in the fixed machinery module. This means that the effective area needed to produce one ha of the considered crop is constant across the world for a given crop. This assumption is not totally correct but has a very small effect. The area needed to produce one kg of product is of course not constant across the world and depend on the yield.

Seed is taken into account in the unified inventory whereas, in the modular inventory, it does not appear in any module. Seeds play however a role for the heavy metal balance and thus for toxicity (both ecological toxicity and human toxicity). We consider that the seed quantity needed to produce one hectare of a given crop is constant. This is an approximation but is reasonable for the purpose of the study. Seeds have never been determinant for the results of a crop LCA so far.

All these operations are done automatically in the FS (section 4.2).

The sum of the impacts produced in each module equals the impacts of the unified system. The modular inventory is thus highly capable to substitute the inventory in its unified form, since it produces the same impacts.

7.1.2 The estimators

The modular inventory requires nine input parameters (yield, kg N fertilisers, etc.). The modular inventory will of course provide better results if these input parameters are accurate for the considered situation. It can be however difficult to find values for these parameters in certain situations (e.g. tropical crop in a difficult geographical context). In those cases, it is possible to use the modular inventory by using estimators. These estimators are based on indices which use FAOSTAT data.

It is very difficult to assess the quality of the FAOSTAT data as well as the adequacy of the chosen index construction based on these data. Above all it is difficult to assess them separately. It is relatively clear that the FAOSTAT database contains some erroneous or misleading data. Furthermore the estimator based on the index cannot describe perfectly the input quantity (even in case of perfect data for the index calculation). A way to assess their joint quality is to compare the obtained estimators with the effective input quantities.

We do this for some of the estimators with the values from ecoinvent for barley:

Table 7-1 Relative error done on the inputs for few countries when using estimators for N fertilisation, P fertilisation, K fertilisation and pesticides for barley. These figures are different for each crop and each country.

Countries	***Dataset***	***N fertil.***	***P fertil.***	***K fertil.***	***Pestic.***
	Ecoinvent input	94.884712	73.18376	0	1.73607258
France	Estimator	134.750214	55.0104112	32.7797961	2.57248707
	rel. Difference	**42%**	**-25%**	**NA**	**48%**
	Ecoinvent input	77.031216	59.3416416	12.1882166	0.83750813
Spain	Estimator	44.3356796	22.6597644	11.0212374	0.67281503
	rel. Difference	**-42%**	**-62%**	**-10%**	**-20%**
	Ecoinvent input	150.5775	43.10025	0.735915	0.97485998
Germany	Estimator	145.51588	44.0671919	28.8716718	1.6381478
	rel. Difference	**-3%**	**2%**	**3823%**	**68%**

We first notice that the estimators solely roughly correspond to the related input quantity and that, in some cases, they do not correspond at all. It is a risk that has to be assumed when using the estimator instead of a precise input quantity.

Looking at the relation between the different countries and the different inputs instead of looking at the absolute figures, we notice that:

- For N fertilisation: in both the ecoinvent inputs and in the estimators, the succession of the countries is the same. Germany applies the highest quantity of N fertilisers, followed by France and then by Spain.
- For P fertilisation: in ecoinvent, France applies the highest quantity of P fertilisers, followed by Spain and then by Germany, whereas the estimators indicate that France uses the highest quantity of P fertilisers, followed by Germany and then by Spain. An inversion between Germany and Spain is observed.
- For K fertilisation: there is no concordance between the country succession in ecoinvent and the country succession in the estimators. We have to notice the very low level of K fertilisation in France and Germany in ecoinvent, which are not necessarily representative for these 2

countries (but solely for the regions in these countries, for which the ecoinvent datasets are produced).

- For pesticides: the succession is identical in ecoinvent and in the estimators. France applies more pesticides than the other countries, followed by Germany and finally by Spain.
- For the three countries, both ecoinvent and the estimators indicate that the quantity of N applied is higher than the quantity of P applied which is higher than the quantity of K applied on the crop.

A remark has to be done: the ecoinvent input data do not represent the “real” input quantities that are effectively applied in those countries. They are also estimates (of better quality than those obtained with the estimator based on the FAOSTAT data) and these datasets are not necessarily representative for the whole country: the ecoinvent dataset for France refers to an average production in the Barrois region (South West quarter of France), the ecoinvent dataset for Spain refers to an average production in the Castilla-y-Leon (North of Spain) and the ecoinvent dataset for Germany refers to an average production in the Saxony-Anhalt region (North East of Germany). It is thus not possible to know the exact input quantities applied for barley production at the country scale using the ecoinvent datasets.

A way to improve the estimators would be to use the yield of the crop production in the considered situation instead of the yields given in the FAOSTAT database as we do for the global estimators or to use data of greater accuracy than the data of FAOSTAT for the estimators.

7.1.3 The use of the estimators

As seen previously, the estimators calculated with the indices derived from the FAOSTAT database can deviate substantially from the ecoinvent data for the corresponding input. The question is how this deviation on the input is reflected in the environmental impacts. We investigate this question more deeply in a sensitivity analysis in chapter 8.3, which shows the influence of each input on each impact category.

We here try to evaluate the effect of the use of the estimators for barley by comparing the results obtained with the modular inventory using the estimators as input data, the results obtained with the modular inventory using the ecoinvent data as input data and the ecoinvent LCIA data.

We obtain those results for the relative difference between the impacts calculated with the modular inventory using the estimators and ecoinvent on one hand and between the impacts calculated with the modular inventory using the ecoinvent input data and ecoinvent on the other hand:

Table 7-2 Comparison between the results obtained with the modular inventory extrapolation fed with the estimators (classical variant) and ecoinvent LCIA data versus comparison between the results obtained with the modular inventory extrapolation fed with the ecoinvent input data (“control version”) and ecoinvent.

	COUNTRIES					
	France		*Spain*		*Germany*	
Dataset comparison	estimat./ecoinv.	input/ecoinv.	estimat./ecoinv.	input/ecoinv.	estimat./ecoinv.	input/ecoinv.
IMPACTS						
non-renewable energy [MJ-eq]	2%	-22%	-19%	-7%	-12%	-19%
GWP 100a [kg CO2-eq]	-33%	-49%	-57%	-39%	-28%	-28%
photochemical ozone formation [kg ethylene-Eq]	5%	-11%	-20%	-11%	-19%	-23%
nutrient enrichment [kg N-eq]	31%	-3%	-39%	6%	202%	211%
Acidification [kg SO2-Eq]	1%	-24%	31%	113%	129%	135%
Aquatic ecotoxicity, 100a [kg 1,4-DCB-Eq]	-31%	-51%	132%	195%	270%	135%
Terrestrial ecotoxicity, 100a [kg 1,4-DCB-Eq]	-95%	-97%	254%	350%	1135%	685%
Human toxicity, 100a [kg 1,4-DCB-Eq]	-58%	-67%	-63%	-54%	-55%	-60%

We see that the use of the estimators instead of accurate input data (ecoinvent input data) sometimes leads to worst results but some other times to better results. It is highly related to the country: for Spain, the results are really improved by using accurate input data whereas for France and Germany, it tends on contrary to worsen the results.

There is thus no obvious improvement of the results by using more accurate input data for barley in these three countries, assuming that the ecoinvent data are “the best depiction” of the reality. This result is somewhat surprising, as we would have expected a better agreement between model and results by using the

“real” input data from ecoinvent. The whole system is however not linear and small changes in the inputs can lead to important changes in the results.
For GWP we should note that the values in ecoinvent are using the IPCC 2001 emission factors for N_2O, whereas the modular model calculates with the IPCC factors 2006, which result in a lower GWP.

7.1.4 Influence of the tillage on the results

We assumed in this project a constant importance of the tillage for all crops and all countries: we assumed that 93% of the cultivated surface (with any crop and in any country) is under conventional tillage and 7% under no-till. This rough approximation is related to the lack of data at this scale. We have not taken in consideration the reduced tillage.

We test the validity of this approximation by assessing the impact of another tillage importance on the environmental impacts caused by crop cultivation. The scenarios for the importance of no-till are:

- 0% tillage: the considered crop is cultivated under no-till in the whole world. No farmer ploughs his field; seeds are sown directly without seedbed preparation. This scenario is highly improbable, even for a very favourable crop (soy).
- 50% tillage: only 50% of the surface cultivated with the considered crop is tilled conventionally, the other 50% being under no-till. This scenario is very ambitious but could be realistic in few years for a few specific crops.
- 93% tillage: this percentage corresponds to the value assumed in this project and corresponding approximately to the current world average.
- 100% tillage: this is the most pessimistic scenario. The considered crop is cultivated traditionally with a conventional ploughing everywhere. No-till or reduced tillage never occur for this crop. This scenario is not very realistic, although some crops are rarely cultivated under no-till (root vegetable for instance).

Soy being the crop most frequently cultivated under no-till, we test the importance of our scenarios on the results obtained with protein pea. This crop is also a protein crop and is quite favourable to cultivation under no-till. We test them on a cereal crop too, barley, cereals being sometimes cultivated under no-till and sometimes with conventional tillage.

Having first the 0% tillage scenario and then the 100% tillage scenario (transition from an extreme scenario to the other extreme scenario), the impact increase would be:

Table 7-3 Result differences between a situation with no-till (0% tillage) and a situation with the whole area tilled (100% tillage).

Crop	***Protein pea***					
Region	***World median***	***Switzerland***	***France***	***Spain***	***Germany***	
IMPACTS						
non-renewable energy [MJ-eq]	16%	13%	12%	14%	14%	
GWP 100a [kg CO2-eq]	12%	8%	8%	13%	9%	
photo. ozone formation [kg ethylene-Eq]	22%	17%	16%	19%	18%	
nutrient enrichment [kg N-eq]	1%	1%	1%	3%	1%	
Acidification [kg SO2-Eq]	6%	11%	10%	17%	12%	
Aquatic ecotoxicity, 100a [kg 1,4-DCB-Eq]	0%	0%	0%	1%	0%	
Terrestrial ecotoxicity, 100a [kg 1,4-DCB-Eq]	0%	0%	0%	1%	1%	
Human toxicity, 100a [kg 1,4-DCB-Eq]	16%	13%	12%	17%	15%	
Crop	***Barley***					
Region	***World median***	***Switzerland***	***France***	***Spain***	***Germany***	***USA***
IMPACTS						
non-renewable energy [MJ-eq]	16%	8%	8%	15%	8%	14%
GWP 100a [kg CO2-eq]	12%	5%	5%	11%	4%	9%
photo. ozone formation [kg ethylene-Eq]	22%	13%	13%	20%	14%	19%
nutrient enrichment [kg N-eq]	1%	0%	0%	1%	0%	1%
Acidification [kg SO2-Eq]	6%	2%	2%	6%	2%	4%
Aquatic ecotoxicity, 100a [kg 1,4-DCB-Eq]	0%	0%	0%	0%	0%	0%
Terrestrial ecotoxicity, 100a [kg 1,4-DCB-Eq]	0%	0%	0%	0%	0%	0%
Human toxicity, 100a [kg 1,4-DCB-Eq]	16%	7%	7%	15%	8%	13%

The tillage increase from 0% to 100% has no or negligible influence on nutrient enrichment, on aquatic and on terrestrial ecotoxicity. The effect on global warming potential and on acidification is limited (about 10%). The major effects are observed on non renewable energy resources consumption (about 15%), on human toxicity (about 15%) and, above all, on ozone formation (about 20%). The effect of the tillage increase is more important in countries or in regions where the impacts are low (Spain or world median for GWP for instance).
Both the 0% tillage and the 100% tillage scenarios are not realistic, at least for most crops. Considering it and the global uncertainty of the impact calculations, we consider that an increase of 20% of the impacts is reasonable. This leads us to maintain a constant tillage proportion for any crop in any country in the framework of this project (the 93% tillage scenario).

The error in case of assuming a 93% tillage scenario and having 50% tillage in reality would be:

Table 7-4 Result differences between a situation with 93% of the area tilled (as assumed in the project) and a situation with 50% of the area tilled (optimistic scenario).

Crop	***Protein pea***					
Region	***World median***	***Switzerland***	***France***	***Spain***	***Germany***	
IMPACTS						
non-renewable energy [MJ-eq]	7%	6%	5%	6%	6%	
GWP 100a [kg CO2-eq]	5%	4%	3%	5%	4%	
photo. ozone formation [kg ethylene-Eq]	9%	7%	8%	7%	8%	
nutrient enrichment [kg N-eq]	0%	1%	1%	1%	1%	
Acidification [kg SO2-Eq]	3%	5%	5%	7%	5%	
Aquatic ecotoxicity, 100a [kg 1,4-DCB-Eq]	0%	0%	0%	0%	0%	
Terrestrial ecotoxicity, 100a [kg 1,4-DCB-Eq]	0%	0%	0%	1%	0%	
Human toxicity, 100a [kg 1,4-DCB-Eq]	7%	6%	5%	7%	7%	
Crop	***Barley***					
Region	***World median***	***Switzerland***	***France***	***Spain***	***Germany***	***USA***
IMPACTS						
non-renewable energy [MJ-eq]	7%	4%	4%	7%	4%	6%
GWP 100a [kg CO2-eq]	5%	2%	2%	5%	2%	4%
photo. ozone formation [kg ethylene-Eq]	9%	5%	9%	6%	6%	8%
nutrient enrichment [kg N-eq]	0%	0%	0%	0%	0%	0%
Acidification [kg SO2-Eq]	3%	1%	1%	2%	1%	2%
Aquatic ecotoxicity, 100a [kg 1,4-DCB-Eq]	0%	0%	0%	0%	0%	0%
Terrestrial ecotoxicity, 100a [kg 1,4-DCB-Eq]	0%	0%	0%	0%	0%	0%
Human toxicity, 100a [kg 1,4-DCB-Eq]	7%	3%	3%	6%	3%	6%

Considering plausible scenarios, the error would be less than 10% by assuming a constant tillage for any crop in any country. It is a fully satisfying hypothesis regarding the accuracy required in this project.

The hypothesis of a 93% tillage scenario is maintained for any crop in any country is maintained in this project and no further research about tillage has to be undertaken for projects having similar accuracy needs.

7.2 VALIDATION

The whole extrapolation done with the modular inventory (using estimators) has to be validated.

We consider that the LCIA ecoinvent data are best estimates of impacts available. We thus plot the results obtained with the modular inventory (using estimators) against the ecoinvent LCIA data (with the open source statistical package R). We do it for all crops considered in the project which are present in the ecoinvent database too and for all countries that are available in the ecoinvent database. It is not possible to validate ecotoxicity values since new factors were used in the modular inventory as compared to the ecoinvent database. Water use cannot be evaluated too since water use is not consider in most of the ecoinvent inventories. Land use is validate per kg solely; land use per ha is not a meaningful parameter.

The impacts are shown per hectare:

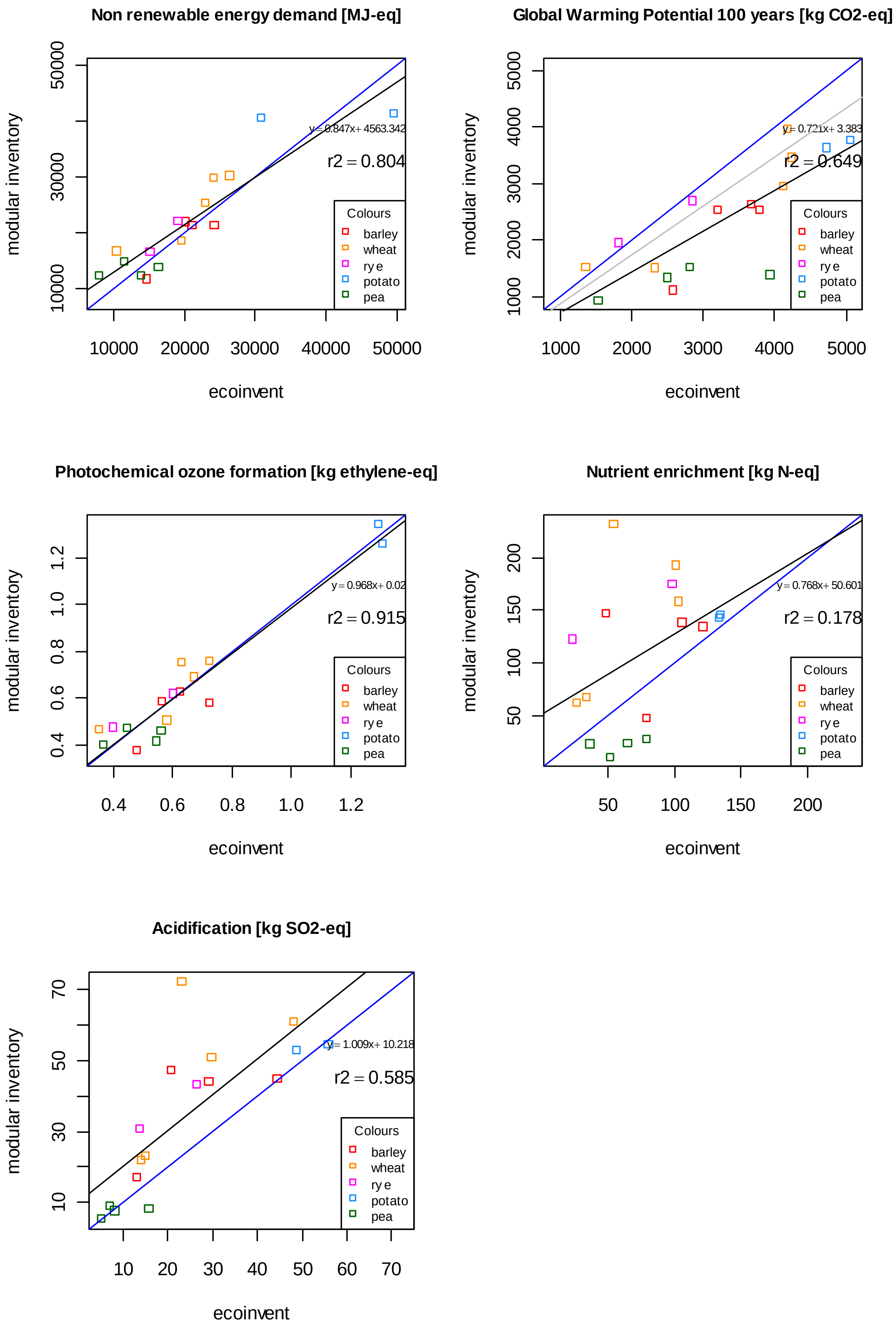
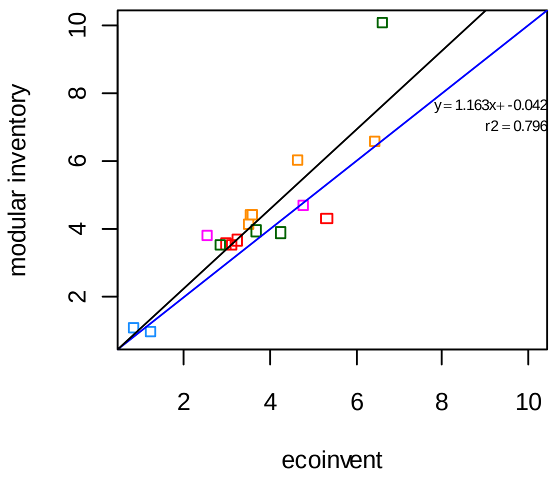


Fig. 7-1 Comparison between the results obtained with the modular inventory extrapolation (using estimators) and the ecoinvent LCIA data for several crops in several countries *per ha*. The results of the modular inventory

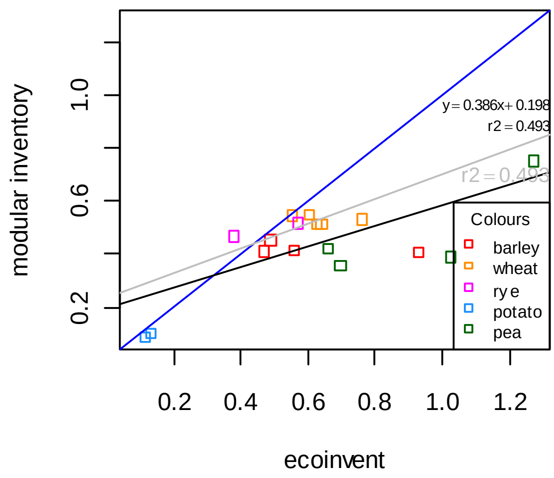
are shown in the Y axe and the ecoinvent LCIA datasets in the X axe. In case of perfect concord between the results of the modular inventory and the ecoinvent LCIA datasets, the data points would be located on the blue line. The black line represents the regression line between the results of the modular inventory and the ecoinvent LCIA datasets. The coefficient of determination (R-squared) is given for each regression line (linear regression). The method for the assessment of GWP has changed between ecoinvent and this project and therefore the GWP values are expected to be lower. An additional regression has been computed with this expected difference on the results (grey line).

And shown per kg:

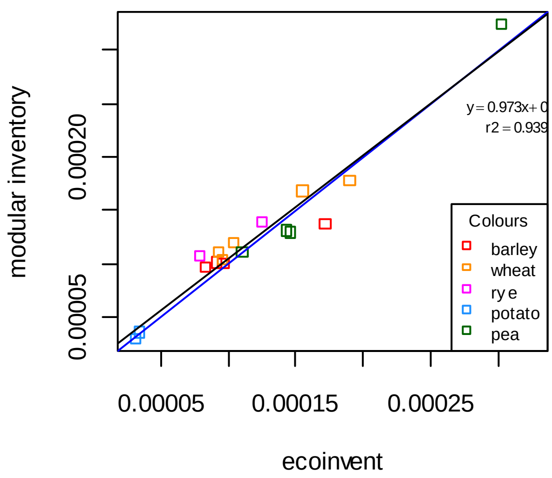
Non renewable energy demand [MJ-eq]



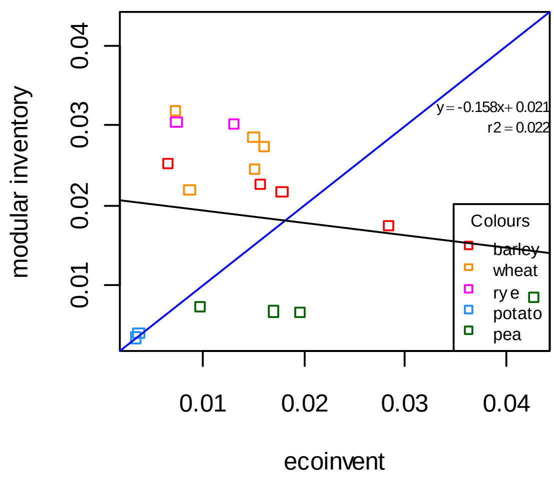
Global Warming Potential 100 years [kg CO2-eq]



Photochemical ozone formation [kg ethylene-eq]



Nutrient enrichment [kg N-eq]



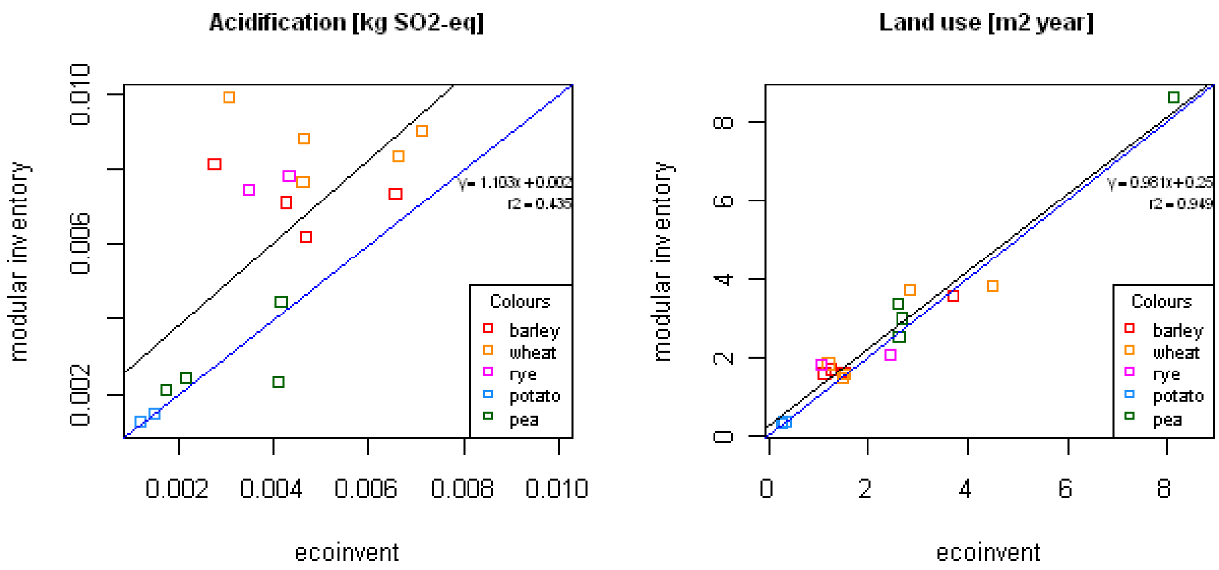


Fig. 7-2 Comparison between the results obtained with the modular inventory extrapolation (using estimators) and the ecoinvent LCIA data for several crops in several countries *per kg*. The results of the modular inventory are shown in the Y axe and the ecoinvent LCIA datasets in the X axe. In case of perfect concord between the results of the modular inventory and the ecoinvent LCIA datasets, the data points would be located on the blue line. The black line represents the regression line between the results of the modular inventory and the ecoinvent LCIA datasets. The coefficient of determination (R-squared) is given for each regression line (linear regression). The method for the assessment of GWP has changed between ecoinvent and this project and therefore the GWP values are expected to be lower. An additional regression has been computed with this expected difference on the results (grey line).

The modular inventory (using estimators) seems to perform well for the assessment of the photochemical ozone formation. It is however difficult to evaluate it properly because of the reduced number of points. It is possible that the two points corresponding to potato have a great influence on the regression curve and on the coefficient of determination (R-squared). This result is however very encouraging for a rapid ozone formation assessment.

The method functions pretty well for the estimation of the non renewable energy demand. It seems to work better for cereals and for peas than for potato.

It is problematic to compare the results obtained with the modular inventory and the ecoinvent data for the GWP, since the GWP was calculated with the IPCC 2001 method in ecoinvent and with the IPCC 2006 method in this project (modular inventory). The introduction of the new IPCC method leads to lower values, since the general emission factors for N2O has been reduced from 1.25% to 1%, the emission factor from symbiotic N fixation has been set to 0 and the factor for induced emissions from nitrate has been reduced from 2.5% to 0.75%. There is a highly significant correlation between the results obtained with the modular inventory and the ecoinvent data, indicating that a reasonable estimation can be obtained by the modular model.

In the case of acidification, the modular inventory overestimates the impacts almost systematically and the R-squared is quite low. The correlation between the modular inventory results and the ecoinvent data is however highly significant. This overestimation can probably be explained by the fact that we assumed the world share of N fertilisers and not the country specific fertiliser use. In the world 2/3 of the N fertilisers are urea, which produces much higher NH_3 losses than other N fertilisers. In the considered country (mainly from Europe), urea is not so widely used. Using country specific fertiliser share would probably improve the quality of the estimates. However, the current design of the model allows for just varying the amount of N fertilisers not the type.

The eutrophication assessment is poorly performed by the modular inventory model. The coefficient of determination is low and not significant. This result is not really surprising, since several simplifications have been made and important influencing factors are not considered. Nitrate leaching is the determining emission for eutrophication. Although nitrate leaching is related to N fertilisation, the relationship is not linear as assumed in the model. Furthermore, neither climatic and soil factors nor the crop rotation and catch cropping was considered. For the Swiss crops, catch crops during winter are included in the ecoinvent datasets fro spring sown crops, whereas in the modular model, the soil is not covered during the winter, which should provoke higher nitrate leaching.

For ecotoxicity and human toxicity, the values calculated in this project are not comparable to ecoinvent, due to the new characterisation factors used, which are not included in ecoinvent. However, it is clear that a good estimate will not be possible with the used approach.

8 Establishment of qualitative and quantitative relationships between the key parameters

We perform two analyses: first a multivariate analysis of datasets from the ecoinvent and from the SALCA databases and second a sensitivity analysis using the modular inventory and the calculated variability of the inputs (i.e. the variability shown in the estimators).

8.1 Multivariate analysis of datasets from the ecoinvent and SALCA databases

In this chapter, a multivariate analysis of the two databases SALCA (with inventories for Swiss arable crops from Nemecek (Nemecek, 2005)) and ecoinvent V2.01 with inventories for crops from the whole world is carried out. Based on a set of midpoint impact indicators, the goal is to show similarities and differences between different inventories for bio-based products. The modular inventory is not part of this analysis.

Previously, this multivariate analysis has been used several times to show similarities between impact categories (*variables*) in order to reduce the complexity of information and to achieve an easier interpretation ((Mouron, 2006), (Nemecek, 2005), (Rossier, 2001)) based on objective statistical criteria.
Here we used the same methodology to show similarities between *cases* (crop inventories).

The detailed results of this analysis are presented in AI.

Between 76 and 80% of the variability could be explained by the first two principal components. The first component was largely related to the crop or crop group, while the second principal component mainly represents the production intensity or the farming system (conventional, integrated, extensive, organic). By applying the method to the ecoinvent datasets we could clearly distinguish the crops grown on previously cleared land (from forest or shrub land), which confirms that such cases have to be treated separately. The method can also help to find proxy data for missing inventories. The analysis of the cereal datasets (wheat and barley) in different countries shows that there exist considerable differences between the countries, while wheat and barley are relatively close together within a given country. As a proxy for French barley, it is therefore preferable to choose French wheat than to use German barley data. The variability of environmental impacts is in general larger per product unit than per area unit. A correlation was found between environmental impacts and the inverse of yield, which can be applied to make rough estimates based on existing datasets.

8.2 Analysis of the key parameter variability

The key parameters are defined as the inputs for each module and the yield in the present work. We thus analyse the variability of:

1. Yield
2. Machinery use
3. Nitrogen fertilisers use
4. Phosphorus fertilisers use
5. Potassium fertilisers use
6. Pesticides
7. Irrigation
8. Drying

8.2.1 Yield

We consider average yields in the period 2003 to 2007 from the database FAOSTAT (FAO, 2009).

Potato

The yield of potato production ranges between about 2 (Burkina Faso) and 44 Tonnes/ha (New Zealand). The following graph shows the yield distribution considering the associated cumulated production. This enables to identify the most important producers and the related yield, as well as to determine the median yield in the world.

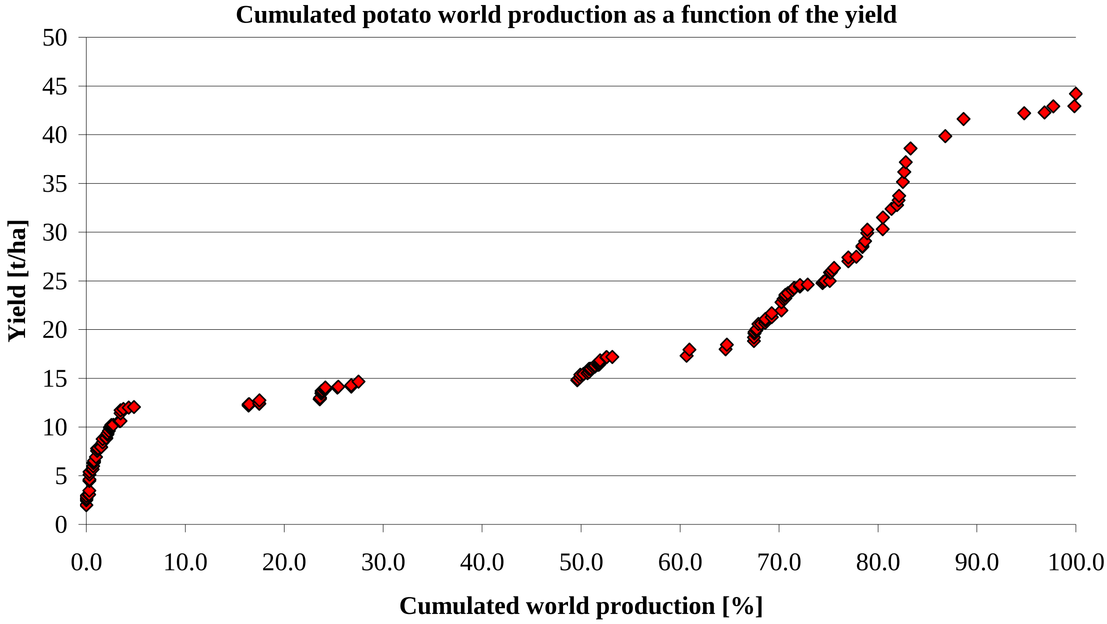


Fig. 8-1 Yields and corresponding cumulated productions for potato.

We can read on the graph that the median of the yield is about 15 tonnes/ha, that a country having a yield corresponding approximately to the median yield produced about 20 or 25% of the world production (China) and that another country with a rough yield of 12 tonnes/ha produces about 10% of the world production (Russia) for instance.

Carrot

The carrot production shows yields between 3.7 tonnes/ha (Madagascar) and 61.8 tonnes/ha (Israel).

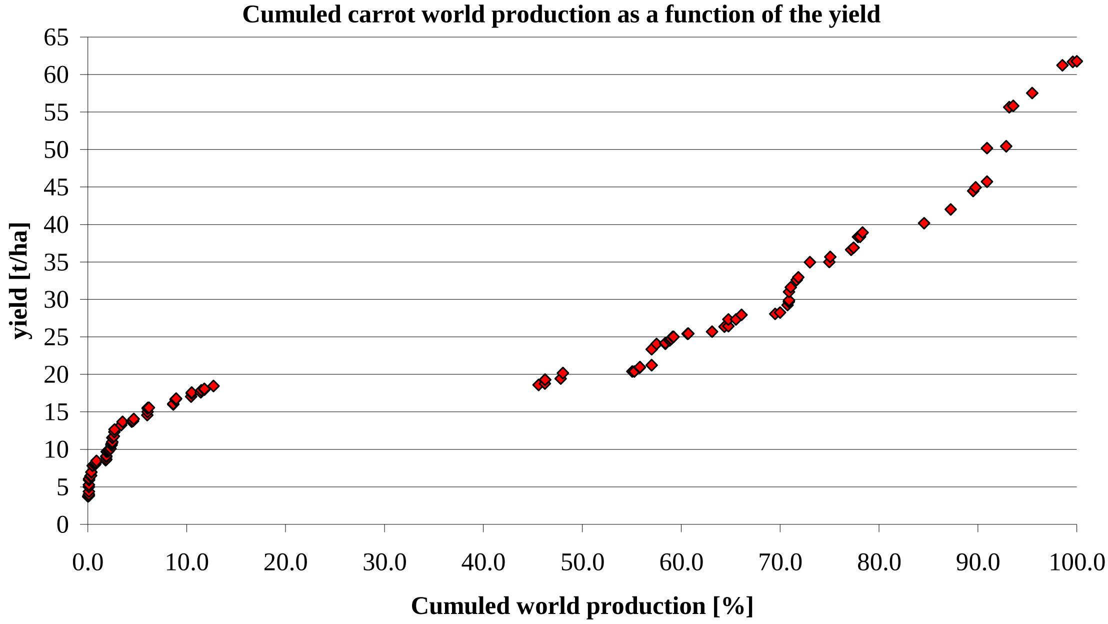


Fig. 8-2 Yields and corresponding cumulated productions for carrot.

Pea

The pea yields range between 0.2 tonnes/ha (Eritrea) and 4.5 tonnes/ha (Ireland).

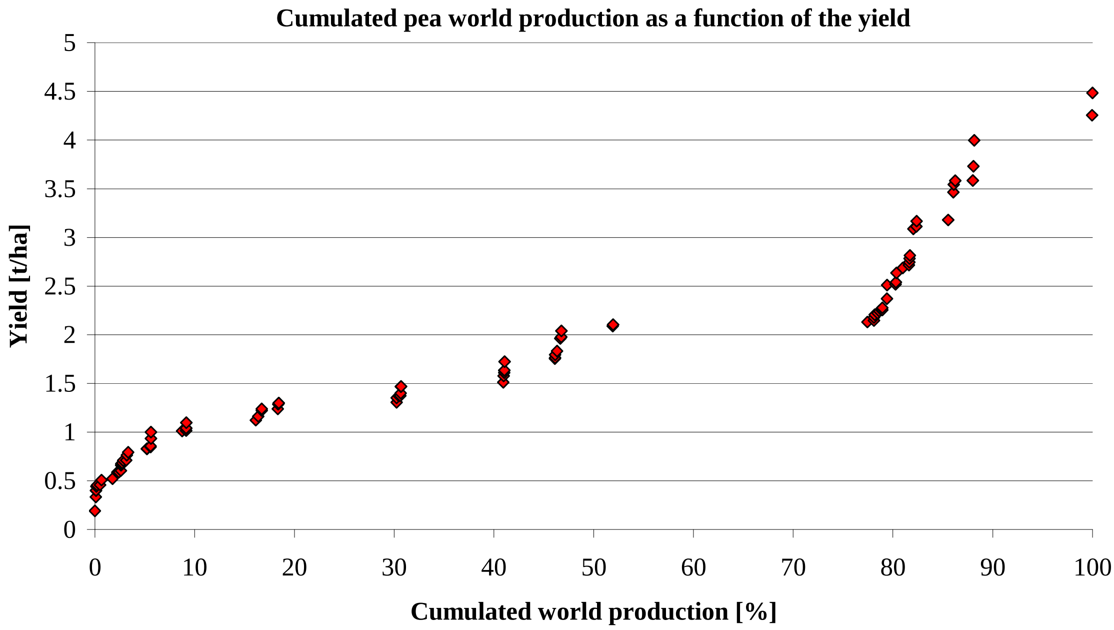


Fig. 8-3 Yields and corresponding cumulated production for pea.

Wheat

The yield in wheat production varies greatly from a producing country to another one: from 0.1 tonnes/ha in Eritrea to 8.8 tonnes/ha in Ireland.

The following graph shows the yield distribution considering the associated cumulated production. This enables to identify the most important producers and the related yield, as well as to determine the median yield in the world.

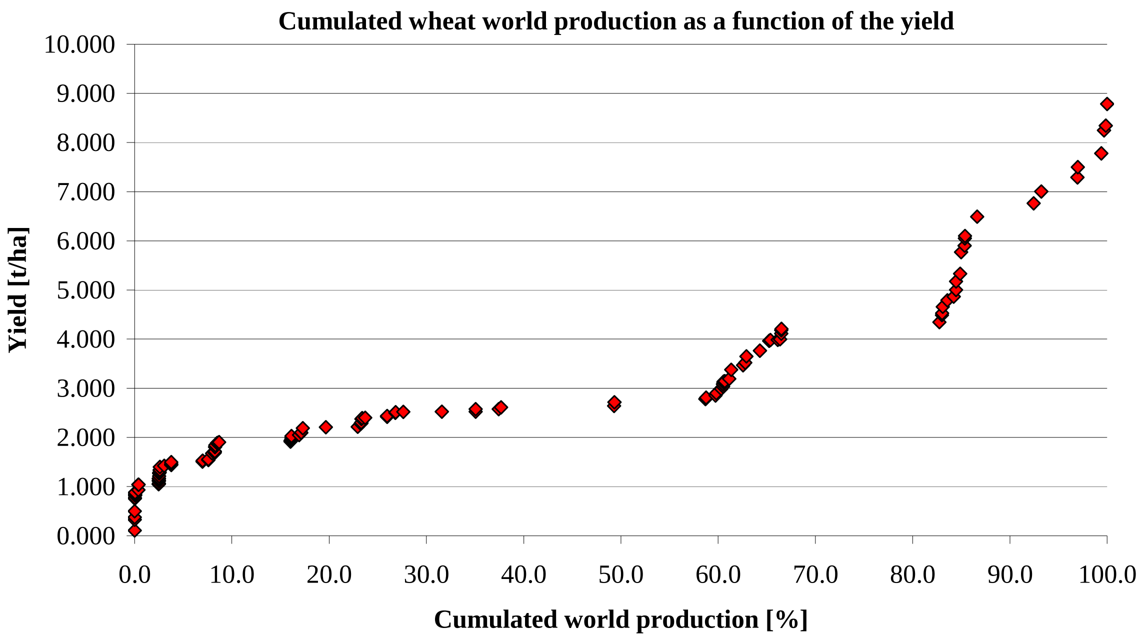


Fig. 8-4 Yields and corresponding cumulated production for wheat.

Barley

Barley yield is the lowest in Eritrea with only 0.2 tonnes/ha and the highest in Belgium with 7.4 tonnes/ha.

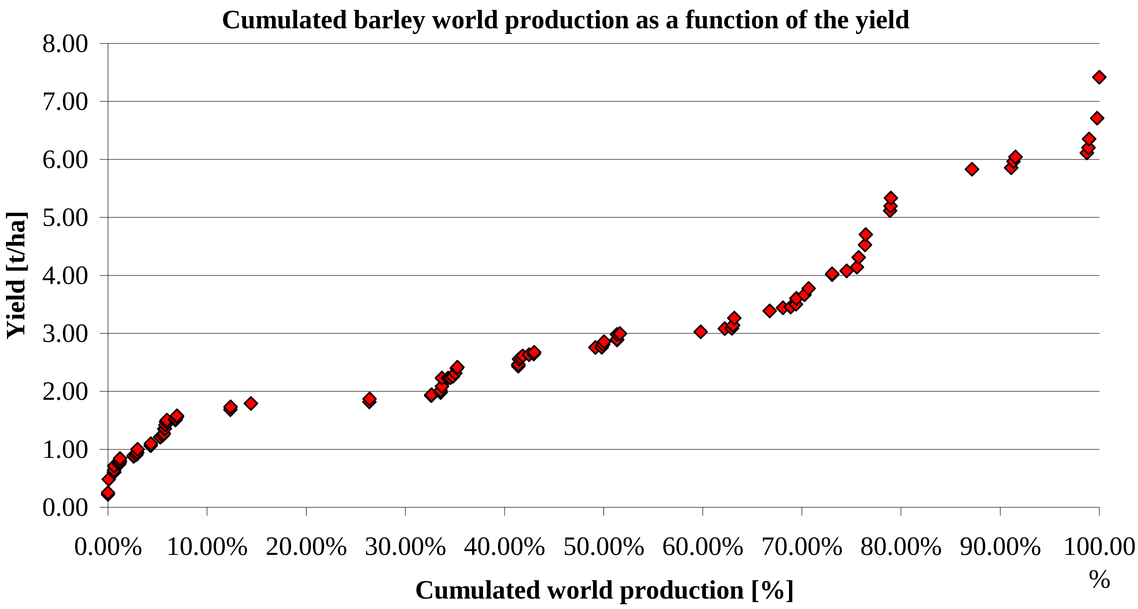


Fig. 8-5 Yields and corresponding cumulated production for barley.

Rye

The rye production has a median yield of about 2.1 tonnes/ha, Australia having the lowest yield (0.6 tonnes/ha) and Luxembourg the highest (6.2 tonnes/ha).

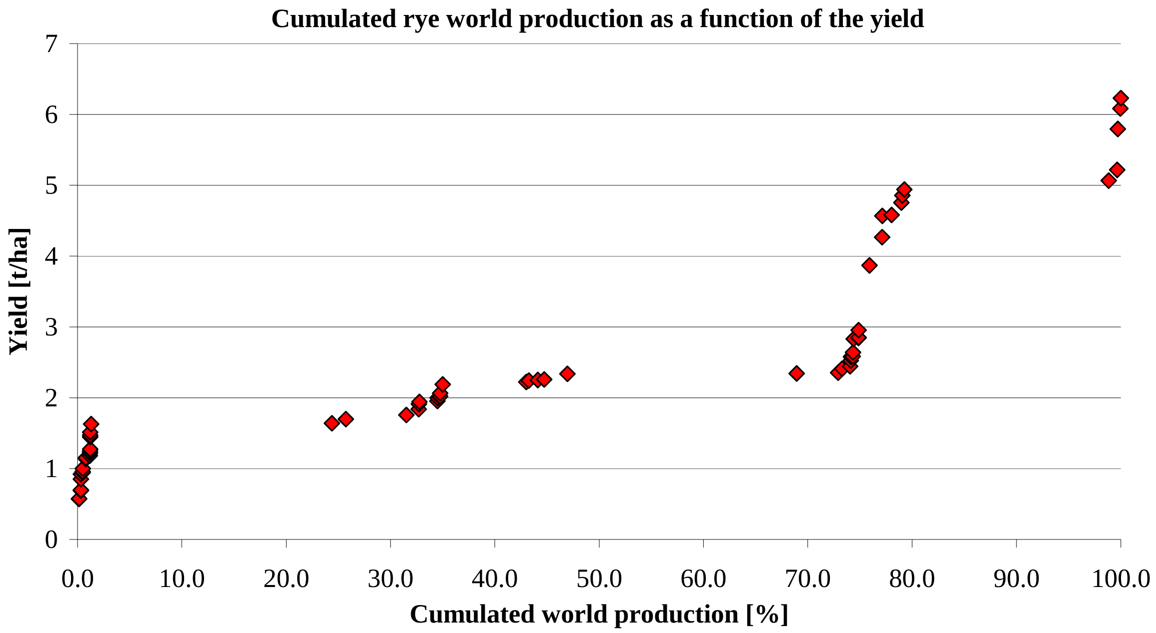


Fig. 8-6 Yields and corresponding cumulated productions for rye.

Cocoa

The cocoa production ranges from 0.05 tonnes/ha in Central African Republic to about 1.2 tonnes/ha in Indonesia.

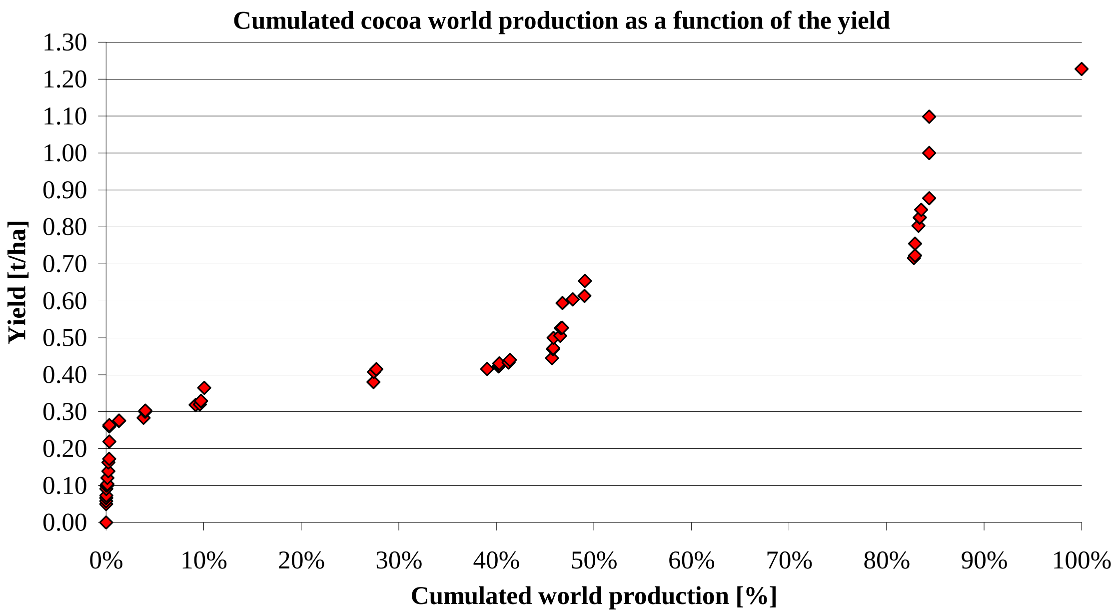


Fig. 8-7 Yields and corresponding cumulated productions for cocoa.

Pepper

The yields range between 0.1 tonnes/ha in the Fiji Islands to 6.5 tonnes/ha in Cambodia.

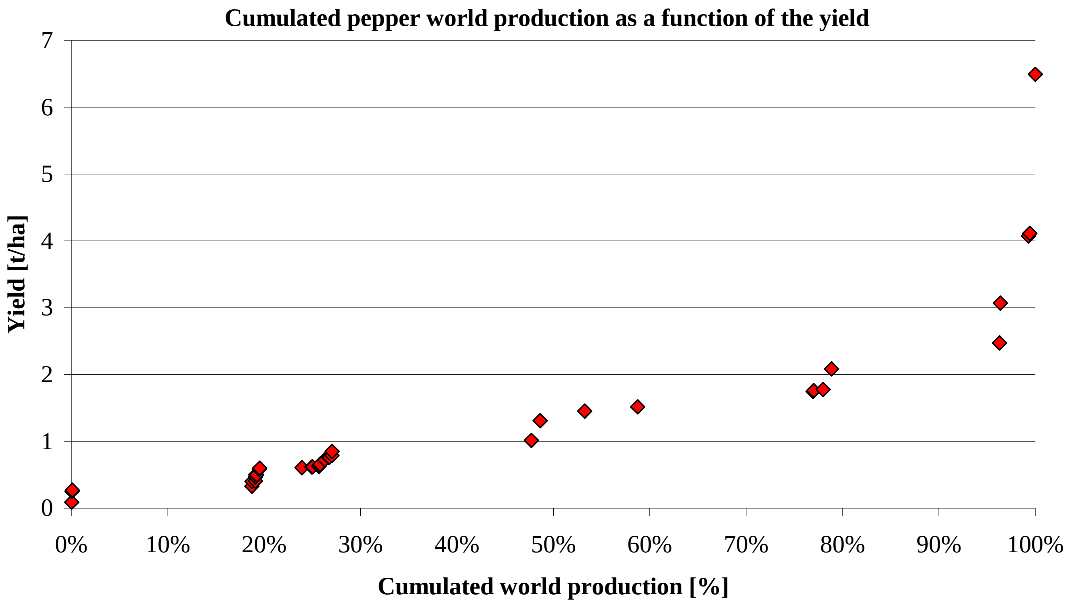


Fig. 8-8 Yields and corresponding cumulated productions for pepper.

8.2.2 Other parameters

For the other parameters, we have derived some indices from the FAOSTAT data (FAO, 2009) which then enables us to estimate the input quantities for each crop in each producing countries (by the means of the estimators) (section 3.3).
In order to analyse the variability of these parameters among the countries (and not among the products), we can simply analyse the variability of the indices (and not necessarily of the estimators). The indices are presented in 0.

The variability of the inputs (estimated by the means of the estimators) is given for each crop in the chapter related to the application of the methodology (section 6.1).

8.3 SENSITIVITY ANALYSIS

A sensitivity analysis has been performed on the modular inventory system. The goal is to identify the contribution of each input to each impact category. It is performed by using:

1. The median and different quantiles of the inputs (10% and 90%), considering the cumulated production, as estimated from the FAOSTAT database.
2. The unit impacts

For each impact category, the impacts are calculated by keeping constant six of the seven variable input parameters to the median value and by varying the remaining one from the 10% quantile to the 90% quantile (section 6.1). This is done successively for each variable input parameter.

The results of the sensitivity analysis are presented for each crop with the relative difference (expressed in percents) between the results obtained with the median for each input on one hand and obtained with the median for each input except one (10% and 90% quantiles):

Table 8-1. Results of the sensitivity analysis for several crops. The figures correspond to the relative differences between the results obtained with the considered input quantile and the results obtained with the median. The colours have these significations: white = no or negligible influence (variation of less than 5%), green = reduced influence (variation between 5% and 10%), kaki = noticeable influence (variation between 10% and 50%), orange = important influence (variation between 50% and 100%), red = very important influence (variation greater than 100%).

POTATO	INPUTS													
	MachVar		*Nfert*		*Pfert*		*Kfert*		*Pestic*		*Irrigat*		*Drying*	
Quantiles	q10%	q90%	q10%	q90%	q10%	q90%	q10%	q90%	q10%	q90%	q10%	q90%	q10%	q90%
IMPACTS														
non-renewable energy [MJ-eq]	-1%	7%	-11%	22%	-2%	3%	-1%	4%	-2%	7%	-27%	62%	0%	0%
GWP 100a [kg CO2-eq]	-1%	5%	-28%	55%	-2%	2%	-1%	3%	-1%	4%	-9%	21%	0%	0%
photo. ozone formation [kg ethylene-Eq]	-1%	11%	-5%	11%	-1%	1%	-1%	3%	-2%	6%	-15%	34%	0%	0%
nutrient enrichment [kg N-eq]	0%	0%	-64%	125%	-4%	5%	0%	0%	0%	0%	0%	1%	0%	0%
Acidification [kg SO2-Eq]	0%	3%	-47%	93%	-3%	3%	0%	1%	-1%	2%	-3%	6%	0%	0%
Water use [m3]	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	-85%	195%	0%	0%
Aquatic ecotoxicity, 100a [kg 1,4-DCB-Eq]	0%	0%	0%	1%	-3%	4%	0%	0%	-76%	288%	0%	0%	0%	0%
Terrestrial ecotoxicity, 100a [kg 1,4-DCB-Eq]	0%	0%	0%	0%	0%	0%	0%	0%	-99%	377%	0%	0%	0%	0%
Human toxicity, 100a [kg 1,4-DCB-Eq]	-1%	7%	-4%	8%	-1%	2%	-1%	3%	-43%	165%	-11%	25%	0%	0%

CARROT	INPUTS													
	MachVar		*Nfert*		*Pfert*		*Kfert*		*Pestic*		*Irrigat*		*Drying*	
Quantiles	q10%	q90%	q10%	q90%	q10%	q90%	q10%	q90%	q10%	q90%	q10%	q90%	q10%	q90%
IMPACTS														
non-renewable energy [MJ-eq]	0%	3%	-7%	7%	-1%	1%	-1%	2%	-1%	7%	-47%	36%	0%	0%
GWP 100a [kg CO2-eq]	0%	4%	-27%	28%	-1%	1%	-1%	2%	-1%	5%	-20%	16%	0%	0%
photo. ozone formation [kg ethylene-Eq]	0%	7%	-5%	5%	-1%	0%	-1%	2%	-1%	7%	-30%	24%	0%	0%
nutrient enrichment [kg N-eq]	0%	0%	-73%	74%	-2%	2%	0%	0%	0%	0%	-1%	0%	0%	0%
Acidification [kg SO2-Eq]	0%	3%	-46%	46%	-2%	1%	0%	1%	-1%	4%	-7%	6%	0%	0%
Water use [m3]	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	90%	70%	0%	0%
Aquatic ecotoxicity, 100a [kg 1,4-DCB-Eq]	0%	0%	0%	0%	-3%	2%	0%	0%	-94%	445%	-1%	1%	0%	0%
Terrestrial ecotoxicity, 100a [kg 1,4-DCB-Eq]	0%	0%	2%	-2%	13%	-11%	1%	-3%	-113%	534%	-5%	4%	0%	0%
Human toxicity, 100a [kg 1,4-DCB-Eq]	0%	8%	-6%	6%	-1%	1%	-1%	3%	-15%	71%	-42%	33%	0%	0%

PEA	INPUTS													
	MachVar		*Nfert*		*Pfert*		*Kfert*		*Pestic*		*Irrigat*		*Drying*	
Quantiles	q10%	q90%	q10%	q90%	q10%	q90%	q10%	q90%	q10%	q90%	q10%	q90%	q10%	q90%
IMPACTS														
non-renewable energy [MJ-eq]	-1%	4%	-1%	2%	-3%	9%	-1%	4%	-2%	7%	-5%	36%	-7%	1%
GWP 100a [kg CO2-eq]	-1%	3%	-11%	38%	-2%	7%	0%	3%	-1%	4%	-1%	10%	-4%	0%
photo. ozone formation [kg ethylene-Eq]	-1%	6%	0%	1%	-1%	5%	0%	2%	-2%	6%	-2%	19%	-2%	0%
nutrient enrichment [kg N-eq]	0%	1%	-26%	92%	-10%	34%	0%	0%	0%	0%	0%	1%	0%	0%
Acidification [kg SO2-Eq]	-1%	4%	-6%	22%	-6%	21%	0%	2%	-1%	4%	-1%	7%	-2%	0%
Water use [m3]	0%	0%	0%	0%	-2%	5%	-3%	24%	0%	1%	-69%	517%	0%	0%
Aquatic ecotoxicity, 100a [kg 1,4-DCB-Eq]	0%	0%	0%	0%	-14%	45%	0%	1%	-55%	162%	0%	1%	0%	0%
Terrestrial ecotoxicity, 100a [kg 1,4-DCB-Eq]	0%	1%	0%	0%	0%	1%	0%	0%	-69%	202%	-1%	4%	-1%	0%
Human toxicity, 100a [kg 1,4-DCB-Eq]	-2%	9%	-1%	2%	-4%	14%	-1%	7%	-7%	20%	-5%	37%	-3%	0%

WHEAT	INPUTS													
	MachVar		*Nfert*		*Pfert*		*Kfert*		*Pestic*		*Irrigat*		*Drying*	
Quantiles	q10%	q90%	q10%	q90%	q10%	q90%	q10%	q90%	q10%	q90%	q10%	q90%	q10%	q90%
IMPACTS														
non-renewable energy [MJ-eq]	-1%	6%	-21%	55%	-3%	7%	0%	1%	-1%	5%	-21%	54%	-3%	1%
GWP 100a [kg CO2-eq]	-1%	5%	-45%	115%	-2%	5%	0%	1%	-1%	3%	-6%	15%	-1%	1%
photo. ozone formation [kg ethylene-Eq]	-2%	11%	-14%	36%	-2%	4%	0%	1%	-2%	7%	-14%	35%	-1%	0%
nutrient enrichment [kg N-eq]	0%	0%	-71%	185%	-3%	7%	0%	0%	0%	0%	0%	0%	0%	0%
Acidification [kg SO2-Eq]	0%	2%	-61%	159%	-3%	6%	0%	0%	0%	1%	-2%	4%	0%	0%
Water use [m3]	0%	0%	0%	0%	0%	1%	0%	0%	0%	0%	-77%	193%	0%	0%
Aquatic ecotoxicity, 100a [kg 1,4-DCB-Eq]	0%	0%	0%	1%	-4%	8%	0%	0%	-84%	316%	0%	0%	0%	0%
Terrestrial ecotoxicity, 100a [kg 1,4-DCB-Eq]	0%	0%	-1%	2%	-4%	7%	0%	0%	-82%	310%	-1%	2%	0%	0%
Human toxicity, 100a [kg 1,4-DCB-Eq]	-2%	9%	-17%	45%	-5%	10%	-1%	2%	-12%	44%	-18%	46%	-1%	0%

BARLEY	INPUTS													
	MachVar		*Nfert*		*Pfert*		*Kfert*		*Pestic*		*Irrigat*		*Drying*	
Quantiles	q10%	q90%	q10%	q90%	q10%	q90%	q10%	q90%	q10%	q90%	q10%	q90%	q10%	q90%
IMPACTS														
non-renewable energy [MJ-eq]	-2%	9%	-21%	74%	-4%	11%	0%	3%	-2%	8%	-2%	7%	-2%	1%
GWP 100a [kg CO2-eq]	-2%	6%	-40%	140%	-3%	7%	0%	2%	-1%	4%	0%	2%	-1%	0%
photo. ozone formation [kg ethylene-Eq]	-3%	13%	-12%	41%	-2%	6%	0%	2%	-2%	8%	-1%	4%	-1%	0%
nutrient enrichment [kg N-eq]	0%	0%	-67%	234%	-4%	10%	0%	0%	0%	0%	0%	0%	0%	0%
Acidification [kg SO2-Eq]	-1%	3%	-55%	192%	-4%	9%	0%	1%	0%	2%	0%	0%	0%	0%
Water use [m3]	0%	1%	-1%	4%	-6%	16%	0%	1%	0%	1%	-67%	253%	0%	0%
Aquatic ecotoxicity, 100a [kg 1,4-DCB-Eq]	0%	0%	0%	1%	-3%	8%	0%	0%	-58%	251%	0%	0%	0%	0%
Terrestrial ecotoxicity, 100a [kg 1,4-DCB-Eq]	0%	0%	0%	1%	-3%	8%	0%	0%	-58%	251%	0%	0%	0%	0%
Human toxicity, 100a [kg 1,4-DCB-Eq]	-3%	13%	-17%	59%	-6%	16%	-1%	4%	-10%	44%	-2%	6%	-1%	0%

RYE	INPUTS													
	MachVar		Nfert		Pfert		Kfert		Pestic		Irrigat		Drying	
Quantiles	q10%	q90%	q10%	q90%	q10%	q90%	q10%	q90%	q10%	q90%	q10%	q90%	q10%	q90%
IMPACTS														
non-renewable energy [MJ-eq]	-2%	8%	-19%	61%	-4%	7%	-1%	1%	-1%	5%	-1%	5%	-2%	0%
GWP 100a [kg CO2-eq]	-2%	5%	-41%	129%	-3%	4%	-1%	1%	0%	2%	0%	1%	-1%	0%
photo. ozone formation [kg ethylene-Eq]	-3%	11%	-10%	32%	-2%	4%	-1%	1%	-1%	5%	-1%	3%	0%	0%
nutrient enrichment [kg N-eq]	0%	0%	-70%	222%	-3%	5%	0%	0%	0%	0%	0%	0%	0%	0%
Acidification [kg SO2-Eq]	-1%	3%	-55%	174%	-4%	6%	0%	0%	0%	1%	0%	0%	0%	0%
Water use [m3]	0%	1%	-1%	4%	-8%	13%	0%	1%	0%	0%	-63%	229%	0%	0%
Aquatic ecotoxicity, 100a [kg 1,4-DCB-Eq]	0%	0%	0%	1%	-4%	7%	0%	0%	-42%	226%	0%	0%	0%	0%
Terrestrial ecotoxicity, 100a [kg 1,4-DCB-Eq]	0%	0%	-1%	2%	-4%	7%	0%	0%	-41%	221%	0%	0%	0%	0%
Human toxicity, 100a [kg 1,4-DCB-Eq]	-3%	12%	-17%	53%	-6%	11%	-2%	2%	-6%	30%	-1%	5%	-1%	0%

COCOA	INPUTS													
	MachVar		Nfert		Pfert		Kfert		Pestic		Irrigat		Drying	
Quantiles	q10%	q90%	q10%	q90%	q10%	q90%	q10%	q90%	q10%	q90%	q10%	q90%	q10%	q90%
IMPACTS														
non-renewable energy [MJ-eq]	0%	0%	-27%	207%	-3%	9%	-1%	2%	-49%	38%	0%	0%	0%	0%
GWP 100a [kg CO2-eq]	0%	0%	-53%	400%	-1%	5%	0%	1%	-17%	13%	0%	0%	0%	0%
photo. ozone formation [kg ethylene-Eq]	0%	0%	-22%	165%	-2%	7%	-1%	2%	-57%	44%	0%	0%	0%	0%
nutrient enrichment [kg N-eq]	0%	0%	-65%	493%	-3%	10%	0%	0%	0%	0%	0%	0%	0%	0%
Water use [m3]	0%	0%	-12%	91%	-30%	108%	-2%	7%	-30%	26%	0%	0%	0%	0%
Acidification [kg SO2-Eq]	0%	0%	-58%	437%	-2%	7%	0%	0%	-10%	8%	0%	0%	0%	0%
Aquatic ecotoxicity, 100a [kg 1,4-DCB-Eq]	0%	0%	0%	0%	0%	0%	0%	0%	-100%	77%	0%	0%	0%	0%
Terrestrial ecotoxicity, 100a [kg 1,4-DCB-Eq]	0%	0%	0%	0%	0%	-1%	0%	0%	-100%	78%	0%	0%	0%	0%
Human toxicity, 100a [kg 1,4-DCB-Eq]	0%	0%	-5%	35%	-1%	3%	0%	1%	-91%	70%	0%	0%	0%	0%

PEPPER	INPUTS													
	MachVar		Nfert		Pfert		Kfert		Pestic		Irrigat		Drying	
Quantiles	q10%	q90%	q10%	q90%	q10%	q90%	q10%	q90%	q10%	q90%	q10%	q90%	q10%	q90%
IMPACTS														
non-renewable energy [MJ-eq]	-6%	11%	-40%	67%	-5%	13%	-8%	28%	-9%	18%	0%	0%	0%	0%
GWP 100a [kg CO2-eq]	-2%	4%	-60%	100%	-2%	5%	-3%	9%	-3%	6%	0%	0%	0%	0%
photo. ozone formation [kg ethylene-Eq]	-11%	21%	-34%	56%	-3%	8%	-6%	22%	-17%	33%	0%	0%	0%	0%
nutrient enrichment [kg N-eq]	0%	0%	-69%	116%	-1%	3%	0%	0%	0%	0%	0%	0%	0%	0%
Acidification [kg SO2-Eq]	-1%	2%	-62%	103%	-3%	8%	-1%	4%	-2%	4%	0%	0%	0%	0%
Water use [m3]	-3%	5%	-11%	19%	-37%	95%	-13%	49%	-4%	8%	0%	0%	0%	0%
Aquatic ecotoxicity, 100a [kg 1,4-DCB-Eq]	0%	0%	-1%	1%	-6%	14%	-1%	2%	-77%	151%	0%	0%	0%	0%
Terrestrial ecotoxicity, 100a [kg 1,4-DCB-Eq]	0%	0%	0%	0%	3%	-7%	0%	0%	-88%	172%	0%	0%	0%	0%
Human toxicity, 100a [kg 1,4-DCB-Eq]	-1%	1%	-2%	3%	0%	1%	-1%	2%	-81%	158%	0%	0%	0%	0%

The sensitivity of an impact category to an input is related to two aspects: first to the quantity of this input and second to the importance of the impact per unit of this input. If an impact per input unit is important, a small variation in the input quantity will lead to an important variation of the impact.

We can notice that for most crops, N fertilisation is a key driver for most impacts. The influence is strong on the energy demand, GWP, ozone formation, acidification, eutrophication and human toxicity. The big exception is the legume pea, which requires no N fertilisation and where N fertilisers are applied only in small quantities. This shows that knowledge of the quantities of N fertilisers is a key for a good inventory.
Pesticide use dominates aquatic and terrestrial ecotoxicity as well as human toxicity, which was expected. The variability is probably underestimated in this analysis, since we varied only the applied quantity, whereas is reality the active ingredients will change as well, most likely leading to a higher variability.
For some crops like potato and carrots, but also for pea, and wheat, irrigation plays an important role for a number of impacts.
The variability of machinery use has only a modest impact on the energy demand, ozone formation, GWP and human toxicity.
P fertilisation plays a certain role for pea, cereals, cocoa and pepper, while it has only a small influence on the impacts of the other crops.
K fertilisation had only a relevant influence for pepper, but was almost negligible for the other crops.
Product drying had a very little influence for most crops. We must however, keep in mind that these crops are either not requiring product drying or the drying is done by sun and wind without fossil fuels. For the cereals and pea, where drying is done, it is not a hot spot. The result would be different if we had analysed e.g. grain maize.

The results are presented graphically for barley in AVII, the other results are contained in the EXCEL files.

8.4 CROP GROUPING: SIMILARITY CRITERIA

Crop grouping is a strategy to simplify the LCA complexity of bio-based products while attempting to preserve the result quality. Crops can thus be grouped if they have similar environmental impacts solely.

The major problem when dealing with environmental impacts of bio-materials is that the environmental impacts have been completely characterized for only few cases and, in the most of the cases, not quantified at all.

This diagnosis of data scarceness in the environmental impacts domain leads us to rely on other criteria that can relatively easily be determined from public sources. We have to group the crops not directly in terms of environmental impacts similarity but in terms of other parameters influencing the environmental impacts. The procedure is indirect and its success depends on the ability of the selected criteria to depict the environmental impacts.

The grouping criteria and the resulting crop grouping can be different for each impact category. In fact, each environmental impact is caused by certain mechanisms which are influenced by key factors. Eutrophication is for example related to nitrate leaching and to the phosphorus losses through erosion, leaching, run-off and drainage. In that case, 2 elements and 5 mechanisms play a role, which are influenced by several factors like fertilizer application, site-specific conditions, crop properties and so on.

A good way to deal with crop grouping is to perform a sensitivity analysis, in order to identify the key inputs for each impact. This is done in section 8.3. A grouping can then be performed using the similarity of the key inputs as grouping criteria.

The problem is often that the knowledge about the inputs used is not complete. In absence of detailed knowledge of the production process, the inputs used and crop management we can use these criteria for a first grouping:

1. Duration of cultivation: permanent crop or annual crop

By experience we know that permanent and annual crops have quite different impacts. For permanent crop, the duration of the use of one plantation is a key factor. The duration determines the time period during which emissions related to a given crop occur.

2. Taxonomy

Taxonomy explains the crop response to different biotic and abiotic factors. Two crops belonging to the same family, the same genus or the same species are generally susceptible to the same pests, have similar natural enemies, approximately the same minerals content, comparable water needs. The taxonomy classification thus often influences the agricultural practices. It is however a complex parameter and it is not certain that it can be used straightforward for crop classification in LCIA. On the one hand, there is no guarantee that two closely related species have similar impacts. On the other hand, taxonomically different species can lead to similar impacts.
In general, we can recommend choosing a taxonomically similar crop for the inventory extrapolation from a crop to another but some extrapolation can also be done with crops belonging to another family.
Examples of taxomonically similar crops are cereals like wheat, barley, rye, rape seed and mustard, corn and sorghum, peas and beans, apple and pears. Taxonomically different crops can also have similar growth cycles and similar use of inputs. This is e.g. the case for wheat and rape seed; they have significantly different yield, but both crops need similar machinery, management and inputs.

3. Harvested plant organs

The harvested plant organs as well as the other crop constituents and their possible use are of major importance for allocation above all. The example of grain and silage maize clearly shows the relevance of this criterion. Another example would be green (pods) and dry beans (only grains).
In case of potato, the tubers accounts for about 70% of the total crop weight. The rest is constituted of stems and leaves which are not further used. They are generally left on the field. 100% of the environmental impacts are thus allocated to the potato in case of potato production.

In case of cocoa, only 42% of the drupe is constituted of cocoa bean. 2% of the drup is mucilage and 56% is the pod. The pod is used for animal feed or for soap production. An allocation of the environmental impacts should be done according to the economic value of each constituent or according their weight.
The harvested part of plant also conditions the machinery requested for harvest.

4. Farming system and production intensity

The multivariate analysis shows the importance to consider the farming system and the production intensity. In a first step it is important to consider organic farming separately, which has a strong effect on the fertilisers and pesticides used as well as the yield. Organic farming was however not the purpose of the study. The modular inventory has been developed for the characterisation of conventional production, not for the characterisation of organic farming.

5. Region: soil and climate conditions

The soil properties affect the substance fate and its distribution between the different environmental compartments (soil, water, air). The clay content as well as the soil depth play a role in the nitrate leaching for instance, which is often a major emissions causing eutrophication.
The climate determines the need for irrigation, pests and diseases as well as many emissions, depending on precipitation, temperature, wind and humidity of the air.

These five criteria can be used without a detailed knowledge of the production process. If more information is available on the production process, in particular the machinery used, fertilisation, plant protection, irrigation, product drying, this information also can be used to group crops. Data on the production process (machinery used, fertilisation and so on) should have a more important weight than the five criteria mentioned above (duration of cultivation, taxonomy, harvested plant organs, farming system, region) to decide for grouping or not grouping some crops. The hierarchy for the consideration of data on the production process in order to group crops depends on the impact: plant protection should be considered first when grouping crops of similar toxicology whereas N fertilisers should be considered first when grouping crops of similar eutrophication.

From the sensitivity analysis we can conclude that the amounts of N fertiliser, amount of irrigation and the Diesel used together with the yield are key figures. The amount of N fertiliser per kg of product can be used as a first criterion for assessment. We further see that irrigation is a dominating factor as well. For toxicity assessments, pesticides are of course the dominant inputs, whereas they can be ignored, if no toxicity assessment is carried out. Product drying is important for wet products that need to be dried, while it is not so important for the other products. The use of machinery, P and K fertilisers are less important and therefore need not necessarily be considered in the grouping. We should keep in mind that other factors known as important have not been considered in this study such as protected production, especially in heated greenhouses, and land use changes (deforestation, etc.) can have a dominant role for global warming and other impacts.

9 Discussion and conclusion

9.1 LIMITATIONS OF THE MODULAR CROP INVENTORY APPROACH

The modular crop inventory approach has the following limitations:

- Factors that were not considered
- Modelling simplifications and
- Quality of the underlying data.

Factors not considered:

- It is limited to commercial production only. Subsistence farming, with little or no use of external inputs and machinery is not considered. The real variability of the world production might be therefore underestimated.
- Organic production was excluded. The FAOSTAT database does not contain data that would make a reliable modelling of organic production possible.
- Pesticides could only roughly be estimated. Only the average quantities applied per country are known, which allows at best for a very rough estimate. The changes of active ingredients between countries could not be considered. A comparison with ecoinvent data could not be performed, since new characterisation factors have been introduced.
- Manure and other organic fertilisers were not considered. We assumed that cash crops are mainly fertilised by mineral fertiliser and farmyard manure is applied primarily to the grassland. However, this is not true for all countries and will lead to some over- and underestimation of impacts. Mineral fertilisers generally lead to a higher energy demand, but lower acidification and eutrophication.

Modelling simplifications:

- The impacts were modelled as linearly dependent on the input, which is not true in all cases.
- Drying was only roughly approximated.
- The models used in SALCAcrop were developed for Swiss conditions. While they are also applicable under similar climatic and soil conditions, e.g. in Central Europe, the transferability to substantially different conditions e.g. in the tropics is questionable.

Quality of the underlying data:

- The FAOSTAT database was used for the calculation of the various indices as well as for the yield data. This database gives a rather complete dataset for all countries, but the quality of the data is not always very high. During data processing we found some figures that were obviously wrong. For an assessment over a number of countries or the whole world, this should still give a reasonable estimate. However, if data for a single country are requested, the quality of the underlying data needs to be checked an erroneous parameters should be corrected. The method does not work for crops where the FAOSTAT database contains no yield data and these data cannot be found in other sources neither.
- The base inventory plays a critical role. All calculations are relying on the base inventory. A parameter that is not representative will give a biased estimate for the respective module over the whole world. Great care must therefore be taken for defining this inventory. Preferably it should be based on several inventories from several countries, which should give more robust estimates.

9.2 APPLICABILITY OF THE MODULAR CROP INVENTORY

The method can be used

- To assess the worldwide (or at least for a larger area) variability of the impacts of crops with the limitations listed above.
- For an assessment of the worldwide mean or median. Use makes more sense at very large scales (partial compensation of the errors expected).

- For a first screening of countries, where a production could be eco-efficient. This should be followed by a detailed assessment of the most promising productions.
- Where the considered product has only a relatively small contribution to the total life cycle impact.
- For estimates of the energy demand, ozone formation and GWP; for acidification only to a limited extent.
- For the comparison between two crops, if the base inventories are created from sufficiently representative data (preferably several inventories).

It should not be used

- Where the product plays a dominant role in the overall life cycle.
- For eutrophication reliable estimates are not possible and as it is the case for the toxicity impacts.
- It should not be applied for the characterisation of a given product in a specific situation (except if a conventional LCA would be unfeasible) and should not be used directly to compare the production of two products in the same country or the production of a given product in two different countries (risk of false conclusions in some cases). Prior to such comparisons, the underlying data and indices need to be thoroughly checked.

9.3 APPLICABILITY OF THE YIELD EXTRAPOLATION

This method is much simpler than the modular approach, since it does account only for the yield differences. It can be used without a large file system and without having access to generic LCA tools like SALCA crop. It can be used for geographical as well as product extrapolation is cases, where only very rough indications on environmental impacts are required.

The first validations done in Sections 6.2 and 6.3 indicate that in can work reasonably well in some situations, in particular if the soil, climate and management conditions are similar and if the products or crops are not too different (see similarity criteria in Section 8.4). A wider application of the extrapolation is needed to evaluate its potentials and limits.

9.4 PATHS FOR FUTURE DEVELOPMENT

1. More data points are needed for a wider validation. The datasets in the databases ecoinvent and SALCA are too limited to allow a good validation. Other sources should therefore be used, such as other LCA databases and LCA literature. However, methodical problems will have to be solved, as the results were obtained using different databases and methodology, which could strongly affect the validation. Corrections and recalculations of impacts are necessary to use such data for a validation sensu stricto. In a broad sense, the impact values from other databases and from literature could be used in order to illustrate the range of impact values obtained by traditional LCA for a product and locate the value obtained with the modular inventory in the set of the values obtained by traditional approach.
2. The yield extrapolation method should be further explored and compared to the modular approach.
3. The tool can be used as a research tool, provided that the user is quite familiar with LCA and EXCEL. However, for a wider application, a more user-friendly software should be programmed, which would increase the accessibility to non-experts. This would be a relatively standard database application and its programming should not be too demanding.
4. For a wider application the database needs to be extended to more crops.
5. With a larger and more comprehensive database, the question of crop grouping should be addressed. Which crops are expected to be similar and which product should be used in absence of specific data? The modular approach could possibly be adapted also to cover product extrapolation to a certain extent.
6. N fertilisation and N emissions are key issues. Further work is needed to refine the estimates of fertilisers required and of N emission estimates.
7. The global fertiliser share does not reflect the situation in all countries appropriately, which is probably one reason for the overestimate of the acidification. It should be further refined by using national statistics, at least for N fertilisers.
8. Organic fertilisers could be included. At least in some countries they play an important role. Estimates could base on the livestock density in a given country. This should improve the quality of the extrapolations.

9. The assessment of the pesticides could possibly be improved, but it will remain a difficult and very uncertain matter, since detailed statistics of active matters applied per crop are available in a few countries only. Nevertheless by relying the base inventories on larger statistics, the impacts would be more representative.
10. Drying should be made dependent on the yield.
11. For irrigation and drying the climatic factors (potential evapotranspiration and precipitation) are the determining factors. The estimates could be improved much by using climate data as proposed in AV.
12. Soil tillage: the current assumption of 7% no-till areas worldwide should be improved. As shown in section 7.1.4, this factor is not without importance. First we know that the area is very different by country and continent. Second, although statistics on no-till areas per crop are not available, we know that some crops (e.g. potato) are much less grown without tillage than others (e.g. soya beans). By combining these statistics with expert guesses, a better extrapolation would be possible with a reasonable effort.
13. The emission models should be adapted to different conditions and in particular take into account soil and climate data, at least at a regional level.
14. The agricultural management indices could be improved a) by checking and correcting indices that are suspected to be wrong and b) by replacing missing values by values of similar countries instead of using a global average.

9.5 CONCLUSIONS

Two methods for geographical and product extrapolation are proposed and explored in this report: a simple yield correction and a more complex modular crop inventory method.
Both are expected to allow extrapolating the environmental impacts of crops to other geographical contexts and other products. They show a promising way to improve the availability of LCA data at a reasonable cost. The limits of these approaches absolutely need to be respected (Section 9.1); it is advised to use these methods only in the cases described in Section 9.2. Further validation is required and further development should enhance the quality of the assessments so that the extrapolations can be more widely used and provide better life cycle assessments and carbon footprints.

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11 Index of tables and figures

11.1 TABLES

11.2 FIGURES

12 Appendix

AI. Statistical analysis of ecoinvent and SALCA datasets

The following analyses were carried out by using the Statistica Package V7.0.

12.1 Swiss crop inventories from SALCA

The analysis was performed after transforming the impact indicators by natural logarithm (ln), which resulted in roughly normal distributions. 70 datasets for arable crops were analysed. The impacts were analysed per kg D.M. yield.

The following impact categories were included in the principal component analysis:

- energy demand (ecoinvent method)
- global warming potential (100 years, method: IPCC 2001)
- ozone formation potential (method: EDIP97)
- eutrophication potential (method: EDIP97)
- acidification potential (method: EDIP97)
- terrestrial ecotoxicity potential (method: EDIP97)
- aquatic ecotoxicity potential (method: EDIP97)
- human toxicity potential (method: CML01).

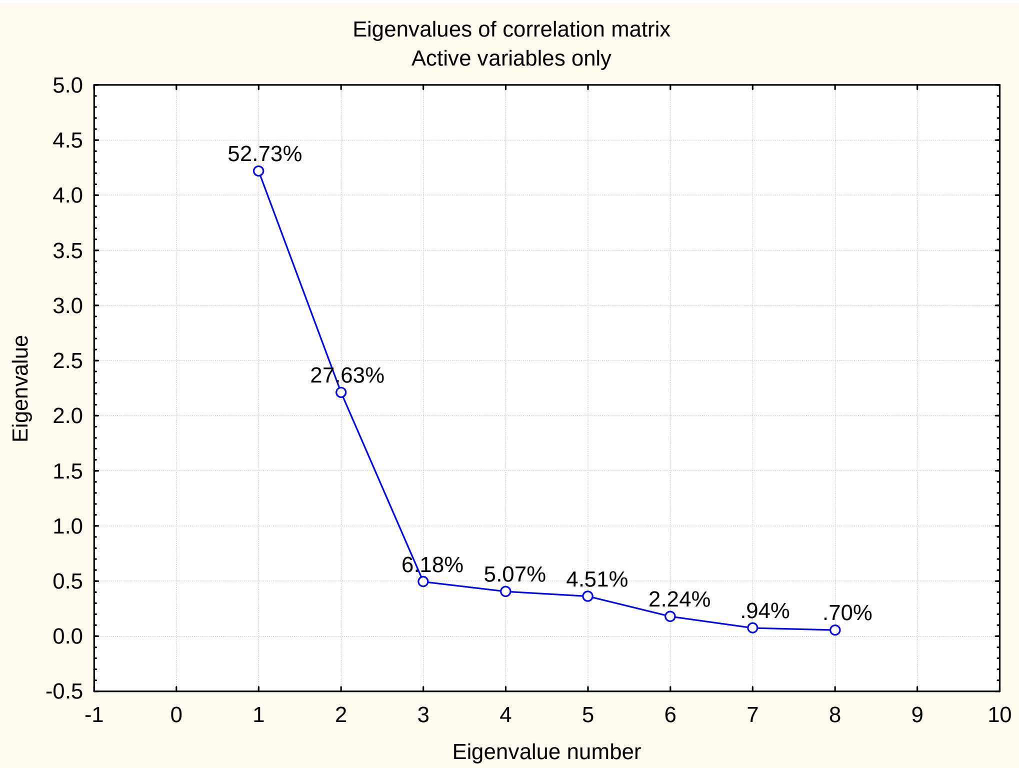


Fig. 12-1 Scree plot of the eigenvalues of the eight principal components for the SALCA data.

The screeplot (Fig. 12-1) shows that only the first two principal components (or factors) have an Eigenvalue >1 and only these two need to be considered for the further analysis. Together they explain 87% of the variance. The first component explains by far more variance than the second.

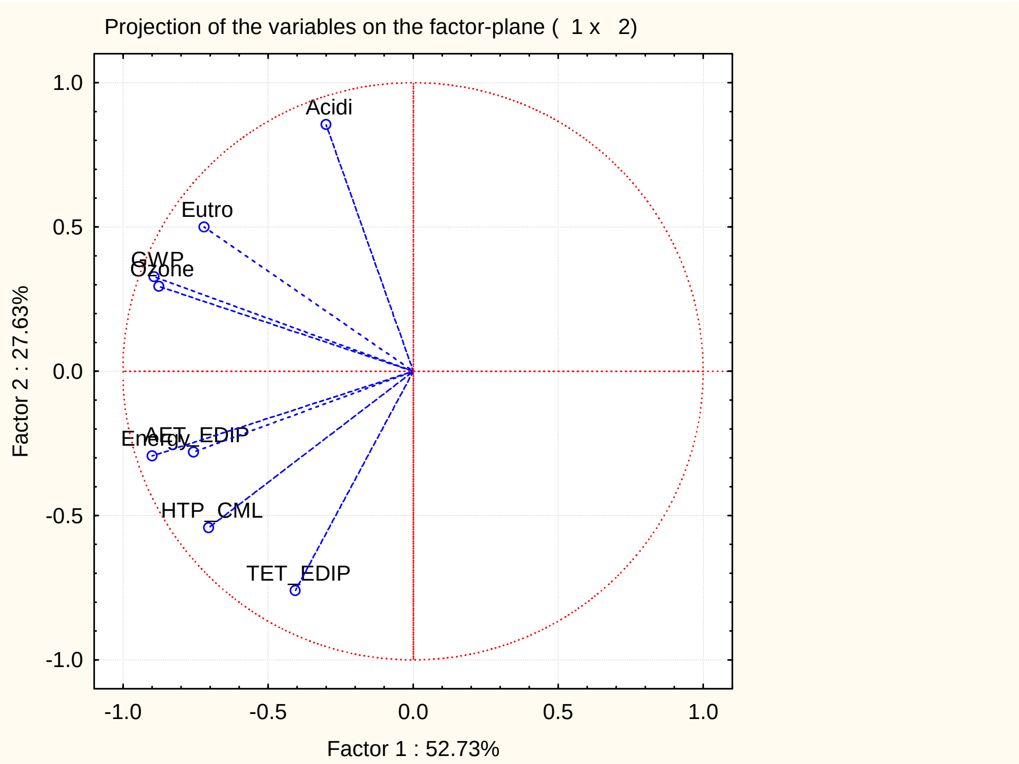


Fig. 12-2 Factor coordinates of the impact categories (variables).

Factor 1 is closely related to energy, global warming, ozone formation and aquatic toxicity. Factor 2 more to acidification and terrestrial ecotoxicity (the latter showed a very close relationship to the use of pesticides). Human toxicity and eutrophication are related to both factors.

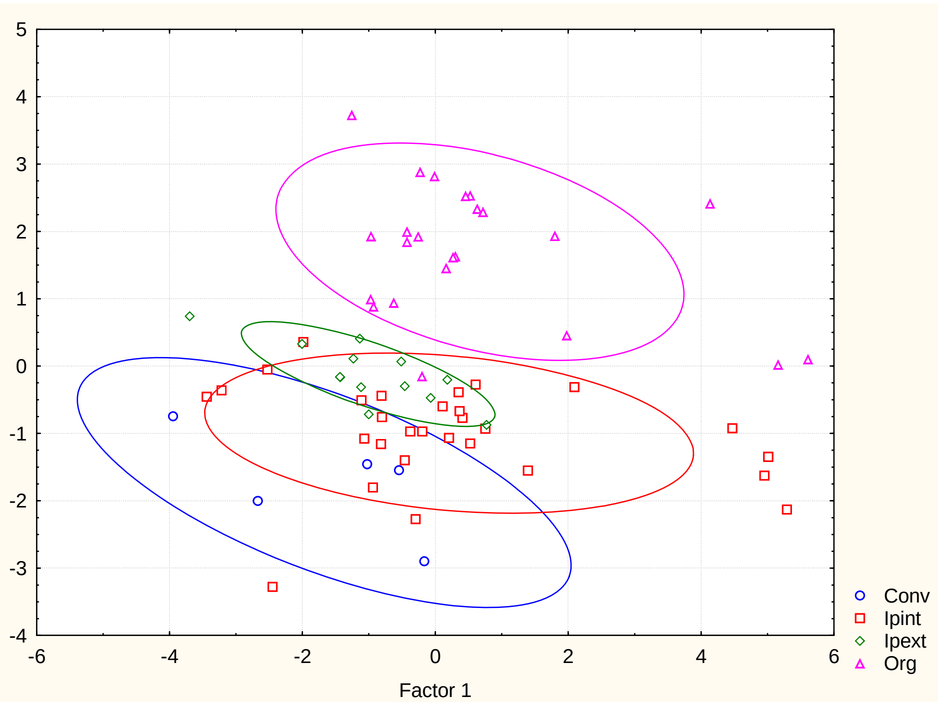


Fig. 12-3 Factor coordinates of the different products (cases). Factor 2 is shown on the Y-axis, differentiated according to the production region (lowlands, hills and mountains). The ellipses symbolise the bivariate standard deviation of the subpopulations.

The production region has no systematic effect on the environmental impacts (Fig. 12-3). This is in agreement with the conclusions of the study. Note, that not all crops can be grown in the hill and mountain regions, the analysis is therefore somewhat biased.

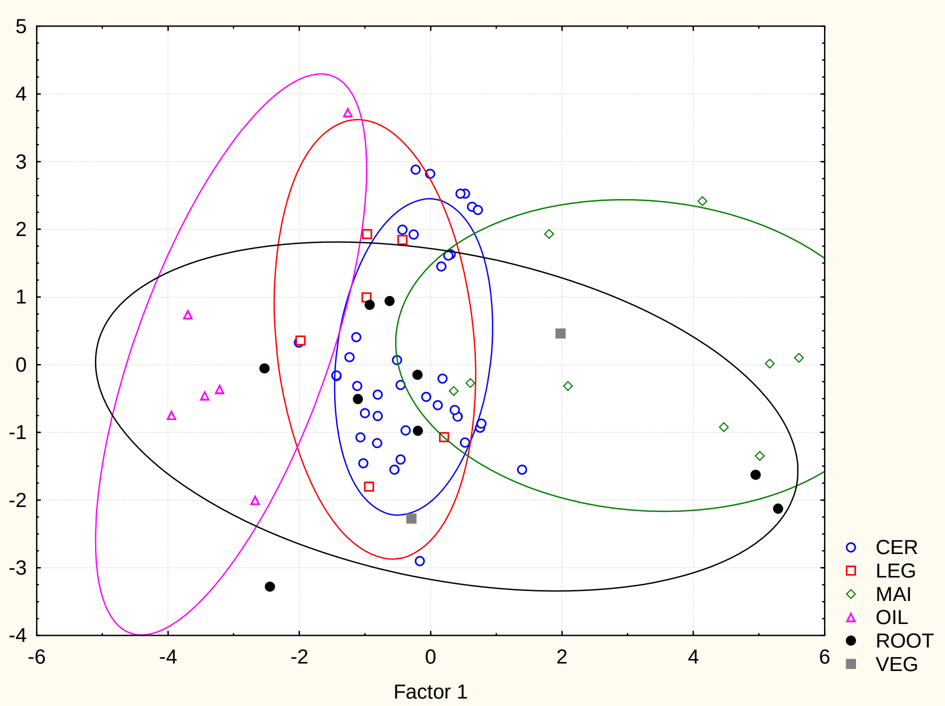


Fig. 12-4 Factor coordinates of the different products (cases). Factor 2 is shown on the Y-axis, differentiated according to the farming system: conventional (Conv), integrated intensive (IPint), integrated extensive (IPext) and organic (Org). The ellipses symbolise the bivariate standard deviation of the subpopulations.

The farming system has a systematic effect which can be mainly distinguished by factor 2. As shown above, this is related to ecotoxicity on the one hand and acidification and to a lesser extent eutrophication on the other hand.

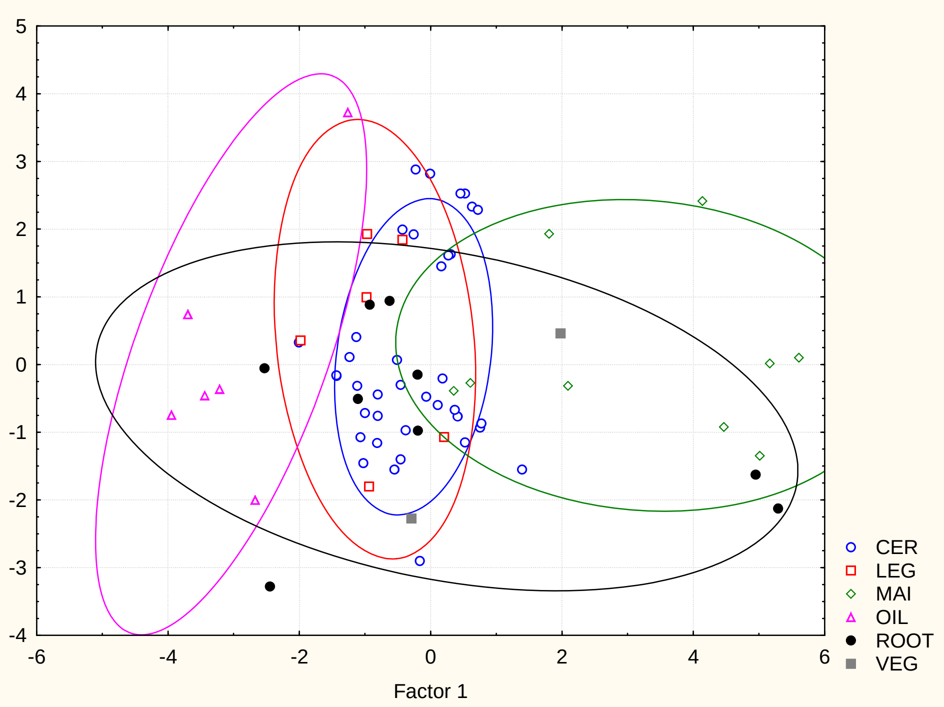


Fig. 12-5 Factor coordinates of the different products (cases). Factor 2 is shown on the Y-axis, differentiated according to the crop group: cereals (CER: wheat, barley and rye), legumes (LEG: pea, faba bean and soya bean), maize (MAI: grain and silage maize), oil crops (OIL: rape seed and sunflowers) root crops (ROOT: potato, beets and carrots), vegetables (VEG: cabbage). The ellipses symbolise the bivariate standard deviation of the subpopulations.

The different crop groups can mainly be distinguished by factor 1 (Fig. 12-5). Some groups seem relatively homogeneous (e.g. cereals, grain legumes and oil crops) at least on factor 1, while others are highly heterogeneous (maize and root crops).

We will now have a closer look into some of the groups.

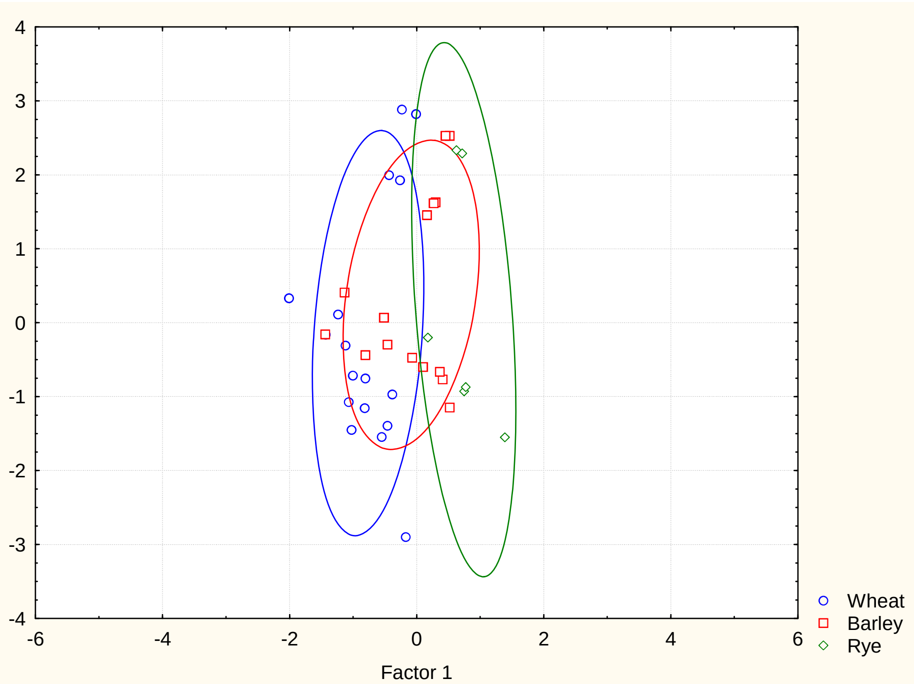


Fig. 12-6 Factor coordinates of the cereal group.

Wheat and barley appear to be quite similar (Fig. 12-6), while rye is a bit more distinct from the other two species. The differences can be largely explained by the yields; wheat is bread wheat in the Swiss case (with the lowest yields), barley (higher yields than wheat) and rye (higher yields than barley) are feed cereals.

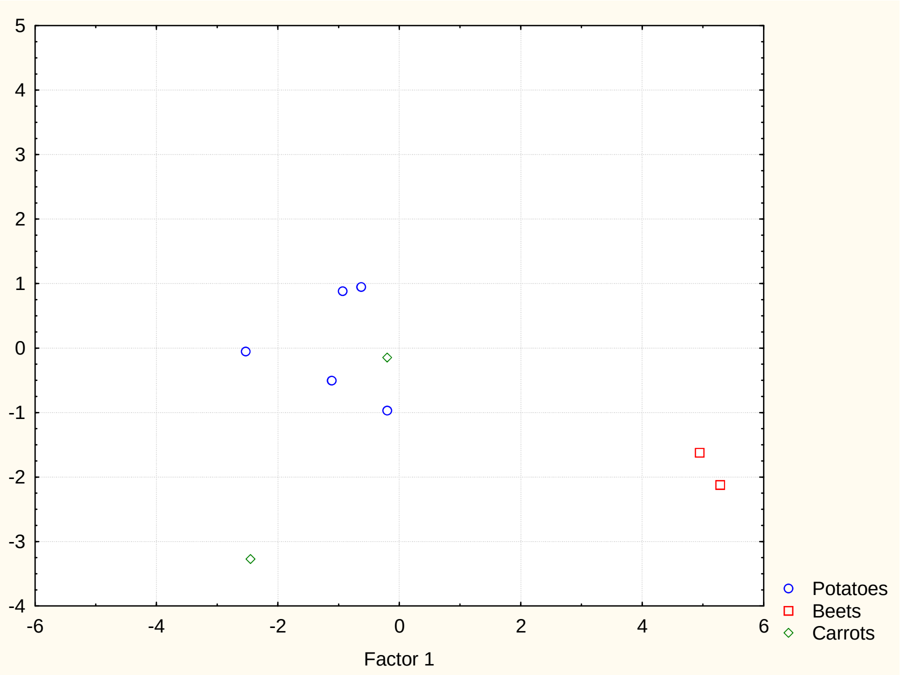


Fig. 12-7 Factor coordinates for the root crop group.

We can see a relative similarity of the potato datasets (Fig. 12-7). Beets appear to be a completely distinct group. Organic carrots (the upper of the two points) show some similarities with potatoes, while carrots from integrated production seem to be very different. The latter result is due to the pesticides used in integrated carrot production.

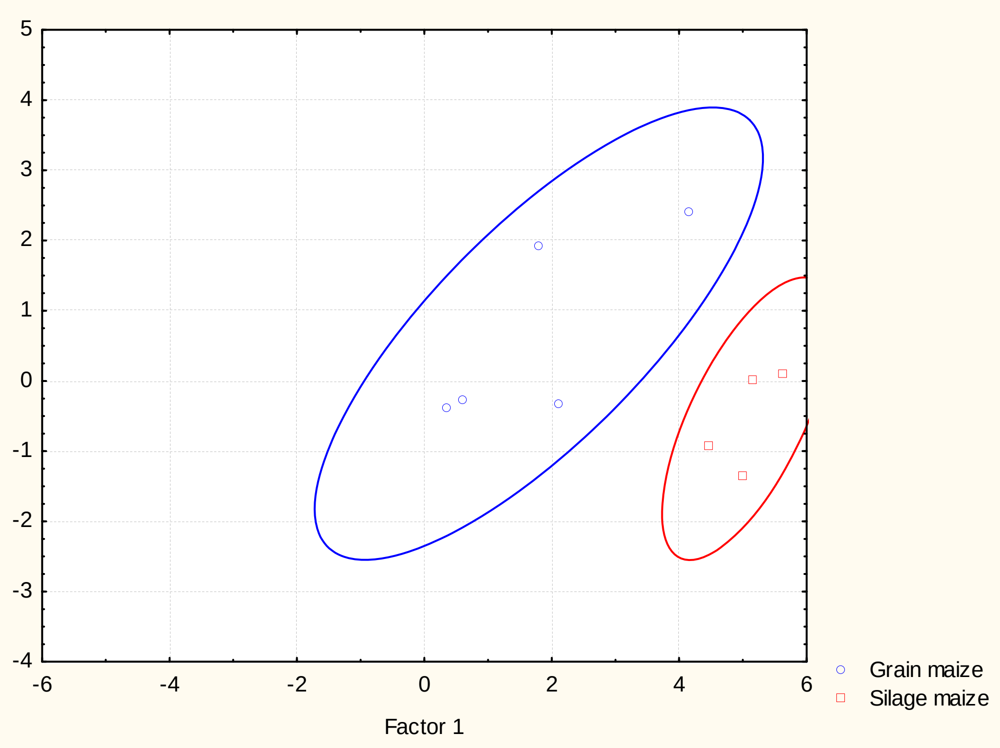


Fig. 12-8 Factor coordinates for the maize group.

For maize we obtain two more homogeneous groups, if we distinguish silage and grain maize (Fig. 12-8).

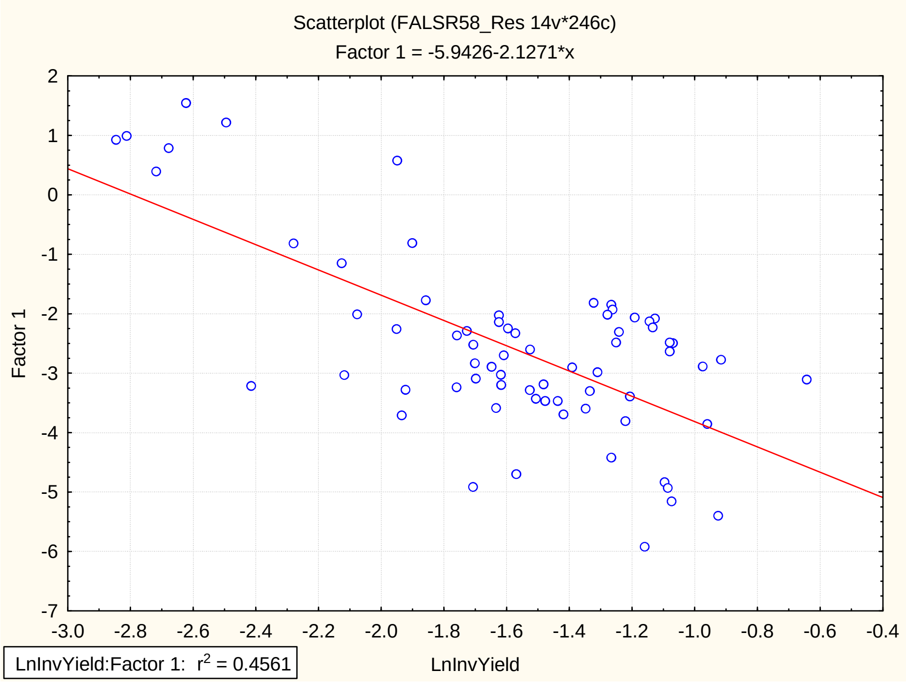


Fig. 12-9 Regression between the natural logarithm of the inverse of yield and Factor 1.

Factor 1 shows are relatively good relationship to the natural logarithm of the inverse of yield (Fig. 12-9). The inverse of the yield is used to get a linear relationship (we would expect the relationship impact-yield to be close to a hyperbole). This means that crops with higher yields are on the right side of the graph (high values of factor 1).

	Energy	GWP	Ozone	Eutro	Acidi	TET_EDIP	AET_EDIP	HTP_CML
LnInvYield	0.55	0.91	0.79	0.77	0.56	-0.12	0.47	0.28

Table 12-1 Correlations between the natural logarithm of the inverse of yield. Significant correlations are marked by yellow colour.

A relationship exists between the natural logarithm of the inverse yield and some of the impact indicators (Table 12-1). Relatively high correlations were found for global warming, ozone formation and eutrophication. Medium correlations exist to the energy demand, acidification and aquatic ecotoxicity. No or only very weak correlations were found for terrestrial ecotoxicity and human toxicity.

12.2 Crop inventories from ecoinvent (worldwide)

The same impact categories were analysed as for the SALCA datasets (see previous paragraph). The analysis is performed in the environmental impact per kg D.M. of product, transformed by natural logarithm.
In a first analysis, the crops grown on previously cleared forest or shrub land (sugar cane BR, soya beans BR and palm fruit bunches MY) were found to be quite distinct from the other datasets and were therefore excluded from further analysis.

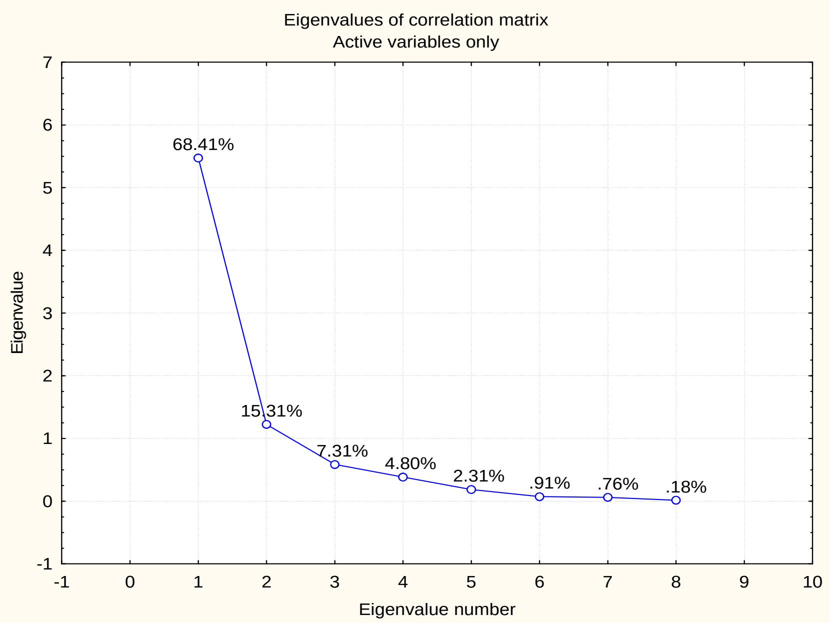


Fig. 12-10 Scree plot of the Eigen values of the eight principal components for the ecoinvent data.

For the ecoinvent data as well, two principal components are sufficient to explain 84% of the variance.

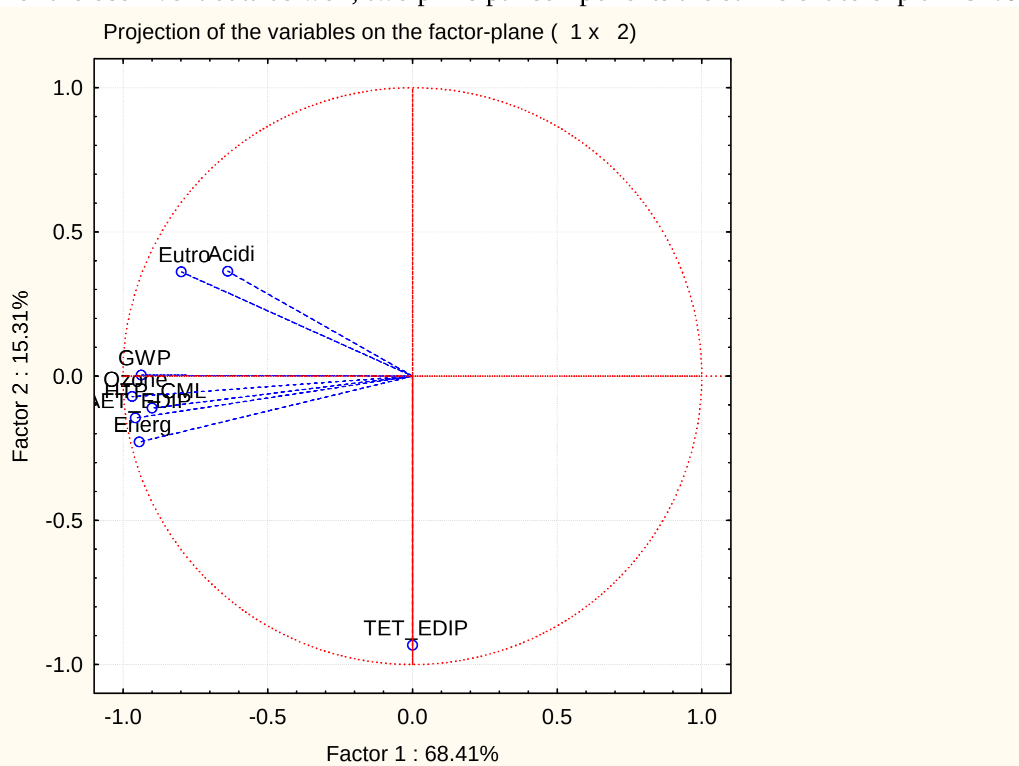


Fig. 12-11 Factor coordinates of the impact categories (variables) for the ecoinvent data.

Factor 1 is closely related to energy, global warming, ozone formation, aquatic and human toxicity. Factor 2 more to acidification, eutrophication and terrestrial ecotoxicity.

An analysis by country makes little sense, since there are too little crops, where data are available for several countries. Only for the cereals we analyse by countries (Fig. 12-14).

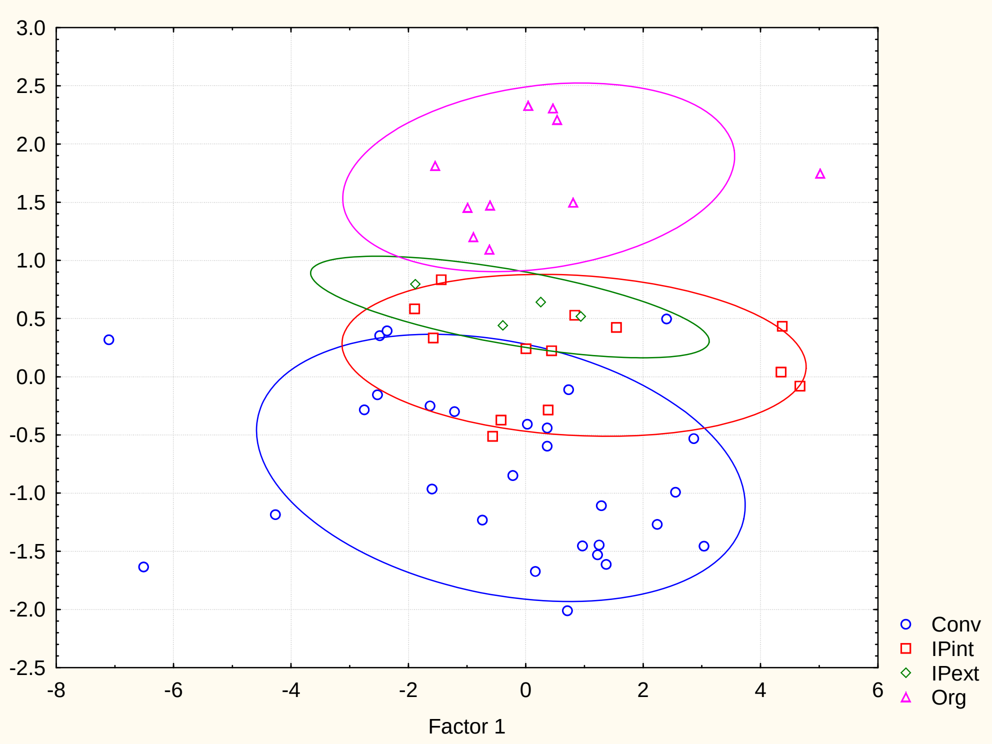


Fig. 12-12 Factor coordinates of the different products (cases). Factor 2 is shown on the Y-axis, differentiated according to the farming system: conventional (Conv), integrated intensive (IPint), integrated extensive (IPext) and organic (Org). The ellipses symbolise the bivariate standard deviation of the subpopulations.

As for the SALCA data, we find a similar grouping for the farming systems (Fig. 12-12). Note that IPint, IPext and Org datasets are from Switzerland, while the conventional production data are from the other countries. Therefore we have not only an effect of the farming system, but also of the production country.

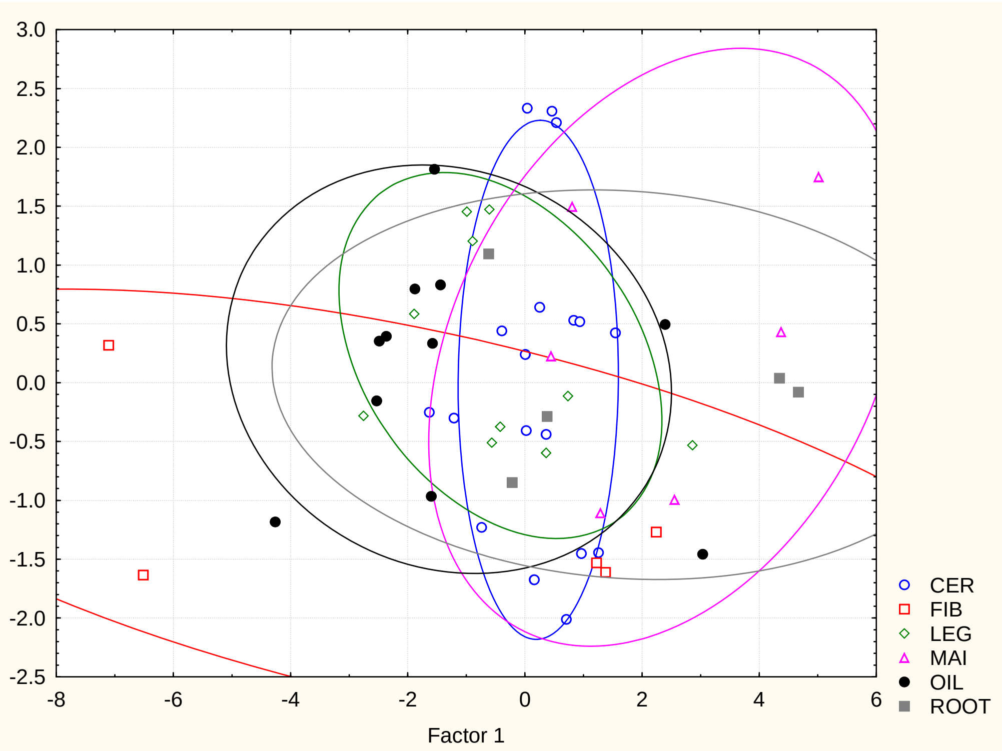


Fig. 12-13 Factor coordinates of the different products (cases). Factor 2 is shown on the Y-axis, differentiated according to the crop group: cereals (CER: wheat, barley, rye and rice), legumes (LEG: pea, faba bean and soya

bean), maize (MAI: grain and silage maize), oil crops (OIL: rape seed, sunflowers, palm oil) root crops (ROOT: potato, beets and carrots). The ellipses symbolise the bivariate standard deviation of the subpopulations.

The datasets for cereals and legumes are more of less close together. Cereals spread little on factor 1, but highly on factor 2 (i.e. we have a strong impact of the farming systems and intensity). For oil crops we can distinguish the two points at the right side, which is cotton seed. The bottom left point is rape seed from the US, which has a low yield.

Fibre crops: jute and kenaf seem to be quite close (3 points at the right side), while cotton not surprisingly is clearly distinct from these (the 2 points at the left).

Root crops: potatoes seem to be relatively close together, but clearly different from the beets (the 2 points on the right side). The 3 potato datasets are in the order (from bottom to top): US, CH-IP, CH-organic.

In the maize group we can again distinguish grain maize from silage maize.

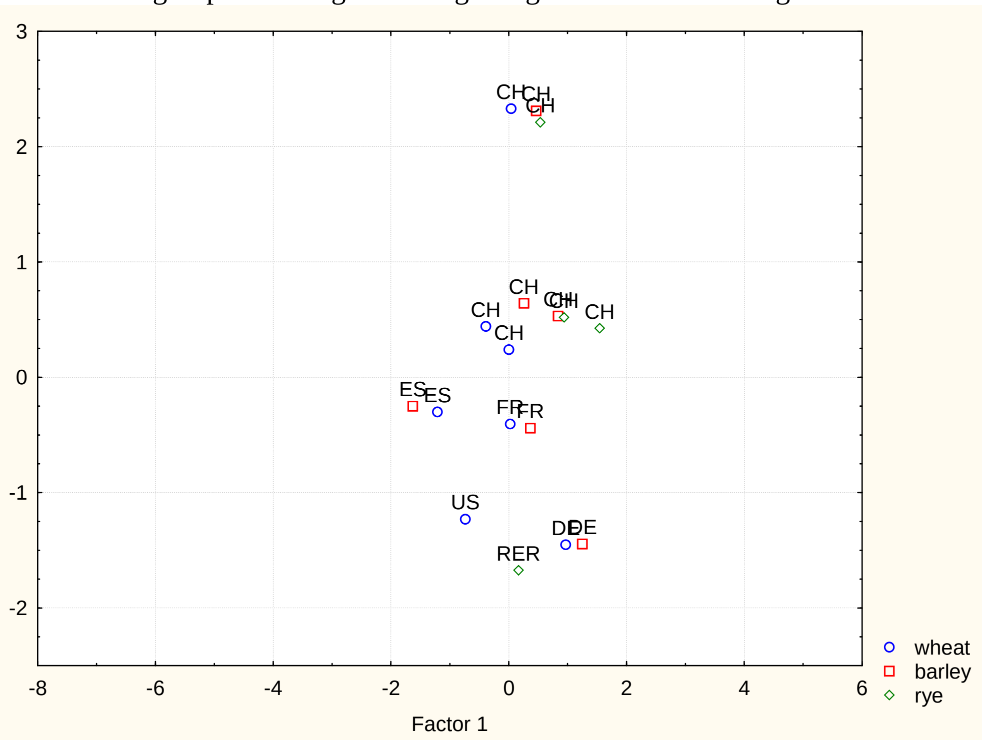


Fig. 12-14 Factor coordinates of the cereal group.

We will analyse in more detail the cereal group (Fig. 12-14): the upper 3 points are organic cereals. They have to be considered separately. For the other datasets, the country is more relevant than the specie, the different species being close together within a given country. It is therefore preferable to approximate French barley by French wheat than to take German barley data as a proxy.

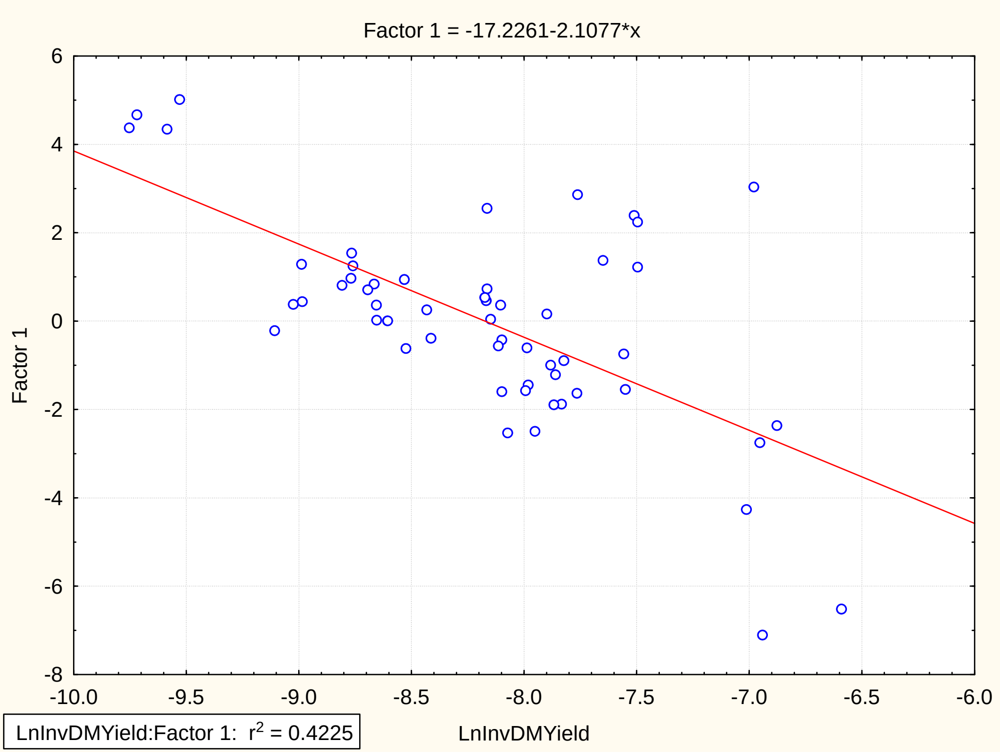


Fig. 12-15 Regression between the natural logarithm of the inverse of yield and Factor 1.

Again, we can see that the yield has an important effect on Factor 1 (Fig. 12-15).

Energ	GWP	Ozone	Acidi	Eutro	TET_EDIP	AET_EDIP	HTP_CML
0.55	0.59	0.65	0.34	0.47	0.23	0.50	0.44

Table 12-2 Correlations between the natural logarithm of the inverse of yield and the environmental impacts per kg DM of product. Significant correlations are marked by yellow colour.

The relationship between the yield and the environmental impacts is weaker than for the Swiss data (Table 12-2), because the datasets are more heterogeneous in ecoinvent.

AII. World fertiliser share

Table 12-3 N fertilizer share at the global scale (IFA, 2009)

N fertiliser types	Percentage of the total N fertiliser applied at the global scale
Ammonium nitrate	8 %
Urea	66 %
Urea ammonium nitrate	5 %
Monoammoniumphosphate (MAP)	3 %
Diammoniumphosphate (DAP)	5 %
Ammonium nitrate phosphate	0 %
Calcium ammonium nitrate	4 %
Ammonium sulphate	4 %
Calcium nitrate	0 %
Liquid ammonia (dir. Application)	5 %

Table 12-4 P fertilizer share at the global scale (IFA, 2009)

P fertilizer types	Percentage of the total P fertilizer applied at the global scale
Triple superphosphate	9 %
Single superphosphate	24 %
Monoammoniumphosphate (MAP)	24 %
Diammoniumphosphate (DAP)	42 %
Ammonium nitrate phosphate	0 %
Hyper phosphate (ground rock, dir.application)	1 %
Basic slag	0 %

Table 12-5 K fertilizer share at the global scale (IFA, 2009)

K fertilizer types	Percentage of the total K fertilizer applied at the global scale
Potassium chloride	96 %
Potassium sulphate	4 %
Potassium nitrate	0 %
Patentkali	0 %

The fertiliser shares have been estimated using the IFA data (IFA, 2009).

For nitrogen, the following categories are available in the IFA database:

- Ammonia direct application
- Ammonium nitrate
- Ammonium phosphate
- Ammonium sulphate
- Calcium ammonium nitrate
- N K compounds
- N P K compounds
- Nitrogen solutions
- Other N straight
- Other N P
- Urea

In ecoinvent and SALCA, the following categories are available:

- Ammonium nitrate
- Urea
- Urea ammonium nitrate
- Monoammoniumphosphate (MAP)
- Diammoniumphosphate (DAP)
- Ammonium nitrate phosphate
- Calcium ammonium nitrate
- Ammonium sulphate
- Calcium nitrate
- Liquid ammonia (dir. Application)

Some quantities can thus be used directly in SALCA: ammonia direct application, ammonium nitrate, urea, calcium ammonium nitrate and ammonium sulphate.

The others have to be adapted: ammonium phosphate, N K compounds, N P K compounds, nitrogen solutions, other N straight, other N P.

Some information could be collected for some of them[5]: ammonium phosphate is used in MAP (37%) and in DAP (63%), about 90% of nitrogen solutions is urea ammonium nitrate. We assigned these proportions to the corresponding categories in SALCA.

The rest (N K compounds, N P K compounds, 10% of nitrogen solutions, other N straight, other N P) has been shared over the SALCA categories proportionally to the current share (without the rest).

For phosphorus and potassium the same procedure has been applied: detect the fertiliser categories which are the same in IFA and in SALCA. Assign these shares. Distribute the rest proportionally.

AIII. NO-TILL IN THE WORLD

The percentage of the cultivated area under no-till is not available for each country.

Rolf Derpsch (Derpsch, 2008)communicated us values for some countries (Table 12-6) in [ha], which he presented on the 4th World Congress on Conservation Agriculture in New Delhi in February 2009. In order to transform these values in percentage, we used the values of the area of arable land and permanent crop of the FAO (FAOSTAT) of the same year when available. When no year is stated in Table 12-6, we use the FAO area data of 2005 which is the most recent year in the FAO database. We do the same for the data after 2005 in Table 12-6: we take the area of arable land and permanent crop of 2005 in order to compute the percentage. The results are presented in Table 12-8.

Table 12-6 Importance of no-till worldwide (personal communication with Rolf Derpsch)

Country	Year	Area under no-till [ha]	Commentaries
USA	2004	25 300 000	
Canada	2008	13 480 000	
Brazil	2006	25 500 000	
Argentina	2006	19 700 000	
Paraguay	2008	2 400 000	
Bolivia	2007	706 000	Data for soybean only
Uruguay	2007	672 000	
Venezuela	2005	300 000	
Chile	?	180 000	
Colombia	2008	100 000	
Australia	2008	12 000 000	
New Zealand	2008	160 000	
China	2008	1 330 000	
Kazakhstan	2008	1 300 000	
Indo-Gangetic Plains	2008	5 000 000	Data for wheat only
India	?	?	
North Korea	?	3 000	
Spain	?		10% of the cultivated area
France	?	200 000	
Finland	2008	200 000	
Ukraine	?	100 000	
Switzerland	?		3.5 % of the cultivated area
Germany	?	5000	

[5] Personal communication with Olivier Rousseau, IFA (12 February 2009)

Country	Year	Area under no-till [ha]	Commentaries
South Africa	2008	368 000	
Southern and Eastern Africa	?	20 000	Kenya and Tanzania
Tunisia	2007	6 000	
World	2008	105 863 000	

Table 12-7 Approximate of the agricultural area under no-till

country	Area tot [ha]	percentage
USA	176974000	14.296%
Canada	52110000	25.868%
Brazil	66600000	38.288%
Argentina	29505000	66.768%
Paraguay	4298000	55.840%
Bolivia		
Uruguay	1412000	47.592%
Venezuela	3450000	8.696%
Chile	2315000	7.775%
Colombia	3613000	2.768%
Australia	49742000	24.124%
New Zealand	3406000	4.698%
China	156327000	0.851%
Kazakhstan	22500000	5.778%
Indo-Gangetic-Plains		
India		
North Korea	3000000	0.100%
Spain	18630000	10.000%
France	19635000	1.019%
Finland	2240000	8.929%
Ukraine	33353000	0.300%
Switzerland	434000	3.500%
Germany	12101000	0.041%
South Africa	15712000	2.342%
Southern and Eastern Africa		
Tunisia	4884000	0.123%
World	1561681700	6.779%

Table 12-8 Approximate of the no-till area percentage at the continental and global scale

Continent	Percentage of the agricultural area under no-till
North America	17 %
South America	44 %
Oceania	23 %
Asia	1 %
Europe	3 %
World	7%

AIV. AGRICULTURAL MANAGEMENT INDICES

Table 12-9 Agricultural indices for all countries which have an agricultural area. They are developed using the FAO data. When no data is available for a country, the mean value of the other countries is applied (1 for most of the indices, 0.7943 for drying).

				INPUTS			
Countries	**MachVar**	**Nfert**	**Pfert**	**Kfert**	**Pestic**	**Irrigat**	**Drying**
Afghanistan	0.0007	0.0439	0.0341	0.0443	1.0000	1.8827	0.6620
Albania	0.5233	0.7172	1.1767	0.0243	1.0000	2.7960	0.4980
Algeria	0.5836	0.1249	0.1147	0.1535	0.2135	0.3845	0.9310
American Samoa	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.7943
Andorra	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.7943
Angola	1.0000	0.0175	0.0212	0.0403	1.0000	0.1276	0.9771
Antigua and Barbuda	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.7943
Argentina	0.4531	0.4012	0.6251	0.0645	2.2776	0.2950	0.9470
Armenia	1.2697	0.3528	0.0223	0.0013	1.0000	2.8598	0.4865
Aruba	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.7943
Australia	0.3420	0.3271	0.9008	0.2899	1.0000	0.2786	0.9500
Austria	10.6954	3.0632	1.5674	2.9519	2.0457	0.3559	0.9361
Azerbaijan	0.6071	0.1276	0.0257	0.0598	1.0000	3.9269	0.2949
Bahamas	1.0000	1.0000	1.0000	1.0000	1.0000	0.4641	0.9167
Bahrain	1.0000	13.1165	0.4624	0.6077	1.5574	3.7131	0.3333
Bangladesh	0.0047	1.8982	1.1261	1.1982	0.2746	3.0962	0.4441
Barbados	1.0000	1.2405	0.3524	0.0845	1.0000	1.6381	0.7059
Belarus	0.5772	0.9158	0.6690	3.8437	1.0000	0.1281	0.9770
Belgium	5.2763	1.0000	1.0000	1.0000	9.3508	0.2583	0.9536
Belize	0.5317	1.4073	2.3542	0.8739	10.6814	0.2087	0.9625
Benin	1.0000	0.0342	0.0360	0.0386	1.0000	0.0231	0.9959
Bermuda	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.7943
Bhutan	1.0000	1.0000	1.0000	1.0000	0.0422	1.3044	0.7658
Bolivia	0.0856	0.0379	0.0753	0.0568	1.0000	0.2280	0.9591
Bosnia and Herzegovina	1.2326	0.3605	0.3150	0.4472	1.0000	0.0151	0.9973
Botswana	0.7224	1.0000	1.0000	1.0000	1.0000	0.0147	0.9974
Brazil	0.5729	0.5233	1.7589	2.9503	0.8960	0.2441	0.9562
British Virgin Islands	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.7943
Brunei Darussalam	0.2099	0.0263	0.0508	0.0882	1.0000	0.3165	0.9432
Bulgaria	0.5249	1.5354	1.6723	0.0815	1.0000	0.9293	0.8332
Burkina Faso	1.0000	0.0591	0.0422	0.0533	0.1527	0.0290	0.9948
Burundi	0.0058	0.0069	0.0269	0.0011	0.0506	0.0870	0.9844
Cambodia	0.0372	0.0213	0.0834	0.0092	1.0000	0.3907	0.9299
Cameroon	1.0000	0.0517	0.0576	0.1339	0.0724	0.0202	0.9964
Canada	0.7126	0.5094	0.4995	0.3567	1.0000	0.0839	0.9849
Cape Verde	1.0000	1.0000	1.0000	1.0000	1.0000	0.3438	0.9383
Cayman Islands	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.7943
Central African Republic	0.0012	1.0000	1.0000	1.0000	1.0000	0.0055	0.9990

Countries	MachVar	Nfert	Pfert	*INPUTS* Kfert	Pestic	Irrigat	Drying
Chad	0.0023	1.0000	1.0000	1.0000	1.0000	0.0430	0.9923
Channel Islands	1.0000	1.0000	1.0000	1.0000	1.0000	2.2702	0.5924
Chile	1.2123	1.8977	2.8548	2.6353	5.0449	4.5282	0.1870
China	0.4099	3.0273	2.7237	1.6968	0.0002	1.9798	0.6445
Colombia	0.2842	1.5400	1.3282	3.3863	11.9279	1.3232	0.7624
Comoros	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.7943
Congo	0.0650	1.0000	1.0000	1.0000	1.0000	0.0205	0.9963
Congo, Democratic Republic of	1.0000	1.0000	1.0000	1.0000	1.0000	0.0079	0.9986
Cook Islands	1.2536	1.0000	1.0000	1.0000	0.2873	1.0000	0.7943
Costa Rica	0.6869	2.0811	1.7448	7.8651	21.5605	1.1202	0.7989
Côte d'Ivoire	0.0596	0.0613	0.1115	0.2150	1.0000	0.0586	0.9895
Croatia	3.7425	0.9014	1.0507	2.4261	1.0000	0.0324	0.9942
Cuba	0.8475	0.1503	0.1573	0.4360	1.0000	1.1006	0.8024
Cyprus	3.8181	1.0279	1.5848	1.3280	14.0184	1.6338	0.7067
Czech Republic	1.4153	1.5223	0.6965	0.9166	1.0452	0.0405	0.9927
Denmark	2.7551	1.2459	0.2729	1.4707	1.2538	1.0884	0.8046
Djibouti	1.0000	1.0000	1.0000	1.0000	1.0000	5.5696	0.0100
Dominica	1.0000	0.0782	0.4329	0.5844	1.0000	1.0000	0.7943
Dominican Republic	1.0000	1.0000	1.0000	1.0000	3.4814	1.1610	0.7915
Ecuador	0.2898	0.7963	0.5903	1.3482	2.4798	1.8570	0.6666
Egypt	1.2619	7.2488	2.3159	0.6809	1.0000	5.5233	0.0083
El Salvador	0.1906	0.6507	0.5762	0.3981	1.0000	0.2754	0.9505
Equatorial Guinea	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.7943
Eritrea	0.0446	0.0329	0.0133	0.0033	1.0000	0.1969	0.9646
Estonia	3.2090	0.7386	3.0409	0.9523	0.2587	0.0368	0.9934
Ethiopia	0.0114	0.0964	0.2528	0.0005	0.0470	0.1319	0.9763
Faroe Islands	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.7943
Fiji	1.0000	0.3778	0.0978	0.0070	1.0000	0.0586	0.9895
Finland	4.2725	1.2816	0.6226	1.9093	0.4796	0.2089	0.9625
France	3.0242	1.8671	1.3755	2.5145	4.7238	0.7305	0.8688
French Guiana	1.0185	1.0000	1.0000	1.0000	1.0000	0.6962	0.8750
French Polynesia	0.5438	0.2251	0.4148	0.6159	1.0000	0.2264	0.9593
Gabon	1.0000	0.0163	0.0162	0.1267	1.0000	0.0788	0.9859
Gambia	0.0131	0.0511	0.0725	0.0618	1.0000	0.0331	0.9941
Georgia	0.8244	0.2451	0.0462	0.0449	1.0000	2.4527	0.5596
Germany	4.0367	2.3916	0.9695	2.1426	2.1040	0.2242	0.9598
Ghana	0.0266	0.0246	0.0216	0.1414	0.0348	0.0272	0.9951
Greece	3.1009	1.1743	1.1719	0.7597	2.2873	2.1164	0.6200
Grenada	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.7943
Guadeloupe	1.0000	1.0000	1.0000	1.0000	1.0000	1.5396	0.7236
Guam	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.7943
Guatemala	0.1628	0.8908	0.9922	0.2580	1.0000	0.3560	0.9361
Guinea	0.1414	0.0187	0.0100	0.0123	0.0940	0.2997	0.9462
Guinea-	1.0000	1.0000	1.0000	1.0000	1.0000	0.2535	0.9545

Countries	MachVar	Nfert	Pfert	INPUTS Kfert	Pestic	Irrigat	Drying
Bissau							
Guyana	0.3594	0.3822	0.0801	0.0556	1.0000	1.6381	0.7059
Haiti	1.0000	1.0000	1.0000	1.0000	0.0112	0.4658	0.9164
Honduras	1.0000	0.3919	0.2058	0.0579	1.9649	0.3120	0.9440
Hungary	1.2172	1.1582	0.7576	1.1486	0.8755	0.2743	0.9508
Iceland	67.2542	19.1261	31.9667	29.5604	0.6041	1.0000	0.7943
India	0.6664	1.0744	1.0094	0.6460	0.2515	1.7919	0.6783
Indonesia	0.4396	1.0967	0.5566	0.7345	1.0000	0.6970	0.8749
Iran, Islamic Republic of	0.6838	0.8300	0.8989	0.4096	1.0000	2.6160	0.5303
Iraq	0.6077	1.0000	1.0000	1.0000	0.0983	3.2628	0.4142
Ireland	6.4301	4.6622	3.3732	4.4097	1.6580	1.0000	0.7943
Isle of Man	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.7943
Israel	2.6979	1.4314	4.8871	73.4647	4.8254	2.6162	0.5303
Italy	7.7112	1.1919	1.2598	1.4779	6.1485	2.0502	0.6319
Jamaica	1.0000	0.3493	0.5237	0.2375	5.3574	0.4903	0.9120
Japan	28.1286	1.9561	5.6982	6.1162	1.0000	3.0445	0.4534
Jordan	1.0000	2.7318	13.7267	7.0517	1.9334	1.5277	0.7257
Kazakhstan	0.1386	0.0490	0.1288	0.0063	0.3050	0.8783	0.8423
Kenya	0.1111	0.2109	0.6562	0.1380	0.5124	0.0965	0.9827
Kiribati	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.7943
Korea, Democratic People's Republic of	1.0000	1.0000	1.0000	1.0000	1.0000	2.7944	0.4983
Korea, Republic of	7.3121	3.1060	4.4654	6.6509	10.9953	2.6344	0.5270
Kuwait	1.0000	15.3981	1.0000	1.0000	1.7895	4.1612	0.2529
Kyrgyzstan	0.8179	0.2804	0.0404	0.0007	1.0000	4.1458	0.2556
Lao People's Democratic Republic	1.0000	1.0000	1.0000	1.0000	0.0020	0.9345	0.8322
Latvia	2.7679	0.4033	0.3747	0.5263	0.2979	0.1103	0.9802
Lebanon	1.1712	0.7694	1.6008	0.5266	5.1896	1.7856	0.6794
Lesotho	0.2716	1.0000	1.0000	1.0000	1.0000	0.0500	0.9910
Liberia	1.0000	1.0000	1.0000	1.0000	1.0000	0.0278	0.9950
Libyan Arab Jamahiriya	0.9152	0.4384	0.6245	0.1480	1.0000	1.2325	0.7787
Liechtenstein	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.7943
Lithuania	3.1750	0.2410	2.0088	3.7202	0.2439	0.0229	0.9959
Luxembourg	5.6499	4.4517	1.7079	2.5647	1.0000	1.0000	0.7943
Madagascar	0.0097	0.0188	0.0246	0.0362	0.0257	1.7038	0.6941
Malawi	1.0000	0.2384	0.1507	0.1724	0.2034	0.1209	0.9783
Malaysia	1.0000	1.1761	0.6324	5.2974	1.0000	0.2680	0.9519
Maldives	1.0000	0.0239	0.0340	0.0466	1.0000	1.0000	0.7943
Mali	0.0305	1.0000	1.0000	1.0000	1.0000	0.2743	0.9508
Malta	2.3271	0.9174	0.6863	1.0577	19.0401	1.0921	0.8039
Marshall Islands	1.0000	0.0008	0.0041	0.0058	1.0000	1.0000	0.7943
Martinique	1.0000	1.0000	1.0000	1.0000	1.0000	1.9301	0.6535
Mauritania	0.0377	1.0000	1.0000	1.0000	1.0000	0.5477	0.9017
Mauritius	1.0000	1.1953	1.3083	5.9212	14.6859	1.1139	0.8000

Countries	MachVar	Nfert	Pfert	*INPUTS* Kfert	Pestic	Irrigat	Drying
Mayotte	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.7943
Mexico	0.5657	0.6350	0.6632	0.4060	1.0000	1.2686	0.7722
Micronesia, Federated States of	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.7943
Moldova	0.9843	0.1437	0.0397	0.0297	1.0000	0.7771	0.8605
Mongolia	0.1995	0.0610	1.0000	0.0004	1.0000	0.3945	0.9292
Montserrat	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.7943
Morocco	0.2554	0.3878	0.8780	0.3855	1.0000	0.8686	0.8441
Mozambique	1.0000	0.0575	0.0282	0.0456	0.0079	0.1460	0.9738
Myanmar	0.1260	0.0076	0.0082	0.0236	0.0134	1.0206	0.8168
Namibia	1.0000	0.0326	0.0121	0.0136	1.0000	0.0543	0.9902
Nepal	1.0000	0.2473	0.3170	0.0461	1.0000	2.6225	0.5291
Netherlands	7.4192	9.0403	2.1160	11.8951	8.9424	3.3420	0.4000
Netherlands Antilles	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.7943
New Caledonia	9.1921	1.4910	3.0858	3.1828	1.0000	5.6857	0.0100
New Zealand	1.0244	1.7380	5.2356	2.5985	0.8399	0.8443	0.8484
Nicaragua	1.0000	0.2630	0.2797	0.2313	2.1499	0.1573	0.9718
Niger	1.0000	0.0045	0.0050	0.0010	1.0000	0.0281	0.9950
Nigeria	1.0000	0.0532	0.0476	0.0618	1.0000	0.0467	0.9916
Niue	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.7943
Northern Mariana Islands	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.7943
Norway	7.4907	1.6236	2.3199	3.8330	0.6395	0.8071	0.8551
Occupied Palestinian Territory	1.5414	1.0000	1.0000	1.0000	1.0000	0.3957	0.9290
Oman	0.1197	1.7150	0.4034	4.0833	5.9026	4.4360	0.2035
Pakistan	0.7220	1.8556	1.3049	0.0623	0.4652	4.3442	0.2200
Palau	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.7943
Panama	0.6675	0.3679	0.1998	0.2864	5.9485	0.3446	0.9381
Papua New Guinea	0.0848	0.1848	1.2660	0.0761	1.0000	1.0000	0.7943
Paraguay	1.0000	0.1690	0.9310	1.0723	2.8130	0.0965	0.9827
Peru	0.1395	0.7508	0.5732	0.6322	0.9690	1.5514	0.7214
Philippines	0.2691	0.8270	0.6594	0.3618	1.0000	0.8068	0.8551
Poland	5.1202	0.9784	1.0441	2.1056	0.5351	0.0424	0.9924
Portugal	3.7418	1.0131	1.7807	1.6907	5.0791	1.7626	0.6835
Puerto Rico	1.0000	1.0000	1.0000	1.0000	1.0000	2.0294	0.6356
Qatar	0.1699	10.8460	0.0375	0.2834	3.0696	3.4479	0.3810
Réunion	1.0000	1.0000	1.0000	1.0000	1.0000	1.7050	0.6939
Romania	0.8945	0.4325	0.3999	0.0967	1.1122	1.7958	0.6776
Russian Federation	0.2698	0.1035	0.1024	0.1508	0.1933	0.2051	0.9632
Rwanda	1.0000	1.0000	1.0000	1.0000	0.1310	0.0355	0.9936
Saint Helena	0.1689	1.0000	1.0000	1.0000	1.0000	1.0000	0.7943
Saint Kitts and Nevis	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.7943
Saint Lucia	1.0000	1.0000	1.0000	1.0000	5.9607	0.9283	0.8333

Countries	MachVar	Nfert	Pfert	*INPUTS* Kfert	Pestic	Irrigat	Drying
Saint Pierre and Miquelon	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.7943
Saint Vincent and Grenadines	1.0000	1.0000	1.0000	1.0000	1.0000	0.6962	0.8750
Samoa	1.0000	0.0023	0.0048	0.0055	0.1527	1.0000	0.7943
San Marino	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.7943
Sao Tome and Principe	1.0000	1.0000	1.0000	1.0000	1.0000	1.0164	0.8175
Saudi Arabia	0.1533	0.8157	1.4065	0.1105	0.6199	2.5640	0.5397
Senegal	0.0152	0.1017	0.1662	0.1612	0.1643	0.2590	0.9535
Serbia and Montenegro	4.1066	0.9904	0.8623	1.4600	0.7720	0.0467	0.9916
Seychelles	1.0000	1.0000	1.0000	1.0000	1.5799	0.1671	0.9700
Sierra Leone	0.0078	1.0000	1.0000	1.0000	1.0000	0.2636	0.9527
Singapore	1.0000	119.6766	5.4986	1.0000	1.0000	1.0000	0.7943
Slovakia	0.8185	0.7913	0.5031	0.7049	1.7115	0.7091	0.8727
Slovenia	24.3642	2.6077	2.9221	4.7497	5.7531	0.1379	0.9752
Solomon Islands	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.7943
Somalia	1.0000	1.0000	1.0000	1.0000	1.0000	0.8806	0.8419
South Africa	0.2196	0.4259	0.5191	0.4030	1.3799	0.5310	0.9047
Spain	2.4627	0.9945	1.1483	1.3985	1.5898	1.1458	0.7943
Sri Lanka	0.4549	1.4362	0.7374	1.7729	0.8090	1.6578	0.7023
Sudan	0.0413	0.0500	0.0148	0.0001	0.0498	0.5800	0.8959
Suriname	1.0000	1.1614	0.1681	0.2828	2.2284	4.1528	0.2544
Swaziland	1.0000	1.0000	1.0000	1.0000	1.0000	1.4504	0.7396
Sweden	3.4397	1.0583	0.7333	0.9615	0.5499	0.2386	0.9572
Switzerland	11.5946	1.6974	1.4512	3.0876	3.1720	0.3213	0.9423
Syrian Arab Republic	0.8850	0.7416	0.8885	0.0269	0.5074	1.3736	0.7534
Tajikistan	0.9812	1.0000	1.0000	1.0000	1.0000	3.8002	0.3177
Tanzania, United Republic of	1.0000	0.0617	0.0402	0.0300	0.0035	0.0985	0.9823
Thailand	1.2755	0.9873	0.9545	1.1116	1.0204	1.5104	0.7288
The former Yugoslav Republic of Macedonia	4.0970	0.3552	0.1428	0.4578	0.7627	0.5005	0.9101
Timor-Leste	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.7943
Togo	1.0000	0.0340	0.0671	0.0941	1.0000	0.0148	0.9973
Tonga	1.0000	0.7804	0.8348	0.0861	1.0000	1.0000	0.7943
Trinidad and Tobago	1.0000	1.9890	0.1412	0.3765	1.0000	0.1826	0.9672
Tunisia	0.3799	0.1801	0.4233	0.0557	0.1685	0.4596	0.9175
Turkey	1.7062	0.9854	0.9534	0.2231	0.9972	1.0892	0.8044
Turkmenistan	1.3649	1.0000	1.0000	1.0000	1.0000	4.6738	0.1608
Turks and Caicos Islands	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.7943
Tuvalu	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.7943

Countries	MachVar	Nfert	Pfert	INPUTS Kfert	Pestic	Irrigat	Drying
Uganda	0.0288	0.0079	0.0138	0.0119	1.0000	0.0068	0.9988
Ukraine	0.6048	0.2009	0.0941	0.1432	1.0000	0.3727	0.9331
United Arab Emirates	0.0697	1.7902	0.4001	1.6834	1.0000	1.6381	0.7059
United Kingdom	4.2642	3.1110	1.7996	3.5564	4.8486	0.1639	0.9706
United States of America	1.3088	1.2647	1.2305	1.7886	1.8525	0.7006	0.8742
Uruguay	1.2584	0.6835	2.7593	0.1785	2.3175	0.8228	0.8523
US Virgin Islands	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.7943
Uzbekistan	1.6088	1.0000	1.0000	1.0000	1.0000	4.8116	0.1361
Vanuatu	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.7943
Venezuela, Bolivarian Republic of	0.7210	1.3251	0.8813	1.2260	1.0000	0.9388	0.8314
Viet Nam	2.0029	2.1590	2.4079	2.4869	2.5181	1.8810	0.6623
Wallis and Futuna Islands	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.7943
Western Sahara	0.1081	1.0000	1.0000	1.0000	1.0000	1.0000	0.7943
Yemen	0.1793	0.0780	0.0063	0.0110	1.0000	1.6913	0.6963
Zambia	0.0537	1.0000	1.0000	1.0000	1.0000	0.1609	0.9711
Zimbabwe	0.3334	0.2977	0.3926	0.2713	0.7534	0.2893	0.9481

AV. IRRIGATION

An alternative procedure for the estimation of the need for irrigation would follow these steps:

- Use monthly climate data (CRU: http://www.cru.uea.ac.uk/cru/data/hrg.htm or NCEP/NCAR: http://www.cdc.noaa.gov/data/gridded/data.ncep.reanalysis.derived.surface.html), extract the rainfall and compute the evapotranspiration for each crop and the difference between rainfall and evapotranspiration on each data location (resolution: 0.5° x 0.5° or 10' x 10' for CRU; 2.5° x 2.5° for NCEP/NCAR)
- You now have the water needs for each crop for each month in each data location.
- The water needs of a crop are rarely satisfied totally in most regions of the world, especially when the water resources are limited and other more valuable crops present. The above computed value has to be corrected.
- Correction:
    - For each country: determine all crops which are cultivated in the country (or at least the main crops in term of area) and their respective cultivation area. Divide each of these areas by the total cultivated area in order to get the contribution, in terms of area, of each crop in the country. Source: FAOSTAT
    - In a given country, crops are not distributed randomly in space and time. Each crop has different requirements in terms of temperature, light, soil, etc. They are, in the best case (which of course doesn't always correspond to the reality), organized spatially and temporally according these requirements. If two crops are in competition for a region at a given time of year, the most valuable crop will be cultivated at the best location and the other crop will be cultivated somewhere else. Concretely:
        1. Determine the market value for each crop.
        2. Determine the crop requirements for each crop. Source: FAO Ecocrop for instance.

3. Allocate first the proportion of area of the most valuable crop at the best location and at the best time period for this crop considering its requirements (after having removed the city areas, the road areas and so on). Do the same for the second most valuable crop. Repeat this operation until all crops have been allocated to a location and to a period. You now have a pattern in time and space of the crop landscape for the country.

- For each crop, select the water needs computed previously at the newly determined location. If the water need is positive, we should supply water in order to get the best yields. The available water is however generally insufficient for supplying the needs of all crops. Apply this procedure:
  1. For each country: determine the percentage of the agriculture area that is equipped for irrigation.
  2. Devote it first to the most valuable crop: compare the area proportion equipped for irrigation with the proportion of area occupied by the most valuable crop. If the proportion of area equipped for irrigation is bigger, then retrieve the area proportion occupied by the most valuable crop and compare the rest with the second most valuable crop. If it is bigger, retrieve the area proportion occupied by this second crop and compare the rest with the third most valuable crop and so on. This procedure enables to determine which crops can be irrigated with the current irrigation facilities.
  3. Assume that, when a crop requires additional water and when irrigation facilities have been devoted to it, the whole needs are covered. Compute then the irrigation in m^3/ha.

You can aggregate (average) these data over a region, a continent or over the world. You however have to keep in mind that the more you aggregate the less the data are representative for what happens at a given location.

This procedure is the most systematic procedure and probably one of the most precise too that can be recommended currently at the global scale. It is however based on the main hypothesis that the crops and the irrigation are organized in a logical way within a country and that the main organization criteria is money. Furthermore it is assumed that, when irrigation is provided, the whole water needs are covered.

It is a time and resource consuming approach, but has to be done only once. The computer requirements are a UNIX/Linux based system in order to treat the climate data, a GIS and some open source graphical software. It could be a topic for a PhD thesis.

In our time scale and with our informatics resources, this approach is unfeasible. Additionally, we know that the ETHZ is intensively working in this field and has some performing tools in order to investigate this question deeply.

We will invest only few resources in this aspect, since it is not worth to investigate more when we can not perform a procedure as described above.

AVI. MANUAL FOR THE FS USE

12.2.1 Goal

The Unilever file system (here after UFS) can be used for computing environmental impacts in a given country by using the production inventory of a reference country (base system) or for computing the median (and quantiles) of environmental impacts of the whole world production.

A template collection has been created. Each template corresponds to a file that you need for your calculation.

12.2.2 Procedure for UFS use

If you have a new crop (e.g. sunflower), you have to perform the following operations:

1. Choose a folder for your project (with any name).

2. Copy the whole folder entitled “FAO_data_LCIA” there.

3. Create a new folder named with the name of your crop (e.g. “sunflower”).

4. In this new folder (e.g. “sunflower”), create a folder called “PI_CP_RAW”.

5. In this folder (“PI_CP_RAW”), make your production inventory and entitle it with the name “PIbase_syst_crop.xls” (e.g. “PIbase_syst_sunflower.xls”).

6. Create your control panel by opening “PIbase_syst_crop.xls” (e.g. “PIbase_syst_sunflower.xls”) in Excel and by using the SALCA macro MakeProdInv. Save the result with the name “CPbase_syst_crop.xls” (e.g. “CPbase_syst_sunflower.xls”) in the same folder (“PI_CP_RAW”).

7. Launch TEAM and use the 3 successive operations “Create control panel for” (use the KulturDet inventory view), “Apply assessment methods” and “List inventories and create workbook”. Save the result with the name “RAWbase_syst_crop.xls” (e.g. “RAWbase_syst_sunflower.xls”) in the same folder (“PI_CP_RAW”).

8. Open this file in Excel and use the SALCA macro “LCIASummary-Zusammenfassung der Wirkungsabschätzung”. Save the results with the name “LCIAbase_syst_crop.xls” (e.g. “LCIAbase_syst_sunflower.xls”) in the same folder (“PI_CP_RAW”).

9. These four files in your folder “PI_CP_RAW” constitute the raw data for your base system (reference country).

10. Return in your folder having the name of your crop (e.g. “sunflower”).

11. Copy the file “temp_LCIA.xls” here and rename it with the name of your crop “crop_LCIA.xls” (e.g. “sunflower_LCIA.xls”). Open it in Excel. A window appears on your display for the update of the links to other data. Click on update. You have to modify the 2 links: replace LCIAbase_syst_temp.xls with LCIAbase_syst_crop.xls (e.g. “LCIAbase_syst_sunflower.xls”) and PIbase_syst_temp.xls with PIbase_syst_crop.xls (e.g. “PIbase_syst_sunflower.xls”). Save. Check that the column “diff.rel” contains only some 0%. This file distributes automatically the remaining impacts (direct field emissions) on the correct columns (modules). The sum of the impacts considered for each module is now equal to the impacts of the whole system.

12. Search data for the yield and for the production for your crop in the FAO database (http://faostat.fao.org/) and produce a file with the same structure as the file “temp_yield_production.xls”. Save it with the name of your crop “crop_yield_production.xls” (e.g. “sunflower_yield_production.xls”) in the same folder.

13. Copy the file “temp_world.xls” here and rename it with the name of your crop “crop_world.xls” (e.g. “sunflower_world.xls”). Open it in Excel. You have to modify several links. The link to the file “agricultural_indices.xls” should be valid (if it is not the case, modify this link and point the links to the file “agricultural_indices.xls” which is in the folder named “FAO_data_LCIA”.). Replace the link temp_LCIA.xls with the link crop_LCIA.xls (e.g. “sunflower_LCIA.xls”), temp_yield_production.xls with crop_yield_production.xls (e.g. “sunflower_yield_production.xls”) and PIbase_syst_temp.xls with PIbase_syst_crop.xls (e.g. “PIbase_syst_sunflower.xls”). Save. In the second and third table (“inp-imp pro ha” and “inputs-impacts pro kg”), select the cells containing the country names (column A) and delete the content of these cells. Open the file “crop_yield_production.xls” (e.g. “sunflower_yield_production.xls”) and select the countries alphabetically sorted (table 2). Copy these cells and paste them in the second and third table (“inp-imp pro ha” and “inputs-impacts pro kg”). Delete all the cells below the last country. Go in the second table (“inp-imp pro ha”) and check that the 5th column only contains some 1 and the 6th column only 0.93. Identify the row number of your reference country. In the columns “MachVar”, “Nfert”, ”Pfert”, ”Kfert”, “Pestic” and “Drying”, you can see that this row appears in the formulas.

Replace this row with the row corresponding to your reference country in the formulas. In the column “Irrigat”, another row appears. If you used the same country as for the rest of your inventory, replace this row in the formula with the row corresponding of your base system inventory country. If you used data for irrigation originating form another country, replace the row with the row corresponding to this country. Save and check.

14. Copy the files “temp_inputs_per_kg.xls”, “temp_inputs_per_ha.xls”, “temp_impacts_per_kg.xls” and “temp_impacts_per_ha.xls” here and rename them with the name of your crop (e.g. “sunflower_inputs_per_kg.xls”, “sunflower _inputs_per_ha.xls”, “sunflower _impacts_per_kg.xls” and “sunflower _impacts_per_ha.xls”) and open them in Excel one after the other. Replace the links with the appropriate links (see above for the procedure) in each of them.

12.2.3 Results and modifications

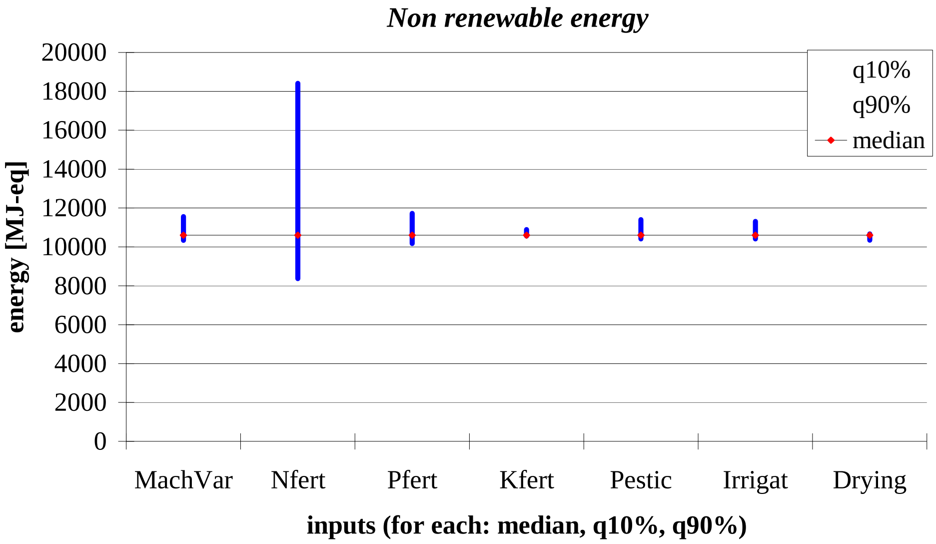
You now have a whole system for your new crop (e.g. sunflower) which provides you the inputs needed for the crop production and the impacts of the crop production in each producing country, as well as the world median and the world quantiles of both the inputs and the impacts.

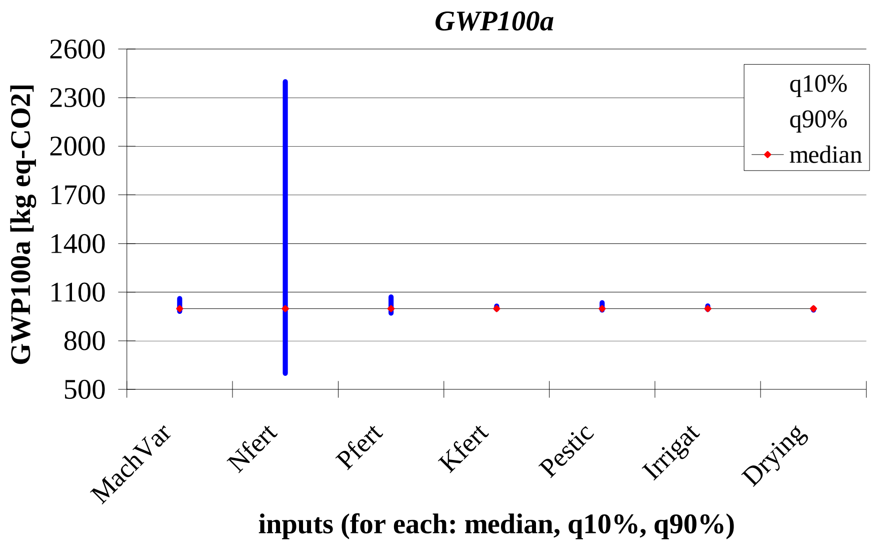
If, for any reason (e.g. bug fix, update, etc.), you modify something in your base system (e.g. consider 6 kg of pesticides applied instead of 10 kg because of the introduction of biological pest control), you just have to modify your production inventory and to calculate your impacts with TEAM again. The calculation of the inputs/impacts in all other countries as well as the median/quantiles of your inputs/impacts will be modified automatically.

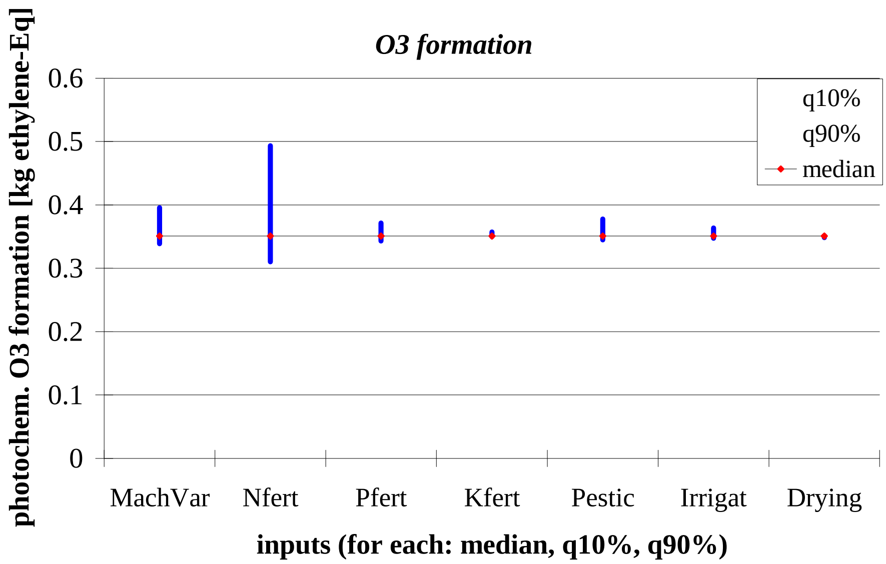
If, for another reason (non representativeness for instance), you change your reference country, you have to modify your production inventory and to calculate your impacts with Team again but you also have to modify something in your “crop_world.xls” file (see step 13 above).

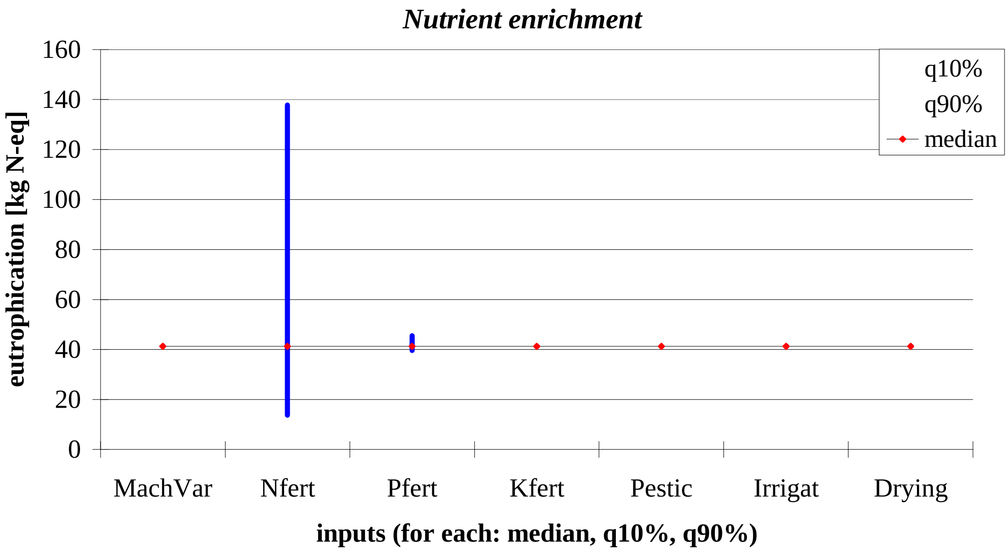
You can thus create a modular inventory or modify an existing one with a low effort.

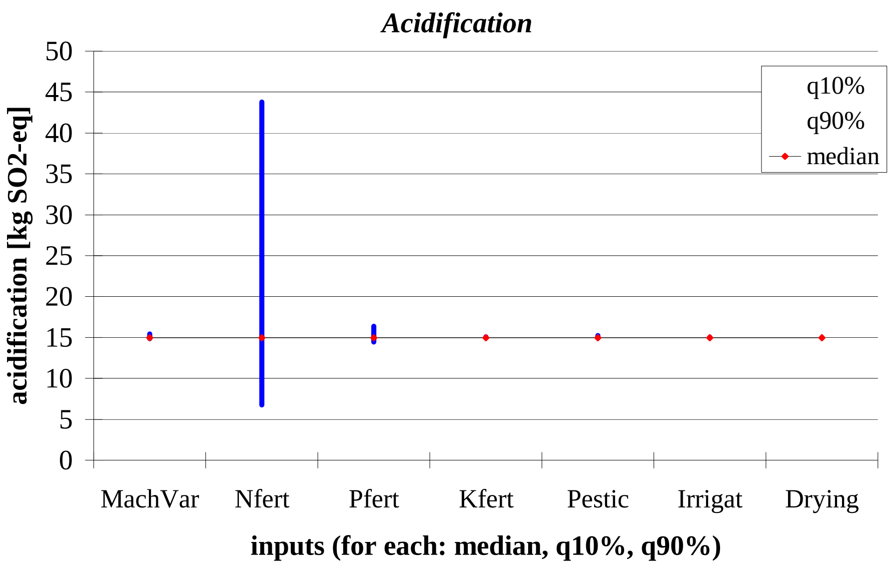
AVII. Results of the sensitivity analyse for barley

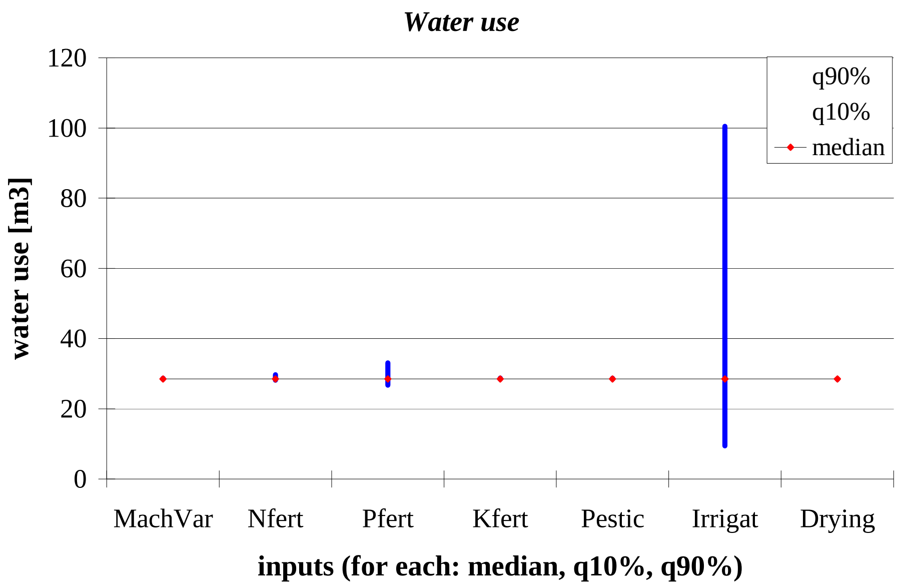


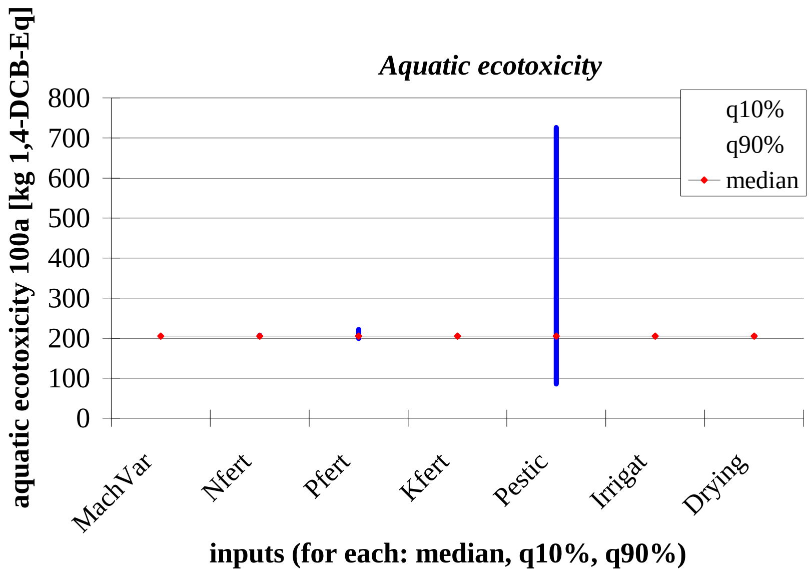

GWP100a
GWP100a [kg eq-CO2]
2600
2300
2000
1700
1400
1100
800
500
q10%
q90%
median
MachVar
Nfert
Pfert
Kfert
Pestic
Irrigat
Drying
inputs (for each: median, q10%, q90%)

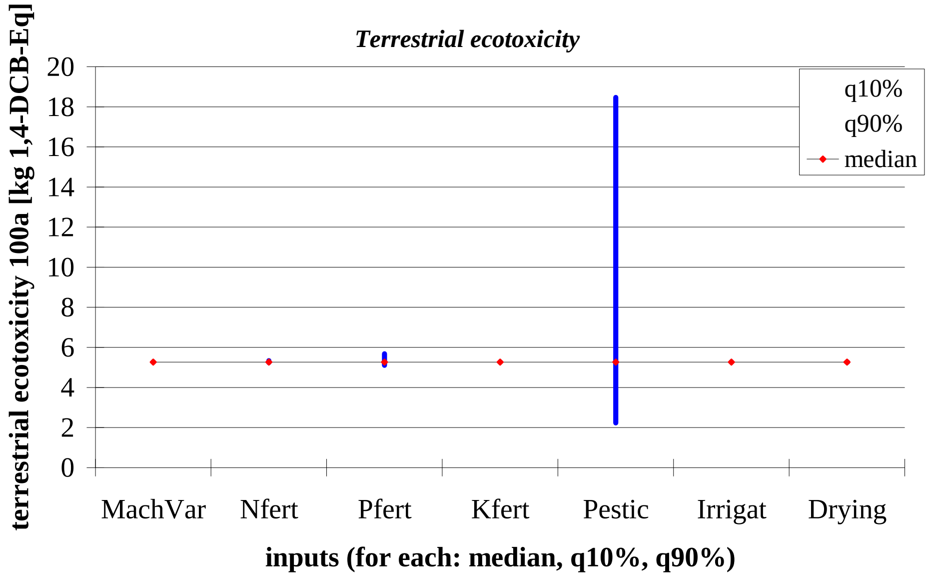

O3 formation
photochem. O3 formation [kg ethylene-Eq]
0.6
0.5
0.4
0.3
0.2
0.1
0
q10%
q90%
median
MachVar
Nfert
Pfert
Kfert
Pestic
Irrigat
Drying
inputs (for each: median, q10%, q90%)


Nutrient enrichment
eutrophication [kg N-eq]
160
140
120
100
80
60
40
20
0
q10%
q90%
median
MachVar
Nfert
Pfert
Kfert
Pestic
Irrigat
Drying
inputs (for each: median, q10%, q90%)


Acidification
acidification [kg SO2-eq]
50
45
40
35
30
25
20
15
10
5
0
q10%
q90%
median
MachVar
Nfert
Pfert
Kfert
Pestic
Irrigat
Drying
inputs (for each: median, q10%, q90%)


Water use
water use [m3]
120
100
80
60
40
20
0
q90%
q10%
median
MachVar
Nfert
Pfert
Kfert
Pestic
Irrigat
Drying
inputs (for each: median, q10%, q90%)


Aquatic ecotoxicity
aquatic ecotoxicity 100a [kg 1,4-DCB-Eq]
800
700
600
500
400
300
200
100
0
q10%
q90%
median
MachVar
Nfert
Pfert
Kfert
Pestic
Irrigat
Drying
inputs (for each: median, q10%, q90%)



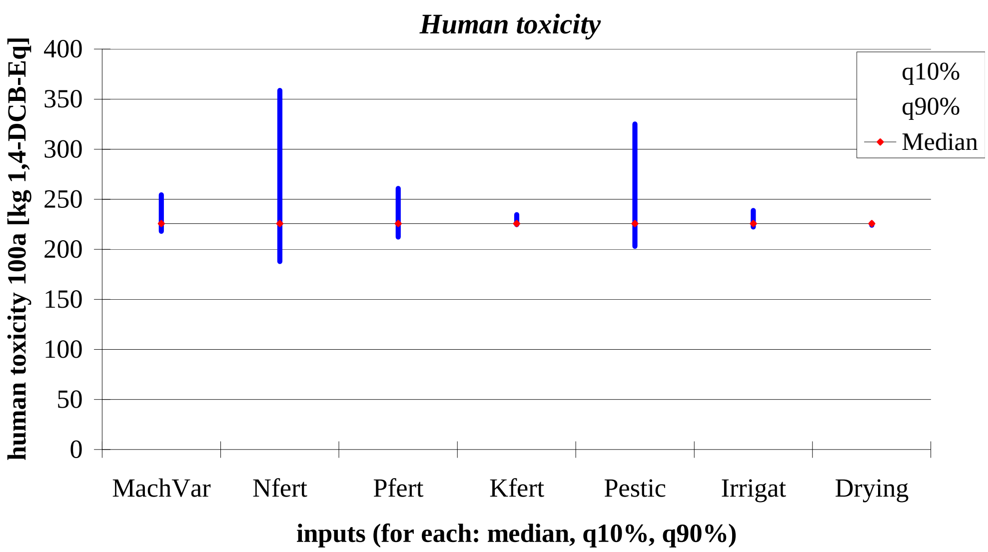


Fig. 12-16 Results of the sensitivity analysis for barley *per ha* for all impact categories. The red dots with the black line represent the impacts when all inputs are set to their median value. This can bee seen as the "world impacts" of barley production on an area of one ha. The blue bars represent the impacts when setting all the inputs except one to their median value and the last one to its 10th quantile ("minimum") and to its 90th quantile ("maximum").