Agricultural Systems 221 (2024) 104107

Contents lists available at ScienceDirect

Agricultural Systems

journal homepage: www.elsevier.com/locate/agsy

Modelling cow longevity policies: Impacts on GHG emissions of the Swiss agricultural sector

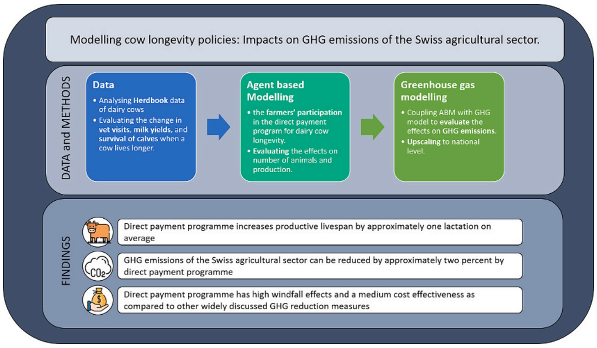
Eva Winter [a,*], Manika Rödiger [b], Jérôme Schneuwly [c], Anina Gilgen [c], Gabriele Mack [a]

[a] Research group Economic Modelling and Policy Analysis, Research Unit Sustainability Assessment and Agricultural Management, Agroscope, Tänikon, Switzerland
[b] Research group Socioeconomics, Research Unit Sustainability Assessment and Agricultural Management, Agroscope, Tänikon, Switzerland
[c] Research group Integrative Agroecology, Research Unit Agroecology and Environment, Agroscope, Reckenholz, Switzerland

HIGHLIGHTS

- Policymakers in agriculture aim to reduce GHGs by promoting dairy cow longevity, cutting replacements and emissions.
- This study analyses the Swiss policy promoting dairy cow longevity and evaluates its effects on production and GHGs.
- An interdisciplinary approach combines data and models, simulating farm responses and linking results to GHG outcomes.
- High payments and 4-month calf fattening reduce GHGs most, but lower payments and 4-month fattening are cost-effective.
- This study explores the Swiss dairy cow longevity policy, assessing its environmental and economic impacts with mixed models.

GRAPHICAL ABSTRACT



Modelling cow longevity policies: Impacts on GHG emissions of the Swiss agricultural sector.

- Analysing **Herdbook** data of dairy cows
- Evaluating the change in **vet visits**, **milk yields**, and **survival of calves** when a cow lives longer.

- the **farmers' participation** in the direct payment program for dairy cow longevity.
- **Evaluating** the effects on number of animals and production.

- Coupling ABM with GHG model to **evaluate** the effects on **GHG emissions**.
- **Upscaling** to national level.

Direct payment programme increases productive livespan by approximately one lactation on average

GHG emissions of the Swiss agricultural sector can be reduced by approximately two percent by direct payment programme

Direct payment programme has high windfall effects and a medium cost effectiveness as compared to other widely discussed GHG reduction measures

ARTICLE INFO

Editor: Paul Crosson

Keywords:
Dairy
Direct payments
Length of productive life
Agent-based modelling
Bio-economic farm optimisation model

ABSTRACT

Context: The agricultural sector has a high potential to reduce greenhouse gas (GHG) emissions. One promising measure is to promote the longevity of dairy cows, as the resulting reduction in replacement heifers reduces the overall GHG emissions of the dairy sector.

Objective: In this study, we analysed the effects of a voluntary policy programme to promote the longevity of dairy cows in Switzerland. We forecasted the effects on agricultural production (milk and meat) and GHG emissions for the Swiss agricultural sector. This voluntary direct programme was implemented by the Swiss government in 2024.

Methods: We used an interdisciplinary method and a data approach that combined several data sources and models. We implemented herdbook data on changes in milk yield and veterinary costs with an increasing number of lactations in a bio-economic farm optimisation approach. The use of an agent-based modelling framework allows the consideration of heterogeneous farm responses to the voluntary direct payment programme, which incentivises an increase in productive life of dairy cows. The results of the agent-based model were then

---

* Corresponding author.
E-mail address: eva.winter@agroscope.admin.ch (E. Winter).

https://doi.org/10.1016/j.agsy.2024.104107
Received 3 May 2024; Received in revised form 1 August 2024; Accepted 23 August 2024
Available online 11 September 2024

implemented in the GHG model SAGE. Four policy scenarios were simulated. They considered two levels of direct payments (low and high) for the voluntary longevity programme and two fattening strategies for those calves no longer needed for cow replacement (4- and 10-month calf fattening). The results of the longevity scenarios were compared with a reference scenario without these direct payments.

Results and conclusions: Our results show a policy scenario with a high level of direct payments and a 4-month calf fattening strategy has the highest GHG emission reduction potential in Swiss agriculture (−1.71 % of total agricultural GHG emissions and 998 CHF/t CO_2 equivalent). However, a lower level of direct payments combined with a 4-month calf fattening strategy is more cost-effective with regard to GHG emission reduction (−1.69 % of total agricultural GHG emissions and 471.5 CHF/t CO_2 equivalent). The other scenarios show lower GHG reduction potential and lower cost effectiveness. We find the voluntary direct payment programme has high wind-fall effects because the payments are not linked to changes in longevity but are distributed as long as the average number of lactations of a cow herd is three or more.

Significance: This study is the first to analyse a voluntary policy programme that incentivises farmers to extend the productive life of their dairy cows. Furthermore, both environmental and economic impacts are estimated with a novel mixed modelling approach.

1. Introduction

Food production generates greenhouse gas (GHG) emissions that directly contribute to climate change. In 2018, about 17 % of global greenhouse gas emissions were caused by agriculture and related land-use emissions (FAO, 2020), and food production is estimated to account for about 20 % to 30 % of the total human-induced environmental impacts (Tukker and Jansen, 2006). Scientific evidence shows that ruminant livestock in particular contributes to GHG emissions and biodiversity loss (FAO, 2006; Scarborough et al., 2023; Willett et al., 2019). The agricultural sector is also predicted to have a large potential to reduce GHG emissions through changes in management practises (Smith et al., 2008). Increasing the productive life of cows seems to be a promising measure for reducing GHG emissions (Alig et al., 2015; Bretscher et al., 2018; Grandl et al., 2019; Leiber et al., 2019; Tarruella et al., 2023).

Further, our food system faces public concerns about animal suffering and animal welfare (Bonnet et al., 2020). For example, there is a growing societal interest in animal welfare and the ethical treatment of animals (Ammann et al., 2023). In this context, increasing the overall life span of cows is considered a more ethically sound management practice (Bruijnis et al., 2013).

The aim of this study is to investigate the impact of a policy programme designed to promote cow longevity on GHG emissions and agricultural production at the national level. In a case study of Switzerland, we analyse the effectiveness of a voluntary direct payment programme that incentivises farmers to increase the productive life of cows. This policy programme was implemented by the Swiss government in 2024. To the best of our knowledge, this is the first specific policy programme targeting dairy cow longevity in Europe. Therefore, we use an ex-ante modelling approach. Two state-of-the-art models were combined to estimate farmers' participation in the policy programme and its impact on GHG emissions at the national level. We also incorporate cow data from Swiss dairy breeders' associations with changes in key performance parameters with increasing productive life into our models.

This study focuses on dairy cows because their life span is between 4.5 and 6 years in most developed dairy sectors, with a productive life span of 2.5 to 4 years (2.5 to 4 calves per dairy cow), although their natural life expectancy is around 20 years (De Vries and Marcondes, 2020). The main arguments against a longer productive life span are an increase in health problems (Burren and Alder, 2013; Fuss and Burren, 2018) and slower breeding improvements (Heikkilä et al., 2008). However, various studies have shown that the economically most viable productive life span is higher than the current life span of cows, as milk yields often increase until the 5th to 7th lactation (Hoop, 2023; Horn et al., 2012; Leiber et al., 2019).

The effects of extending the productive lives of suckler and dairy cows on GHG emission reductions have been analysed in various studies (Alig et al., 2015; Bretscher et al., 2018; Grandl et al., 2019; Leiber et al., 2019). For example, a recent study estimated the GHG abatement potential of extending the productive life of cows from 3 to 5 lactations to be 9–10 %, due to a reduced need for replacement heifers and increased milk yield (Leiber et al., 2019). Two studies analysed the abatement costs of extending the productive life span of dairy cows in Switzerland, and both concluded that this measure would lead to economic benefits (Huber et al., 2023; Kreft et al., 2023).

Our contribution to the literature is threefold. First, this study analyses a voluntary policy programme that incentivises farmers to extend the productive life of their dairy cows. Second, we estimate both the environmental and economic impacts of such a policy programme for the Swiss agricultural sector by linking an agent-based agricultural sectors model and a GHG emission model. Third, our study considers that the emission reduction of the whole agricultural sector is influenced by the rearing period of those calves that are no longer needed for cow reproduction. Therefore, we provide modelling scenarios with different calf rearing systems.

The study is structured as follows: Section 2 provides an overview of policies to promote cow longevity. Section 3 describes the model approaches used and the database. Section 4 presents modelling results on farmer participation in the policy measures, changes in heifer and dairy cow numbers, GHG emissions, and the cost-effectiveness of the policy programme. Sections 5 and 6 discuss the results and draw conclusions.

2. Policy measures fostering cow longevity in Switzerland

In Switzerland, the number of lactations per cow on Swiss dairy farms ranges from 3 to 5 (Heuel, 2024). Fig. 1 illustrates the wide range of the average number of lactations within a sample of Swiss dairy farms from the Farm Accountancy Data Network (FADN) in 2020. Across all

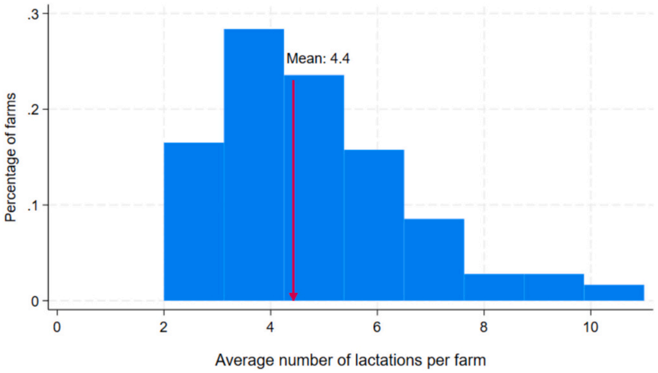


Fig. 1. Range of productive life of cows (measured by the average number of lactations per farm) on Swiss dairy farms in 2020. Calculations are based on a sample of 539 FADN farms (Hoop, 2023).

farms, the average number of lactations is 4.4 (Hoop, 2023).

In response to the potential benefits of a longer productive life span of cows and to incentivise the necessary change, the Swiss government introduced a voluntary direct payment programme for cow longevity in 2024. Farmers are eligible for payments if their dairy cows give birth to an average of three or more calves before slaughter (Schweizerischer Bundesrat, 2021). Payments start at CHF 10 per cow for an average of three calves and rise to CHF 100 per cow for an average of seven or more calves (Table 1).

3. Materials and methods

A multi-methods approach was used in this study (Fig. 2), as described below.

1. We built a database of changes in key performance indicators (i.e. milk yield, calf survival, and veterinary visits as a proxy for cow health) with an increasing number of lactations of cows. To do this, we used herdbook data from the Swiss breeding associations Swiss herdbook and Braunvieh Schweiz.
2. To model dairy farmers' decisions to adopt the longevity policy programme, we used the agent-based agricultural sector model SWISSland. SWISSland simulates the production decisions of 3000 individual farms using single farm optimisation models (Möhring et al., 2016). The farm models were built using the Swiss FADN farm sample, which is representative of the Swiss agricultural sector. For this, our agent-based approach considers the heterogeneity of Swiss dairy farms in terms of cow longevity, milk yield, veterinary costs, and resource endowments. To model farmers' participation in the longevity policy programme, we implemented the herdbook data on changes in key performance parameters in the single farm optimisation models.
1. To estimate the effects of the longevity policy programme on GHG emissions, we used the Swiss Ammonia and GHG Emission (SAGE) model, which estimates the corresponding emissions at the farm level in Switzerland. The emission model follows the guidelines and system boundaries of the Intergovernmental Panel on Climate Change (IPCC). SWISSland and SAGE were linked to achieve synergies between these well-established methods. Farm-level model results from SWISSland on livestock numbers and milk yields were used as inputs for the SAGE model to calculate GHG emissions. Lastly, farm-level emissions were up-scaled to the Swiss agricultural sector.
2. We simulated four policy scenarios. With these, we aimed to analyse the impact of different rearing systems for calves that are no longer needed for cow reproduction on GHG emission reductions. We also analysed the impact of different levels of direct payments on the cost-effectiveness of the policy programme.

3.1. Herdbook data

To model the transition to cow longevity, we analysed the changes in key cow performance indicators over time. To do this, we used herdbook data (i.e. panel data) from 2014 to 2021 for 1,285,513 individual cows, which were provided by the Swiss breeding associations. They included information on milk yield, number of lactations, calving date, age at calving, days in milk, number of veterinary visits, number of surviving calves, and the intercalving period. We used all records with complete lactation to capture the full performance of the cows and the changes between lactations. Therefore, we excluded observations with data for a 100-day record, a 200-day record, and records with ongoing or projected lactations. In addition, plausibility checks were conducted to exclude observations with possible measurement errors. An overview of the plausibility checks can be found in Table A.1 in the Appendix. Eventually, a dataset of 367,057 observations was created for the performance indicators (i.e. milk yield and number of calves) from the 2nd to the 8th lactation. A second table on the number of veterinary visits per lactation as a proxy for the dairy cow health of the cows contained 13,823 observations.

Table 1
Direct payments for longevity of dairy cows from 2024 onwards in Switzerland.

Average number of calves per cow	Direct payments in CHF/ dairy cow
3	10
4	30
5	50
6	80
7 and more	100

Source: Schweizerischer Bundesrat, 2021.

To identify the key performance indicators that changed significantly with an increasing number of lactations, we used OLS regressions with milk yield, veterinary visits, and the number of surviving calves as dependent variables and the number of lactations as independent variables. Indicators that showed a significant change with an increasing number of lactations were included in the dairy farm population of SWISSland.

Our modelling approach also considered that dairy farms with high-yielding cows may respond differently to the longevity policy programme than farms with low-yielding cows. Several studies have shown that low- and medium-yielding cows have a peak in milk production in higher lactations, whereas higher-yielding cows tend to have earlier peaks (Adamie et al., 2023; Hoop, 2023; Horn et al., 2012). Based on this, we used the herdbook data to create five different milk yield classes (i.e. quintiles) and estimated the average change in performance from lactation 2nd to lactation 8th for these classes. Creating quintiles and incorporating distributions into agent-based models is an established method for accounting for heterogeneity in the farm agent population (Troost and Berger, 2015; Winter et al., 2023).

3.2. Agent-based modelling

SWISSland allows for both the modelling of heterogeneous farm responses to policy changes and the assessment of the sectoral impacts resulting from these responses (Mack et al., 2023; Schmidt et al., 2021; Schmidt et al., 2019). Therefore, the SWISSland model consists of two modules: (1) a single farm module consisting of approximately 3077 bio-economic farm optimisation models, and (2) an upscaling module (Fig. 3). SWISSland predicts economic and structural indicators for the Swiss agricultural sector based on 3077 bio-economic farm optimisation models (Mack et al., 2023). The individual models were built on economic and structural data from the FADN (Möhring et al., 2016). The agent population of SWISSland thus represents the FADN farm sample for Switzerland. This sample covers all farm types, regions (plains, hills, and mountains), and farm size categories of the Swiss farm population (Renner et al., 2019). A total of 2258 farms in the agent population have dairy cows.

SWISSland estimates land use and livestock decisions for each farm using profit maximisation over a period of 10–15 years (Mack and Kohler, 2019). In addition, SWISSland models farmers' decisions to adopt voluntary policy programmes, such as the grassland-based milk and meat programme (Bystricky et al., 2023), and programmes to promote pesticide-free arable cropping systems based on profit maximisation (Mack et al., 2023). Farm records from the FADN database (three-year averages of the years 2016–2018) were used to define the farm-specific input parameters (i.e. costs of concentrates, veterinary, and other costs) and output parameters (milk yields and prices) of the optimisation models. Furthermore, the FADN provides data on the adoption of policy programmes to promote animal welfare (i.e. animal-friendly housing systems and regular free-range systems). The farm optimisation models take into account the main production resources, i.

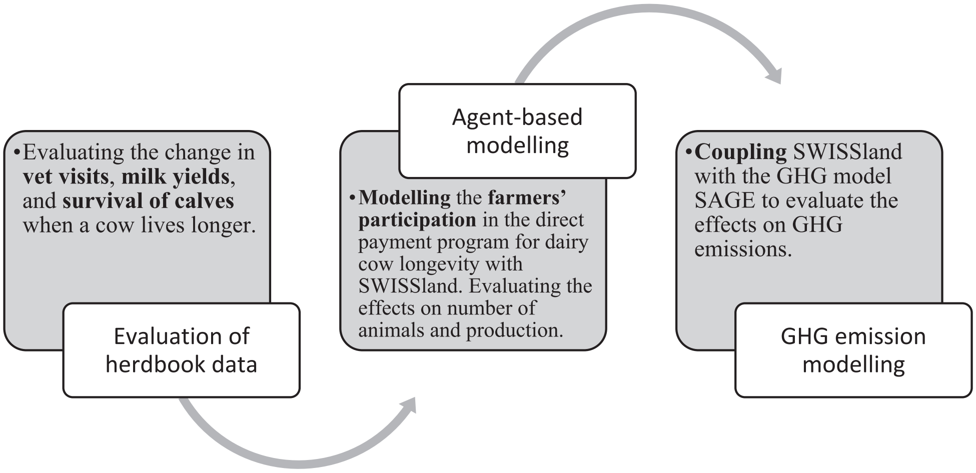


Fig. 2. Overview of the multi-method approach to assessing the impact of longevity policy programmes on GHG emissions.

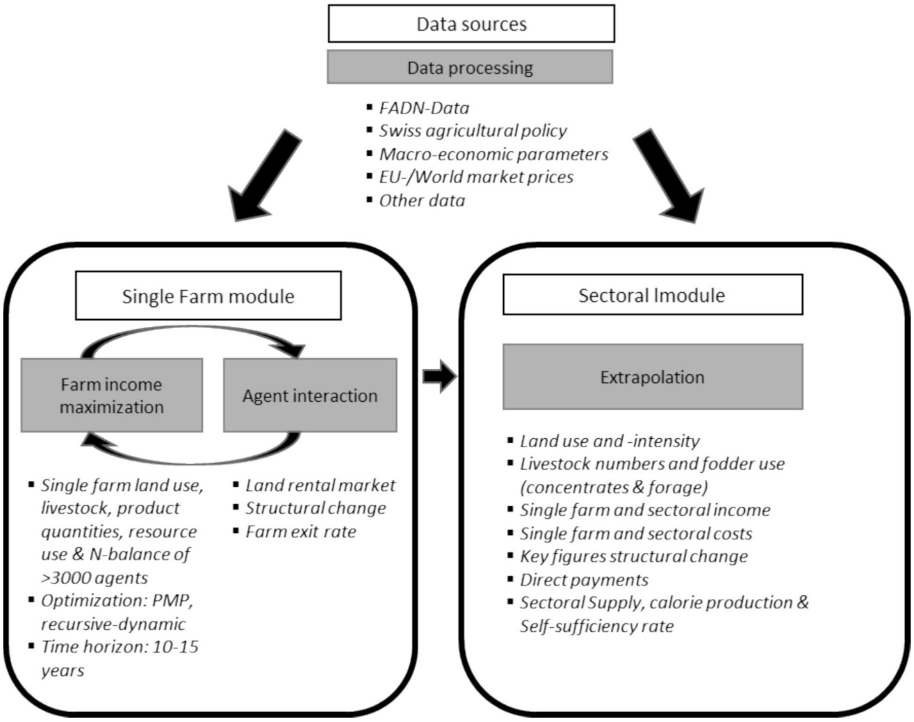


Fig. 3. Overview of the SWISSland model (Dueri and Mack, 2024).

e. land (arable- and grassland), labour (family and non-family), and stables[1] from the FADN records in the base year. In the forecast years, annual investment decisions (i.e. renting land plots, hiring non-family labour, and investing in stables) were determined using profit maximisation (see Mack et al., 2019). Using a recursive dynamic approach, SWISSland assumes that the investments made in one year determine the production resources of the farms in the following years. In addition, a policy scenario up to 2030 (i.e. percentage changes in direct payments, product prices and costs) set by the policy makers at the Swiss Federal Office for Agriculture, is implemented in the farm optimisation models. We also assumed an annual increase in crop yields, as observed in Switzerland over the last 15 years, together with an increase in the use of mineral fertilisers and a decrease in labour demand due to (labour-saving) technological progress. Prices, costs, direct payments, and trends in yields and labour demand represent the exogenous input parameters of the profit maximisation process (see Mack et al., 2019). Within a period of 10–15 years, we model farm exits or farm transfers to a successor based on simplified rules (i.e. when a farmer reaches the retirement age, see Möhring et al., 2016). Based on the changes in the number and type of farms within the agent population, we forecast structural change for the Swiss agricultural sector. The results of the individual farm models are upscaled to the Swiss agricultural sector using extrapolation factors at the farm level. This procedure includes a validation step, i.e., the results of the base year are calibrated to observed statistical values. The resulting correction factors are then applied in the forecast years.

To model the transition to cow longevity for the Swiss agricultural sector, we had to consider that Swiss farms are quite heterogeneous with

---

[1] The number of stables is calculated on the basis of the number of animals in each category. However, we do not have data on the type of stable.

respect to the longevity of their cows. Therefore, we introduced a farm-specific longevity indicator (i.e. average number of lactations per farm) in the dairy farm population of SWISSland. As information on longevity indicators was only available for a special FADN dataset of 539 Swiss dairy farms in 2020 (Hoop, 2023), we merged our SWISSland data basis (i.e. 2138 farms) with this special FADN dataset. To do this, we had to define a common key (i.e. average milk yield per cow) that is available in both datasets. This resulted in an average of 4.3 lactations for the whole population of dairy farms in SWISSland. Fig. A.1 in the Appendix shows the distribution of cow longevity within the 2138 dairy farms in SWISSland. Table 2 provides summary statistics on farm structure, performance, and economic indicators for the dairy farms implemented in SWISSland, based on the Swiss FADN.

In the farm optimisation models, the decision to extend the productive life of cows was determined by assuming a profit maximising agent. Thus, farmers' adoption decisions were calculated on the basis of the changes in costs, revenues, and direct payments, which were caused by changes in key performance parameters and changes in the number of cows and heifers when the productive life is extended. In addition, changes in labour costs for non-family labour (i.e. due to changes in labour demand), feed demand (i.e. roughage) and housing demand due to changes in livestock numbers were taken into account. We modelled farmers' decisions to adopt the policy programme over the period 2024–2027 using a recursive-dynamic approach. This means that if farmers extend the productive life of cows in one year, they can either stay at that level in the following year (i.e. if a further increase is not profitable), or they can extend the productive life further in the following year (i.e. if a further increase is profitable). We also assumed that farmers can extend the productive life of cows by an average of 1 lactation per year.

The annual results of the 3077 farm optimisation models on livestock numbers, land use, and production provide the input parameters for the SAGE model. The interface between SWISSland and the GHG quantification model SAGE is described in detail in section 3.3.4.

3.3. GHG emission model SAGE

The SAGE model was developed to calculate GHG emissions for different types of farms based on the IPCC methodologies and system boundaries (Buendia et al., 2019; Eggleston et al., 2006) and the methodologies used in the Swiss National Greenhouse Gas Inventory (FOEN, 2023). SAGE was first used to calculate the GHG emissions from farms included in the Swiss agri-environmental data network (Gilgen et al., 2023). In the following, we describe in detail the emission pathways implemented in the SAGE model and the data sources. We also describe the interface with the SWISSland model.

Three of the emission pathways implemented in the SAGE model (see FOEN, 2023, page 249) are considered in this study: (a) CH_4 emissions from enteric fermentation of animals; (b) CH_4 and N_2O emissions from manure management and (c) N_2O from agricultural soils. Due to a lack of detailed data at the farm level, direct N_2O emissions from the loss of soil organic matter (mineralisation) and from organic soils under cultivation, as well as CO_2 emissions from liming and urea application, could not be considered for this study. However, emissions from liming and urea application account for only a small proportion of total emissions ($<$1 % of total agricultural CO_2 equivalent; (FOEN, 2022). To convert all greenhouse gas emissions into CO_2 equivalents, GWP100 factors of 25 and 298 were used for CH_4 and N_2O, respectively (Eggleston et al., 2006).

Table 2

Summary statistics: Farm structure, performance, and economic indicators of the 2138 dairy farms implemented in SWISSland (average of base year 2016–2018).

Variable	Average	Standard deviation
Farm structure		
Number of dairy farms	2138	
Number of cows/farm	24.5	16.7
Performance indicators		
Milk yield (kg/cow)	6733	1545
Productive life (number of lactations/farm)	4.3	1.8
Replacement rate (% of cows replaced per year)	23.1	7.5
Economic indicators		
Milk price (CHF/kg)	0.68	(0.19)
Milk revenue (CHF/cow)	4559	(1520)
Veterinary costs (CHF/cow)	254	(134)
Concentrate feed cost (CHF/cow)	535	(368)
Animal insurance costs (CHF/cow)	96	(70)
Other costs (CHF/cow)	78	(113)

Emission factors for CH_4 from enteric fermentation and manure management were derived from the national GHG inventory (FOEN, 2023) and adapted to the animal categories defined in the "Principles of Agricultural Crop Fertilisation in Switzerland (PRIF)" (Richer et al., 2017) (Table A.2 in the Appendix). These emissions are particularly relevant for this study, as methane emissions are strongly influenced by the number of cattle and the milk yield.

To estimate direct and indirect N_2O emissions (mainly from ammonia formation) resulting from manure management, SAGE implemented a manure cascade similar to the ammonia emission model AGRAMMON (Kupper and Häni, 2023). That is, along the path of nitrogen from animal excretion to field application, nitrogen excretion rates according to the PRIF are used and emission factors are applied to calculate the amount of nitrogen that is lost to the atmosphere and the amount reaching the next stage (e.g., if 15 % of nitrogen is lost in the barn, 85 % of the nitrogen will reach the manure storage, where further losses occur). Specific emission factors are applied at each step of the cascade, depending on the livestock category, manure type, and animal husbandry system. Emissions are further corrected based on the implementation of different manure management practices, such as the type of slurry storage cover. Therefore, all nitrogen emissions from manure management and application are calculated at the animal category level. For dairy cows, the nitrogen excretion values have been corrected according to their milk yield, which has a high influence on N_2O emissions. The emission factors are given in % of total ammonia nitrogen (for ammonia) or of total nitrogen (for other nitrogen containing gases N_2O, N_2 and NO) and can be found in the documentation of the technical parameters of Agrammon (Kupper et al., 2022). An exception are the emissions from slurry storage, for which we use values per surface area according to Kupper et al., (2020). In addition, the dynamic ALFAM2 model was used to predict ammonia volatilisation from slurry applied to the field (Hafner et al., 2019).

N_2O emissions from agricultural soils were estimated based on the total nitrogen inputs to managed soils, including direct and indirect emission pathways, as described in the IPCC guidelines (Buendia et al., 2019). For this study, direct emissions from the following nitrogen inputs were included: a) synthetic fertilisers, b) organic fertilisers, c) pasture excretions from grazing animals and d) crop residues. In addition, indirect N_2O emissions in the SAGE model include emissions from leaching and runoff from cultivated soils and emissions from atmospheric deposition of nitrogen volatilised from cultivated soils. Emission factors of cultivated soils (in kg N_2O-N/kg N-input) were taken from the Swiss national inventory document (FOEN, 2023).

In order to calculate the total GHG emissions for the 3077 farms implemented in SWISSland using the SAGE model, detailed information on livestock numbers, fertiliser use, manure management and type of housing system is required. The farm optimisation models of SWISSland provide the following input data for the SAGE model: (1) number of animals per category, (2) milk yield per cow, (3) use of animal-friendly housing systems or regular free-range systems, (4) nitrogen fertiliser use and crop yields. A table describing these variables in detail can be found in the Appendix, Table A.3.

Farm-specific variables on manure management that were not available in the SWISSland model were derived from the SAEDN data network (Gilgen et al., 2023). This network consists of about 300 farms that collect detailed information on agricultural practices. The SAEDN data were averaged over all farms, animal categories and years to complete the SAGE model with key management variables. A complete list of the input variables derived from the SAEDN dataset is given in the Appendix A.4. Finally, based on these variables, a complete input dataset was compiled for all farms implemented in SWISSland.

The results of the SAGE model (i.e. 3077 farms) were scaled up to the Swiss agricultural sector (i.e. 48,344 farms) using upscaling factors at the farm level. This means that the CO2 equivalents of the farms were multiplied by these factors to estimate emissions at the sector level.

3.4. Modelling scenarios

Table 3 provides an overview of the scenarios analysed in this study, including the underlying assumptions. The time horizon for all scenarios was from 2018 to 2027. All scenarios were based on the current agricultural policy (i.e. Parliamentary Initiative 19.475; see BLW, 2021). We compared a longevity scenario and three sensitivity scenarios with a reference scenario. The longevity and sensitivity scenarios model the introduction of the longevity policy programme from 2024 to 2027, while the reference scenario models a counterfactual policy situation in which no such programme was introduced. In the three sensitivity scenarios, we varied key assumptions of the longevity scenario, such as the level of direct payments and the rearing system for calves that are no longer needed to replace old cows. All scenarios assume no further policy changes from 2025 to 2027.

The longevity scenario assumes that calves are fed with milk and slaughtered at around 4 months. We modelled this calf fattening system because it is the most common practice in Switzerland (Spengler-Neff et al., 2021). Production costs and revenues for veal production systems are based on FADN data. The level of direct payments for the longevity policy programme ranges from CHF 10 per cow for an average of three calves per cow to CHF 100 for an average of seven or more calves per cow (see Table 1).

Sensitivity Scenario 1 (Sens1) considers higher direct payments ranging from CHF 10 per cow for three calves to an average of CHF 200 per cow for seven or more calves. Sensitivity Scenario 2 (Sens2) assumes that calves that are no longer needed to replace old cows are fattened for up to 10 months. We calculated this sensitivity scenario because calf fattening for up to 10 months is the second most common practice in Switzerland. The inclusion of this sensitivity scenario allows us to analyse the impact of different rearing systems on the reduction of GHG emissions.

Finally, Sensitivity Scenario 3 (Sens3) is a combination of higher direct payments to promote cow longevity and the 10-month calf fattening system.

4. Results

4.1. Impact of extending the productive life of cows on their performance indicators

The OLS regressions showed that extending the productive life of cows significantly increased milk yield and the number of visits to the vet. For the number of calves surviving per lactation, either no significant effect or a very small effect was found. The results of the OLS regressions are provided in Table A.6 in the Appendix.

Fig. 4 shows the average milk yields with an increasing number of lactations for the five milk yield classes (quintiles, Q). We observed that cows in the two lowest quintiles (3000 to 7119 kg milk/cow) had an increase in milk yield up to the 6th lactation. By contrast, higher yielding cows (Q3–Q4) reached their peak milk production in earlier lactations (5th or 4th lactation), while cows in Q5 reached their highest milk yield already in the 2nd lactation. Furthermore, lower-yielding cows showed a steeper increase in milk yield to peak production than did higher-yielding cows. For example, cows in Q1 had an increase of 20 %, 3 %, and 3 % between the 2nd and 3rd, 3rd and 4th, and 4th and 5th lactations, respectively, whereas in Q4, there was only an increase of 1 %, 2 %, and 0.5 % between the same lactations. In addition, the decrease in milk yield in the higher lactations was greater for higher-yielding cows than for lower-yielding cows. For example, in Q1, milk yield decreased by only 1.7 % and 2.6 % between the 6th and 7th and 7th and 8th lactations, respectively, whereas in Q4, there was a decrease of 3 % and 4 % between the same lactations.

In terms of veterinary visits, we found that lower-yielding cows received slightly fewer visits on average (Fig. 5). The cows grouped in the lowest quintile had the lowest average number of visits, while the highest quintile had the most visits. In all quintiles, the number of veterinary visits increased with the number of lactations. There was no clear trend in the percentage change between lactations in the different groups. The number of observations per quintile is shown in Tables A.7 and A.8 in the appendix. We implemented the information on veterinary visits in SWISSland by increasing the veterinary costs taken from the FADN data in proportion to the increase in veterinary visits.

4.2. Results of the ex-ante modelling: Impact of the cow longevity policy programme on livestock and milk and meat production at the national level

This section presents the results of the ex-ante modelling with SWISSland in years 2 (2025) and 4 (2027) after the introduction of the longevity policy programme. Fig. 6 shows the longevity distribution of dairy farms in Switzerland in the different scenarios. Longevity is measured by the indicator "average number of lactations per farm". In the reference scenario without longevity payments, the longevity distribution of Swiss farms remained unchanged over time. In the longevity scenario (i.e. with longevity payments; calves that are not needed to replace old cows are used for veal production), the proportion of farms with lower cow longevity (i.e. farms with an average of 4 or fewer

Table 3
Overview of scenarios and assumptions.

	Reference	Longevity	Sens1	Sens2	Sens3
Swiss agricultural policy	Parliamentary Initiative (Schweizerischer Bundesrat, 2021)				
Policy programme for cow longevity	–	Introduction during 2024–2027			
Direct payments for longevity*	–	**10 CHF/LU** (3 calves per cow) up to **100 CHF/LU** (7 calves per cow)	**10 CHF/LU** (3 calves per cow) up to **200 CHF/LU** (7 calves per cow)	**10 CHF/LU** (3 calves per cow) to **100 CHF/LU** (7 calves per cow)	**10 CHF/LU** (3 calves per cow) to **200 CHF/LU** (7 calves per cow)
Calf fattening system**	–	4 months milk fattening (veal production)	4 months milk fattening (veal production)	10 months fattening (Beef production)	10 months fattening (beef production)

[*] Detailed direct payments per number of calves are shown in Table A.5.

[**] We assumed that calves that are no longer needed to replace old cows are fattened on the farm. LU: Livestock unit.

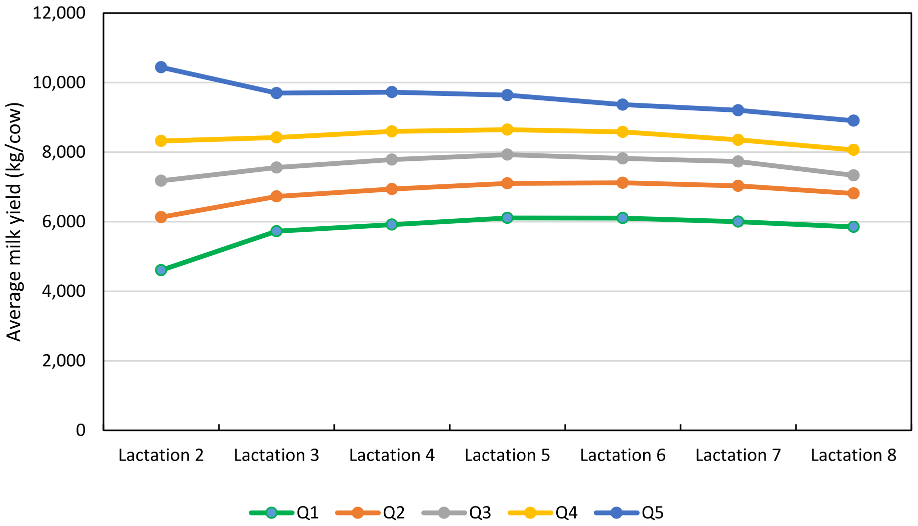


Fig. 4. Milk yield (mean values in kg per cow and per lactation) with an increasing number of lactations for the five different milk yield classes (quintiles).
Q1 = first quintile: 3000–5916 kg/cow; Q2 = second quintile: 5917–7119 kg/cow; Q3 = third quintile: 7120–8223 kg/cow; Q4 = fourth quintile: 8224–9616 kg/cow; Q5 = fifth quintile: greater 9616 kg/cow.

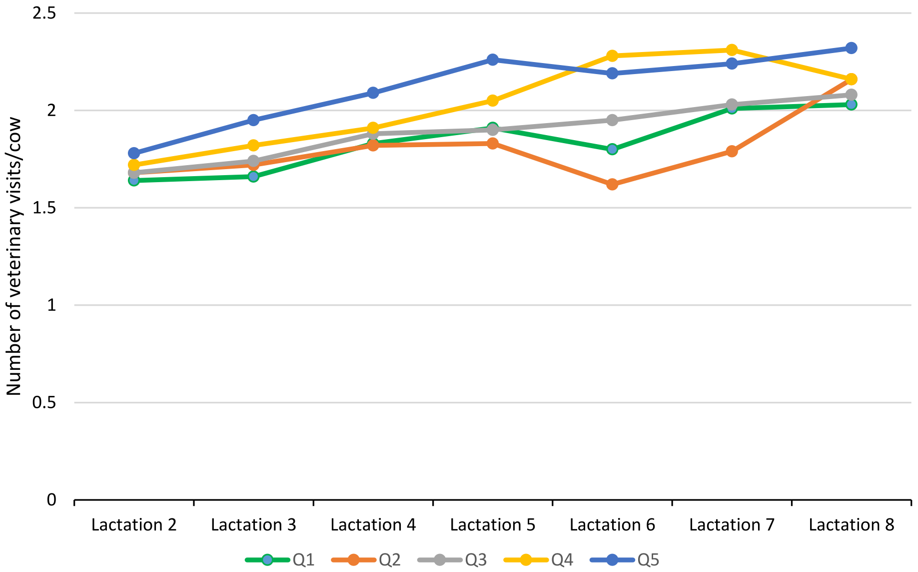


Fig. 5. Number of veterinary visits (mean values per cow) with increasing number of lactations for 5 different milk yield classes (quintiles).
Q1 = first quintile: 3000–5916 kg/cow; Q2 = second quintile: 5917–7119 kg/cow; Q3 = third quintile: 7120–8223 kg/cow; Q4 = fourth quintile: 8224–9616 kg/cow; Q5 = fifth quintile: greater 9616 kg/cow.

lactations) decreases already in the second year after the introduction of the policy programme. The results of Sens1 show that an increase in longevity payments would only slightly increase the productive life of cows in the second year after the introduction of the policy programme (e.g. the number of farms with an average of two lactations per cow would slightly decrease, while the number of farms with an average of seven lactations per cow would slightly increase). These results show that higher financial incentives to promote longevity are not effective in the short term. The results for Sens2 and Sens3 show that the attractiveness of the policy programme decreases when calves that are not needed for replacement are used for beef production. This is because veal prices are almost twice as high as beef prices. Second, beef production systems also require fodder produced on farms, which may be scarce. The modelling results for the fourth year after the introduction of the policy programme show stronger effects compared to the second year for both the longevity scenario and Sens1. However, Sens2 and Sens3 do not show stronger effects in the fourth year compared to the second year.

Changes in cow longevity lead to changes in livestock numbers. Table 4 shows the changes in livestock and production at the national level in years 2 and 4 after the introduction of the longevity policy programme. In the longevity scenario, there is a significant decrease in the number of heifers, as fewer heifers are needed, with a longer productive life of dairy cows (−6 % in year 2 and − 12 % in year 4 compared to the reference scenario). Sens1 follows the general trend of the longevity scenario, but the reductions in heifers are greater (−7 % in year 2 and − 13 % in year 4 compared to the reference scenario). In Sens2, there are fewer shifts than in the reference scenario, in line with the observed low participation of farmers in the policy programme. In both years, there is only a 2 % reduction in the number of heifers compared to the reference scenario. In Sens3, the higher payments do not act as an incentive to participate in the policy programme, resulting in a reduction in the number of heifers of 2 % in year 2 and 2 % in year 4 compared to the reference scenario. From the second to the fourth year

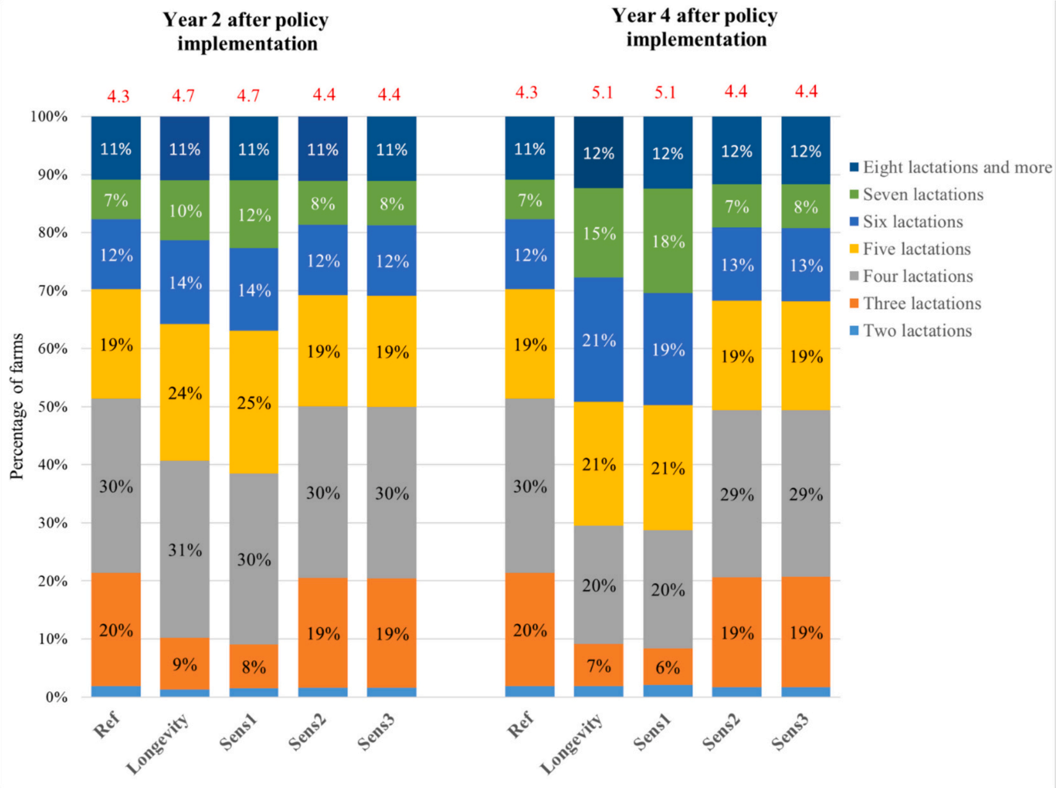


Fig. 6. Results of the ex-ante modelling with SWISSland: Distribution of longevity (measured by the average number of lactations per farm) on Swiss dairy farms in years 2 and 4 of the introduction of the longevity policy programme. Average number of lactations in red. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 4
Results of the ex-ante modelling with SWISSland: Changes in livestock numbers for the Swiss agricultural sector in years 2 and 4 after policy implementation.

	Reference	Longevity	Sens1	Sens2	Sens3
	Year 2 after policy implementation				
	1000 LU	Δ to Ref	Δ to Ref	Δ to Ref	Δ to Ref
Dairy cows	529	1 %	1 %	0 %	0 %
Heifers	186	−6 %	−8 %	−2 %	−2 %
Veal calves	4.6	20 %	22 %	2 %	0 %
Beef cattle	43.1	2 %	2 %	8 %	8 %
Total cattle	762.7	−1 %	−1 %	0 %	0 %
	Year 4 after policy implementation				
	1000 LU	Δ to Ref	Δ to Ref	Δ to Ref	Δ to Ref
Dairy cows	522	−1 %	−1 %	−1 %	0 %
Heifers	182	−12 %	−13 %	−1 %	−2 %
Veal calves	4.47	28 %	34 %	1 %	1 %
Beef cattle	44.9	1 %	1 %	8 %	7 %
Total cattle	753.37	−3 %	−4 %	0 %	0 %

after the introduction of the policy programme, we observed a slight decrease in the number of livestock units. This decreasing trend is caused by structural change (i.e. dairy farms leaving the agricultural sector) and can be observed in all modelling scenarios.

In the longevity scenario, there is a significant increase in the number of veal calves (20 % in year 2 and 18 % in year 4 compared to the reference scenario), as fewer heifers are needed when the productive life of dairy cows is longer. Sens1 follows the general trend of scenario longevity, but the increase in veal calves is more pronounced (+28 % in 2025 and + 34 % in 2027). The number of beef cattle increases only slightly in both years compared to the reference scenario.

In Sens2, surplus calves are used for beef production. There is an 8 % increase in the number of beef cattle in both years compared to the reference scenario. In Sens3, there was also an 8 % increase in the number of beef cattle in both years compared to the reference scenario. Table 5 shows the changes in production (i.e. milk and beef) and income (i.e. average dairy farm income and net operating income of the

Table 5
Results of the ex-ante modelling with SWISSland: Changes in milk and beef production, income per dairy farm and the net operating income for the Swiss agricultural sector in years 2 and 4 after policy implementation.

	Reference	Longevity	Sens1	Sens2	Sens3
	Year 2 after policy implementation				
	1000 t	Δ to Ref	Δ to Ref	Δ to Ref	Δ to Ref
Milk production	3480.3	1 %	1 %	0 %	0 %
Beef production	145.2	1 %	1 %	0 %	0 %
	CHF				
Average income per dairy farm	64,216	1 %	3 %	2 %	4 %
	Year 4 after policy implementation				
	1000 t	Δ to Ref	Δ to Ref	Δ to Ref	Δ to Ref
Milk production	3519.3	−1 %	−1 %	−1 %	−1 %
Beef production	144.8	1 %	1 %	0 %	0 %
	CHF				
Average income per dairy farm	66,309	4 %	7 %	2 %	4 %

agricultural sector) due to the implementation of the longevity policy programme. In year 2 after policy implementation, we find small but positive impacts on production and the income for the Longevity scenario and Sens1. Average dairy farm income increases slightly more for Sens1 and Sens3, as higher direct payments are implemented. In year 4, only beef production in the Longevity scenario and Sens1 is higher than in the Reference scenario, while milk production decreases slightly. For Sens2 and Sens3, the changes are small. In terms of changes in farm income, Sens1 shows the highest increase in average dairy farm income in year 2 and year 4 of the policy implementation.

4.3. Results of the ex-ante modelling with the GHG-model SAGE: impacts of the longevity policy programme on GHG-emissions

Increasing the longevity of cows across the farm population is expected to reduce GHG emissions: the longer the life of a cow, the lower the proportion of unproductive time—that is, the time during which the cow produces GHG emissions but no calves and no milk.

Fig. 7 shows the GHG emissions in CO_2 equivalents in kt across the scenarios for the Swiss agricultural sector. In the longevity scenario in year 2 after policy implementation, the GHG emissions of the Swiss agricultural sector are reduced by only 0.3 % due to only minor changes in livestock numbers. In the fourth year after implementation, we modelled a stronger reduction of 1.7 % in GHG emissions for the Swiss agricultural sector. In Sens1, similar to the longevity scenario, GHG emissions are reduced by 0.3 % in the second year and by 1.7 % in the fourth year after the introduction of the payments.

In Sens2, there are fewer shifts than in the reference scenario, in line with the observed small change in livestock numbers. There is a reduction of 0.1 % in year 2 and 0.3 % in year 4 compared to the reference scenario. In Sens3, despite higher payments, there is almost no change in livestock numbers. There is only a reduction of 0.2 % in year 2 and 0.3 % in year 4 compared to the reference scenario.

Table 6
Cost of the longevity policy programme (CHF million) for the Swiss agricultural sector and cost-effectiveness of different scenarios per 1 % CO_2 equivalent reduction (CHF million) in years 2 and 4 after policy implementation.

	Longevity	Sens1	Sens2	Sens3
	year 2 after implementation			
Total costs (CHF million)	42	89	37	74
Costs per 1 % CO_2 equivalent reduction (CHF million)	140	338	279	452
	year 4 after implementation			
Total costs (CHF million)	43	98	36	73
Costs per 1 % CO_2 equivalent reduction (CHF million)	27	58	128	236

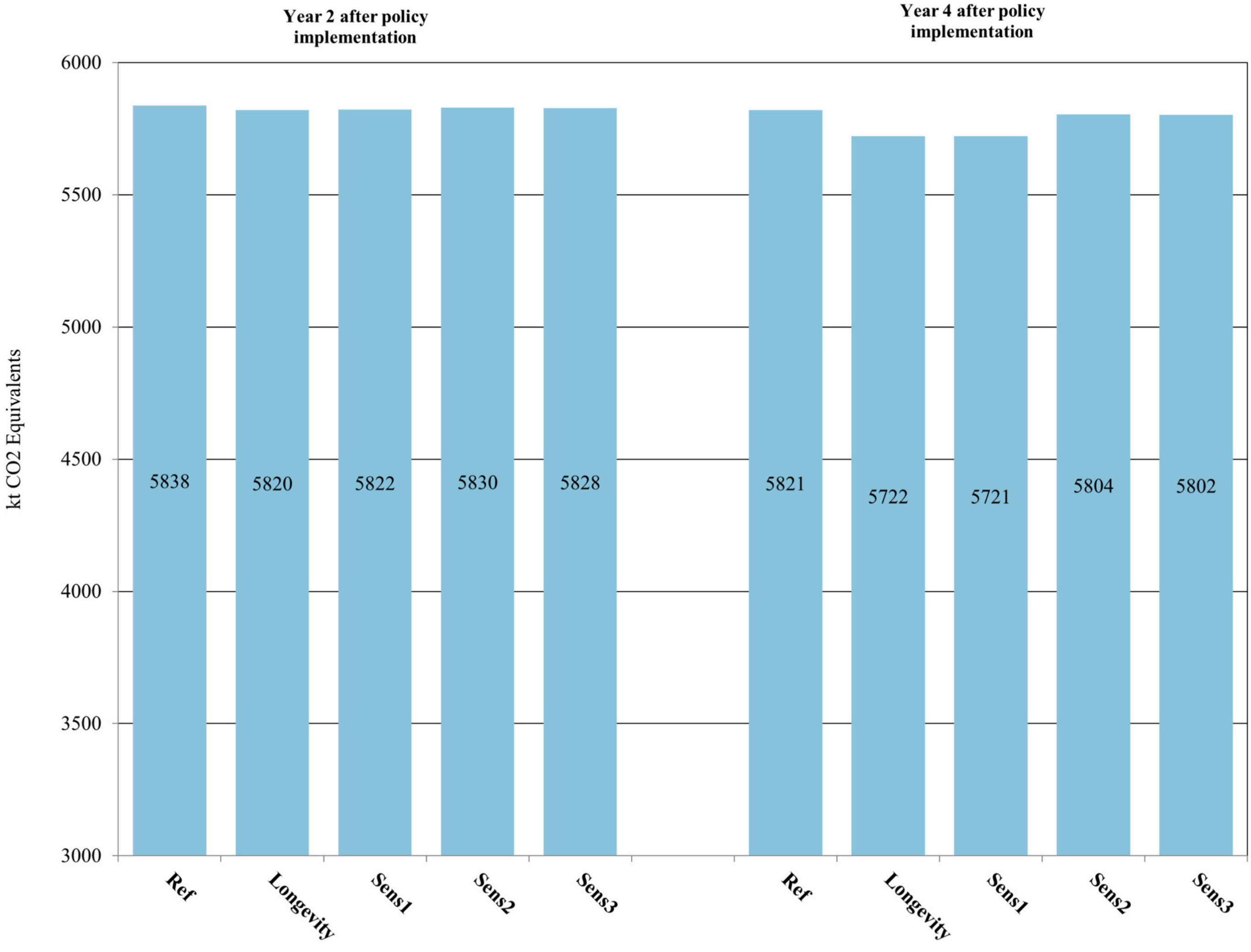


Fig. 7. Forecasting results: GHG emissions in kt CO_2 Equivalents across scenarios for the Swiss agricultural sector.

4.4. Results of the ex-ante modelling: impacts on the cost-effectiveness of the policy programme

Table 6 shows the costs of the policy programme for the different scenarios. Sens2 has the lowest costs, while Sens1 has the highest total costs. The cost-effectiveness per 1 % CO_2 equivalent reduction (58 kt) is also shown for each scenario. The longevity scenario shows the highest cost-effectiveness, with 27 Mio. per 1 % CO_2 equivalent reduction in the fourth year after implementation. Sens3 shows the lowest cost-effectiveness, with 236 Mio. CHF per 1 % CO_2 equivalent reduction in the fourth year after implementation.

5. Discussion

The aim of this study was to analyse the effects of a policy programme to promote cow longevity and reduce greenhouse gas emissions. Our results show that the direct payment programme increased the average number of lactations per farm from about 4.3 to 5.5 and reduced GHG emissions by 1.7 % in the fourth year after the policy programme was implemented.

The analysis of Swiss herdbook data showed that the lowest- and medium-yielding cows (3000 to 9616 kg/a) increased their milk yield up to the 5th or 6th lactation. Our results are in line with an Austrian study on dual-purpose Simmental cows, in which the authors showed that the economically most profitable productive life of a cow is higher than the current average, as milk yield is highest in the 5th or 6th lactation (Horn et al., 2012). A Swiss study calculated the optimal number of lactations from an economic perspective to be between 6 and 7 (Hoop, 2023). Furthermore, we showed that the highest yielding cows (more than 9616 kg/a) had an earlier peak in milk yield (around the 2nd lactation). These results are in line with a Swedish study that found the average milk yield of high-yield dairy cows (Swedish Holstein and Swedish Red, average milk yield per cow and year 9641 kg) to decrease after about 2.6 lactations (Adamie et al., 2023).

We also found that the number of veterinary visits increased as cows aged, suggesting that the health of ageing dairy cows declines, resulting in higher costs per dairy cow. Other researchers have argued that extending the productive life of dairy cows needs to be complemented by management changes to ensure health in higher lactations (Bieber et al., 2019; De Vries and Marcondes, 2020; Rödiger and Home, 2023), such as adapted feeding and housing regimes or longer intercalving periods. However, not all studies support these findings. For example, a study conducted in the Netherlands showed inconclusive results regarding the correlations between longevity and performance indicators (Han, 2023). Further, the present study showed a trend towards more veterinary visits with higher milk yield, suggesting that the health of higher-yielding cows deteriorates with increasing lactation. However, the number of observations of higher lactations in this study was low. Nevertheless, the literature shows that there is a negative correlation between high milk yield and robustness (Rödiger and Home, 2023).

In our study, the majority of farms participated in the cow longevity policy programme. However, windfall effects can be observed, as payments are not linked to increased longevity but are distributed based on meeting a minimum threshold of lactations. We found that farms with high-yielding cows were not induced to switch to a longer productive life because it was not profitable for them. Our results differ from another Swiss study, which showed that increasing the productive life of cows was a profitable measure for all farms (Kreft et al., 2023). The authors found that all farms participated in the longevity programme when profit maximisation was the only consideration. These differences can be explained by the different assumptions made in the two studies. Our study accounted for heterogeneity in milk yield and veterinary costs in a representative sample of the Swiss agricultural sector. Kreft et al. (2023) included only a sample of 65 farms and assumed homogeneous positive abatement costs.

A total of CHF 27 million is required to offset a 1 % CO_2 equivalent reduction in the longevity scenario in 2027. In terms of cost-effectiveness, this corresponds to a reduction of 58 kt CO_2 equivalent and CHF 471.5 per t CO_2 equivalent. Another Swiss study by Huber et al. (2023) found, on average, positive abatement costs (CHF 36/t CO_2 equivalent). In our study, the abatement costs of increasing the longevity of dairy cows were lower than the costs of other management practices. For example, the average marginal abatement cost of replacing concentrates in the study by Huber et al. (2023) was CHF 676/t CO_2 equivalent. However, the average marginal abatement costs of using trail hoses and feed additives in the same study (Huber et al., 2023) were only 166 and 329 CHF/t CO_2 equivalent, respectively, placing the longevity measure in a middle position. Another Swiss study estimated a reduction of 200 kt CO_2 equivalents in Switzerland if the average productive life of dairy cows increased from 3.5 to 4.5 years (Bretscher et al., 2018). This is in the same range as our results, where the average number of lactations per dairy cow increased from about 4.3 to 5.1.

There are some limitations to our study that need to be mentioned. First, we had some data limitations. The Swiss herdbook data are likely to be biased towards shorter productive lives, as all participating farmers are breeders, and farmers' interest in genetic selection has been found to have a negative effect on the longevity of dairy cows (Alvåsen et al., 2018). However, as the productive life varied considerably, we did not consider the bias to be that strong. Another limitation of the data set is the lack of information on changes in milk quality with increasing lactations. With regard to the SAEDN data, the data may contain a self-selection bias, as the sample is not randomly selected, but participation is voluntary. Finally, FADN data on reproduction rates and Swiss herdbook data on milk yield and veterinary costs were matched to SWISSland farms on the basis of milk yield, which is not the only possible influence.

Second, there are some notable limitations of the different models. In SWISSland, decision making is based solely on profit maximisation, excluding aspects such as risk aversion, personal preferences or interactions with neighbouring farms (Möhring et al., 2016), which could reduce the adoption rate. For example, Kreft et al. (2023) presented a modelling scenario in which behavioural aspects other than profit-maximising were taken into account, which resulted in a 20 % lower adoption of GHG mitigation measures compared to pure profit maximisation. This suggests that the adoption rate in this study is likely to be overestimated. Other factors that could reduce the adoption rate of the longevity programme, such as the inflexibility of the current Swiss dairy system that hinders individual actors' efforts to increase cow longevity (Rödiger and Home, 2023), were also not considered. Due to a lack of data, not all agricultural sources of GHG emissions in SAGE could be simulated in this study. For example, CO_2 emissions from urea applications and N_2O emissions from cultivated organic soils were neglected.

Third, another notable limitation of this study is that we focus only on GHG emissions, while other sustainability indicators such as biodiversity loss or nutrient surpluses are not taken into account. Policies that target one specific sustainability indicator may have negative effects on others. For example, while intensive dairy farming can be more GHG efficient than extensively managed dairy farms (Stetter et al., 2023), biodiversity loss and nutrient surpluses are often lower on extensively managed dairy farms (Verduna et al., 2020).

6. Conclusion

This study suggests that direct payments to dairy cows to promote longevity can reduce GHG emissions from agriculture. Specifically, payments of up to CHF 200 per livestock unit could lead to a 1.7 % reduction in total agricultural GHG emissions, equivalent to CHF 998 per t CO_2, which is significantly higher than the average damage cost estimates of GHG emissions. However, the current capped payment system, set at CHF 10–100 per livestock unit, emerges as the most cost-effective option for reducing GHG emissions, with a reduction potential of 1.7 % and a cost of CHF 471.5 per t CO_2. The current system of direct payments can lead to windfall effects, as payments are not linked to increased longevity but are distributed based on a minimum number of lactations. To mitigate these windfall effects, alternative payment structures should be explored.

CRediT authorship contribution statement

Eva Winter: Writing – review & editing, Writing – original draft, Visualization, Formal analysis, Conceptualization. **Manika Rödiger:** Writing – review & editing, Visualization, Formal analysis, Data curation. **Jérôme Schneuwly:** Writing – review & editing, Software, Methodology, Data curation. **Anina Gilgen:** Writing – review & editing, Validation, Methodology, Data curation. **Gabriele Mack:** Writing – review & editing, Writing – original draft, Validation, Supervision, Project administration, Methodology, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors do not have permission to share data.

Acknowledgements

We wish to thank Qualitas AG, especially Jürg Moll and Urs Schnyder, for providing the data. We would further like to thank Nicolas Berger from Swiss herdbook and Cécile Schabana-Meili from Braunvieh Schweiz for their helpful responses to our questions during the data curation. Furthermore, we wish to thank Daniel Bretscher for his guidance on GHG emission modelling.

Appendix A. Appendix

Table A.1
Plausibility checks of herdbook data.

Variable	Original data range	Verified data range	Method
Number of lactations	1 to 50	1 to 19	Literature and own judgement
Milk yield in kg per cow and lactation	minimum: 0 kg milk, median: 7.183 kg, mean: 7246 kg milk, maximum: 54,137 kg milk	Upper bound: 14,161.5 kg	Tukey's upper fence as a cut-off point (Johansen and Christensen, 2018)
Days in milk	minimum: 0, median: 309, mean: 304, maximum: 6363	Upper bound: 477.5 days in milk	Tukey's upper fence
Intercalving period	minimum (1) and maximum (999)	Lower bound: 263.5, upper bound: 501.5	Tukey's lower and upper fences
Number of calves per year		Upper bound: 5	Literature and own judgement
Length of the lactation (partly given in the data set (n = 991,586)).			If not given, the length of lactation was calculated by the days in milk, where available, plus days of dry period, which we assumed to be 60 (n = 1,106,335).
Adaptation to SWISSland: Milk yield and number of lactations per cow	Number of lactations: 1 to 19 Milk yield: Minimum: 0; Upper bound: 14′161.5 kg/cow and year	Number of lactations: 2 to 8 Milk yield: Lower bound 3000 kg/cow and year	Adapted as relevant to implementation in SWISSland

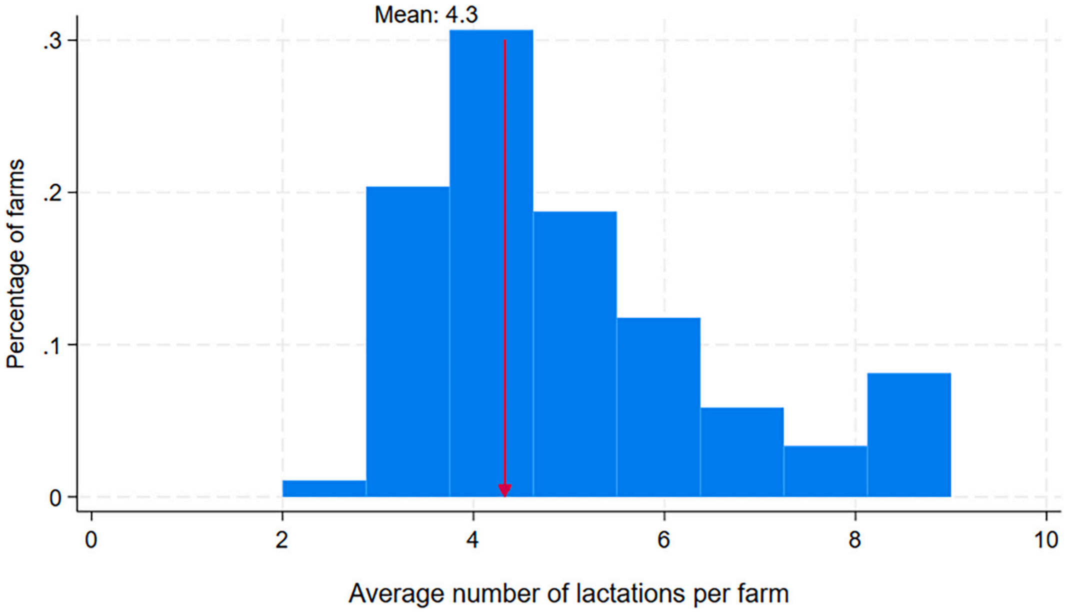


Fig. A.1. Cow longevity distribution in the dairy farm population of SWISSland (2138 dairy farms).

Table A.2

Gross energy intake per head of different livestock types, methane conversion factors and the resulting emission factors used to calculate CH_4 emissions from enteric fermentation. Emission factor and gross energy intake of mature dairy cattle is shown for an animal with an average milk yield of 6733 kg/year, other values are according to national GHG inventory.

Livestock Category	Gross Energy Intake (MJ/head/day)	Methane conversion factor (Ym)	Emission factor (kg CH4/head/year)
Mature Dairy Cattle	308.0	0.0690	139.614
Other Mature Cattle	205.1	0.0650	87.576
Breeding Cattle 1st year	68.4	0.0650	29.202
Breeding Cattle >1 year	129.1	0.0650	55.116
Breeding Cattle 2nd year	129.1	0.0650	55.116
Fattening Calves	47.6	0.0000	0.000
Growing Cattle	55.7	0.0650	23.799
Fattening Cattle	104.5	0.0650	44.621
Nursing Sows	118.8	0.0060	4.681
Dry Sows	47.4	0.0060	1.867
Piglets	13.8	0.0060	0.543
Boars	43.2	0.0060	1.702
Fattening Pig over 25 kg	35.7	0.0060	1.407
Layers	1.9	0.0011	0.015
Growers	0.8	0.0011	0.006
Broilers	1.8	0.0011	0.013
Turkey	4.7	0.0011	0.035
Other Poultry	1.8	0.0011	0.013
Horses >3 years	109.0	0.0245	17.539
Horses <3 years	101.4	0.0245	16.313
Mules and Asses	86.0	0.0245	13.843
Ponies	37.9	0.0245	6.102
Mature Sheep	31.7	0.0650	13.540
Milk Sheep	53.7	0.0650	22.913
Goats	26.3	0.0600	10.381

Table A.3

Input variables for the SAGE model derived from SWISSland.

Variable	Source	Description
Number of animals per category	SWISSland modelling results	Transformation of SWISSland livestock categories and livestock units in livestock number and SAGE livestock categories (See Table A.2)
Milk yield per cow in kg	SWISSland modelling results	
Use of animal-friendly housing systems (yes/no)	SWISSland modelling results	Identification through BTS (BLW, 2024) certification

(continued on next page)

Table A.3 (*continued*)

Variable	Source	Description
Use of regular free-range systems (yes/no)	SWISSland modelling results	Identification through RAUS (BLW, 2024) certification
Nitrogen fertiliser use in tons per farm agent	SWISSland modelling results	Transformation of SWISSland fertiliser categories into SAGE fertiliser categories
Crop yield in tons per crop and farm agent	SWISSland modelling results	Transformation of SWISSland crop categories into SAGE crop categories

Table A.4
Input variables for SAGE derived from the SAEDN data set.

Input variables
Slurry application rate in m^3/ha
Slurry application technique
Slurry application area in ha
Slurry storage covered (yes/no)
Yard and pasture days per year and hours per day and livestock category
Allocation of excretions to slurry and solid manure per livestock category
Percentage of slurry applied after 6 pm
Occurrences of slurry applications on particularly warm days (sometimes/always/never)
Time span from solid manure application to incorporation
Type of bedding per livestock category and Nitrogen contents
Percentage of slurry and manure applied in the summer months June to August

Table A.5
Direct payments targeting dairy cow longevity.

Number of calves	Payment in CHF/dairy cow in longevity and Sens2 scenarios	Payment in CHF/dairy cow in Sens1 and Sens3 scenarios
3	10	10
4	30	60
5	50	110
6	80	160
7	100	200

Table A.6
OLS regression results (Coefficient and *P*-value) on milk yield (kg/cow and lactation), veterinary visits (No/cow and lactation) and surviving calves (No/cow and lactation) as dependent variables and the lactation number as independent variable.

Dependent variables Independent variable	Milk yield	Veterinary visits	Calves
Lactation 3 (compared to Lactation 2)	402.9 (0.00)	0.1 (0.00)	0.006 (0.00)
Lactation 4 (compared to Lactation 2)	530.9 (0.00)	0.2 (0.00)	0.005 (0.00)
Lactation 5 (compared to Lactation 2)	567.3 (0.00)	0.3 (0.00)	0.005 (0.01)
Lactation 6 (compared to Lactation 2)	415.5 (0.00)	0.3 (0.00)	0.007 (0.01)
Lactation 7 (compared to Lactation 2)	207.7 (0.00)	0.4 (0.00)	−0.001 (0.7)
Lactation 8 (compared to Lactation 2)	−188.4 (0.00)	0.4 (0.00)	0.003 (0.7)

Table A.7
Milk yields in kg (mean values) and number of observations with increasing number of lactations for five milk yield classes (quintiles).

Quintiles lower and upper bounds (in 2nd lactation)	Lactation 2 milk yield (n)	Lactation 3 milk yield (n)	Lactation 4 milk yield (n)	Lactation 5 milk yield (n)	Lactation 6 milk yield (n)	Lactation 7 milk yield (n)	Lactation 8 milk yield (n)
First quintile (>3000 < 5916)	4604 (25,812)	5726 (13,613)	5915 (9852)	6107 (6743)	6104 (4061)	6000 (2187)	5849 (1016)
Second quintile (>5916 <7119)	6131 (25,805)	6727 (19,207)	6938 (14,067)	7102 (9595)	7119 (5610)	7030 (2910)	6812 (1318)
Third quintile (>7119 <8223)	7176 (25,800)	7557 (19,956)	7785 (14,340)	7927 (9516)	7818 (5419)	7731 (2604)	7333 (1055)
Fourth quintile (>8223 <9616)	8322 (25,803)	8421 (20,057)	8597 (14,059)	8646 (8844)	8581 (4752)	8353 (2275)	8064 (836)
Fifth quintile (>9616)	10,440 (25,791)	9697 (18,689)	9725 (12,408)	9639 (7442)	9367 (3647)	9204 (1518)	8903 (450)

Table A.8
Number of veterinary visits (mean values) with increasing number of lactations for the 5 milk yield classes (quintiles).

Quintiles lower and upper bounds (in 2nd lactation)	Lactation 2 –vet visits (n)	Lactation 3 –vet visits (n)	Lactation 4 –vet visits (n)	Lactation 5 –vet visits (n)	Lactation 6 –vet visits (n)	Lactation 7 –vet visits (n)	Lactation 8 –vet visits (n)
First quintile (>3000 < 5916)	1.64 (439)	1.66 (246)	1.83 (226)	1.91 (180)	1.80 (128)	2.01 (72)	2.03 (36)
Second quintile (>5916 <7119)	1.68 (666)	1.72 (541)	1.82 (458)	1.83 (358)	1.62 (241)	1.79 (161)	2.16 (79)
Third quintile (>7119 <8223)	1.68 (818)	1.74 (715)	1.88 (574)	1.90 (450)	1.95 (292)	2.03 (173)	2.08 (71)
Fourth quintile (>8223 <9616)	1.72 (835)	1.82 (771)	1.91 (636)	2.05 (505)	2.28 (335)	2.31 (208)	2.16 (61)
Fifth quintile (>9616)	1.78 (1001)	1.95 (841)	2.09 (712)	2.26 (533)	2.19 (310)	2.24 (129)	2.32 (22)

References

Adamie, B., Owusu-Sekyere, E., Lindberg, M., Agenäs, S., Nyman, A.-K., Hansson, H., 2023. Dairy cow longevity and farm economic performance: evidence from Swedish dairy farms. J. Dairy Sci. 106, 8926–8941. https://doi.org/10.3168/jds.2023-23436.

Alig, M., Prechsl, U., Schwitter, K., Waldvogel, T., Wolff, V., Wunderlich, A., Zorn, A., Gaillard, G., 2015. Ökologische und ökonomische Bewertung von Klimaschutzmassnahmen zur Umsetzung auf landwirtschaftlichen Betrieben in der Schweiz. Agroscope Sci. 29, 1–160.

Alvåsen, K., Dohoo, I., Roth, A., Emanuelson, U., 2018. Farm characteristics and management routines related to cow longevity: a survey among Swedish dairy farmers. Acta Vet. Scand. 60, 1–11. https://doi.org/10.1186/s13028-018-0390-8.

Ammann, J., Arbenz, A., Mack, G., Nemecek, T., El Benni, N., 2023. A review on policy instruments for sustainable food consumption. Sustain. Prod. Consum. 36, 338–353. https://doi.org/10.1016/j.spc.2023.01.012.

Bieber, A., Wallenbeck, A., Leiber, F., Fuerst-Waltl, B., Winckler, C., Gullstrand, P., Walczak, J., Wójcik, P., Neff, A.S., 2019. Production level, fertility, health traits, and longevity in local and commercial dairy breeds under organic production conditions in Austria, Switzerland, Poland, and Sweden. J. Dairy Sci. 102, 5330–5341. https://doi.org/10.3168/jds.2018-16147.

BLW, 2021. Verordnungspaket Parlamentarische Initiative 19.475 "Das Risiko beim Einsatz von Pestiziden reduzieren". Erläuternder Bericht zur Eröffnung des Vernehmlassungsverfahrens, Bern.

BLW, 2024. Tierwohlbeiträge (BTS/RAUS/Weidebeitrag) [WWW Document]. Tierwohlbeiträge BTSRAUSWeidebeitrag. URL. https://www.holstein.ch/wp-content/uploads/2018/07/holstein-news_juillet_2018_d.

Bonnet, C., Bouamra-Mechemache, Z., Réquillart, V., Treich, N., 2020. Regulating meat consumption to improve health, the environment and animal welfare. Food Policy 97, 101847. https://doi.org/10.1016/j.foodpol.2020.101847.

Bretscher, D., Ammann, C., Wüst, C., Nyfeler, A., Felder, D., 2018. Reduktionspotenziale von Treibhausgasemissionen aus der Schweizer Nutztierhaltung. Agrar. Schweiz 9, 376–383.

Bruijnis, M., Meijboom, F., Stassen, E., 2013. Longevity as an animal welfare issue applied to the case of foot disorders in dairy cattle. J. Agric. Environ. Ethics 26, 191–205. https://doi.org/10.1007/s10806-012-9376-0.

Buendia, E.C., Tanabe, K., Kranjc, A., Jamsranjav, B., Fukuda, M., Ngarize, S., Osako, A., Pyrozhenko, Y., Shermanau, P., Federici, S., 2019. 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse gas Inventories. IPCC.

Burren, A., Alder, S., 2013. Abgangsursachen und LBE. CHbraunvieh.

Bystricky, M., Bretscher, D., Schori, F., Mack, G., 2023. Reducing feed-food competition with direct payments? An ex-ante assessment of economic and environmental impacts. Q Open 3, qoad002. https://doi.org/10.1093/qopen/qoad002.

De Vries, A., Marcondes, M.I., 2020. Review: overview of factors affecting productive lifespan of dairy cows. Animal 14, s155–s164. https://doi.org/10.1017/S1751731119003264.

Dueri, S., Mack, G., 2024. Modeling the implications of policy reforms on pesticide risk for Switzerland. Sci. Total Environ. 172436 https://doi.org/10.1016/j.scitotenv.2024.172436.

Eggleston, H.S., Buendia, L., Miwa, K., Ngara, T., Tanabe, K., 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. IPCC.

FAO, 2006. Livestock's Long Shadow: Environmental Issues and Options. FAO, Rome Italy.

FAO, 2020. Emissions due to agriculture. Global, regional and country trends 2000–2018. FAOSTAT Anal. Brief Ser. No 18.

FOEN, 2022. Climate. In: Brief. URL. https://www.bafu.admin.ch/bafu/en/home/topics/climate/in-brief.html.

FOEN, 2023. Switzerland's greenhouse gas inventory 1990–2021: National Inventory Document and reporting tables (CRF). In: Submission of April 2023 under the United Nations Framework Convention on Climate Change. Bern.

Fuss, M., Burren, A., 2018. Abgangsursachen und LBE [WWW Document]. Holst. News Switz 4, 1–24. URL. https://www.holstein.ch/wp-content/uploads/2018/07/holstein-news_juillet_2018_d.

Gilgen, A., Blaser, S., Schneuwly, J., Liebisch, F., Merbold, L., 2023. The Swiss Agri-environmental data network (SAEDN): description and critical review of the dataset. Agric. Syst. 205, 103576 https://doi.org/10.1016/j.agsy.2022.103576.

Grandl, F., Furger, M., Kreuzer, M., Zehetmeier, M., 2019. Impact of longevity on greenhouse gas emissions and profitability of individual dairy cows analysed with different system boundaries. Animal 13, 198–208. https://doi.org/10.1017/S175173111800112X.

Hafner, S.D., Pacholski, A., Bittman, S., Carozzi, M., Chantigny, M., Génermont, S., Häni, C., Hansen, M.N., Huijsmans, J., Kupper, T., Misselbrook, T., Neftel, A., Nyord, T., Sommer, S.G., 2019. A flexible semi-empirical model for estimating ammonia volatilization from field-applied slurry. Atmos. Environ. 199, 474–484. https://doi.org/10.1016/j.atmosenv.2018.11.034.

Han, R., 2023. Economic and Environmental Sustainability in relatiOn to Dairy Cow Longevity. URL. https://library.wur.nl/WebQuery/wurpubs/fulltext/635923.

Heikkilä, A.-M., Nousiainen, J.I., Jauhiainen, L., 2008. Optimal replacement policy and economic value of dairy cows with diverse health status and production capacity. J. Dairy Sci. 91, 2342–2352. https://doi.org/10.3168/jds.2007-0736.

Heuel, M., 2024. Nutzungsdauer Schweizer Milchkühe. URL. https://themes.agripedia.ch/nutzungsdauer-schweizer-milchkuehe/.

Hoop, D., 2023. The empirical economic effect of dairy cow longevity in a Swiss setting. Austrian J. Agric. Econ. Rural Stud. 32, 37–44.

Horn, M., Knaus, W., Kirner, L., Steinwidder, A., 2012. Economic evaluation of longevity in organic dairy cows. Org. Agric. 2, 127–143. https://doi.org/10.1007/s13165-012-0027-6.

Huber, R., Tarruella, M., Schäfer, D., Finger, R., 2023. Marginal climate change abatement costs in Swiss dairy production considering farm heterogeneity and interaction effects. Agric. Syst. 207, 103639 https://doi.org/10.1016/j.agsy.2023.103639.

Johansen, M.B., Christensen, P.A., 2018. A simple transformation independent method for outlier definition. Clin. Chem. Lab. Med. CCLM 56, 1524–1532. https://doi.org/10.1515/cclm-2018-0025.

Kreft, C., Finger, R., Huber, R., 2023. Action-versus results-based policy designs for agricultural climate change mitigation. Appl. Econ. Perspect. Policy. https://doi.org/10.1002/aepp.13376.

Kupper, T., Häni, C., 2023. Agrammon Model Description. URL. https://agrammon.ch/.

Kupper, T., Häni, C., Neftel, A., Kincaid, C., Bühler, M., Amon, B., VanderZaag, A., 2020. Ammonia and greenhouse gas emissions from slurry storage - a review. Agric. Ecosyst. Environ. 300, 106963 https://doi.org/10.1016/j.agee.2020.106963.

Kupper, T., Häni, C., Bretscher, D., Zaucker, F., 2022. Ammoniakemissionen der schweizerischen Landwirtschaft 1990 bis 2020. Bernher Fachhochschule, Zollikofen.

Leiber, F., Müller, A., Maurer, V., Schader, C., Bieber, A., 2019. Organic dairy farming: Towards sustainability. In: Improving Organic Animal Farming. Burleigh Dodds Science Publishing Limited, pp. 225–244.

Mack, G., Kohler, A., 2019. Short-and long-run policy evaluation: support for grassland-based milk production in Switzerland. J. Agric. Econ. 70, 215–240. https://doi.org/10.1111/1477-9552.12284.

Mack, G., Ferjani, A., Möhring, A., von Ow, A., Mann, S., 2019. How did farmers act? Ex-post validation of linear and positive mathematical programming approaches for farm-level models implemented in an agent-based agricultural sector model. Bio-based and Applied Economics 8 (1), 3–19. https://doi.org/10.13128/bae-8144 (ISSN 2280-6172).

Mack, G., Finger, R., Ammann, J., El Benni, N., 2023. Modelling policies towards pesticide-free agricultural production systems. Agric. Syst. 207, 103642 https://doi.org/10.1016/j.agsy.2023.103642.

Möhring, A., Mack, G., Zimmermann, A., Ferjani, A., Schmidt, A., Mann, S., 2016. Agent-based modeling on a national scale – experiences from SWISSland. Agrar. Schweiz 30, 1–65.

Renner, S., Jan, P., Hoop, D., Schmid, D., Dux-Bruggmann, D., Weber, A., Lips, M., 2019. Survey system of the Swiss farm accountancy data network with two samples: income situation sample and farm management sample. Agroscope Sci. 68, 1–76.

Richer, W., Flisch, R., Mayer, J., Schlegel, P., Zähner, M., Menzi, H., 2017. 4/ Eigenschaften und Anwendung von Düngern: Grundlagen für die Düngung landwirtschaftlicher Kulturen in der Schweiz (GRUD). (Spezialpublikation No. 8 (6)), Agrarforschung Schweiz. Agroscope, Bern.

Rödiger, M., Home, R., 2023. Systemic enablers and barriers to extending the productive life of dairy cows in Switzerland. J. Rural. Stud. 100, 103031 https://doi.org/10.1016/j.jrurstud.2023.103031.

Scarborough, P., Clark, M., Cobiac, L., Papier, K., Knuppel, A., Lynch, J., Harrington, R., Key, T., Springmann, M., 2023. Vegans, vegetarians, fish-eaters and meat-eaters in the UK show discrepant environmental impacts. Nat. Food 4, 565–574. https://doi.org/10.1038/s43016-023-00795-w.

Schmidt, A., Mack, G., Möhring, A., Mann, S., El Benni, N., 2019. Stricter cross-compliance standards in Switzerland: economic and environmental impacts at farm- and sector-level. Agric. Syst. 176, 102664 https://doi.org/10.1016/j.agsy.2019.102664.

Schmidt, A., Mack, G., Mann, S., Six, J., 2021. Reduction of nitrogen pollution in agriculture through nitrogen surplus quotas: an analysis of individual marginal abatement cost and different quota allocation schemes using an agent-based model. J. Environ. Plan. Manag. 64, 1375–1391. https://doi.org/10.1080/09640568.2020.1823344.

Schweizerischer Bundesrat, 2021. Verordnungspaket Parlamentarische Initiative 19.475 “Das Risiko beim Einsatz von Pestiziden Reduzieren”.

Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H., Kumar, P., McCarl, B., Ogle, S., O’Mara, F., Rice, C., 2008. Greenhouse gas mitigation in agriculture. Philos. Trans. R. Soc. B Biol. Sci. 363, 789–813. https://doi.org/10.1098/rstb.2007.2184.

Spengler-Neff, A., Eppenstein, R., Lerch, M., Schneider, C., 2021. Produktionsformen in der Kälbermast. URL. https://www.milch-und-fleisch.de/wp-content/uploads/1019-kaelbermast.pdf.

Stetter, C., Wimmer, S., Sauer, J., 2023. Are intensive farms more emission efficient? Evidence from German dairy farms. J. Agric. Resour. Econ. 48, 136–157. https://doi.org/10.22004/ag.econ.316758.

Tarruella, M., Huber, R., Mack, G., El Benni, N., Finger, R., 2023. Cost-effectiveness of farm-vs. regional-level climate change mitigation policies. Q Open. https://doi.org/10.1093/qopen/qoad022.

Troost, C., Berger, T., 2015. Dealing with uncertainty in agent-based simulation: farm-level modeling of adaptation to climate change in Southwest Germany. Am. J. Agric. Econ. 97, 833–854. https://doi.org/10.1093/ajae/aau076.

Tukker, A., Jansen, B., 2006. Environmental impacts of products: a detailed review of studies. J. Ind. Ecol. 10, 159–182. https://doi.org/10.1162/jiec.2006.10.3.159.

Verduna, T., Blanc, S., Merlino, V.M., Cornale, P., Battaglini, L.M., 2020. Sustainability of four dairy farming scenarios in an alpine environment: the case study of Toma di Lanzo cheese. Front. Vet. Sci. 7, 569167 https://doi.org/10.3389/fvets.2020.569167.

Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., Garnett, T., Tilman, D., DeClerck, F., Wood, A., 2019. Food in the Anthropocene: the EAT–lancet commission on healthy diets from sustainable food systems. Lancet 393, 447–492. https://doi.org/10.1016/S0140-6736(18)31788-4.

Winter, E., Grovermann, C., Messmer, M.M., Aurbacher, J., 2023. Assessing seed and breeding interventions for organic farming using a multiagent value chain approach. Agric. Food Econ. 11, 22. https://doi.org/10.1186/s40100-023-00262-x.