Q Open, 2023, **0**, 1–25
https://doi.org/10.1093/qopen/qoad002
Advance access publication date: 17 March 2023
Article

OXFORD

Reducing feed-food competition with direct payments? An ex-ante assessment of economic and environmental impacts

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Received: May 27, 2022. **Accepted:** February 7, 2023

Abstract

Worldwide, feed-food competition for arable land is of rising concern. Swiss agricultural policy wants to promote grass-based cattle feeding through a voluntary direct payment program that is currently being revised. The current version of the program requires a minimum share of 75–85 per cent grass-based feed in the yearly rations for ruminants. The revision suggests financial compensation for using concentrates with limited crude protein (CP) content at different levels (18 per cent, 12 per cent, or 0 per cent CP) without limiting the amount of concentrates. In a multimodel approach, we investigated the adoption rate of the new program, and its effect on feed-food competition and environmental indicators at the national scale for Switzerland. We found that the less strict the requirements are regarding the protein content of concentrate feeds, the more cattle farmers will adopt the new program for protein-reduced concentrate feeding. We further found that, compared to the current version of the program, the revised program could have the opposite or none of the intended effects regarding feed-food competition and environmental indicators. Only banning the use of concentrates altogether moves the environmental indicators in the intended direction for the farms participating in the program. This study shows that ex-ante evaluations are important to expose ineffectual policy measures and improve their design before introducing new direct payment programs.

Keywords: Feed-food competition, Grass-based cattle feeding, Ex-ante policy assessment, Direct payments, Environmental impacts.

JEL code: Q18

1. Introduction

Worldwide, feed-food competition for arable land is a rising concern, especially with livestock production being on the rise (FAOSTAT 2021). For decades, the production of crop-based proteins as feedstuff has been increasing, along with the share of concentrates in livestock diets, with soy replacing by-products from cereal use (Manceron, Ben-Ari, and Dumas 2014). The demand for human-edible feed resources for animal nutrition is expected to increase even further in the future (Mottet et al. 2017).

In general, land use for livestock can threaten food security because the protein conversion efficiency of livestock is low compared with consuming grains directly (Manceron, Ben-Ari, and Dumas 2014). However, this is highly dependent on the prevailing feed rations: cattle production systems with mainly grass-based feeding are potential net producers of human-edible energy and protein, while cattle with concentrate use are mostly net consumers (Mosnier et al. 2021), even though more concentrates in the rations enable higher yields (Bargo et al. 2003). On the other hand, grass-fed ruminants also contribute to feed-food competition because currently, a large proportion of used grassland would be suitable for conversion to arable land (Mottet et al. 2017).

However, this would pose a problem because grassland provides a wide range of ecosystem services (Bengtsson et al. 2019). Indeed, in the last few decades, about 30 per cent of permanent grassland in Europe has been lost (Huyghe et al. 2014), and worldwide grassland has been degraded to a large extent (Bardgett et al. 2021). Projections point to further cropland expansion at the expense of grassland (Manceron, Ben-Ari, and Dumas 2014).

Therefore, crop diversification and the conservation of permanent grassland are part of legislated greening actions by stakeholders such as Switzerland or the EU. This is expected to increase soil and ecosystem resilience while preserving soil organic carbon and grassland habitats (Hart 2015). To promote the use of grass in ruminant diets, in the EU a grass premium has been proposed as part of the direct payment system. With this premium, Salou et al. (2019) and Gocht et al. (2016) predicted a decrease in crop production in the EU between 0.6 per cent and 8.3 per cent, while grass production would increase by 5–8 per cent and cattle herds by 0.3 per cent. A total of 3–5 million hectares of cropland would be converted to grassland, but cropland use would partly be transferred to other parts of the world (Gocht et al. 2016; Salou et al. 2019). Overall, positive impacts such as increased carbon sequestration could be achieved by such measures (Gocht et al. 2016; Salou et al. 2019), but the problem of feed-food competition could be exacerbated.

Milk production with a low level of concentrates and a high level of pasture performs better on many environmental indicators than concentrate-intensive indoor feeding (Alig et al. 2015). Using feedstuffs that cannot be used as food, together with a shift in human diets toward fewer animal products, could considerably decrease the environmental impacts of food systems (Schader et al. 2015; von Ow, Waldvogel, and Nemecek 2020) and also feed-food competition.

In Switzerland, arable land is a valuable limited resource. Grassland comprises 70 per cent of the agricultural area (around 1 million hectares), with an additional 0.5 million hectares of alpine meadows. Furthermore, more than half of the cropland area is currently used to produce feed for livestock, and more than 1 million tons of feedstuff are imported from abroad (SBV 2021). With a growing population and food self-sufficiency at only 57 per cent—or 50 per cent excluding animal products produced with imported feed—(FOAG 2021), feed-food competition is of special concern. Therefore, Swiss agricultural policy aims at increasing food security while at the same time enabling the agricultural sector to reach environmental targets such as a lower nitrogen (N) surplus and greenhouse gas emissions.

Part of the strategy to achieve this is to adapt an already existing direct payment program that promotes grass-based feeding in milk and meat production. This program has been in place since 2014 and is now being revised. The current guidelines of the program require a minimum share of 75–85 per cent grass-based feed in the yearly rations for ruminants with a compensation of 200 CHF per hectare grassland (Mack et al. 2017). Positive effects were stagnant rather than increasing concentrate use, and increased income for the participating farms because of lower direct costs and increased revenue (Mack and Huber 2017; Mack and Kohler 2019). However, weaknesses were identified regarding closing nutrient cycles and reducing the share of silage maize as an arable crop in rations. The feeding requirements for participation resulted in very low compliance costs (Mack and Huber 2017) and thus in a considerable dead weight effect, and the actual proportion of concentrate feed in the rations was difficult to control. In the revised version of the program proposed by the Swiss Federal

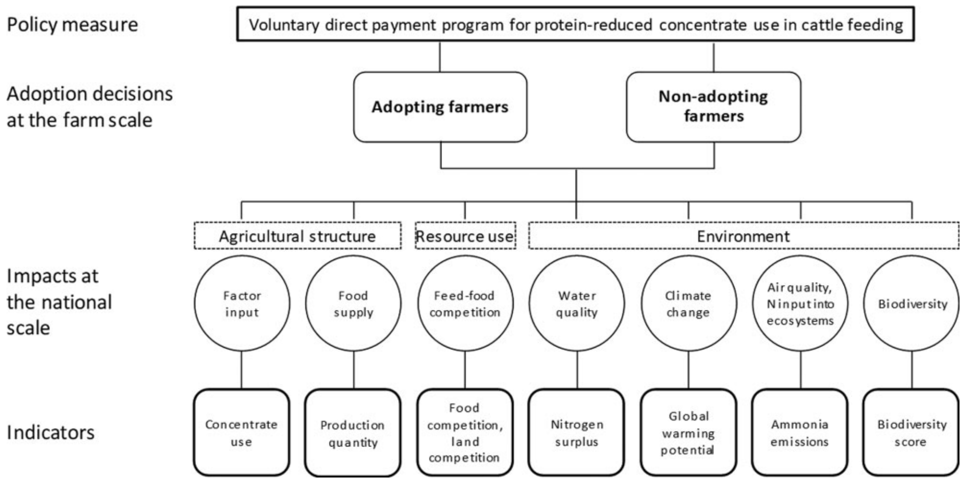

Figure 1. Impacts and indicators of ex-ante policy assessment.

Office for Agriculture, farmers would be allowed to purchase feedstuffs with a maximum crude protein (CP) content of 18 per cent or 12 per cent or would not be allowed to purchase any concentrate feed at all; the farmers would be compensated at different levels up to CHF 360 per hectare grassland. This is expected to achieve a more site-adapted livestock production, with protein being supplied mainly from the farms' own grassland, lowering feed-food competition, and providing benefits regarding nationwide N surplus, greenhouse gas and ammonia (NH_3) emissions, and increased biodiversity.

Our evaluation aims to assess the possible consequences of the suggested direct payment program for protein-reduced concentrate (PRC) use in milk and meat production and the associated trade-offs on a national scale. In doing so, we want to emphasize the importance of ex-ante evaluations to determine whether policies can achieve the desired effect. We analyzed the following:

- The share of Swiss cattle farmers that would adopt the revised program for economic reasons and the effect of this participation rate on milk and meat production and concentrate use at the national scale.
- How the program affects feed-food competition in milk and meat production both at the level of participating farms and at the national scale.
- How the program affects N surplus, greenhouse gas and NH_3 emissions, and the biodiversity of agricultural production at the national scale.

2. Data and methods for ex-ante impact assessment

In the context of introducing new policies, impact assessment in the form of an ex-ante analysis is becoming increasingly important for analyzing the heterogeneous effects of policy options (Tabbush, Frederiksen, and Edwards 2008; Reidsma et al. 2018; Schmidt et al. 2019). For the ex-ante impact assessment, we use a multimodel approach to analyze the structural and environmental effects of the voluntary direct payment program for PRC use and the effect on milk and meat production. The impacts addressed and the indicators for measuring the impacts are depicted in Fig. 1. They were defined together with policymakers. We have investigated factor input and the amount of food supply at the national scale as structural impacts. Furthermore, we have analyzed feed-food competition and environmental impacts on water quality, climate change, air quality/N inputs into ecosystems, and

Figure 2. Steps/chronological sequence in the multimodel approach.

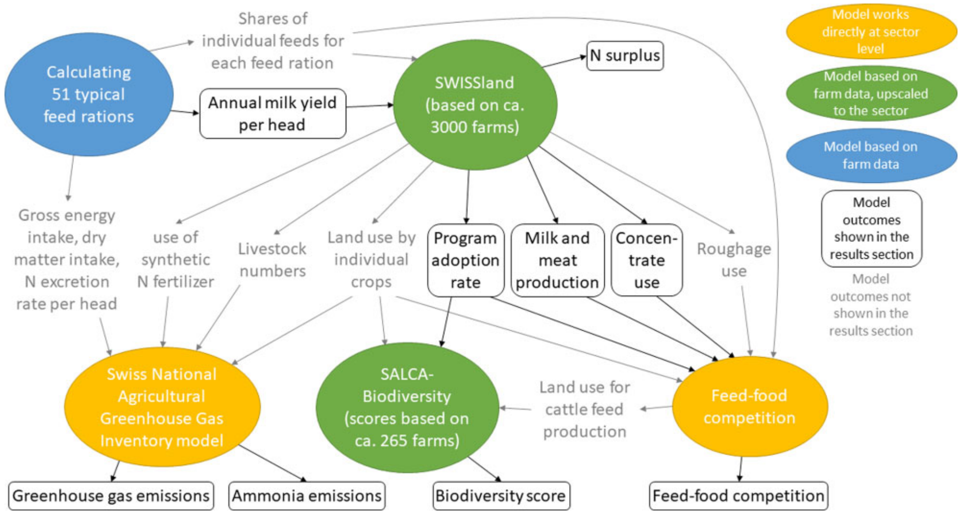

Figure 3. Data flow between the models, scale, and output of each model.

biodiversity. All of these impacts can be reported on the national scale. Some of the models used allow analyses at the farm scale, which we carried out accordingly.

One peculiarity of this policy impact assessment is that policymakers have not yet defined measurable targets for the new version of the program. This means that a comparison of actual values to target values on the basis of measurable threshold values is not possible, nor is a calculation of the degree of target achievement.

In our multimodel approach, we combined different models in four steps (Fig. 2). Each step required the results of the previous steps as input data. Fig. 3 shows the data flow and the scale of calculation for each model we used in more detail. In step 1, we defined the parameters describing a reference and three PRC feed scenarios (PRC scenarios; see Section 2.1). In step 2 (see Section 2.2), we calculated the feed rations for dairy cows, suckler cows, replacement heifers, and fatting bulls for the reference and PRC scenarios. In step 3, the data derived from the feed rations were fed into the agent-based agricultural sector model SWISSland (see Section 2.3), which were used to simulate the individual decisions of farms to adopt or not the program for PRC use based on economic criteria. Using the results from the SWISSland simulations as a basis (livestock numbers, land use, food production, etc.), we modeled feed-food competition and environmental impacts in step 4 (see Sections 2.4–2.7).

2.1. Policy scenarios

The reference and three PRC scenarios differ regarding the maximum CP content in the purchased concentrates. In the reference scenario, farms can participate in the current version of the direct payment program. The C18 scenario allows 18 per cent CP in purchased concentrates, the C12 scenario allows 12 per cent CP, and the C0 scenario bans all purchased concentrates in cattle feeding (Table 1). The data basis for defining the scenarios has been

Table 1. Definition of policy scenarios to promote PRC use in milk and meat production.

	Reference scenario	PRC feed scenarios (PRC scenarios)		
		C18	C12	C0
Feed requirements				
(1) Maximum amount of concentrates	10 per cent of ration's DM	n/a	n/a	n/a
(2) Minimum amount of grass-based feeds	75 per cent (lowlands) or 85 per cent (mountains) of rations' DM	n/a	n/a	n/a
(3) Maximum CP content in purchased concentrates	n/a	18 per cent CP in DM	12 per cent CP in DM	0 per cent CP in DM (ban on purchased concentrates)
Direct payment compensation				
(a) Dairy cows	200 CHF per hectare GL	120 CHF per hectare GL	240 CHF per hectare GL	360 CHF per hectare GL
(b) Other ruminants	200 CHF per hectare GL	60 CHF per hectare GL	120 CHF per hectare GL	240 CHF per hectare GL
Price premium for milk	–	5 per cent	5 per cent	10 per cent

CHF, Swiss Francs; DM, dry matter; GL, grassland.

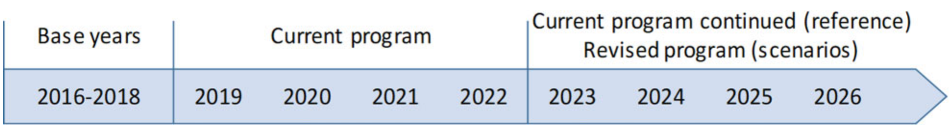

Figure 4. Time axis of the scenarios.

developed in collaboration with policymakers. According to policymakers, farmers should be allowed to use concentrates grown on their own farms without any limitation to the CP content. Because of restrictions in our models, however, we assumed that farms purchased all concentrate feed. Fig. 4 shows the time axis for program implementation in the scenarios. The period of 2023–6 for the new program has been chosen because the usual period for revisions of the agricultural policy in Switzerland is 4 years and the current period ends in 2022. Model results are provided for the last year (2026).

2.2. Calculation of feed rations for cattle for the reference and PRC scenarios

For the PRC scenarios and reference scenario, feed rations typical for Switzerland have been calculated for dairy cows, suckler cows, rearing cattle, and fattening bulls using the method from Schori (2020). The rations meet the feeding guidelines of the direct payment program.

For dairy cows, thirty-six annual basic rations were compiled based on a survey of 157 Swiss farms (Ineichen, Sutter, and Reidy 2016), with forage comprising approximately 85–95 per cent of their total annual rations. Annual basic rations, which consist of summer and winter rations, have been compiled for silage-feeding and silage-free farms. Furthermore, a differentiation was made between rations for the lowlands and mountain regions. The main difference between the two regions in the basic rations was the proportion of whole-

Table 2. Energy and protein content of the concentrates for dairy and suckler cows, heifers, and fattening bulls

	NEL (NEG) (MJ/kg DM)	APDE (g/kg DM)	APDN (g/kg DM)	CP (g/kg DM)
Cereal mixture 11.4 per cent CP	8.4	102	82	114
Cereal mixture 12 per cent CP	8.4	104	85	120
High-energy cereal mixture	8.9 (9.5)	101	87	119
Dairy cow compound feed 18 per cent CP	8.1	128	130	179
Heifer compound feed 18 per cent CP	8.3	143	138	179
Fattening bull compound feed 18 per cent CP	8.9 (9.5)	140	138	180
Dairy cow protein concentrate 44 per cent CP	8.1	237	325	444
Heifer and bull protein concentrate 51 per cent CP	8.1 (8.6)	300	388	509

NEG, net energy for gain.

plant maize and the energy and protein content of the forage. We also assumed that summer feeding periods were shorter in the mountain region than in the lowland region (182 versus 210 days). To account for the distribution of calving dates throughout the year, annual basic rations have been established for two calving dates: 1 March and 1 November. The energy and nutrient contents of the forage included in the basic rations are based on existing surveys and the literature (for detailed information, see Schori 2020). A cereal mixture with 11.4 per cent CP, a dairy cow compound feed with 18 per cent CP, and a protein concentrate with 44 per cent CP in the dry matter were used to supplement all dairy cow basic rations to meet the guidelines of the reference, C18, and C12 scenarios. Table 2 lists the energy and protein content of the concentrates used. The ration calculations are based on the feed contents of net energy lactation (NEL) and the absorbable protein in the intestines when fermentable energy (APDE) or N (APDN) limits microbial growth in the rumen. Moreover, daily rations for each week, including concentrate supplementation, have been calculated according to maintenance requirements, milk production, and pregnancy of dairy cows, as well as the dry matter intake estimates (Münger, Schori, and Schlegel 2021). Finally, the weekly rations were summed up over a 1-year period. To calculate the concentrate supplementation of the C12 scenario, a second cereal mixture of 12 per cent CP with slightly different nutrient contents (Table 2) was necessary. The two cereal mixtures were considered to be one concentrate feed in the further evaluation of this scenario. The average milk yield of the dairy cows per standard lactation (305 days) for the reference scenario in the lowland and mountain regions has been derived from Schmid et al. (2021) (see Table S1). In the PRC scenarios, the feed rations were calculated for the same milk yields as in the reference scenario whenever possible; otherwise, the milk yield has been reduced. For the C18 scenario, however, a ration with an increased milk yield compared with the reference scenario has been calculated. The requirements of the program for the C18 scenario would allow this because the amount of concentrates is not limited, and the compound feed with 18 per cent CP has a slight protein surplus compared with the NEL content. All feed ration calculations were performed for multiparous cows with a body weight of 650 kg.

For suckler cows, one typical ration has been compiled per scenario (Table S1). The basic rations consisted of grazed herbage, hay, and grass silage. For the concentrate supplementation of suckler cows (maximum 55 kg dry matter per cow and year), the same concentrate feeds were used as for dairy cows. The amounts of concentrates were calculated the same way as for dairy cows, except that a standard lactation milk yield of 3,200 kg and a body weight of 670 kg have been assumed.

For rearing cattle intended to replace dairy cows, six rations were calculated for the entire rearing period: one for the reference, two for the C18 scenario [two different first calving ages, 24 and 29 months, corresponding to early-maturing cow types and the average first calving age in Switzerland (Schori 2020)], two for the C12 scenario (two different basic rations), and one for the C0 scenario. A total of seventeen subrations covered the period from the birth of the rearing calf (40 kg body weight) to the first calving (640 kg body weight). For five rations, we have assumed a first calving age of 29 months. The fodder used in the basic rations was hay, grass silage, maize silage, milk, and straw, depending on the weight of the rearing cattle. Based on the nutrient and energy requirements for rearing calves and cattle (Morel and Kessler 2017; Münger and Kessler 2017), the corresponding concentrate amounts for the various subrations have been calculated and summed up to the rations for the rearing period. For concentrate supplementation, depending on the scenario, we have formulated a cereal mixture with 12 per cent CP, a compound feed for heifers with 18 per cent CP, and a protein concentrate for heifers and bulls with 51 per cent CP (see Table 2).

For fattening bulls, we have created five rations, each with 10 subrations, covering the entire rearing and fattening period (40–550 kg body weight). One ration was provided for each scenario, except for the C12 scenario, for which two rations were calculated. Depending on the scenario, different daily body weight gains were achieved with average nutrient and energy concentrations of the roughage: 1,000 g in the reference scenario, 1,400 g in the C18 scenario, 1,000 g and 1,100 g in the C12 scenario, and 800 g daily weight gain in the C0 scenario. The forages used in the basic ration were grass silage, maize silage (not in the C0 scenario), and hay. Based on nutrient requirements for rearing calves and fattening bulls (Morel and Kessler 2017; Morel et al. 2017), the amounts of concentrate were calculated for all subrations and summed up for the rations per fattening period. For concentrate supplementation, depending on the scenario, we have used a high-energy cereal mixture, a compound feed for fattening bulls with 18 per cent CP, and/or a protein concentrate for heifers and bulls with 51 per cent CP.

2.3. Modeling the adoption of the program for PRC use and structural impacts at the national scale

We have modeled the farmers' adoption of the program for PRC use and the resulting structural impacts at the national scale by using the agent-based agricultural sector model SWISSland. This model was developed to support policy decisions by assessing the ex-ante impacts of new agricultural policies. SWISSland combines an agent-based approach with a microeconomic model at the farm scale (Möhring et al. 2016). In SWISSland, the agents are represented by almost 3,000 Swiss farms based on data from the Farm Accountancy Data Network (FADN) from 2016 to 2018 (hereafter referred to as base years). For each farm, the FADN dataset provides data on production resources (land area, labor resources, and housing capacity) at the farm level and on production costs (e.g. costs for concentrate feeds), revenues, product prices, and direct payments at the production activity level. We calculated the amount of concentrates for each cattle type based on the FADN concentrate costs in the base years using the method of Schmid and Lanz (2013). The roughage intake of cattle was estimated using the average intake corrected with the total roughage supply of the farm. SWISSland allows the modeling of different grassland production activities (intensive, extensive, and organic). Ex-ante production decisions (land use and livestock) of individual farms were determined based on a nonlinear optimization models applying positive mathematical programming (see Mack et al. 2019). We use recursive-dynamic farm-level optimization models. For each farm, we build up land resources and stables over the years based on their land leasing and investment decisions. For modeling farm exit decisions, we consider demographic effects such as the pension age of the farmers. SWISSland simulates structural change processes and income trends in Swiss agriculture over a period of up to 15 years. A land market implemented at the municipality level simulates the plot-by-plot leasing of land to surrounding neighboring agents that is common in Switzerland. Allocation of plots to tenants and lease pricing is modeled taking into account the farm-specific land rents. A detailed description of the SWISSland model is provided in Möhring et al. (2016).

The agents' individual program adoption versus non-adoption strategies were determined based on their compliance costs and direct payments of the program. Adoption decisions are forecasted under the assumption that farmers maximize their income. This means that farmers will adopt voluntary direct payment schemes when their compliance costs are lower than direct payments. The compliance costs reflect the foregone income when the feed rations of the reference scenario are adjusted to be in line with the rules of the revised program. We assumed that only farms that had already adopted the old program before 2023 would be eligible for participating in the revised program in the C18, C12, and C0 scenarios. The FADN records provide information on the program participation status of the farms in the base years. From 2019 to 2022, we assumed that the participation status of the farms would remain constant. Changes in feed rations and milk yields associated with the adoption of the revised program of the individual farms were calculated based on the results found in Section 2.2. Percentage changes for each cattle type were calculated for the following parameters: (1) milk yield, (2) amount of concentrates, (3) amount of forage, and (4) N content in the concentrate feed. For dairy cows, changes in feed rations and milk yields were calculated for four different feeding systems (adapted to lowland and mountain regions, with and without silage), hence allowing us to model the heterogeneity of dairy cow feed rations in Switzerland. Based on these percentage changes, we vary the observed feed rations of the farms in the base year to comply with the feeding requirements of the program. In response to the program adoption, farms can also change their crop choice and number of livestock. They can also specialize in certain production activities. However, farms cannot adopt new production activities that were not observed in the base year.

Model results for each agent on program adoption, concentrate input, milk yield, and agricultural income were scaled up to the national level based on the upscaling factors provided by the FADN system (Zimmermann et al. 2015).

2.4. Modeling feed-food competition at farm scale and the national scale

Two indicators for feed-food competition were calculated according to the method described in Nemecek et al. (2020) and Zumwald et al. (2019):

(i) The food competition indicator (*FC*) compares the human-digestible energy and protein content (*HDE*, *HDP*) of milk and meat with the corresponding human-digestible content in the feed that is needed to produce the milk and meat (formula 1). The protein values are corrected with a quality factor (*PQ*). The human-digestible energy and protein content of milk, meat, and feeds are listed in Table S3.

$$\text{(a)}\ FC_{HDE} = \frac{HDE_{\text{feed}}}{HDE_{\text{milk}} + HDE_{\text{meat}}}$$

$$\text{(b)}\ FC_{HDP} = \frac{HDP_{\text{feed}} \times PQ_{\text{feed}}}{HDP_{\text{milk}} \times PQ_{\text{milk}} + HDP_{\text{meat}} \times PQ_{\text{meat}}} \tag{1}$$

(ii) The land competition indicator (*LC*) calculates the amount of human-digestible energy and protein that could potentially be produced on the land used for feed production. The basis of this is four crop cycles from Zumwald et al. (2019) for different soil and climate conditions that are completely focused on food production, that is, they are without temporary grassland. The digestible energy and protein content of milk and meat are put into relation to this value (formula 2). The protein values are corrected with a quality factor. The potential amount of food production on land (HDE_{land}, HDP_{land}) is based on energy- and protein-maximizing crop cycles adapted to different soil and climate conditions in Switzerland. Table S3 shows the protein and energy production potential per hectare and land use for feed production

Figure 5. Scheme of a farm gate N balance according to Schmidt et al. (2017).

in the scenarios.

$$\text{(a)}\ LC_{HDE} = \frac{HDE_{\text{land}}}{HDE_{\text{milk}} + HDE_{\text{meat}}}$$

$$\text{(b)}\ LC_{HDP} = \frac{HDP_{\text{land}} \times PQ_{\text{land}}}{HDP_{\text{milk}} \times PQ_{\text{milk}} + HDP_{\text{meat}} \times PQ_{\text{meat}}} \quad (2)$$

2.5. Modeling the N surplus at the national scale

The SWISSland model has been used to assess how the program for PRC use affects the N surplus at the national scale. For this purpose, SWISSland uses a farm gate N balance based on Oenema, Kros, and de Vries (2003) (see Schmidt et al. 2017). This accounts for N input and output, both of which are assessed based on the Swissland model results (Möhring et al. 2016). N input comes from fertilizers, feed, animals, and N fixation and deposition. N output comprises the amount of N leaving the farm through the agricultural products sold.

We estimated the N in fertilizers used by each farm based on their fertilizer costs per hectare, which were available in the FADN database for most of their crops. Dividing the costs per hectare by the average fertilizer price, we obtained the amount of fertilizer per hectare. Multiplying this figure by an average N content and the crop production volumes provided the N input from fertilizers at the farm level.

Based on the amount of concentrates fed to cattle in the base years, we calculated the N input from the concentrates. N input from purchased animals was calculated by multiplying the simulated change in animal numbers in the scenarios by the average animal N content. In addition, the costs for purchased roughage available in the FADN database were used to estimate the amount of purchased roughage for each FADN farm. The amount of purchased roughage accounts for the N-input at farm level. However, purchased roughage is assumed constant in the ex-ante analysis.

Inputs through N deposition were calculated using standard values from Jan, Calabrese, and Lips (2013). The fixation rate per hectare strongly depends on land use. For pastures and meadows, values were calculated using the equations from Boller, Lüscher, and Zanetti (2003), here estimating clover share based on common seed mixtures, and by using Swiss standard yields and fertilizer application rates from Flisch et al. (2009). For soybeans and legumes, we assumed a fixation rate of 130 kg per hectare and year (Sorg 2005; Salvagiotti et al. 2008).

Figure 5 gives an overview of the farm gate N balance based on Schmidt et al. (2017). On the left side are all the inputs that enter the farm, and on the right are all the outputs that leave the farm.

2.6. Modeling greenhouse gas and NH_3 emissions on a national scale

Sectoral NH_3 and greenhouse gas emissions were estimated using the Swiss National Agricultural Greenhouse Gas Inventory model (Bretscher et al. 2021). The inventory model is based on the 2006 IPCC Guidelines (IPCC 2006) and is adapted to the national circumstances of Switzerland. As a central module, the inventory model uses the Swiss national NH_3 inventory AGRAMMON (Kupper et al. 2022) to model nationwide N flows in livestock manure and commercial fertilizers. Thus, the emission estimates comprise all sources from agricultural activities on farms, save for emissions from energy use and changes in soil organic carbon, as covered by the system boundaries of the IPCC guidelines (IPCC 2006). For the reference and PRC scenarios, we adjusted data on agricultural structures (livestock numbers, crop areas, and use of synthetic N fertilizers) according to the outputs of SWISSland. We used data from the different feeding rations to calculate the weighted average gross energy and dry matter intake and N excretion rates for all cattle categories. For this purpose, the values for the different feed rations described in Section 2.2 have been weighted according to the number of animals in the different production zones and based on their participation in the program for PRC use in each scenario. Values for the feed rations of animals not participating in the program were taken from Bretscher et al. (2021). Methane (CH_4) emissions from enteric fermentation were calculated as a fixed proportion of the gross energy intake (i.e. fixed CH_4 conversion rates), as described in Bretscher et al. (2021). NH_3, CH_4, and nitrous oxide (N_2O) emissions from manure management were estimated based on the excreted amounts of volatile solids, N, and the management in different storage systems. NH_3 and N_2O emissions from agricultural soils were calculated based on the amount of N inputs into soil in the form of animal manure, mineral fertilizers, crop residues, and mineralization of soil organic matter. Furthermore, the inventory model considers indirect emissions of N_2O through atmospheric N deposition, N leaching, and run-off. Greenhouse gas emissions were aggregated using the GWP_{100} values from IPCC (2007).

2.7. Biodiversity

We calculated the biodiversity effect for the entire agricultural land at the national scale and for land used for cattle feed production in each scenario, both for all farms and for only those farms participating in the program for PRC use. We obtained data from the Swiss Central Evaluation of Agri-Environmental Indicators (CEAEI 2020) for the years 2012–4. There, the biodiversity scores are calculated annually for individual crops using the SALCA-biodiversity method (Jeanneret et al. 2014). These scores describe the impact of all management activities on a field on eleven indicator species groups (flora of crops and grasslands, birds, mammals, amphibians, snails, spiders, carabids, butterflies, wild bees, and grasshoppers). The higher the score, the more biodiversity-friendly the production is. We have obtained biodiversity scores of all the relevant crops for the lowland and mountain regions, calculating an average value for each crop over the years 2012–4 and the two regions (Table S4). We combined these data (a) with figures on the use of agricultural land in the scenarios (Table S5) and (b) with the land use for cattle feed production (see Section 2.4). We obtained three metrics for each scenario: the area-weighted average biodiversity score (a) for the total agricultural land, (b) for the land used by all farms for cattle feed production, and (c) for the land used for cattle feed production by the farms participating in the program.

3. Results

3.1. Feed rations

Table 3 and in more detail Tables S1 and S2 list the dry matter intake of the annual basic rations as well as the fresh matter concentrate intake of dairy cows, suckler cows, fattening

Table 3. Basic ration and concentrate intake of the annual rations for dairy and suckler cows.

		Basic ration (kg DM head^{-1} a^{-1})	Cereal mixture (kg FM head^{-1} a^{-1})	Compound feed 18 per cent CP (kg FM head^{-1} a^{-1})	Protein concentrate (kg FM head^{-1} a^{-1})
Dairy cows	Milk yield (kg head^{-1} a^{-1})				
Reference	6,400–7,000	5,191–5,541	350–591	0	51–313
C18	6,400–7,600	5,191–5,570	89–719	176–955	0
C12	6,000–7,600	4,874–5,594	569–1,021	0	0
C0	5,000–5,400	5,141–5,573	0	0	0
Suckler cows	Milk yield (kg head^{-1} a^{-1})				
Reference	3,200	4,353	35	0	12
C18	3,200	4,353	33	24	0
C12	3,200	4,353	63	0	0
C0	3,200	4,408	0	0	0
Fattening bulls	Weight gain fattening period (g head^{-1} d^{-1})				
Ref	1,000	3,041	323	0	60
C18	1,400	2,120	0	640	0
C12	1,000–1,100	2,359–3,006	424–832	0	0
C0	800	4,087	0	0	0
Replacement heifers	First calving age (months)				
Reference	29	5,777	29	0	47
C18	29	5,781	0	71	0
C12	29	5,816	32	0	0
C0	29	5,844	0	0	0

FM, fresh matter.

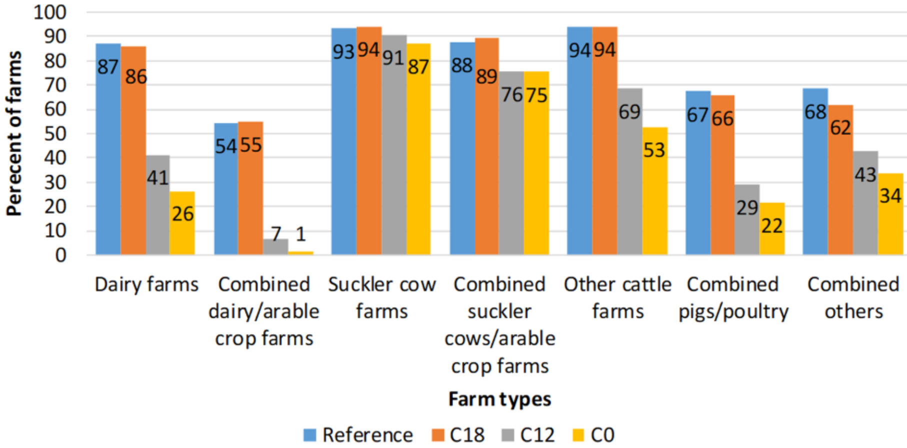

Figure 6. Percentage of farms adopting the program for PRC use in milk and meat production in the reference and PRC scenarios at the national scale (2026). Dairy farms represent 31 per cent of the total farm population; combined dairy/arable crop farm represent 5 per cent; suckler cow farms 8 per cent; combined suckler cow farms 3 per cent; other cattle farms 2 per cent; combined pigs/poultry 9 per cent; and combined others represent 8 per cent of the total farm population.

bulls, and replacement heifers. Depending on the scenario and conditions, the dairy cows produced between 5,000 and 7,600 kg of milk, ate between 4,874 and 5,594 kg of dry matter from the basic rations, and received between 0 and 1,132 kg fresh matter of concentrates. The suckler cows produced 3,200 kg of milk, ate around 4,400 kg of dry matter from the basic rations, and received 0–63 kg fresh matter of concentrates. Depending on the scenario and resulting daily weight gain, the fattening bulls ate 2,120–4,087 kg of dry matter from the basic rations and were supplemented with 0–832 kg fresh matter of concentrates during the entire fattening or growth period. The replacement heifers ate 5,777–5,844 kg of dry matter during the period before first calving. The calculated amounts of concentrate were modest for replacement heifers and were between 0 and 76 kg.

3.2. Program adoption and structural impacts

For most dairy, suckler cow, and other cattle farms, it is profitable to adopt the program for PRC use in the C18 scenario (Fig. 6). In the C12 scenario, it is profitable for only 41 per cent of the dairy farms and 7 per cent of the combined dairy/arable crop farms but is still profitable for more than 90 per cent of the suckler cow farms. In the C0 scenario, even with 360 CHF paid per hectare of grassland, it is profitable only for 26 per cent of dairy farms and 1 per cent of combined dairy/arable crop farms to adopt the program. In contrast, 75–87 per cent of suckler cow and combined suckler cow farms profit from adopting the C0 program in this scenario.

Figure 7 shows the percentage of animals fed according to program regulations. In the C18 scenario, 73 per cent of all cattle are fed according to the program regulations. The compliance rate is particularly high for suckler cows. In contrast, less than a quarter of all dairy cows are fed according to the program regulations in the C12 and C0 scenarios.

The effect of the program for PRC use on national milk and beef production is small. In all scenarios, beef production does not change compared with the reference. Although milk production also remains stable in the C12 scenario, it decreases slightly in the C0 scenario (–2.8 per cent). In contrast, the C18 scenario actually yields more milk than the reference (+5.7 per cent).

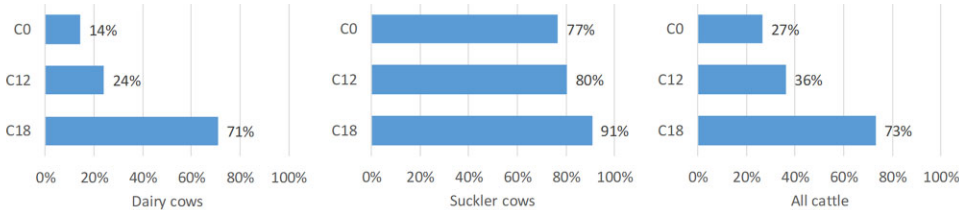

Figure 7. Percentage of animals fed according to the feeding restrictions of the program for PRC use in milk and meat production in the PRC scenarios at the national scale (2026).

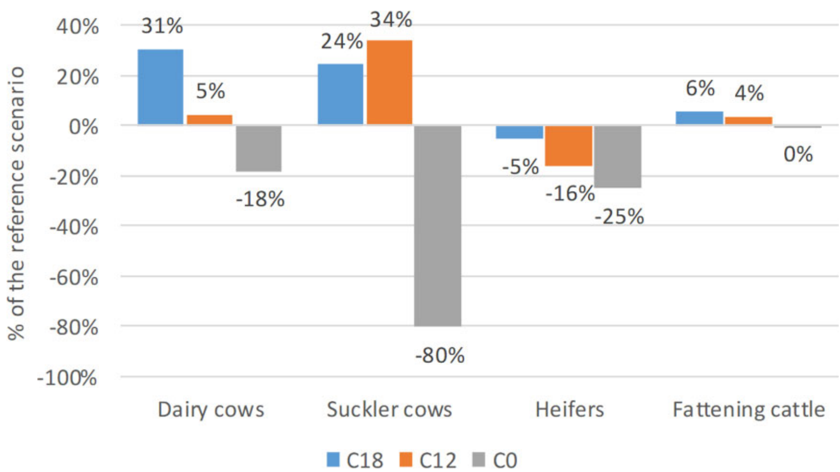

Figure 8. Percentage change in average concentrate feed intake per animal in the PRC scenarios compared with the reference (2026).

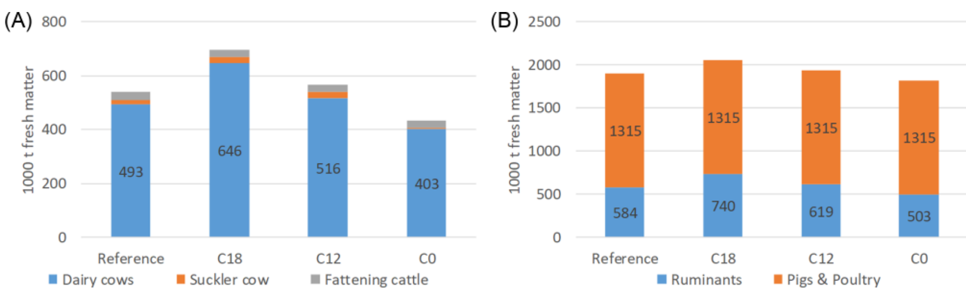

Figure 9. (a) Yearly concentrate feed intake of cattle at the national scale in the reference and PRC scenarios and (b) total concentrate intake of all livestock at the national scale (2026).

Regarding the average concentrate intake per animal, both the different PRC scenarios and different animal categories yield contrasting results (Fig. 8). Heifers are the only animal category in which the average concentrate intake decreases in all scenarios compared with the reference. For dairy and suckler cows, the average concentrate intake decreases only in the C0 scenario, and sharply so. In the other scenarios, and for fattening cattle, concentrate intake even increases, most notably for dairy cows in the C18 scenario. This is made possible by the definition of the rations (see Section 2.2).

In particular, the concentrate intake of dairy cows has implications for concentrate use at the national level (Fig. 9). Dairy cows contribute the largest share of the overall concentrate input for cattle (Fig. 9a). Therefore, the nationwide concentrate use for cattle increases by 30 per cent in the C18 scenario; it still increases slightly in the C12 scenario and only decreases in the C0 scenario. This trend also emerges when regarding nationwide concentrate use by all animal categories (Fig. 9b), leading to an overall increase by 8 per cent in the C18 scenario and only a slight decrease by 4 per cent in the C0 scenario.

However, the results clearly show that program adoption has mainly an impact on milk production and concentrate inputs, as well as fodder costs, whereas farms adopting the new program do not change their land use and livestock.

3.3. Feed-food competition

The food competition indicator lies below 1 in all scenarios (Fig. 10). This means that milk and meat provide more digestible energy and protein for humans than the human-digestible energy and protein contained in the feed. Looking at the national level (Fig. 10a), food competition increases in the C18 and C12 scenarios compared with the reference. Only in the C0 scenario does food competition decrease. The contribution of individual feedstuffs for potentially feeding humans does not change significantly in the scenarios. Maize silage and grains deliver the highest amount of human-digestible energy, and soybean meal delivers the highest amount of human-digestible protein.

Looking only at the farms participating in the program for PRC use (Fig. 10b), farms using concentrates with a maximum of 18 per cent CP (C18 scenario) increase both the amount of concentrate used and, to a lesser extent, their milk yield, resulting in higher food competition than in the reference. On farms using concentrates with a maximum of 12 per cent CP (C12 scenario), the amount of milk and meat produced decreases more than the human-digestible energy and protein content of the concentrates used, which also leads to higher food competition. Thus, in these two cases, implementing the revised program would produce the opposite of the intended results for the participating farms. Food competition drops significantly only on farms that do not use any concentrate feed at all (C0 scenario). It is not zero because these farms still feed some maize silage, which has nutritional value for humans.

The results show that even if individual farms were to change their cattle feeding rations, this would not have a large impact on the food competition in the nationwide farming sector. All numbers on the production of milk and meat, the amounts of individual feeds, and the land use in the scenarios are contained in Tables S5 and S6.

The values for land competition are greater than 1 in all scenarios, both for the entire sector and for only the farms participating in the program for PRC use (Fig. 11). This means that milk and meat provide less human-digestible energy and protein than could be produced on the land used for feed production if food crops were cultivated instead. The area potentially available for growing food crops consists of arable land and grassland. Assuming that grassland should not be converted to arable land, and that the share of temporary grassland should remain unchanged to maintain soil quality, prevent nutrient leaching, provide green manure, etc., the nationwide sector could still produce more human-digestible energy from existing arable land than is contained in milk and meat, but only about half as much human-digestible protein (Fig. 11a). This is also the case in the C18 and C12 scenarios when looking only at the farms participating in the program (Fig. 11b). In contrast, in the C0 scenario, the participating farms produce much more human-digestible energy and protein in milk and meat than could be produced on the arable land used for feed production. In all other scenarios, when it comes to human-digestible energy, it would be better to grow food crops on arable land instead of feed crops, but this would not be the case for human-digestible protein.

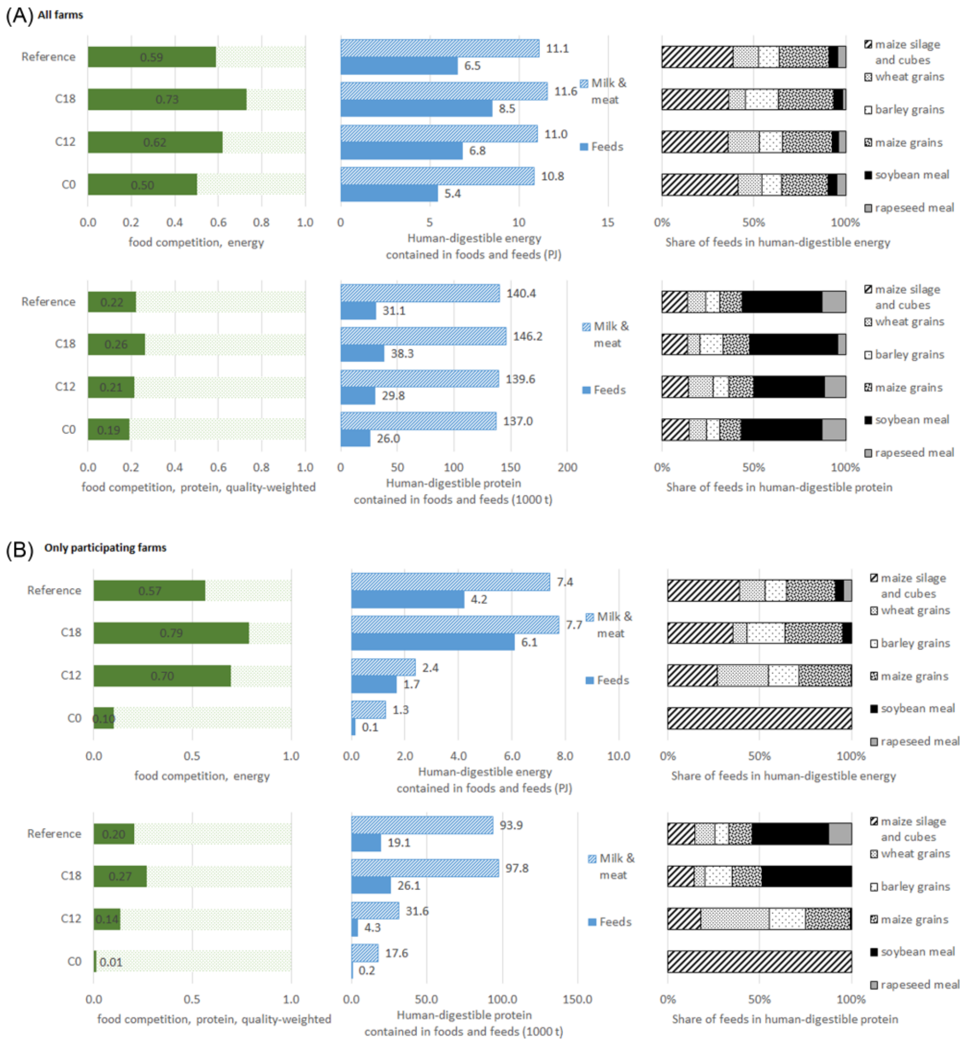

Figure 10. Food competition in all scenarios, human-digestible energy and protein content in produced foods and used feeds in the entire Swiss cattle sector, and the share of individual feedstuffs in the available human-digestible energy and protein (2026). (A) all farms (nationwide); (B) only farms participating in the program for PRC use in milk and meat production. For food competition, a value of 1 represents the amount of human-digestible energy and protein contained in milk and meat.

3.4. Environmental impacts

3.4.1. Nitrogen surplus on the national scale

The C18 scenario leads to an increase in the total N intake of cattle by 9 per cent because the volume increases while the N content in concentrate feed decreases. Conversely, in the C12 and C0 scenarios, N intake of cattle decreases by 3 per cent and 16 per cent, respectively (Fig. 12a). However, the total N intake by livestock changes only slightly in the scenarios (Fig. 12b) because the pig and poultry sectors are not affected by the program. In the C18 scenario, the total N intake of livestock increases by 3 per cent, while it decreases by 1 per cent in the C12 scenario and by 5 per cent in the C0 scenario. The program leads to only small changes in the N surplus at the national scale. For the C18 scenario, we observe

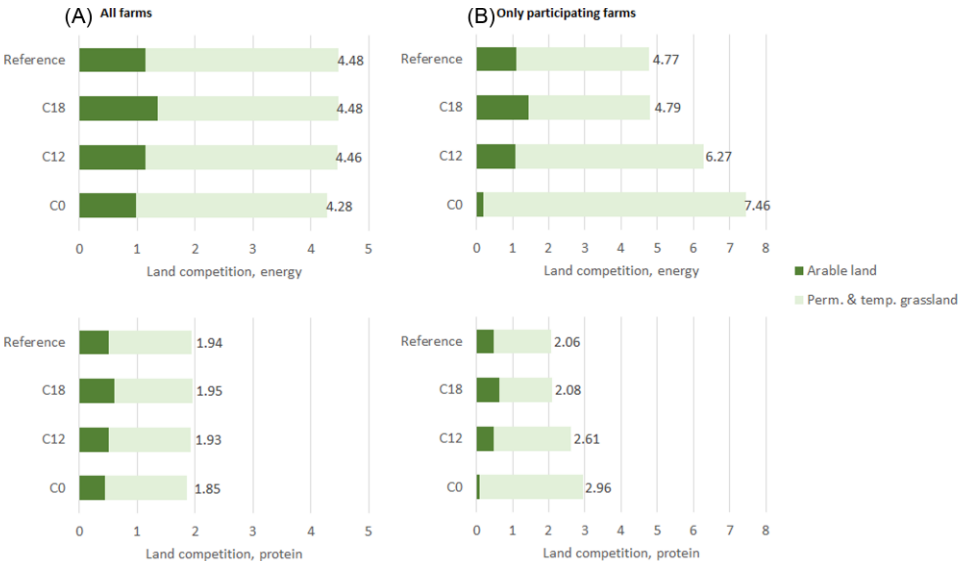

Figure 11. Land competition between feedstuff and food for humans in all scenarios (2026). (A) all farms (nationwide); (B) only farms participating in the program for PRC use in milk and meat production. A value of 1 represents the amount of human-digestible energy and protein contained in milk and meat.

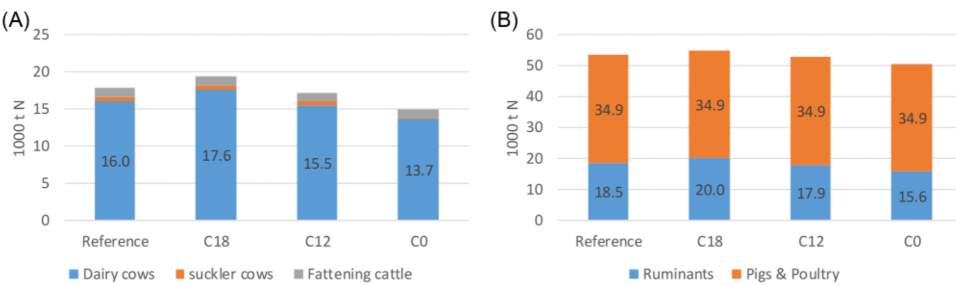

Figure 12. (A) Nitrogen intake in feed by cattle and (B) nitrogen intake in feed by all livestock at the national scale per year in the reference and PRC scenarios (2026).

a slight increase in the N surplus by 0.6 per cent because of the higher N input through concentrates, which cannot be compensated for by a higher N output. In the C12 scenario, the N surplus at the national scale decreases by 1.9 per cent, and in the C0 scenario, it decreases by 5.1 per cent.

3.4.2. Greenhouse gas emissions

The lowest greenhouse gas emissions are found for the C0 scenario, with a decline of 0.6 per cent compared with the reference scenario (Table 4). In the C12 and C18 scenarios, total greenhouse gas emissions increase by 0.2 per cent and 1.2 per cent, respectively. Nationwide livestock numbers and mineral fertilizer input, which usually have the greatest influence on overall greenhouse gas emissions, are very similar across the different PRC scenarios. Accordingly, the influence of these structural changes on overall greenhouse gas emissions is minimal in this case. Likewise, changes in feed properties and their influence on gross energy intake and N excretion rates (Table S7) only marginally affect the overall greenhouse gas emissions. This is partly because of the small differences between the rations and partly because of the low participation rate of the farms in the program. Changes in the gross

Table 4. Annual greenhouse gas and NH_3 emissions of the agricultural sector in the reference and PRC scenarios (2026).

	Greenhouse gas emissions				
	CH_4	N_2O	CO_2	Total	NH_3 emissions
Scenario	1,000 *t*	1,000 *t*	1,000 *t*	1,000 *t* CO_2-equivalent	*t* NH_3-N
Reference	150.7	6.3	44.3	5,686	40,698
C18	154.0	6.2	44.3	5,754	40,322
C12	151.3	6.3	44.3	5,698	40,616
C0	149.2	6.3	44.4	5,650	40,722

energy intake and N excretion rates of dairy cows have the largest influence on emissions in all scenarios. This can be explained by the large contribution of this animal category to overall emissions. In the reference scenario, dairy cows are responsible for 56 per cent of all CH_4 emissions and 47 per cent of all N_2O emissions from livestock. The other cattle categories contribute 33 per cent to CH_4 and 31 per cent to N_2O emissions. The C18 scenario leads to a higher gross energy intake and, hence, higher CH_4 emissions from enteric fermentation and manure management from dairy cows. In contrast, in the C0 scenario on farms participating in the program, dairy cows have a slightly smaller gross energy intake and N excretion rate, leading to lower CH_4 and N_2O emissions. However, these potential benefits are not exploited because, in this scenario, only a few farms participate in the program. Because the use of synthetic fertilizers does not change significantly in the different scenarios, their influence on the differences in greenhouse gas emissions is negligible. The same is true for the other agricultural emission sources (e.g. emissions from crop residues or the use of urea and lime).

3.4.3. NH_3 emissions

The lowest NH_3 emissions are observed in the C18 scenario, where they decrease by 0.9 per cent compared with the reference. In the C12 and C0 scenarios, NH_3 emissions decrease by 0.2 per cent and increase by 0.1 per cent, respectively. Thus, the impacts of the program for PRC use on nationwide NH_3 emissions are very low. However, the patterns are somewhat different from greenhouse gas emissions. Structural changes exert little influence on NH_3 emissions. However, from a management perspective, NH_3 emissions are mainly influenced by changes in the N excretion rates and, thus, by the farmer's ability to balance the feed ration in terms of energy and N. Therefore, higher production intensity leads to similar or even lower NH_3 emissions when the higher amount of protein that is fed is balanced by the higher energy density of the feed. Under these circumstances, more of the feed protein is transferred to the animal products, thus decreasing the amount of N lost to the environment. The changing feeding practices of both dairy cows and other cattle categories contribute more or less equally to the small impacts. In the C18 scenario, the slight decline is mainly because of the lower N excretion rates of dairy cows and fattening cattle. In the C0 scenario, the lower N excretion rates of dairy cows because of lower feed intake are leveled out by the low participation rate of farms. Additionally, the higher N excretion rates of breeding cattle, which are caused by the limitation of balancing feed rations in this scenario, reverse the otherwise slight downward trend in emissions. NH_3 emissions from sources other than livestock—namely, synthetic fertilizers—do not change significantly. This is partly because of the relatively low emission factors per kilogram of N compared with animal manure and partly because of the negligible changes in the total amount of synthetic fertilizers applied.

Table 5. Average biodiversity score per hectare for total agricultural land (nationwide), for the land used by all farms for cattle feed production, and for the land used for cattle feed production only by the farms participating in the program for PRC use in milk and meat production (2026).

	Reference	C18	C12	C0
The sector's total agricultural land	9.00	9.01	9.00	9.00
Land used by all farms for cattle feed production	9.54	9.37	9.54	9.62
Land used by farms participating in the program for cattle feed production	9.63	9.39	9.82	10.24

3.4.4. Biodiversity

The biodiversity score of the land used for cattle feed production is higher than that of the total agricultural land (Table 5). This is because most of the grassland is used for cattle, but only a smal proportion of the arable land is used for cattle, and grassland has a higher biodiversity score than arable land (see Table S4). The biodiversity score of land used exclusively for feed production on farms participating in the program for PRC use is even higher. This means that the program reaches farms that have higher biodiversity scores than non-participating farms, both in the reference and the scenarios with the revised version of the program.

At the national level, shifts between crops or intensity levels occur on a maximum of 1.5 per cent of agricultural land across all scenarios, so the impact of the scenarios on the biodiversity score is very small, and the program for PRC use has no decisive impact on the average biodiversity score. Positive effects in some areas are offset by negative effects in other areas. Considering only the land used for cattle feed production, the C18 scenario performs less favorably than the reference scenario. Restricting the use of concentrates to a maximum CP content of 18 per cent favors crops with a lower biodiversity score (the land used for grain and silage maize increases by 38 per cent on the farms participating in the program), while the used grassland area decreases slightly. In the other two scenarios, the farms participating in the program perform better than those participating in the old version of the program in the reference. In particular, the C0 farms improve because they no longer use any arable crops for feed except for some silage maize. Indeed, limiting the CP content of concentrates to 12 per cent also improves biodiversity (the land used for unfavorable crops such as maize, fodder beets, rapeseed, and soybeans decreases by 40–100 per cent). Overall, limiting the CP content of concentrates to 12 per cent or banning the use of concentrates has a positive impact on biodiversity when considering only the land used for feed production on farms participating in the program. However, no effect on biodiversity is visible at the national level.

3.5. Overall comparison of results

Figure 13 gives an overview of the percentage change of the indicator results compared to the reference at the national scale. We left out food and land competition protein, as the percentage difference between scenarios and reference is very similar to that of food and land competition energy. For the most part, there are only minor differences between the PRC scenarios and the reference. Only in the case of food competition are the effects more pronounced, with the C0 scenario performing more favorably and the C18 scenario performing less favorably than the reference.

4. Discussion

4.1. Direct payment system

Overall, the program for PRC use shows little or even adverse effects on the investigated indicators, especially when considering not only the participating farms but also the

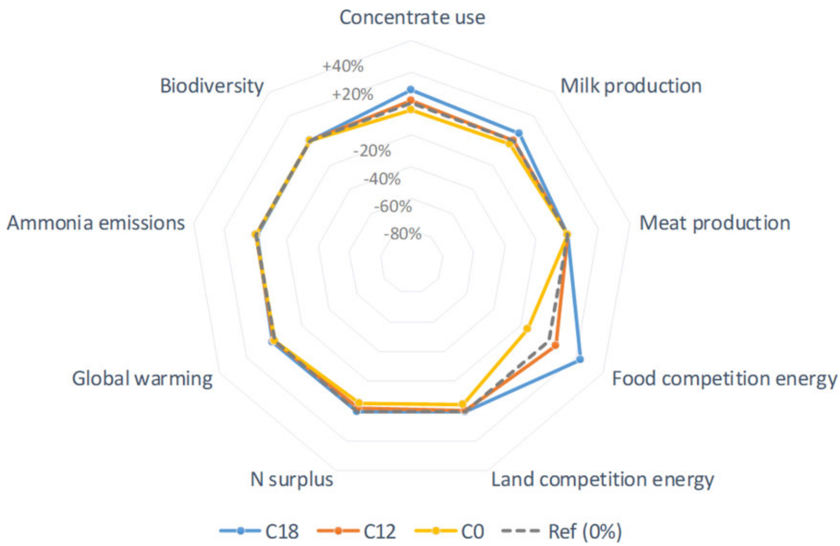

Figure 13. Percentage change of the indicator results compared to the reference at the national scale (2026).

nationwide agricultural production. The financial incentive to participate is either too small (in the case of concentrate-free feeding strategies) or the regulations are such that they enable an intensification with a higher amount of concentrates and milk yield increase (in the case of limiting the CP content of concentrates to 18 per cent). In its less strict revised forms (C18 and C12 scenarios) but also in the current form (reference), the program maintains structures instead of bringing about change. Similar outcomes have been reported for EU greening requirements, which are formulated in such a way that many farmers already reach the goals and do not have to change anything (Hart 2015). A possibility not considered in the revised program would be to limit the amount of concentrates that can be purchased, not only the CP content. This could also lead to lower feed-food competition of the participating farms in the C18 and C12 scenarios, and could have a favorable impact on the environmental indicators, as on the participating farms, land use and external N inputs would decrease. However, any adverse effects on animal yields and a possibly even lower participation rate would have to be considered likewise.

Switzerland already achieves a high share of grassland in ruminant rations (Ineichen et al. 2014) when compared with other countries (see Denmark, Germany, and Italy, as mentioned in Guerci et al. 2013), where there might still be potential to increase milk yield derived from the basic ration with less concentrate use. Furthermore, for Switzerland, with its low degree of self-sufficiency in foods, reducing productivity while maintaining consumption patterns would mean shifting environmental burdens abroad. Therefore, other areas of influence may be more promising for achieving agro-environmental goals. For example, achieving consumption patterns with fewer animal-based foods would improve all considered environmental indicators (De Vries and de Boer 2010; von Ow, Waldvogel, and Nemecek 2020). In addition, site-adapted fertilizer management could have a favorable impact on N surplus and greenhouse gas emissions (Snyder et al. 2009; Argento et al. 2022). Furthermore, taking pigs and poultry feeding into account and advancing the feeding of residues from food processing could improve feed-food competition much more than focusing on cattle alone (Manceron, Ben-Ari, and Dumas 2014; Schader et al. 2015; Mottet et al. 2017).

4.2. Scenario assumptions

The direct payment system could also offer all three levels of protein-reduced feeding and financial compensation at the same time. This would suggest another scenario in which farmers can freely choose between the three options of PRC use. However, since the most promising option in terms of feed-food competition and environmental impacts (no concentrate use in the C0 scenario) is not chosen by many farmers if it is the only option available, there is no reason to assume that more farmers would choose it if they had the other options available at the same time. And since the results of the C12 and C18 scenarios are the same or more unfavorable than the reference, offering C0 as an additional option would not make such a mixed scenario perform better than the current C0 scenario. In a mixed scenario, the results for our indicators would lie somewhere in between the scenarios we already investigated.

We have assumed that grassland management remains unchanged in the participating farms. Further investigation is needed to assess the extent to which grassland management changes would influence the structural and environmental impacts of the program. More frequent harvesting or conversion of permanent to temporary grassland could lead to higher efficiency of grass-based feeding without concentrates and, therefore, to a higher adoption rate in the C0 scenario. However, the favorable impact of the no-concentrate feeding strategy on biodiversity could be undone because the grassland management intensity would be increased, and thus grassland would receive a lower biodiversity score.

In our calculations, we assumed that all concentrates used by participating farms are purchased and comply with the program's protein content restrictions. However, the regulations of the program would allow farmers to grow their own concentrate feed without any limitations on CP content (see Section 2.1). On the one hand, this would affect only a minority of farms because in Switzerland, specialized grassland farms that do not produce concentrates on their own land are the most important farm type for cattle farming[1]. On the other hand, farms growing and using concentrates with a higher protein content could further weaken the already low impact of the program on the investigated environmental indicators and feed-food competition.

In SWISSland, we model for each ruminant farm observed feed ratios based on FADN data and vary them to comply with the new policies. This allows us to calculate the compliance costs of the new program based on the farms' observed feed ratios prior to the reform. However, this approach reduces flexibility in farm adaptation for agents who would find it optimal to choose a feed combination not in the preselected set of options. This assumption might lead to an overestimation of the farms' compliance costs and, in turn, to an underestimation of the program adoption.

Modeling results on the adoption are based on the assumption that farmers are purely profit maximizers. Consequently, we do not consider factors such as risk perception and preferences, environmental attitudes, non-cognitive skills, and the general openness of farmers toward this new voluntary environmental program. To reduce the model bias against reality (see Troost et al. 2023), we assumed that those farmers who have already adopted the previous program on PRC use might also be open-minded to the new program, while those who have previously not adopted the old program will not be open-minded to the new program. Therefore, a database on the adoption of the old program by FADN farms was used. Furthermore, we do not consider the administrative burden associated with the adoption of the new direct payment program. However, we assume the administrative burden will not increase in comparison to the previous version. The present analysis refers to a system restricted to the Swiss agricultural sector. Indeed, the program for PRC use in the C12 and C0 scenarios could reduce feed imports from abroad and, thus, the unfavorable environmental impacts associated with imports. In both scenarios, the participating farms do not use soybean products, and in the C0 scenario, overall concentrate use is strongly reduced. Especially regarding water scarcity and biodiversity, the impacts in Switzerland's most important countries of origin for feeds can be higher than in Switzerland (Boulay et al. 2018; Chaudhary and Brooks 2018; Bystricky et al. 2020). Reducing concentrate feed could also reduce greenhouse gas emissions abroad because feed imports contribute more than 4 per cent to the greenhouse gas footprint of Swiss agriculture (FOAG 2021). Greenhouse gas emissions related to agricultural inputs from abroad are not covered by our method. Considering them, the C0 scenario would reduce greenhouse gas emissions more than is currently estimated.

4.3. Methodological choices

The method for feed-food competition was originally developed for a comparison of meat and milk from individual farms and applied by us unchanged. When comparing different scenarios on the national level, however, the method could be adapted. If the focus is on crops and land as limited resources, then it would make sense to consider not only the feed or land directly used for milk and meat production but also the surplus feed or land that is no longer used for feeding animals if less feed is needed in one scenario than in another. In our case, the food competition results of the reference and the C0 scenarios would improve compared with the other two scenarios because they use less concentrate feed, freeing up the surplus concentrate feed for human consumption. The difference in the results between the scenarios would increase, but the interpretation would remain the same. For the land use indicator, the reference, C12, and C0 scenarios would receive a bonus compared with the C18 scenario, with the best result for the C0 scenario because it has the lowest land use for milk and meat production, freeing up the most land for food crops. Again, the rating order of the scenarios would not change.

4.4. Uncertainty factors

Model results of our study represent point predictions, which are based on a broad range of exogenous assumptions regarding price and cost development, direct payments, and assumptions regarding technical and breeding progress (see Möhring et al. 2016). With every exogenous assumption, uncertainties regarding the adoption rate and consequently the environmental impacts of the program are introduced into the model (Troost and Berger 2015). The development of milk and concentrate prices are the most influential exogenous assumptions for program adoption by farmers. However, these assumptions in particular are based on expert knowledge (see Mack and Möhring 2021). Therefore, we discuss below how an increase or decrease in milk and concentrate prices would affect program adoption. We expect that if concentrate prices were to increase under *ceteris paribus (c.p.)* conditions, then the adoption rate of dairy farms would likely decrease in the C18 and C12 scenarios due to rising concentrate costs. In contrast, we would expect an increased adoption rate of dairy farms in the C0 scenario because farmers could achieve higher cost savings in this case. If milk prices were to increase *c.p.*, then the adoption of dairy farms would likely increase in the C18 scenario because the program would lead to increased milk production. In the C12 scenario, on the other hand, the adoption rate of dairy farms would likely decrease. This would also be the case in the C0 scenario, as the program would lead to higher losses in milk revenues. For suckler cow farms and farms with rearing calves, we expect that the adoption rate would not be affected by concentrate and milk prices, as program adoption has little effect on concentrate costs for these farms. We also expect that nationwide milk production would further increase in the C18 scenario as milk prices rise. In the C0 scenario, national milk production would be similar to that in the reference scenario. Changes in the adoption rate of the direct payment program would also affect feed-food competition and environmental indicators. With a higher adoption rate of the program in the C18 scenario, the negative effects on feed-food competition and environmental indicators would increase, while the results would remain similar in the C12 scenario, and the positive effects in the C0 scenario would increase. With a decreasing adoption rate, the effect in the scenarios would be reversed.

5. Conclusions

Swiss agricultural policy wants to promote grass-based cattle feeding through a voluntary direct payment program that is currently being revised. The revision that we analyzed in this paper suggests financial compensation for using concentrates with limited CP content. In a multimodel approach, we investigated the program adoption rate, feed-food competition, and environmental indicators at the national scale for Switzerland.

The less strict the requirements regarding the protein content of concentrate feeds, the more cattle farmers will likely adopt the new voluntary program for PRC feeding. When the CP content of concentrates is limited to 18 per cent, participation would be economically advantageous for the majority of Swiss cattle farmers. However, this variant of the program allows for a higher amount of concentrates and higher milk yields than in the reference and has the opposite of the intended effect regarding feed-food competition and environmental indicators (only NH_3 emissions are slightly reduced). In the variant with a 12 per cent limit of CP content in concentrates, participation is less profitable and therefore lower, and feed-food competition and environmental effects at the national scale tend not to differ greatly from the reference. Banning the use of concentrates altogether moves the indicators in the intended direction for the farms participating in the program. A low participation of the agents when banning the use of concentrates shows the economic disadvantage of this scenario, which might also lead to a lower participation of farms in reality. Our study has shown that ex-ante evaluations are important to expose ineffectual policy measures and improve their design before introducing new direct payment programs. We suggest that to achieve the intended improvements of structural and environmental indicators at the national scale, the investigated program has to be sharpened, for example, with maximum amounts of concentrate feed allowed, in addition to limiting protein content. In the case of reducing feed-food competition and improving the environmental impacts of the food sector, other fields of influence have to be included in agricultural policy, such as the consumption patterns of the population, working on site-adapted fertilizer management, and taking the pig and poultry sectors into account. This is especially true in countries like Switzerland, where cattle feeding already relies on concentrates much less than in other countries. The model results of our study represent point predictions that are based on a broad range of exogenous assumptions regarding prices and costs. A sensitivity analysis on the assumptions with a high uncertainty could reveal effects that were not anticipated and should be included in further policy modeling studies.

Supplementary material

Supplementary data are available at *Q Open* online.

Data availability

The data underlying this article are available in the article and in its online supplementary material.

End Note

1 In Switzerland, the open arable land covers only 26 per cent of the utilized agricultural area. In the mountain region, it covers less than 12 per cent of the overall utilized agricultural area.

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