FiBL

Sustainable and healthy diets: Trade-offs and synergies

Final scientific report

NRP 69 "Healthy Nutrition and Sustainable Food Production"

FiBL: Matthias Stolze (PI), Christian Schader, Adrian Müller, Anita Frehner

Flury & Giuliani: Birgit Kopainsky

Rütter Soceco: Carsten Nathani, Julia Brandes

Uni Zürich: Sabine Rohrmann, Jean-Philippe Krieger, Giulia Pestoni

ZHAW: Christine Brombach, Stefan Flückiger, Matthias Stucki

Treeze: Rolf Frischknecht, Martina Alig

SGE: Angelika Hayer

Research Institute of Organic Agriculture FiBL | Ackerstrasse 113 | Postfach 219
5070 Frick | Switzerland | Phone +41 62 865 72 72 | info.suisse@fibl.org | www.fibl.org

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1. Lay summary of the project and results

Recommendations for sustainable and healthy diets

How can we achieve a healthy and sustainable diet? The interdisciplinary project was looking for answers to this question based on different scenarios of how eating habits among the Swiss population could develop until 2050. It analysed how diets have an impact on public health and sustainability. Based on the analysis of representative data on Swiss food consumption and the analysis of the scenario results, the project team developed a set of recommendations targeted to different stakeholder groups.

Background

Our eating habits have far-reaching consequences for our way of life: the ways in which food is produced, processed and consumed affects the environment, the economy and society as a whole. At the same time, many common illnesses are linked to nutrition. For these reasons, sustainability and health will be important factors in future diets. The interdisciplinary research project analyses synergies and trade-offs between these two areas. It presents different scenarios and proposes strategies to make nutrition in Switzerland healthier and more sustainable.

Aim

The study analysed how the eating habits of the Swiss population affect the environment, the economy, society, and public health. The interdisciplinary research team highlighted the eating habits of the Swiss population and their consequences in terms of public health on the basis of statistical analysis. It anticipated possible diets in 2050 based on different scenarios and assess them in terms of sustainability and health. Based on the results, the researchers provide recommendations to specific target groups involved in shaping sustainable and healthy nutrition.

Relevance

The project adopted a new holistic approach in assessing the impact of nutrition on the environment, the economy and society at home and abroad, and on public health in Switzerland. The researchers investigated how eating habits could develop and the possible consequences until 2050. Based on different scenarios, they identified synergies and trade-offs between sustainability and public health. By submitting recommendations to decision-makers and consumers, the project will contribute to reducing diet-related environmental, social and health costs.

Results

The project shows that a change towards healthier eating would in principle simultaneously also benefit environmental and social sustainability. For instance, eating less meat would be beneficial for all dimensions of sustainability. Furthermore, it would reduce the gap between the average Swiss diet to the recommendations given by the Swiss Society for Nutrition and the Alternate Healthy Eating Index. Economic impacts of such shift in diets would be two-fold: On the one hand, the value added in the Swiss Food Sector is likely to go down. On the other hand, expenditure of consumers will also drop. The net self-sufficiency of the Swiss Food Sector will increase as imports will go down.

However, when it comes to more specific questions, such as "what kind of meat needs to be reduced?", substantial trade-offs need to be accepted. While an environmentally optimal scenario with respect to local resource use would include only the meat from the dairy sector and some meat coming from monogastrics fed on by-products, social impacts abroad may increase depending on the countries of origin of pulses, which would need to be imported.

Furthermore, there is a mismatch between an optimal healthy diet and an environmentally optimal food system. In other words, consumption of only high-quality meat does not comply with using natural resources efficiently, because meat products of lower quality could substitute high-quality meat in terms of energy and protein delivery but may be associated with negative health impacts (e.g. highly processed meat). Furthermore, the dietary recommendations regarding dairy products and ruminant meat lead to considerably inconsistencies on the production side due to the coupled character of these products. The study identified several such mismatches and the consequences in terms of land use, environmental impacts, dietary patters and health impacts. Additionally, several likely responses by different types of operators in the food systems can be identified and would require targeted policies in order to account for them.

Implications of the research

From the results of this research project, several important recommendations can be given to policy makers, consumers, and food producers. For policy makers, it would be important to stronger align food, health and agricultural policy to each other – what is needed is a food policy that is consistent on all levels, from agricultural production to dietary recommendations. This would lead to the reduction of support for agricultural products, that come with a larger gap between the Swiss average diet and recommendations for healthy eating, i.e. particularly sugar and meat. Eating less meat and less sugar are known recommendations with respect to health but they also benefit the environment. If a fundamental transition towards a more sustainable food system and healthier diets is aimed for, food industry can support this by investing in new technologies, which ease concepts of a circular economy (such as re-use of nutrients) and the development of new livestock feeding concepts.

2. Executive Summary of research and results

This project aimed at analysing trade-offs and synergies between healthy nutrition and sustainable food systems. First, we identified nutritional patters of the Swiss population based on representative consumption data. The health impacts of these nutritional patterns were then analysed based on a review of the scientific literature on health impacts of food commodities and diets and by calculating the Alternate Healthy Eating Index (AHEI), the Mediterranean Diet Score (MDS) and Disability Adjusted Life Years (DALYs) of the nutritional patterns.

Second, we comprehensively analysed health, environmental, social and economic impacts and related trade-offs and synergies for a number of future scenarios of Swiss agricultural production and food consumption. For this, we used a modelling approach, linking three different models: a global mass flow model, a system dynamics model and an environmentally extended input-output model.

We modelled ten different scenarios for the Swiss Food Sector in 2050. These scenarios were either developed in a participatory process during a series of interviews and group discussions with different groups of stakeholders or optimised environmental impacts while at the same time complying with different nutritional and agronomic restrictions. Three main scenarios were analysed with all three models in detail. Among these main scenarios was the SwissFoodPyramid2050 Scenario, which assumes a widespread implementation of the nutritional recommendations according to the Swiss Food Pyramid. The FeedNoFood2050 Scenario assumes an improved use of agricultural land by feeding only grass and by-products to livestock, which was not competing with direct human nutrition, i.e. did not require arable land (neither in Switzerland nor abroad). The third scenario was a reference scenario, which assumes no changes in diets until 2050 and which was used to compare the two alternative scenarios. The other scenarios were targeted at specific questions such as minimizing greenhouse gases.

Our results illustrate two visions of how healthy diets and sustainable food systems could look like. Both the SwissFoodPyramid2050 and the FeedNoFood2005 scenarios would require similar dietary changes, such as a reduction of meat consumption and an increase of consumption of pulses. However, there are also fundamental differences between the diets in the two alternative scenarios, e.g. regarding the type of meat consumed. These differences can be interpreted as trade-offs which result from agronomic boundary conditions such as the coupled production of milk and meat, the availability of natural resources, such as grassland and co-products of food processing and health aspects of Swiss diets. Of primary importance in this respect was the use of permanent grasslands and the co-production of veal and beef with dairy production due to environmental reasons and reasons for optimally utilizing available resources. This means, if permanent grassland should be maintained as an ecosystem, dairy production would provide the basis for animal proteins. Thus, while in the FeedNoFood2050 Scenario veal and rather low-quality beef from dairy cows is consumed instead of meat from monogastrics, the SwissFoodPyramid2050 Scenario would result in a higher amount of meat from monogastrics.

Our results imply that there is a lack of a comprehensive food systems view in the current discussion on healthy and sustainable diets. Stronger coherence between health, food and agricultural policy is needed to account for systemic boundary conditions and thus to allow for minimising trade-offs and maximise synergies. Current agricultural policies fail to address the health perspective. Financial support for meat and sugar producers, which lead to lower prices for those products and ultimately to a higher consumption than without these policies, are two obvious examples. Yet, comprehensive visions such as the SwissFoodPyramid scenario, the FeedNoFood Scenario or optimised scenarios would require an even more complex policy mix of incentives, regulations and information campaigns. This would probably need an adaptation of the current institutional setting and division of competences between the Federal Offices for Agriculture (FOAG) and for the Environment (FOEN), the State Secretariat for Economic Affairs (SECO) and the Federal Food Safety and Veterinary Office (FSVO).

A commonly shared vision, including specific goals with respect to how the Swiss food system should look like, is urgently needed. Developing such a vision needs to involve all operators and stakeholders of the food system, as our results imply that more sustainable and healthy diets do not necessarily go along with financial benefits of both producers and consumers. These trade-offs and the knowledge of behavioural economics need to be considered for designing settings which create mutual benefits for operators in the food sector. For instance, neither the majority of consumers, food industry nor agricultural producers can be expected to respond altruistically as an entire sector in the long term. Therefore, policy needs to set financial incentives for internalising environmental and social externalities in order to push and pull the food system towards sustainability. Furthermore, it is crucial to account for agronomic boundary conditions and systemic aspects, such as the *r*ole of ruminants in utilizing grasslands and the unavoidable link of milk and meat production.

3. Objectives of the research project, hypothesis and methods

This project pursued the following objectives:

- To statistically analyse current dietary patterns of the Swiss population based on the extensive consumption data provided by menuCH and to assess the health impacts of those dietary patterns;
- To define scenarios until 2050 for potential future dietary patterns in Switzerland, and relate those to health and sustainability aspects;
- To assess how effective different consistent scenarios could be regarding increasing public health and sustainability of the Swiss food system and thus how they perform regarding a range of public health and sustainability criteria. For this and the scenario calculations, an integrated model was developed that allows assessing the environmental, social and economic impacts of the Swiss agri-food

system, both in Switzerland and abroad, as well as the health impacts of dietary patterns;

- To derive target group specific recommendations for the realisation of sustainable and healthy diets and to design and implement dissemination activities for these recommendations.

We addressed following main research questions:

1. What are the environmental, social and economic impacts of a transition of the Swiss food system to healthy diets, both in Switzerland and abroad?
2. What are the trade-offs and synergies between different aspects of health and sustainability with respect to dietary choices, public health policies and interventions?
3. How can dietary patterns be adjusted and production systems be optimised to balance sustainability and public health goals?
4. What are practical dietary recommendations and food policy implications for Switzerland that help to optimise environmental, social and economic sustainability and public health?

In order to achieve the above aims, we first assessed dietary patterns (menuCH) and their health impacts by means of literature review and calculating the Alternate Healthy Eating index (AHEI) as well as Disability/Disease Adjusted Life Years (DALYs) associated with the respective diets (WP2). By means of literature review and stakeholder consolation, we identified major trends in nutrition and the food sector for 2050 for defining main scenarios that are relevant with respect to trade-offs and synergies between healthy nutrition and sustainable food systems (WP3). The main component of our project was the model-based integrated analysis of these scenarios and the trade-offs and synergies occurring between health and sustainability by means of three complementary models with different foci in the food system (WP4 and WP5). Finally, we developed recommendations with respect to diets and policy interventions (WP6) (Figure 1).

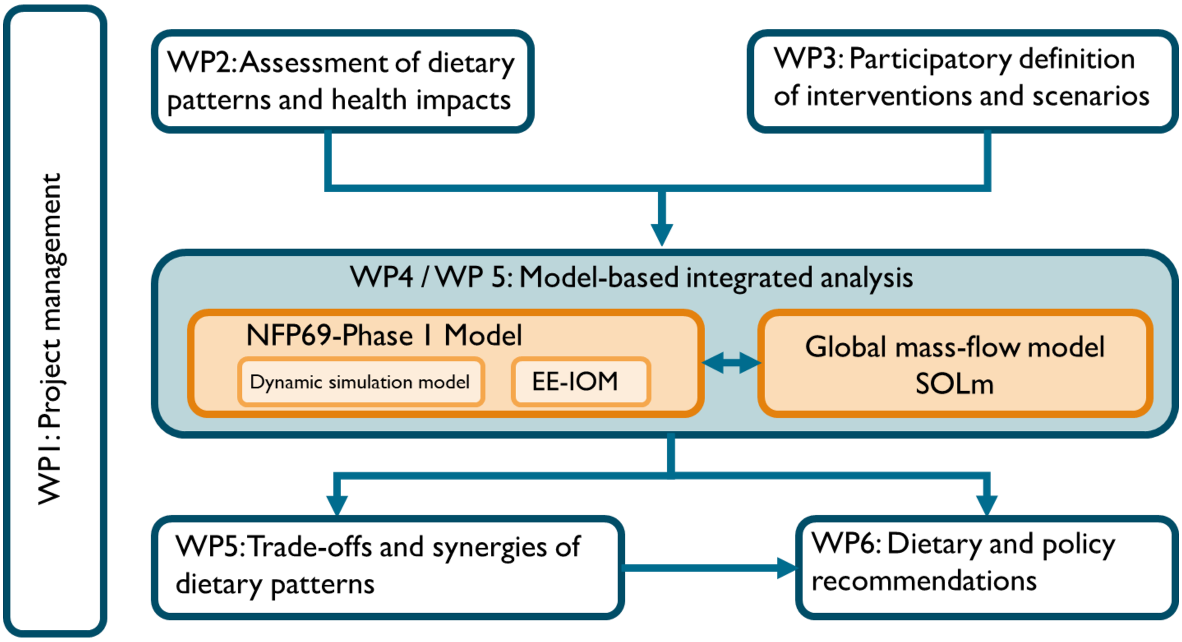


Figure 1: Overview of project structure

4. Results, including how do results compare to international state of the art

In this Section, we present our results by work package. The later sections will summaries and synthesise the results across work packages.

4.1 WP2: Assessment of dietary patterns and health impacts

4.1.1 Literature review and expert consultation on health impacts

The aim of the analysis of health impacts by means of literature review and expert consultation was to summarise the current state of the art on dietary health impacts of different food groups and the level of consensus among experts for different impacts as a basis of deciding how to model health impacts in an integrated approach in WP4 and WP5.

Approach

For the literature search, we conducted a *Literature Consensus Review*: In a first step, a literature review was conducted. Thereby, key findings of reviewed articles, meta-analysis and systematic reviews from Europe and worldwide were extracted and a summary of the key findings was produced. The *Summary of Key Findings* presented the linkage between food groups and lifestyle factors and their risk to develop one of the chosen chronic diseases and subsequently proposed a first idea of the main drivers in nutrition and health.

In a second step, a panel of expert was selected in order to give feedback on the *Summary of Key Findings.* The purpose of this approach was to produce a *Consensus Expert Summary*. By doing so, the group was able to identify possible weaknesses or inconsistencies of the *Summary Key Findings* based on their knowledge and field of expertise. The findings or outcome is a *Literatur*e *Consensus Review* based on the literature search and grounded by expert consultation with the overall aim to give recommendations on main nutritional drivers for public health in Switzerland. More details on the approach can be found in Brombach *et al.* (2017).

Results of the *Consensus Literature Review* show the most valid evidence for *nuts and seeds, legumes and beans* and *whole grains* in chronic disease prevention and consequently can be termed as the strongest nutritional drivers in prevention of the investigated diseases (T2DM, CHD, CVD, cancer, stroke, and obesity). Additionally, *physical activity* has been identified as a very strong lifestyle factor in chronic disease prevention. Therefore, the importance of these nutritional drivers plus physical activity should be implemented in guidelines for public health. However, this work focused on certain types of chronic diseases only and the impact of other chronic diseases (such as mental illnesses, respiratory diseases or diseases of the gastro-intestinal tract) needs to be taken into account as well in order to give general recommendations. On the contrary, *processed meat, heavy alcohol use* and *physical inactivity* have been identified as the most important chronic disease promoters and thus, should be limited or avoided in the individuals' diet and lifestyle.

The results of this paper are encouraging and should be validated in future work. Therefore, it is suggested to have a closer look on certain food groups (such as energy-dense food, dairy products or vegetable oils) in order to investigate complex interactions in more depth. It would be beneficial to choose one food group and investigate their impact on chronic disease prevention. In doing so, it is highly emphasized to follow a top-down approach since a sustainable diet is very complex and implies several key categories, which highly influence each other as presented in the introduction section. Even though, this paper provided sufficient evidence for the most important nutritional drivers in the prevention of certain types of chronic disease, portion size and amount of the food group (e.g. nuts and seeds) needs to be considered as well since it is important to firstly, not exceed energy intake and secondly, to follow a varied diet.

Main findings

The main findings are summarised in Table 1 and the text below

Fruit & Vegetables: The current literature provides controversial findings. Most of the reviewed papers have shown either a positive or no effect of fruit & vegetable consumption and the development of chronic diseases. Hence, this food group is identified as a medium nutritional driver.

Nuts & Seeds: The current literature provides strong evidence for nuts & seeds consumptions and its positive effects on chronic diseases due to its high-potential ingredients. Since nuts & seeds are high in energy, more focus should be applied to portion size and frequency. Nonetheless, this food group is identified as a strong nutritional driver due to the strong evidence of its high beneficial effects.

Vegetable Oils: This food group seems to be a strong nutritional driver in decreasing the risk of chronic diseases. Anti-oxidant compounds such as PUFAs (polyunsaturated fatty acids), polyphenols, tocopherols and carotenoids might play an important role in chronic disease prevention. Nevertheless, the literature highlighted beneficial effects strongly depend on quality, processing method, temperature and storage. Hence, this food group is identified as a medium nutritional driver.

Fish: Controversial findings have been detected on the positive effects of fish consumption in the prevention of chronic diseases. Level of contamination, persistent organic pollutions as well as type of fish seems to be an important factor in the risk prevention of chronic diseases. This food group was first identified as a weak nutritional driving factor based on the literature search. Yet, it is classified as a medium driving factor due to the feedback from some experts of the expert panel and due to the latest paper by Calder (2017). The paper illustrated that there is growing evidence for the beneficial effects of fish consumption on chronic diseases due to its N-3 fatty acids. Nevertheless, more studies on this food group are needed to confirm the classification as a medium nutritional driver and to further examine the potential risks of contamination.

Legumes & Beans: The current literature provides strong evidence for legumes & beans and their positive effects on chronic diseases (except for peas and fermented soy foods, where one controversial finding has been found in the literature). Hence, this food group is identified as a strong nutritional driver.

Whole Grains: The current literature provides strong evidence for whole grains and their positive effects on chronic diseases, because whole grains in general, and fibre in particular are an important carrier of health-promoting bio-actives. Hence, this food group is identified as a strong nutritional driver.

Dairy Products: In almost all chronic diseases, controversial findings have been found among the literature search with regard to yogurt, fermented milk and cheese. It has been shown that this food group can have positive, neutral or negative effects. Possible explanations might be that other factors such as type of production (e.g. fermentation) or type of fat (e.g. low-fat, whole fat) should be considered as well as mineral nutrients and vitamins (e.g. calcium, Vitamin D, microbiota). This food group requires further study to elucidate the effects due to product type is too diverse and hence is identified as a weak nutritional driving factor.

Starches and Refined Grains: The reviewed papers provide convincing evidence for starches and refined grains and their harmful effects to develop chronic diseases with exception of the systematic review by Williams (2012). Hence, this food group is identified as a medium chronic disease promoter.

Sugar-added Food: The current literature provides controversial evidence of sugar consumption and its association to the risk of chronic diseases. Most of the reviewed papers provide evidence that it might have harmful effects when the amount of sugar exceeds normal food intake compared to neutral effects when sugar consumption is replaced with energy-equivalent macronutrients. Total energy intake seems to play a key role in this association. More data is needed to define the weight of its harmful effects on the risk of chronic diseases and to give more recommendations on the Upper Limits of sugar intake. Similar findings occur in the association of Sugar Sweetened Beverages and their effects on the development of chronic diseases. A current topic is the impact of High Fructose Corn Syrupe as one of the main sugar-added product, but this investigation is out of scope of this summary paper. Taking above into account, this food group is identified as a medium chronic disease promoter.

Processed Meat: The reviewed papers provide strong evidence that processed meat consumption (serving of 50g per day) increases the risk of certain types of chronic diseases. Hence, this food group is identified as a strong chronic disease promoter.

High-Trans-Fat Food: The current literature provides evidence that consumption of high-trans-fat food might have either harmful or no effects on the risk of chronic diseases. Nevertheless, only limited or no evidence has been found for some chronic diseases with regard to this food group and thus conclusions have to be made with caution. Based on the reviewed data, this food group is identified as a medium chronic disease promoter.

High-Sodium Food: The reviewed literature provides convincing evidence for high-sodium food and its harmful effects on the risk of chronic diseases except for T2DM and obesity for which no findings are provided in the reviewed papers. Nonetheless, the impact of high-sodium food on salt-sensitives and salt-resistant individuals need to be taken into account. This food group was first identified as a strong chronic disease promoter based on the reviewed literature, yet it is classified as a medium chronic disease promoter since the reviewed papers did not consider the genetic background of individuals. Further studies needs to be done to examine the gene variants associated with salt sensitivity, whose proteins interfere in cell functions and hence may have an impact on the risk to develop a certain chronic disease in relation to salt intake.

Energy-Dense Food (food which are highly processed, and contain high amounts of energy but little vital nutrients): Based on the limited amount of data, it is difficult to classify energy-dense food into a specific category. Indeed, there is a tendency that energy-dense food might be a chronic disease promoter rather than a nutritional driver, especially when it comes to obesity. Recent research could also detect a positive association between energy-dense food intake and the higher risk to develop T2DM. Therefore, this food group needs to be further investigated to draw further conclusions.

Alcohol: To see whether alcohol intake promotes or inhibits the risk of chronic disease, it is important to separate alcohol consumption in light/moderate or heavy use. Moderate or light use seems to have either protective or neutral effects, whereas heavy use might have harmful effects on the incidence of chronic diseases. Hence, moderate alcohol use is identified as a weak driver and decreases the risk of chronic diseases (except for cancer where controversial results have been found), while heavy use is identified as a strong promoter of chronic diseases.

Physical Activity: The evidence is very strong and the literature shows very clear results that physical activity seems to have a high beneficial effect in reducing the risk of chronic diseases and hence is identified as a strong driver in the risk reduction of chronic diseases. Thus, the evidence shows clear results that physical inactivity seems to be a strong chronic disease promoter.

Table 1: Overview of the impacts of different food groups on health drivers and disease promotors

	Health Driver			Disease Promoter		
	Decreases the risk to develop Chronic Diseases			*Increases the risk to develop Chronic Diseases*		
	Food group	*CD*	*Effect**	*Food group*	*CD*	*Effect**
Strong	**Nuts & Seeds**	T2DM CVD CHD Cancer	+ + + +	**Processed Meat**	T2DM CVD CHD Stroke Cancer	- - - - -
	Legumes & Beans	T2DM CVD CHD Cancer	+ + + +	**Alcohol → heavy use**	all 6 diseases	-
	Whole grains	T2DM CVD CHD Obesity Cancer	+ + + + +	**Physical Inactivity**	all 6 diseases	-
	Physical activity	all 6 diseases	+			
Medium	**Fruits & Vegetables**	CVD Obesity	+ +	**Starches Refined Grains**	T2DM CVD CHD Cancer Stroke	-/0 -/0 - -/0 -
	Vegetable Oils (depending on processing method; quality)	CVD CHD Stroke Obesity	+ + + +	**SSB**	T2DM CVD CHD Cancer Stroke Cancer	-/0 -/0 - -/0 - -
	Fish (effects depending on contamination)	CVD CHD Stroke	+ + +	**High-trans-fat Food**	T2DM CVD CHD Cancer Obesity	- -/0 - -/0 -
				High-Sodium Food	CVD CHD Cancer Stroke	-/0 -/0 - -/0
Weak	**Dairy Products**	5 diseases → controversial findings (except for CHD)	+/0/-			
	Alcohol → moderate use	T2DM CVD CHD Stroke Cancer	+/0 +/0 +/0 +/0 +/0/-			

*+ beneficial effect; - harmful effect; 0 neutral effect

CD chronic diseases, CVD cardio-vascular diseases, CHD coronary heart diseases, T2DM type 2 diabetes mellitus

4.1.2 Assessment of dietary patterns and health impacts

From a public health perspective, determinants of diet choices are crucial to identify, but they are unclear today in Switzerland. Hence, we sought to define current dietary patterns and their sociodemographic and lifestyle determinants using the national nutrition survey *menuCH*. The cross-sectional population-based survey menuCH was conducted between January 2014 and February 2015 in ten study centres across Switzerland. Swiss residents aged 18 to 75 years old were drawn from a stratified random sample provided by the Federal Statistical Office. From a gross sample of 13,606 individuals, 5496 were successfully contacted by mail or phone, and 2086 accepted to schedule an interview in one of the study centres (38% net participation rate). Among the 2086 participants, 2057 had two complete 24-h dietary recalls (24HDRs) and were included in the analysis. Two twenty-four hour dietary recalls (24HDR) were used to assess the participants' diet: The first 24HDR was conducted face-to-face and the second one was done two to six weeks later on the phone.

The amounts of foods consumed (in grams) were summed within each of the 17 categories and over each 24HDR. We then used a two-step procedure to identify dietary patterns. First, we used multiple factorial analysis (MFA). In a second step, the seven first principal components were used as inputs to hierarchical clustering using the Ward criterion.

Based on the clustering, four dietary patterns were identified ("Swiss traditional": high intakes of dairy products and chocolate, *n* = 744; "Western 1": soft drinks and meat, *n* = 383; "Western 2": alcohol, meat and starchy, *n* = 444; and "Prudent": *n* = 486; Figure 2). In a second step, we used multinomial logistic regression to examine the determinants of the four dietary patterns: ten sociodemographic or lifestyle factors (sex, age, body mass index, language region, nationality, marital status, income, physical activity, smoking status, and being on a weight-loss diet) were significantly associated with the dietary patterns. Notably, belonging to the French- and Italian-speaking regions of Switzerland increased the odds of following a "Prudent" diet (Odds ratio [95% confidence interval]: 1.92 [1.45, 2.53] and 1.68 [0.98, 2.90], respectively) compared to the German-speaking regions.

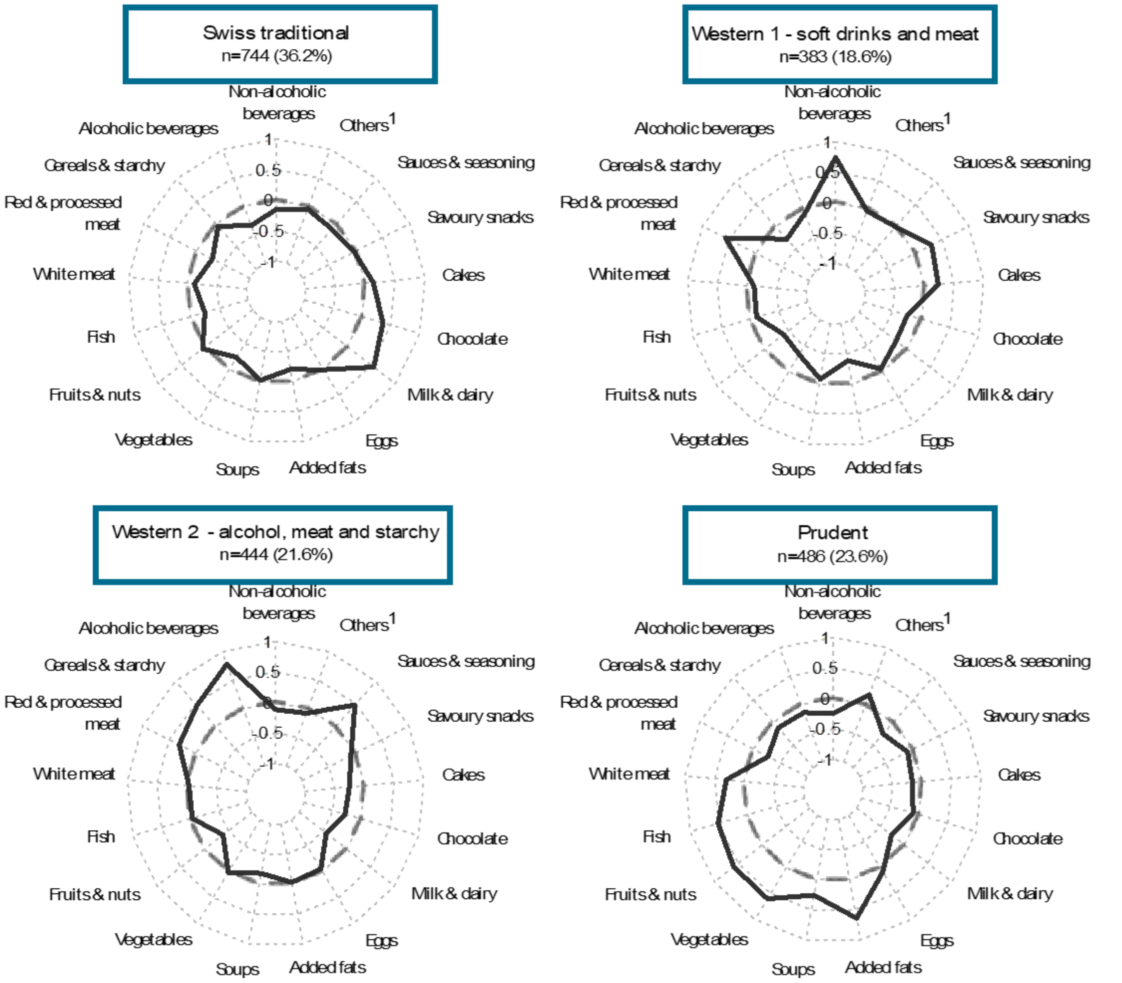


Figure 2: Food consumption profiles in the four dietary patterns relative to the overall population. Energy-standardised consumptions of the 17 food categories were centred and reduced for the overall study population (z-standardisation). Each axis of the radar plots indicates the mean of the centred-reduced energy-standardised consumptions of one food category within one dietary pattern, i.e., how the consumption in a dietary pattern deviates from the consumption in the overall population. A positive and a negative value indicate consumptions above and below the mean of the overall population, respectively. [1] Others include meat substitutes, milk substitutes and meal replacements

4.1.3 Alternate Healthy Eating Index (AHEI)

Based on the menuCH data, we also calculated two dietary scores that characterise the „healthiness“ of a person's diet, i.e., the Alternate Healthy Eating Index (AHEI) (McCullough and Willett, 2006) and the Mediterranean Diet Score (Sofi *et al.*, 2008).

The AHEI was based on the Healthy Eating Index, which aims to assess the adherence to the Dietary Guidelines for Americans. The updated 2010 version of the AHEI was further based on discussions with nutrition experts and on a comprehensive literature review, which allowed us to identify foods and nutrients associated with lower risks of major chronic diseases. The AHEI includes 11 components: vegetables, fruits, whole grains, sugar-sweetened beverages and fruit juices, nuts and legumes, red and processed meat, trans fat, fish, polyunsaturated fatty acids, sodium and alcohol. The score of single components can range from 0 to 10 points, with intermediate food intakes scored proportionately between the minimum and the maximum score. Overall, the total AHEI can range from 0 to 110 points, with 0 meaning minimal adherence and 110 meaning maximal adherence.

The Mediterranean Diet Score (MDS) was constructed in 1995 with the aim of assessing adherence to the traditional Mediterranean diet and was revised in 2003 to include fish intake. The score includes nine components: vegetables, legumes, fruits and nuts, cereals, fish, meat, dairy products, fat intake and alcohol. For each component, a value of either 0 or 1 point is assigned to the participants depending on different sex-specific cut-offs. Overall, total MDS can range from 0 to 9 points, with 0 meaning minimal adherence and 9 meaning maximal adherence to the traditional Mediterranean diet.

Linear regression models were used to investigate the determinants of diet quality and chi-square tests were used to test for differences in single score components between language regions. Significantly higher diet quality scores were observed for individuals who were female, older, normal weight, non-Swiss, with tertiary education or moderate-to-high physical activity level. We also observed differences between the Swiss language regions such that individuals living in the Italian- and French-speaking part of Switzerland tended to have a healthier diet compared with the German- speaking parts (Figure 3). This was observed for the AHEI (Figure 3a) and the Mediterranean Diet Score (Figure 3b). More specifically, the higher diet quality observed in the French- and Italian-speaking regions was mediated by higher scores in the components of alcohol, dairy products, fat, fish, sugar-sweetened beverages and whole grains.

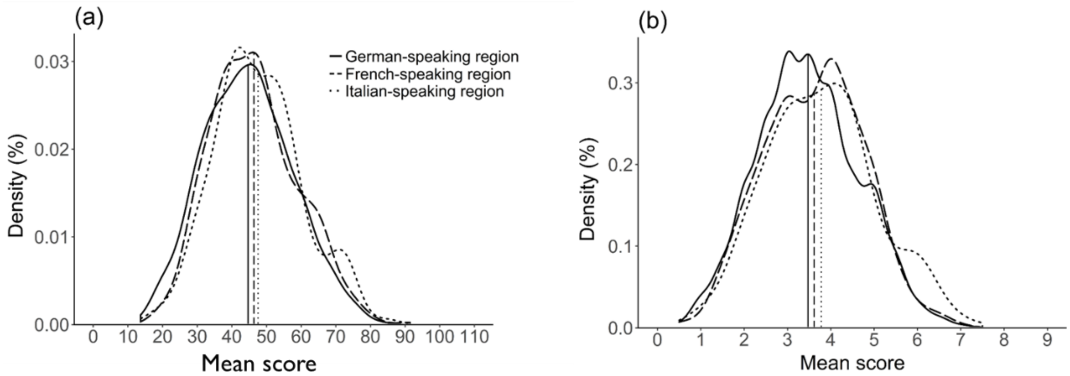


Figure 3: Weighted density plots of (**a**) Alternate Healthy Eating Index (AHEI) and (**b**) Mediterranean Diet Score (MDS) by language region (n = 2057). The density plot is a smoothed representation of a histogram and shows the distribution of a variable. In the graph, the total area under the curve is 1 (i.e., the integral of the variables is scaled to 1). The density plot allows for a direct comparison of the language regions, although each region has a different number of participants. The density plots were weighted for sex, age, marital status, major area of Switzerland, nationality, household size, season and weekday. Vertical lines represent the weighted mean for each language region.

Combining both types of dietary patterns, we observed that individuals, who follow a prudent dietary patterns, have the highest Heathy Eating Index and those with the pattern „Western 1", the lowest Healthy Eating index.

Our findings highlight the influence of sociodemographic and lifestyle parameters on diet and the particularities of the language regions of Switzerland. These results may help to better characterize population groups requiring specific dietary recommendations, enabling public health authorities to develop targeted interventions.

4.1.4 Disability-Adjusted Life Years (DALYs)

In a following step, we assessed whether following a healthy diet was related to fewer healthy life years lost. Since we were not able to link menuCH data to morbidity or mortality, we applied the dietary patterns observed in menuCH to an older Swiss study (NFP-MONICA cohort), in which diet has, although in a more crude way, been assessed and for which mortality follow-up until the end of 2016 of the participants is available. We calculated DALYs for individuals whose deaths were attributed to a NCD in the NFP-MONICA cohort. We considered the following : all neoplasms (ICD-8: 140-239; ICD-10: C00-D48), diseases of the circulatory system (ICD-8: 390-459; ICD-10: I00-I99), diseases of the respiratory system (ICD-8: 460-519; ICD-10: J30-J98), diabetes mellitus (ICD-8: 249-250; ICD-10: E10-E14) and chronic liver diseases (ICD-8: 570-573; ICD-10: K70 and K74). DALYs were computed as the sum of the Years of Life Lost due to premature mortality (YLL) and the Years Lost due to Disability (YLD).

A total of 4,590 deaths occurred during the study follow-up, among which 3,378 deaths were caused by NCD, representing a total of 58,770.6 DALYs from NCD. The vast majority of DALYs were attributable to cancers (32572.5) and cardiovascular diseases (21944.8). In both the crude and multivariable adjusted two-part model, the "Swiss Traditional" pattern was not associated to an increase in DALYs compared to the "Prudent" pattern" (

Table 2). In the crude model, the “Western” pattern was associated to an increase of 0.55 DALYs (95% CI 0.24; 0.86) compared to the “Prudent” pattern. After multivariable adjustments, individuals following a “Western” pattern had on average 0.29 DALYs (95% CI 0.02; 0.56) more than those following a “Prudent” pattern, equalling to a loss of healthy life of more than three months.

Table 2: Regression coefficient and 95% confidence intervals (CI) of the association between dietary patterns and DALYs in the census-linked cohort

		Prudent	Traditional	Western
n		6601	2849	2508
DALY	**sum**	23696.9	9218.7	10734.1
YLL	**sum**	16829.0	6623.8	7874.2
YLD	**sum**	6868.0	2594.9	2859.9
DALY	**mean ± SD**	3.6 ± 7.8	3.2 ± 7.8	4.3 ± 8.7
YLL	**mean ± SD**	2.5 ± 6.1	2.3 ± 6.1	3.1 ± 6.8
YLD	**mean ± SD**	1.0 ± 2.3	0.9 ± 2.2	1.1 ± 2.4
Crude		Reference	-0.01 [-0.29; 0.26]	**0.55 [0.24; 0.86]**
Adjusted		Reference	-0.01 [-0.28; 0.24]	**0.29 [0.02; 0.56]**

4.2 WP3: Participatory definition of interventions and scenarios

4.2.1 Literature review and expert consultation on future trends

We face different societal trends, which at present seem to influence the food system and the view on it. This was explored in a literature and expert interviews on main trends and its developments on the food system. We conducted qualitative interviews with experts form the Swiss food system (administration, politics, catering business, researchers, health care, food trend scouts, and medical research). A detailed German report was produced (Flückiger *et al.*, 2017). The following paragraphs cover only the main aspects extracted from this report.

Approach

At the beginning of the literature research the following criteria were defined for including a reference in the review: a) Publication from 2010 – 2017, b) English and German references, c), Description of trends until 2050. The search was conducted in „Web of Science“ (www.webofknowledge.com) and „Google Scholar“ (http://scholar.google.ch/). The analysis came up with the following main trends:

Main Findings

Westerns diet with lower meat consumption (denoted as “flexitarian style”)

This trend will have a strong effect on society, environment, health and agriculture

Vegetarianism and veganism

This trend will have effects on society, health, agriculture

Trends relating to convenience food, functional food

This will have medium level effects on society, health, and environment

Organic and eco foods

This will have medium to strong effects on society, markets, and agriculture, but not on health

Regional and do-it-yourself

This will have strong effects on society and values

Special diets such as Mediterranean and New Nordic Diet

This will have little effect on society and medium effect on health

Experts furthermore agreed on the following statements:

a) Nutrition has a major impact on health and the environment.
b) Consumption of meat products will have to be reduced, at global and at Swiss level.
c) The Swiss population will have to adapt to changing food supply on the market, such as new products.
d) An increase in regional, convenience, and vegetarian food were viewed as most frequent food trends.
e) Trends have different impacts on society, markets and health.

However, there were different ideas about solutions (emphasis) between scientists, government and consumer organizations.

4.2.2 Formulation of consistent scenarios via stakeholder workshops

Approach

Based on the literature reviews and expert interviews on future trends in the food sector we challenged interviewees with both findings of the food trends and health promoters and barriers. Their responses were used during a stakeholder workshop, to further consolidate consistent scenarios in order to explore the option space for the future Swiss food system.

Main results

Several scenarios were defined and then analysed using an integrated health sustainability model (see Section 4.3). All scenarios are framed for the year 2050, which is a time horizon frequently used in food system scenario analysis. Generally, rather extreme situations have been chosen, to reveal the consequential trade-offs and synergies of changes in different key parameters in the food system. It has to be emphasized that these scenarios should not be interpreted as forecasts, as they were not defined with respect to the most probable development trajectory, but with regard to corner stones that can serve as advantage to make significant improvements in the food system. Where possible, specifications within scenarios were tied to existing scenarios from previous publications (e.g. FOEN Climate report 2017, SFOE Energy perspectives 2050, and FSO Scenario population development). This ensures that key parameters of the scenarios, which are not specifically adjusted in this analysis, are based on best estimates available.

Based on trends identified in the previous analysis and inputs from the stakeholder workshop, three scenario groups have been defined with the following foci: (1) health, (2) environmental sustainability and resource use, and (3) consumer preferences. Further, a reference scenario for 2050 was defined as comparison baseline for the other scenarios.

4.2.2.1 Reference scenario

The reference scenario serves as baseline projection for the future state of the Swiss food system. For this, current production and consumption patterns of Switzerland are scaled such that they fit for projected boundary conditions for the year 2050. 10.28 Mio people are expected to live in Switzerland by then (BfS, 2015b), and the area available for agricultural use is expected to decrease by almost 20% from today due to pressures on land from different sources, such as living area, biogas production, transport infrastructure, etc., to 863’500 ha (BfS, 2015a). As this means that more people live in Switzerland with less agricultural area, a higher share of food products has to be imported if productivity does not increase substantially. Import shares were taken from FAOSTAT 2008, and scaled such that domestic production did not exceed the projected available land for 2050.

Consumption patterns for the reference scenario have been specified based on the menuCH-data (WP2). As the menuCH-data are representative only for specific regions and age groups, scaling factors were applied to estimate consumption patterns for whole Switzerland. Production patterns are assumed to develop based on the Swiss Agricultural Outlook 2014-2014 (Möhring et al., 2015). Furthermore, to also account for developments of production types, it is assumed that the share of products produced organically doubles as compared to today values (Bio Suisse, 2017).

4.2.2.2 Scenario with focus on human health

For this scenario, consumption patterns of Switzerland are defined based on dietary recommendations following the Swiss Food Pyramid (SFP). Thus, this scenario is based on the assumption that the whole Swiss population follows the guidelines of the Swiss Society for Nutrition, which allows analysing the full consequences of these recommendations. All other key parameters are defined such that they are consistent with the SFP, and are kept as close to the reference scenario as possible.

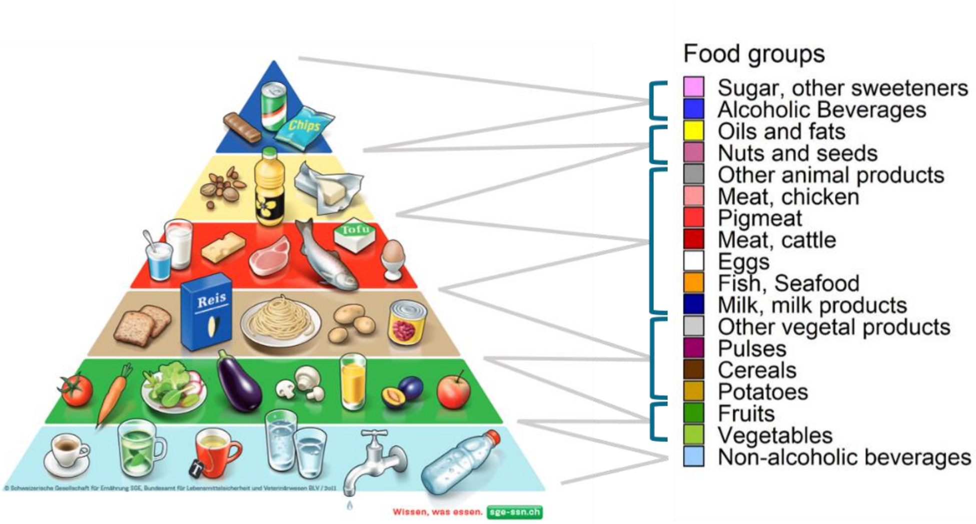


Figure 4: Swiss Food Pyramid linked to the food groups of the analysis

4.2.2.3 Scenario with focus on environmental sustainability and resource use

The scenario focusing on environmental sustainability and resource use follows the narrative of optimal resource use in a systems context; resources are allocated such that their role from a food systems view is optimised, which especially influences animal production drastically compared to today. Today, feed produced for animals is often produced on agricultural land which could be used for production of food for direct human consumption, thus, a feed-food competition occurs (Schader et al., 2015, Muller et al., 2017, van Zanten et al., 2018). Therefore, in this scenario, animals are fed only with by-products (monogastrics, such as pigs and chickens), and grassland (ruminants, such as cattle). By this, animals convert streams that humans cannot eat directly to animal-source food, such as milk, meat and eggs, but do not compete for resources with humans. Implicit in this assumption is that animal numbers are limited to the amount of grassland and by-products available; therefore, the amount of animal-source food consumed in Switzerland in this scenario is limited to what can be produced with these feed streams in Switzerland, as it is also assumed that imports for animal-source food are not allowed. For consumption, this signifies a reduction between 60 and 80% for meat, depending on meat type (which is equivalent to about 9 g bovine meat, 16 g pig meat, and 7 g chicken meat per day). This includes however not only the most prominent parts of animals, but also processed products from less valuable parts of the animals. For milk products, the reduction from the reference lies between 20 and 40 %, depending on milk product type. Eggs are expected to decrease by 85%.

Grassland can be further distinguished in permanent grassland and temporary grassland; permanent grassland is mostly on land that cannot be used to produce other crops, and therefore, for permanent grasslands, it is easier to rule out competition for food production. However, with temporary grassland, it is less straightforward: temporary grasslands are grasslands that are part of crop rotations, and thus, lie on areas where also food products can be grown. The reason that temporary grasslands are often sown within crop rotations is that they can fix nitrogen from the air in the soil, and by this, contribute to soil fertility. Thus, because temporary grasslands are often implemented in agricultural practice but they theoretically contribute to feed-food competition, we model two sub-scenarios: first, the scenario FeedNoFood2050 with the inclusion of temporary grasslands, and second, FeedNoFoodNoTemp2050 without temporary grasslands.

Further assumptions for this scenario group focus on the substitution of the animal-source food that was reduced: as a plant-based, protein-rich substitution, pulses were selected and thus increased until the protein intake of the SFP2050 scenario was met. All other plant-based food groups are kept in relative area and consumption shares as in the reference. Further, the share of organic produce was assumed to double with respect to the reference scenario.

4.2.2.4 Scenario with focus on consumer preferences

In the stakeholder workshop it was further initiated that consumer preferences should be in focus for one scenario group. More specifically, it was noted that on the one hand this could include wishes for more regionalised, seasonal products, high animal welfare standards, improved health and environmental aspects (reduced wastage, reduced nitrate leaching, more vegetables, etc.) and products with labels, and on the other hand, a low willingness to pay for food products and services. This results in main inconsistencies, such as between increased vegetable production versus reduced wastage, reduced nitrogen use and increased seasonal and regional production, or between increased organic production and reduced imports. Although such a scenario would not be consistent, it is important to discuss scenarios with a focus on consumer preferences, as this can help to reveal inconsistencies of consumer preferences.

For the following analysis, it was decided not to implement scenarios with a focus on consumer preferences in the models, because it proved extremely difficult to construct a scenario that would be feasible for the models and at the same time include these consumer wishes. However, the fact that such a scenario can hardly be quantified is already an important result, because it makes obvious that such a focus on consumer preferences can lead to food system states that exhibits inconsistencies and also impossibilities. This insight can be used as information for consumers, to point out that inconsistencies arise if different and contradicting consumer preferences are implemented.

4.2.2.5 Characterisation of consumption patterns

In Figure 5 on the left, the domestically available amount (i.e. including production and net imports) per person per scenario is presented. On the right, the total content of carbohydrates, energy, fat and protein per scenario is shown. The red lines indicate the minimum requirement set for the scenarios, and the dotted lines indicate the minimum (and maximum) of the DACH reference values.

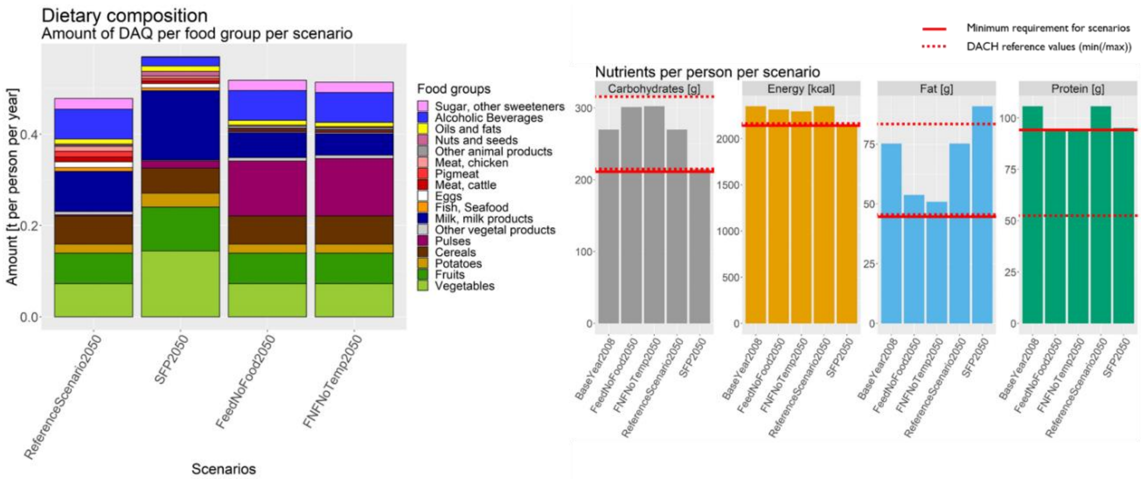


Figure 5: Left: domestically available quantity (in t per person per year) per scenario per food group. Right: Total nutrients available per person per scenario.

4.3 WP4: Development of an integrated health-sustainability model

The integrated model is built from three models that each focus on specific complementary aspects. These are the system dynamics model, focusing on an economically and agronomic consistent model of the Swiss agricultural production sector, the environmental extended input output model, focusing on the other economic sectors in Switzerland besides agriculture, including their environmental impacts, and the SOL-model, focusing on global agricultural production, nutrient flows and consumption, including environmental impacts of the global agricultural production. These models are shortly described in the following.

4.3.1 System dynamics model

The system dynamics model is a further development of the dynamic simulation model built in the NRP69 phase 1 project 406940_145178 "Environmental-economic models for evaluating the sustainability of the Swiss agri-food system" (Kopainsky *et al.*, 2018). The model has a number of key characteristics that are important for the interpretation of the results generated by this model:

- Time horizon: The simulation model spans a time horizon from 2000 to 2050. The historical time period allows calibrating and validating model simulations against historical data. The long time period into the future allows for an analysis of the impacts of changing societal and global mega-trends (e.g. climate change, population growth, resource scarcity) on the Swiss agri-food system. 2050 as time horizon for ex-ante assessments is used by many agri-food system studies assessing global trends and developing strategies for coping with them (cf. Wood *et al.* (2010)).
- Level of aggregation: The analysis is on sector level, i.e. it does not allow for differentiation e.g. between regions, farms and farm sizes.

- Interventions: The analysis focuses on strategic focus areas (e.g. changes in diets), rather than on individual policy and management actions (e.g. sugar tax).
- Results: The simulation model generates time series data and thus behaviour patterns over time for key indicators. These behaviour patterns are relevant for a relative rather than a numerical comparison of results. The simulation model provides an evidence base for strategic decisions (i.e., relative calibration and temporal sequencing) of interventions. It cannot be used for absolute calibration and timing of individual policy and management actions and for formulating operational implementation plans.

The dynamic simulation model is a bio-economic simulation model:

- The biophysical model component maps the processes underlying the production of food in Switzerland. This model component includes land used for the different production activities, livestock as well as nutrient accumulations.
- The economic model component maps production costs and revenues, which provide incentives for shifts in the allocation of land to different production categories. At the same time, these processes are responsible for the inertia of the agri-food system to changes in demand, prices and framework conditions.

Figure 6 provides an overview of the major feedback loops represented in the dynamic simulation model. For illustration purposes, Figure 6 does not differentiate between the five animal products and the ten plant products and most of the interactions between product types. The model calculates domestic agricultural production (in the 15 product categories) as well as demand for and prices of these products. Production, demand and prices result from and drive changes in profitability of the 15 product categories. Simultaneously, they affect and are affected by nutrient dynamics in the sense that different levels and intensities of production activities result in different levels of nutrient inputs and uptake. Also, the costs of production inputs such as synthetic fertilizer, labour (drivers linked to "production costs" with a solid black line) or feed (indicated by the solid grey line between "price" and "production costs") lead to shifts in land use and production intensity. In terms of land use, the model differentiates between arable land, temporary meadows as well as permanent meadows and pastures (which together sum up to total agricultural land) as well as land used for non-agricultural purposes. The mobility between the land use categories is restricted and respects topographic and climatic conditions in Switzerland. Finally, net imports close the gap between demand and domestic production of goods in the product categories.

Figure 6 lists a number of exogenous variables. These exogenous variables are used to specify the different scenarios. Scenario variables in grey colour are identical across all scenarios while scenario variables in red change according to the specific framework conditions described by each scenario.

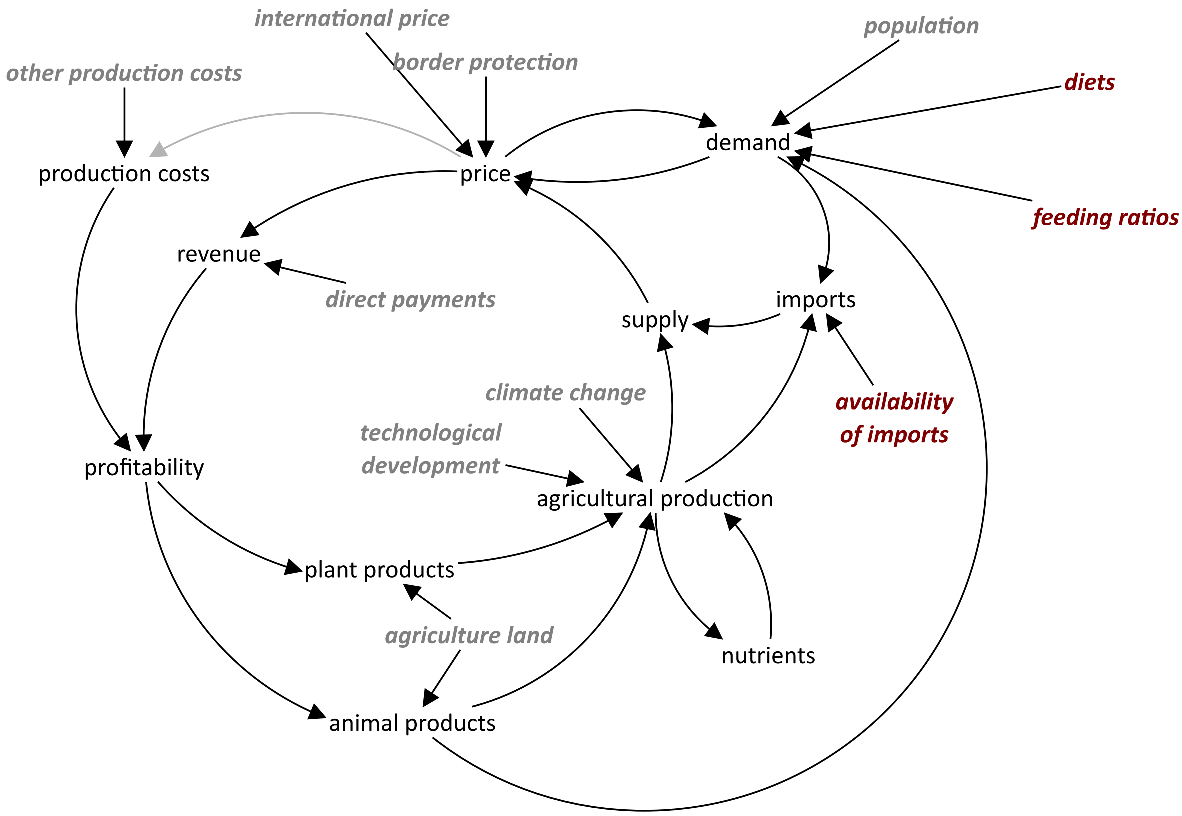


Figure 6: Major feedback loops in the dynamic simulation model. Exogenous scenario variables – grey: same for all scenarios; burgundy: different for each scenario.

A separate module in the system dynamics model studies the transition process from conventional (conventional and integrated production) to organic production. This module is used to specify the share of organic production in the different scenarios.

Supporting information 1 provides a detailed overview of the most important processes and indicators in the dynamic simulation model. The table describes the main processes represented in each model sector. It also lists the main inputs (that is, variables from other sectors) as well as outputs (that is, variables that are used in other sectors) per sector and the exogenous parameters used in the sector.

4.3.2 Environmentally extended input output model

4.3.2.1 Overview

An environmentally extended input-output model (EE-IOM) allows calculating the economic impacts of changes in production and consumption patterns. By including additional data, it allows to calculate the impacts of economic changes on environmental and social indicators.

The Swiss EE-IOM relies on an environmentally extended input-output table (EE-IOT) as the database. The core economic part of the EE-IOT is a classical IOT representing the interlinkages between the industries of an economy and between industries and final demand sectors (household and government consumption, capital formation and exports) in monetary units. The IOT distinguishes the use of domestic and imported goods and services. It is extended with data on direct resource use and emissions as well as social impacts by domestic industries and households. Environmental and social impacts induced by Swiss imports in foreign countries are incorporated through environmental and social impact intensities linked to the imported products. The environmental impact intensities are based on LCA data, while the social impact intensities are based on the Social Hotspots Database (SHDB, Benoit-Norris *et al.* (2012)).

The Swiss EE-IOT is based on an earlier version developed by Nathani C. *et al.* (2016). It was developed further in this project by further disaggregating the agricultural and food processing industries to better represent the envisaged scenarios. Organic agricultural and food production was separated from non-organic production. Meat processing was disaggregated into production of red meat, white meat and processed meat. Regarding beverage production, we distinguish alcoholic from non-alcoholic beverages. In total, the new EE-IOT distinguishes 135 industries and product groups, of which 63 belong to agriculture, fisheries and the food industry.

For each industry and for households the EE-IOT contains data on several hundred pollutants and resources that can be aggregated to various midpoint and endpoint environmental indicators (cf. below).

Social impacts are represented by almost 150 indicators that are aggregated in the Social Hotspots Index (cf. below).

In this project, the following economic, environmental and social indicators are used to analyse the sustainability of food consumption and production in the different scenarios:

- economic indicators:
- household consumption expenditure for food and food services
- gross value added
- employment
- environmental indicators
- greenhouse gas emissions
- biodiversity loss potential
- eutrophication
- environmental footprint according to the ecological scarcity method
- social indicators
- social hotspots index
- production-related health impacts

In the following, the environmental indicators are briefly introduced.

4.3.2.2 Description of environmental and social indicators

Greenhouse gas emissions

The climate change effect of greenhouse gases is expressed by the Global Warming Potential (GWP) according to the 4th Assessment Report of the Intergovernmental Panel on Climate Change (expressed in kg CO_2-equivalents according to IPCC (2006)). The indicator covers the so-called "Kyoto-Substances" CO_2, CH_4, N_2O, PFC, HFC, SF_6 and NF_3. The climate-impacting ozone-depleting substances regulated by the Montreal Protocol are not included. The additional warming effects of the stratospheric emissions from aircrafts are taken into account according to Fuglestvedt *et al.* (2010) and Lee *et al.* (2010).

Biodiversity loss potential

Land use is one of the major causes of biodiversity and species loss. The indicator "potential species loss from land use" (Chaudhary *et al.*, 2016) quantifies the damage potential of land use on biodiversity. The indicator quantifies the loss of species in amphibians, reptiles, birds, mammals and plants by the use of arable land, permanent crops, pasture, intensively used forest, extensively used forest and urban areas. It weights endemic species higher than species that are common. Species loss is determined in relation to the biodiversity of the natural state of the area in the region concerned. The indicator aggregates the regional loss of commonly occurring species and the global loss of endemic species into "globally lost species". It is expressed in equivalents of potentially globally lost species per million species (potentially disappeared fraction of species (PDF))·(Chaudhary *et al.*, 2016; Chaudhary *et al.*, 2015).

Eutrophication footprint

The release of nitrogen into the environment causes a wide range of problems. The most obvious of these is marine eutrophication ("over-fertilization" of the Oceans): The indicator used in this study quantifies the amount of nitrogen that potentially enters the oceans through the emission of nitrogen compounds in water, air and soil and thus may contribute to over-fertilization (Goedkoop *et al.*, 2009; IPCC, 2006). Nitrogen quantities are taken into account according to their marine eutrophication potential (kg N-equivalents).

Environmental footprint (UBP-method 2013)

The method is based on Switzerland's legally or politically defined environmental goals (distance to target) and evaluates resource extraction (energy, primary resources, water, land), pollutant inputs into the air, water and soil, waste and noise (Frischknecht and Büsser Knöpfel, 2013). The indirect additional climate change effects of stratospheric emissions from aircrafts are taken into account. The method is also called the Ecological Scarcity Method (UBP) and is used by numerous Swiss companies.

Social hotspots index

The social hotspots index (SHI) is a composite social impact indicator that aggregates the social indicators included in the Social Hotspots Database (SHDB). This database includes country and partly industry specific data for almost 150 indicators from the following social areas: labour rights and decent work, health and safety, human rights, governance and community infrastructure. The single indicators are aggregated to social theme, social area indicators and finally to the SHI according to the weighting scheme proposed by Pelletier *et al.* (2013). The use of this index implicitly assumes that the imported products in the year 2050 will be supplied by the same countries as today and that the social situation will remain unchanged until 2050. Therefore the results for social impacts should be interpreted with due caution. They do not represent projections for the year 2050 but provide hints to possible social impacts that could be caused by the consumption and production shifts in the different scenarios.

Production-related health impacts

The production-related health impacts measure the disease burden caused by food consumption along the entire supply chain as DALYs (disability adjusted life years). They are determined according to the method ReCiPe 2008 (Goedkoop et al. 2009). The method takes into account the impacts of climate change, ozone depletion, human toxicity, photochemical oxidant formation, particulate matter formation and ionizing radiation on human health. This indicator does not include the direct health impact of food diets.

4.3.2.3 Modelling steps

The EE-IOM was used in the following manner to calculate the economic, environmental and social impacts of changes in Swiss consumption and production of food.

In a first step, an EE-IOT for the reference year 2050 was estimated for each scenario including the ReferenceScenario2050. The estimate for the ReferenceScenario2050 was based on existing projections for the development of core economic indicators of the Swiss economy to the year 2050 (Ecoplan, 2015) including GDP, output and employment by industry, imports by product group and final demand by product group and final demand sector. Including these data allowed incorporating general structural change until the year 2050 in the EE-IOT. Data on household consumption expenditure for food products were based on the scenario assumptions mentioned above (cf. Section 4.2.2). Data on domestic agricultural production was based on the output of the dynamic simulation model (cf. Section 0). Imports of agricultural products were determined as balance items from domestic use and production. The estimate of the IOT for each other scenario reflects the changes in scenario assumptions on food consumption and dynamic simulation model outputs on domestic agricultural production between the respective scenario and the ReferenceScenario2050. Even though the basic IO model is static, the coupling of the EE-IOM with the SDM can be regarded as a method to incorporate technological and intra-sectoral structural change into an IO model. The environmental and social impact coefficients and multipliers were assumed to remain constant until 2050. This simplifying assumption probably leads to an overestimation of impacts since progress in eco-efficiency and social standards is disregarded.

In a second step, for each scenario the impact of food consumption on economic, environmental and social impact indicators was calculated with the scenario specific EE-IOTs. First, the impact of food consumption on sectoral output and imports was determined with the standard Leontief quantity model (Miller and Blair, 2009). Gross value added and employment were then calculated with sector specific coefficients that incorporate improvements in labour productivity. The domestic and foreign environmental impacts were determined by multiplying output with sector-specific environmental intensities and by multiplying imports with product group specific environmental multipliers. The domestic and foreign social impacts were calculated accordingly by using social impact intensities and multipliers determined with data from SHDB.

The impacts of changes in food consumption and production on economic, environmental and social indicators were determined as deviations from the results for the ReferenceScenario2050.

4.3.3 Global mass flow model (SOLm)

The SOL-Model ("Sustainable Organic Livestock Model" – SOLm) is a global mass and nutrient flow model of the entire food system with a focus on production and consumption (and less so on processing). It has originally been developed to address questions related to organic livestock production (hence its name), and has then been used to assess global scenarios for organic crop and livestock production, for livestock production without food-competing feed and for scenarios of wastage reduction and for regional scenarios of sustainable agriculture in the alpine region in Switzerland and Austria (FAO, 2014; Muller *et al.*, 2017; Schader *et al.*, 2015a; Stolze *et al.*, 2019).

SOLm is based on the agricultural statistics from the Food and Agriculture Organization of the United Nations FAOSTAT and originally includes all countries (about 200) and activities (about 180 crop and 20 livestock production activities) as reported in FAOSTAT. While earlier versions worked with primary product equivalents, SOLm has been developed further in this project to also include all commodities (about 600) as covered in FAOSTAT to link to the menuCH data, which is reported on commodity level, and to allow for assessing health aspects.

The structure of SOLm is displayed in Figure 7 and Figure 8 below. For the production part, the flows generally start from cropped areas that are managed with a number of inputs such as fertilizers, produce certain outputs (such as the main products, but also residues, etc.) and lead to certain emissions and losses (such as GHGs or nitrogen leaching). Part of this production is used to feed the animals, which in turn also produce main product outputs, by-products (such as manure) and emissions (e.g. methane from enteric fermentation). Manure is then recycled back to the croplands and grasslands. The main nutrient flows and emissions are calculated by the approaches used for the national greenhouse gas inventories according to the guidelines of the IPCC (Tier 1; refined to tier 2 and 3, depending on the focus of the analysis and data availability).

The consumption part (Figure 8) is based on the Food Balance Sheets from FAOSTAT that are organised around the "domestically available quantity" (DAQ) of each commodity, which is derived from its production, imports, exports and stock changes, thus relating the available quantity in a country to the production part in the country itself and in trade partners. This DAQ is then utilized in various ways, such as e.g. for food, for feed or bioenergy, and part is lost as waste.

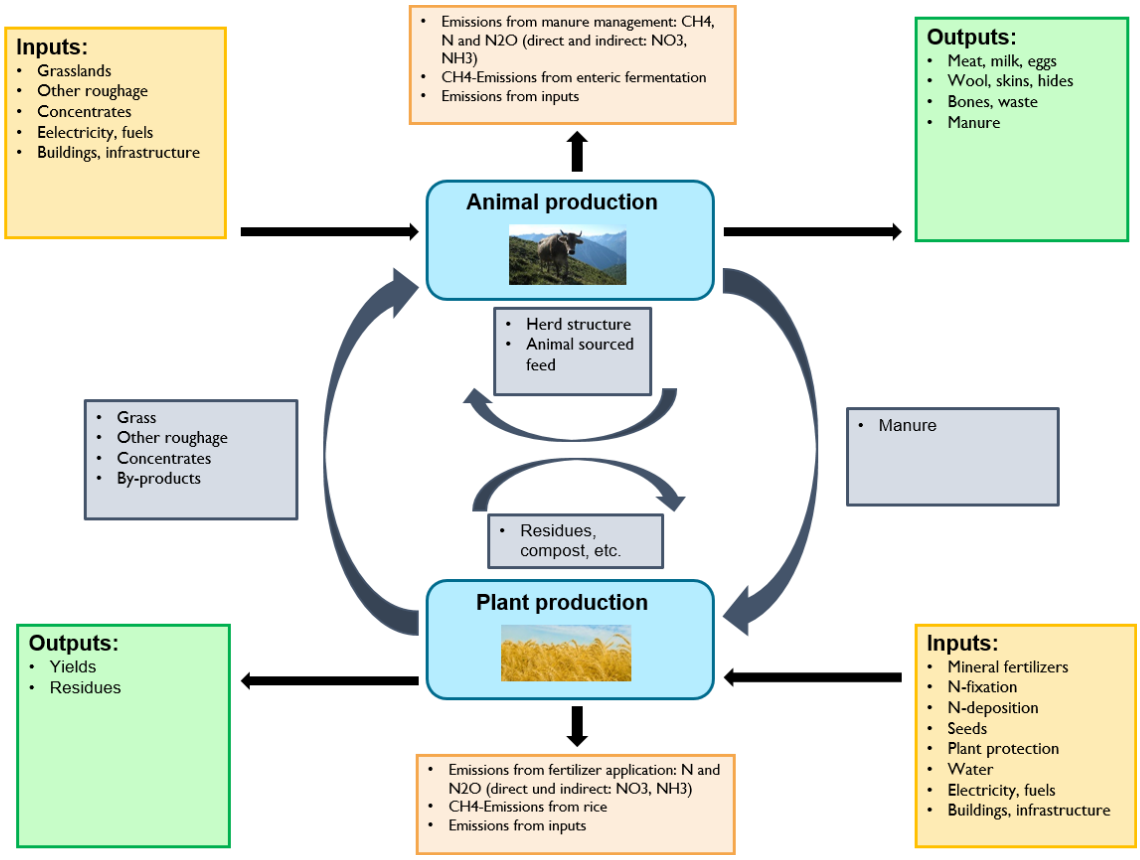


Figure 7: Structure of SOLm, production part. Specification of crop and livestock production activities and their inputs, outputs and losses.

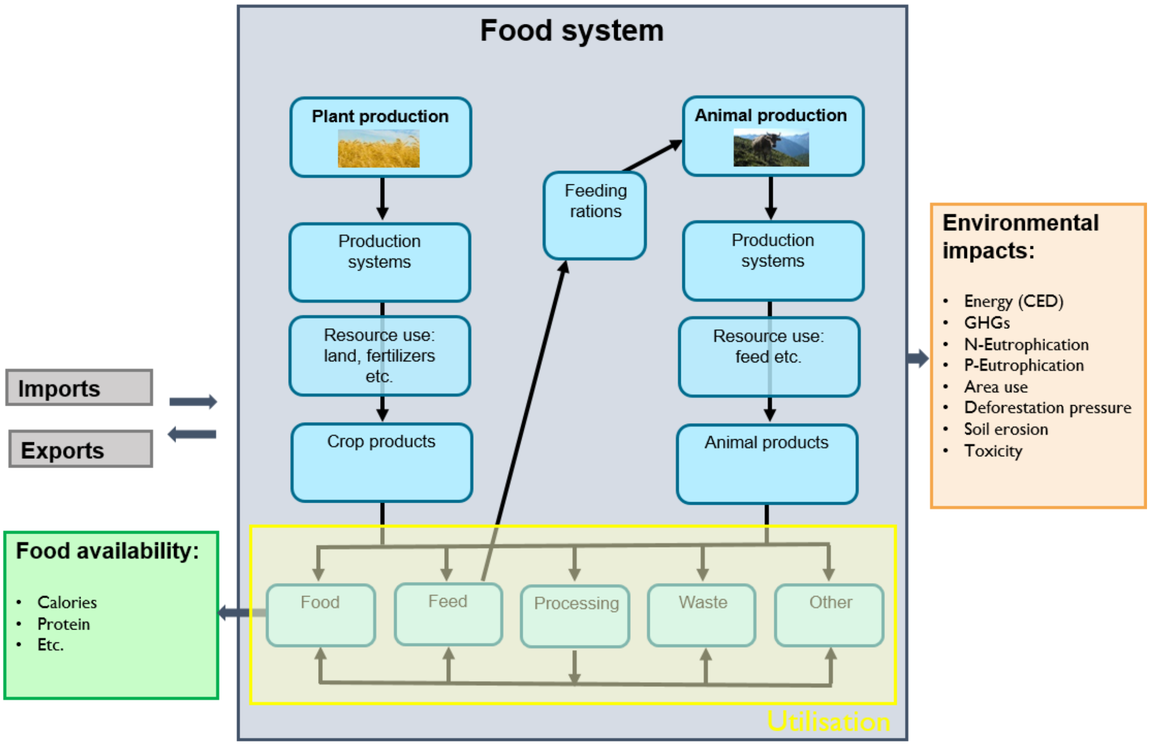


Figure 8: Structure of SOLm, food system perspective.

Environmental indicators

In the following, we shortly describe the environmental indicators covered in SOLm. For more details, we refer to the methods parts and supplementary information of Schader *et al.* (2015b).

Land occupation

This indicator covers how much land is used for agricultural production, both under crop and grassland management.

Deforestation and use of organic soils

Based on specific data on deforestation and use of organic soils from FAOSTAT, average per ha values per country are derived from the relation of deforestation areas and organic soil areas to the total agricultural area, thus resulting in an average fraction of hectare being deforested or being located on organic soils for each hectare under agricultural use. Given that this information is not spatially explicit, this can be interpreted as a pressure indicator for deforestation or organic soil use per hectare cropland and grassland and thus for changes in land use, in particular.

Greenhouse gas emissions

This covers all emissions from agricultural operations (fertilized soils, manure management, enteric fermentation), as well as emissions that stem from the production of direct inputs (e.g. mineral fertilizers) and from deforestation and utilization of organic soils. Embedded emissions (e.g. emissions from feed production for livestock) can be included or reported separately. GHG emissions are calculated according to the IPCC guidelines. GHG emissions from deforestation and managed organic soils are taken from FAOSTAT and related to the per-ha deforestation/organic soil use indicator described just above. Further, GHG emissions from transport are calculated based on the approach proposed in (Itten and Stucki, 2017). GHG emissions from processing are taken from the calculations in the model EE-IOM (Section 4.3.2.2).

Nitrogen and phosphorus surplus

This calculates N/P balances according to the OECD guidelines, i.e. the difference between nutrient outputs (in yields and residues) and nutrient inputs (mineral fertilizers, manure, other organic fertilizers, nitrogen fixation, nitrogen deposition). It does not account for nutrient flows into and from the soil pools.

Pesticide use

This is captured via a qualitative indicator based on the strictness of pesticide regulation and the ease of access to pesticides in a country, as well as on the relative pesticide use intensity on single crops.

Erosion

This is based on a literature review on available soil erosion data which is then assigned to single crops on a country-average basis, accounting for the relative risk of erosion for certain crops such as maize. This latter part is captured via a qualitative indicator that can take the values 0, 1 or 2.

Energy use

Non-renewable energy use: The life cycle impact assessment methodology 'cumulative energy demand' (CED) is used to calculate non-renewable energy use. Renewable energy components are disregarded. The share of non-renewable energy for fuels and electricity was assumed to stay constant in all scenarios and no technical progress in energy efficiency was assumed.

Modelling steps

The model is run in two modes. Either as a mass-flow model without optimisation, starting from assumptions on area use, production systems (organic/conventional) and feeding rations (i.e. mainly concentrate use rates), or as an optimisation model on the level of diets. For the mass-flow runs without optimisation, the model is initialised with assumptions on these aspects (area uses and central parameters such as feeding rations, utilization of DAQ for food and feed, etc.) and it is calibrated with FAO data and more detailed data from the Grundlagenbericht for Switzerland (average over 2012 – 2014). The general approach regarding assumptions on various parameters that are not changed due to scenario assumptions is to keep them identical or as similar as possible to the baseline (e.g. relative shares of various cereals in total cereals, etc.). Comparison of the results from a scenario run that replicates the baseline regarding agricultural production and DAQs with national GHG inventories for agriculture and with OECD nitrogen and phosphorus balances serve for consistency checks.

For optimisation scenarios, the model starts with the impacts per commodity as derived from the mass flow runs and then optimizes the diets according to certain goals, such as to minimise GHG emissions (conditional to certain requirements regarding food nutrient supply and minimal/maximal share of various commodities in the diet).

4.3.4 Optimisation scenarios

Instead of defining explicit dietary scenarios as detailed above, dietary scenarios can also be derived through an optimisation procedure, as described in the following. For this, a diet optimisation model has been built to the SOLm model. This optimisation model is set up as a linear programming model with the following structure:

Minimise $Z = \boldsymbol{c}'\boldsymbol{x}$

Subject to $\boldsymbol{Ax} \geq \boldsymbol{b}$

And $\boldsymbol{x} \geq 0$

where **x** is a vector of different food products; **c** is a vector of environmental impacts occurring per unit of food product produced; **A** is a matrix of technical coefficients; and **b** is a vector of quantitative constraints. The objective function is either defined to directly minimise single environmental impacts (Z) (→ aiming for the ideal), or then, as an absolute value function, where the goal is to minimise the difference to the reference scenario or the Swiss Food Pyramid scenario while fulfilling certain environmental targets (→ accounting for acceptability).

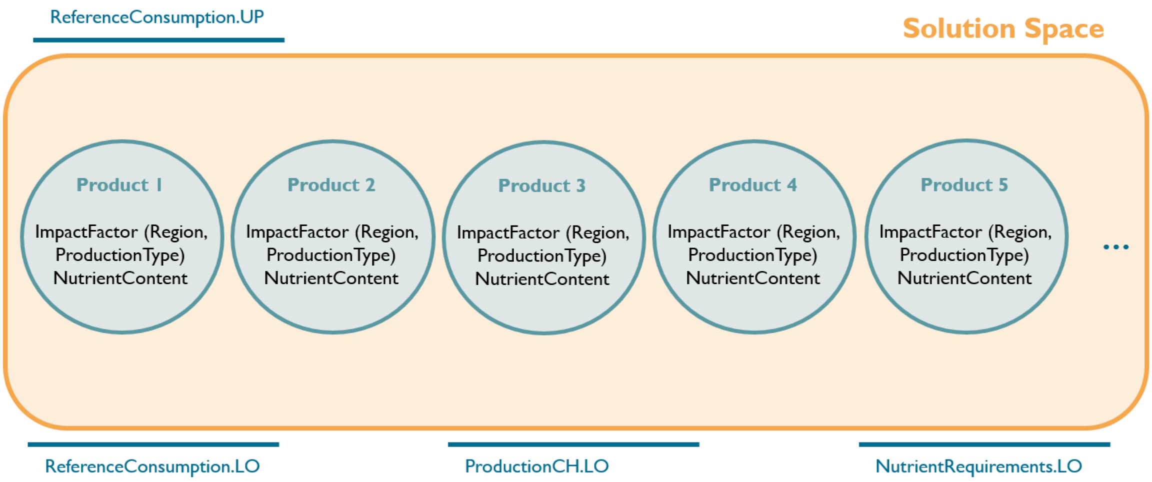


Figure 9: Schematic representation of the setup of the optimisation model. The circles represent food products, where each product has several environmental impact factors (→ vector **c**). The restrictions (referred to with .LO and .UP) constrain the possible solution space.

Aiming for the ideal: The first group of optimization scenarios addressed with this model aims at minimizing different environmental impacts, i.e. at achieving the ideal from an environmental point of view. Next to the objective function that defines which environmental impacts should be minimised, it is necessary to define several restrictions to be able to find a meaningful solution. These are restrictions on human nutrient requirements (energy, protein, and carbohydrates intake), domestic land use (restriction that all agricultural land in Switzerland has to be used – differentiated between land under crop and grassland management), reference consumption (lower restriction for plant products only; final dietary pattern can differ max. -70% from the current diet for plant-source food, and +200% for all food products, to avoid over-specialisation).

Two scenarios of this type are defined for the aiming for the environmentally ideal case:

1. **minGWP2050:** minimize greenhouse gas emissions while fulfilling the posed requirements
2. **minLU2050:** minimize land use while fulfilling the posed requirements.

Accounting for acceptability: The second group of optimisation scenarios was set up to find dietary scenarios that perform better than the current regarding environmental impacts, but do not differ too much from the current diet. This should ensure that these scenarios impose higher acceptability rates in the population, and are thus easier to implement. They could be looked at as a 'pathway to the ideal'. Thus, the target function in this second group is to minimize the difference to the current diet (absolute value function). Then, again the human nutrient requirements are introduced, as well as the restriction on the use of agricultural land in Switzerland. Further, environmental targets are defined as restriction; for greenhouse gas emissions, a reduction of one third as compared to 1990 is required (based on Klimastrategie Landwirtschaft 2011, BLW), and for arable land, the target is set to 0.21 ha/capity/year (based on the concept of a fair diet in Röös *et al.* (2016)).

Additionally, a scenario that takes the Swiss Food Pyramid (SFP) into account but modifies it such that it performs better for environmental impacts was specified. Therefore, as a second scenario for this group, a scenario minimizing the difference to the SFP2050 while fulfilling the same restrictions as posed above was defined.

In summary, the following two scenarios are defined for the second group of optimisation scenarios:

1. **minpenalty2050:** minimise deviation to the reference scenario while fulfilling the posed requirements
2. **minpenaltySFP2050:** minimise deviation to the SFP2050 scenario while fulfilling the posed requirements.

Figure 10 below displays the dietary composition in these optimization scenarios.

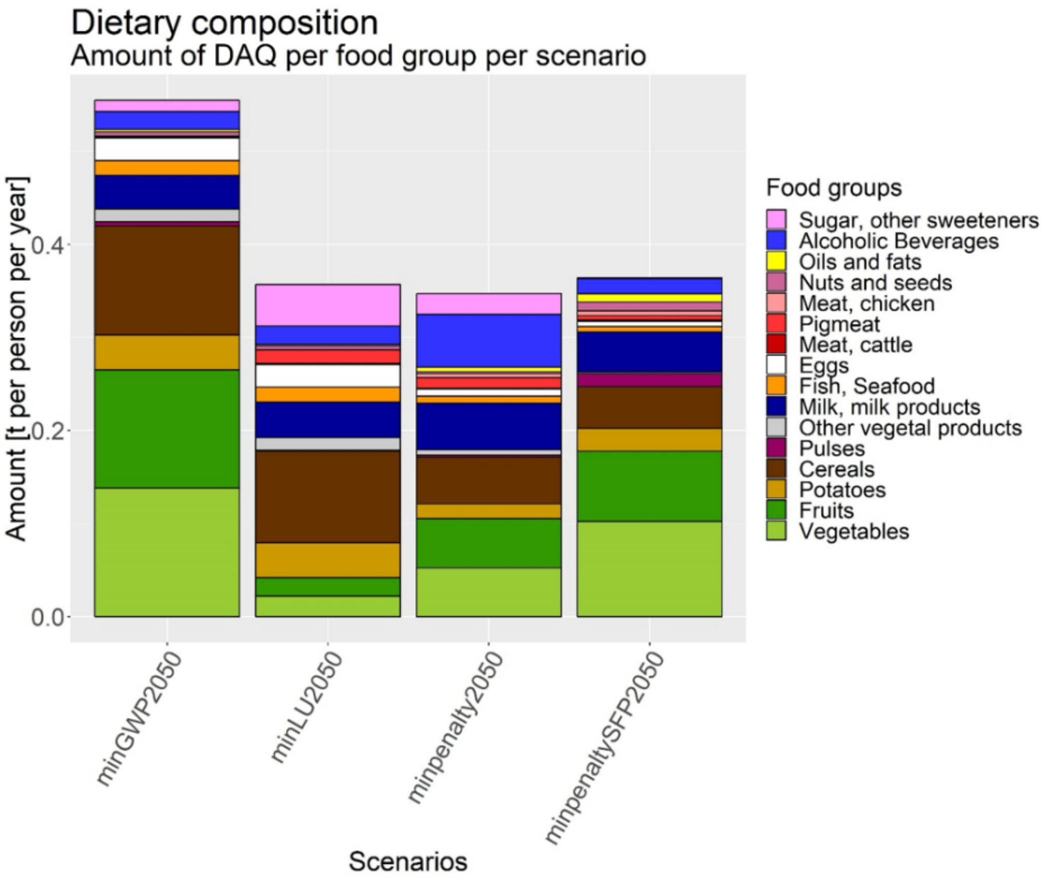


Figure 10: Domestically available quantity (in tonne per person per year) per optimisation scenario per food group.

For the two scenarios of the group 'accounting for acceptability', mainly the production and import structure changes, but the quantities available do not change substantially. Thus, products are sourced from where environmental impacts are lowest, but changes between food groups are avoided if possible by this modelling routine. On the other hand, the two scenarios of the group 'aiming for the ideal' result in significant changes in consumption patterns, with increases in cereals, fruits and vegetables for the scenario minGWP2050, and increases of cereals and sugar-based products for the scenario minLU2050.

4.3.5 Integrated health-sustainability model

The models presented in the previous sections differ in focus and scale, and therefore, can be integrated to enable a comprehensive assessment encompassing different perspectives on the Swiss food system. The model **SDM** is able to model the dynamics of the production structure of the agricultural sector for the selected future scenarios. It is therefore the model that is run first; as inputs, explicit specifications for consumption patterns are provided, and the SDM then generates production structures, that take long-term adaptation processes of different actors into account. These production structures are then used as input for the models SOLm and EE-IOM (Figure 11).

The model **SOLm** focuses on agricultural production processes from a bio-physical point of view, by which agricultural outputs and environmental impacts are calculated. Results from this model are environmental impacts (Global Warming Potential, land occupation, N-surplus, and P-surplus) that take the consequences of changes in food system states into account. Further, the Alternate Healthy Eating Index (AHEI) is calculated for the final consumption pattern per scenario.

The third model employed – the model **EE-IOM** – is able to extend the analysis to other dimensions of sustainability – the economic and social dimension – and also to other sectors of the economy. It links inputs across all sectors of the economy and then, by using fixed impact factors, different environmental impacts (global warming potential, biodiversity loss potential, eutrophication, and ecological scarcity), economic impacts, and social impacts are calculated.

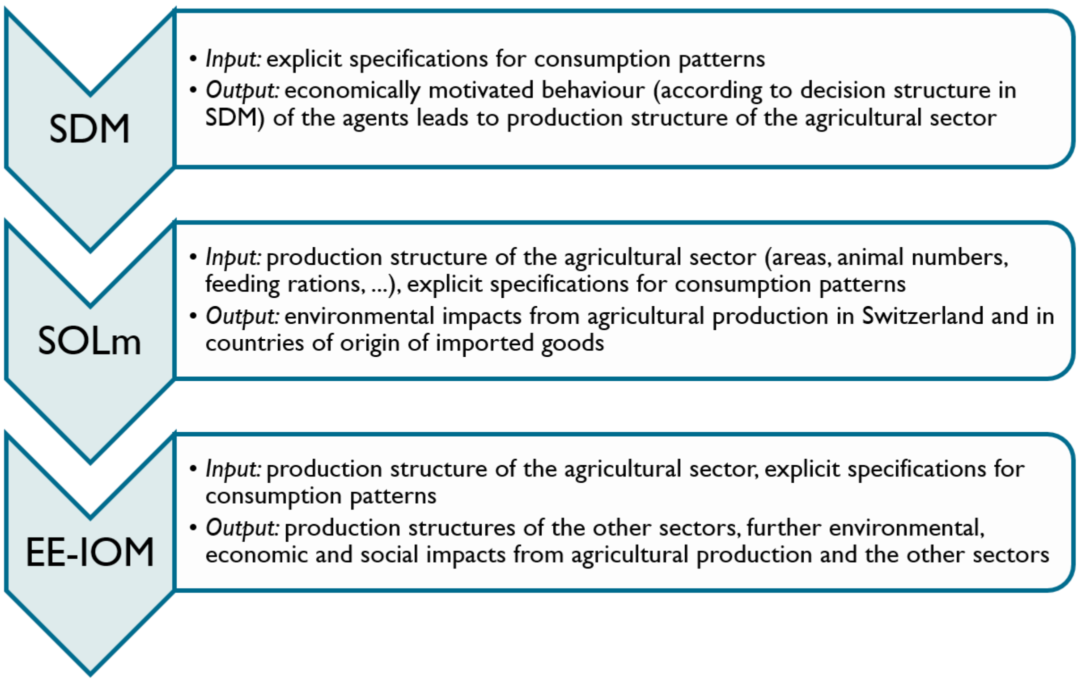


Figure 11: Overview of model interactions

Table 3 provides an overview of all scenarios and their specifications in the different models. As described in Section 4.2.2, the **ReferenceScenario2050** represents the Swiss food sector in a business-as-usual situation in which the same consumption and production patterns as today are prevalent.

The alternative scenarios are grouped into predefined scenarios, which subsume a nutritional pattern a) according to the Swiss Food Pyramid (**SFP2050**) and b) following the rule not to eat animal-sourced products, which have been in competition with plant products for arable land (**FeedNoFood2050**). The **ReferenceScenario2050**, **SFP2050** and **FeedNoFood2050** were the main scenarios, which have been calculated for the integrated analysis by means of all three models. Additionally, there were sub-scenarios calculated alongside, which addressed specific questions to be addressed by one or two models. Within the group of predefined scenarios, a more radical scenario **FeedNoFoodNoTemp2050** was calculated, which additionally excludes temporary meadows in rotations (modelled by SDM and SOLm). Further, the question of food waste reduction (50% and 100%) at consumer stage was addressed by the SDM in **ReferenceScenario2050_FW50** and **ReferenceScenario2050_FW100**.

The optimisation scenarios were only addressed by SOLm. **minGWP2050** and **minLU2050** minimise the Global Warming Potential and Land Use, respectively, under the condition that all land in Switzerland is used and enough food is produced to maintain the population level in 2050. The scenarios **minpenalty2050** and **minpenaltySFP2050** were addressed by the models SDM and SOLm.

Table 3: Overview of scenarios modelled with the different model types

Scenario group	Scenario name	Diets	Characteristics	SDM	EE-IOM	SOLm
Reference scenario	**ReferenceScenario2050**	Based on menuCH-data	Reference projections for main parameters	X	X	X
Predefined scenarios	**SFP2050**	According to Swiss Food Pyramid (SFP)	Reference projections for main parameters	X	X	X
	FeedNoFood2050	Animal-source food limited to feed from non-food-competing sources in Switzerland, including temporary grasslands	Reduced productivity of animals, share of organic doubled from reference	X	X	X
	FeedNoFoodNoTemp2050	Animal-source food limited to feed from non-food-competing sources in Switzerland, excluding temporary grasslands	Reduced productivity of animals, share of organic doubled from reference	X		X
	ReferenceScenario2050 _FW50	Based on menuCH-data	Reference projections for main parameters, reduction of food waste at consumer stage by 50%	X		
	ReferenceScenario2050 _FW100	Based on menuCH-data	Reference projections for main parameters, reduction of food waste at consumer stage by 100%	X		
Optimisation scenarios	**minGWP2050**	Diet minimising GHG emissions under certain restrictions	Endogenous production and import structure. Production is influenced by the restriction that all land in Switzerland has to be used. Further, human nutrient requirements and deviation from reference consumption of plant-source foods are restricted.			X
	minLU2050	Diet minimising land occupation under certain restrictions	Endogenous production and import structure. Production is influenced by the restriction that all land in Switzerland has to be used. Further, human nutrient requirements and deviation from reference consumption of plant-source foods are restricted.			X
	minpenalty2050	Diet close to reference with restrictions on performance for environmental indicators	Endogenous production and import structure. Production is influenced by the restriction that all land in Switzerland has to be used. Further, human nutrient requirements, GHG emissions and land use are restricted.	X		X
	minpenaltySFP2050	Diet close to SFP2050 with restrictions on performance for environmental indicators	Endogenous production and import structure. Production is influenced by the restriction that all land in Switzerland has to be used. Further, human nutrient requirements, GHG emissions and land use are restricted.	X		X

4.4 WP5: Model-based integrated analysis

This section presents and discusses the modelling results. It focuses on various aspects and for each presents results from the single and integrated models for the different scenarios.

4.4.1 Agricultural production

As a result of population and economic growth, total available agriculture land will continue to decline to 86% of today´s value (1.02 million ha) by 2050. At the same time, productivity increases in plant production and animal husbandry are projected to be too low to fully compensate for land loss (Möhring *et al.*, 2015a). Therefore, domestic production declines for most products (Figure 12). The exception to this rule are the products that react sensitively to changes in demand, especially vegetables and fruits. Hence, of an overall decline in domestic production, more imports are necessary (not shown in Figure 12).

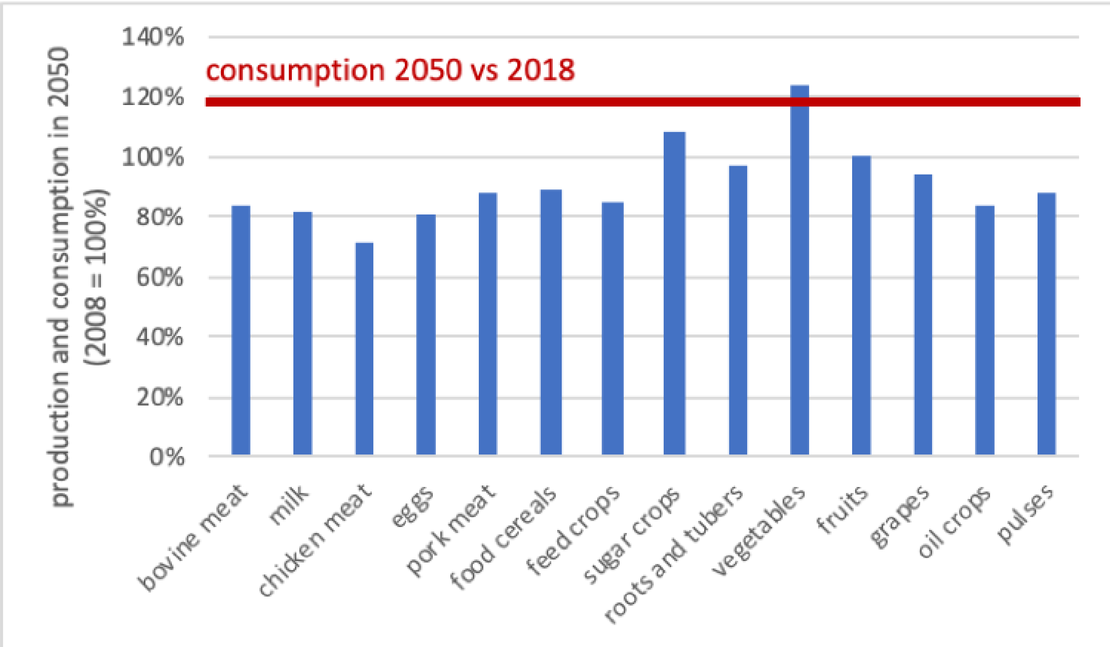


Figure 12: Total domestic production 2050 (blue bars) and consumption 2050 (red line) relative to base year

Figure 13 details the continents of origin for the imports in the year 2050, differentiated for the most important product groups. The same distribution of imports as today is assumed. Import shares are calculated based on FAOSTAT data and an approach developed in Kastner *et al.* (2011), which adjusts import shares – based on reported production and import quantities – such that the primary production country is retrieved. The figure mainly shows that continents of origin vary considerably between product groups. This is particularly important in terms of environmental and social impacts of imports in the different scenarios (cf. Sections 4.4.3 and 4.4.5).

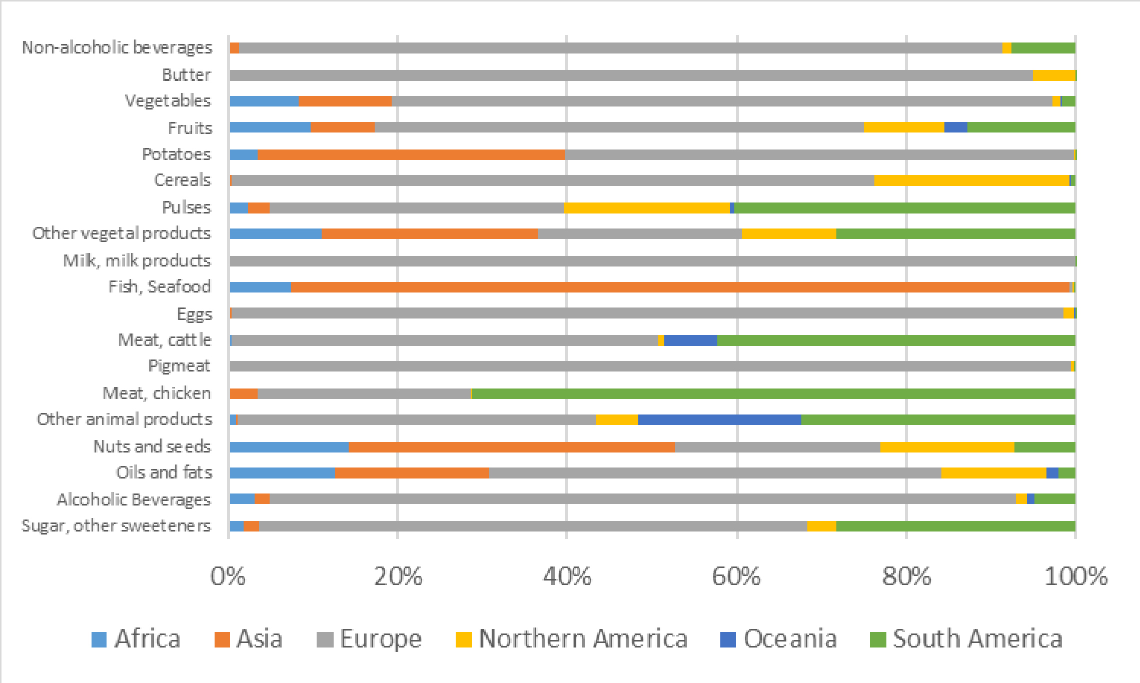


Figure 13: Continents of origin for imports of food products to Switzerland in 2050

4.4.1.1 Land use

Population and economic growth lead to loss in agriculture land that is identical across the four scenarios. How the remaining agriculture land is used depends on the scenario. Under ReferenceScenario2050 and SFP2050 conditions with continued high consumption of dairy products, there are no major shifts between the use of potential arable land for either temporary meadows or arable land. In the FeedNoFood2050 scenario – where productivity of dairy cows and bovine cattle is lower than under baseline conditions but where the same animal requires more grass products per head – temporary meadows are used to the maximum (i.e., at today's level). Only in a feed no food scenario where temporary meadows are not allowed do the temporary meadows transition entirely to arable land. The difference in land use between the two feed no food scenarios is visualized in Figure 14. The "data" line in Figure 14 to Figure 18 shows the historical behaviour of the indicator as recorded in statistical data.

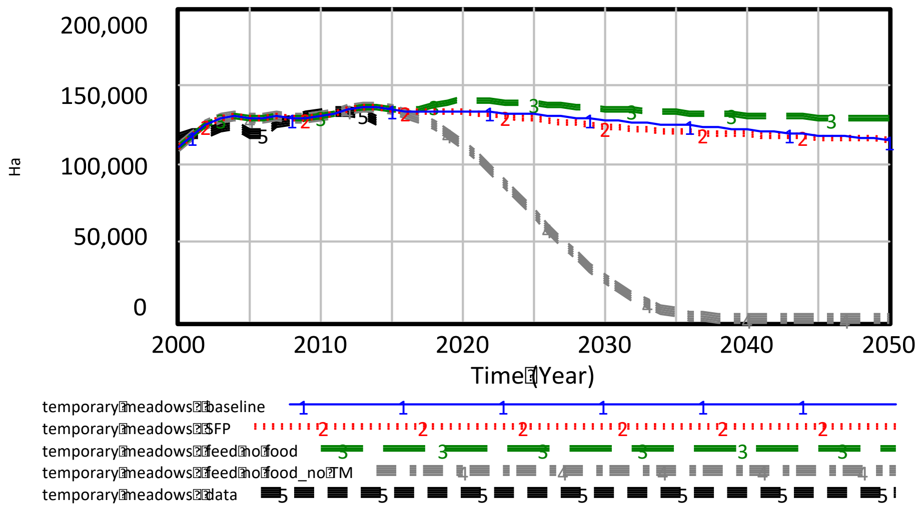


Figure 14: Development of temporary meadows in the four scenarios

4.4.1.2 Plant production

Figure 15 to Figure 17 show the development of plant production over time for the four scenarios and for selected plant products. They also show that model behaviour demonstrates a good fit to data during the historical time period.

Overall, plant production declines slightly in the ReferenceScenario2050. The time-dependent behaviour of domestic production and of imports is, however, different for different plant products. Cereals for human consumption (Figure 15) do not experience major changes in consumption patterns across all four scenarios. The only scenario with major differences in behaviour is the feed no food scenario where no temporary meadows are allowed in the crop rotation. In this scenario, all the arable land that is currently used for temporary meadows becomes available for plant production. Consequently, domestic production increases and imports decline.

While vegetables (Figure 16) and pulses (Figure 17) experience the same shift from imports to domestic production, more differences between scenarios are visible. In the Swiss Food Pyramid scenario, a substantial increase in vegetable consumption leads to considerable expansion of vegetable production, which even manages to crowd out imports to some extent (Figure 16). Pulses (Figure 17) replace animal products in the diet in both feed no food scenarios. Therefore, their production increases substantially and so do their imports.

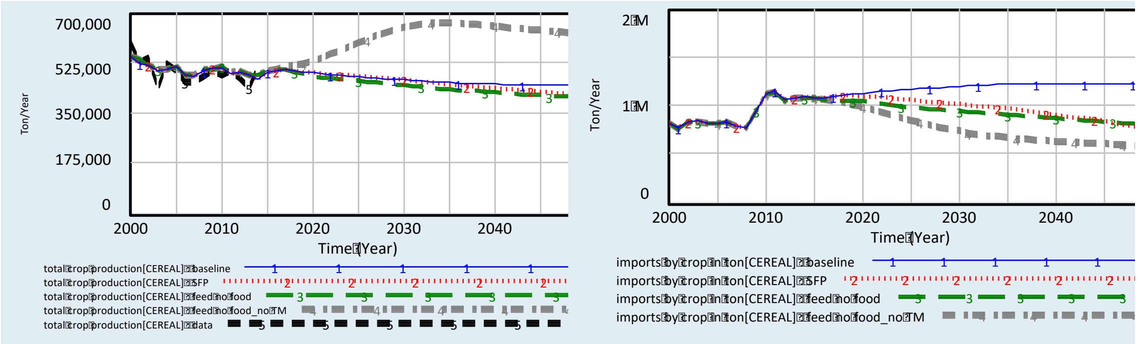


Figure 15: Domestic production and import volumes food cereals

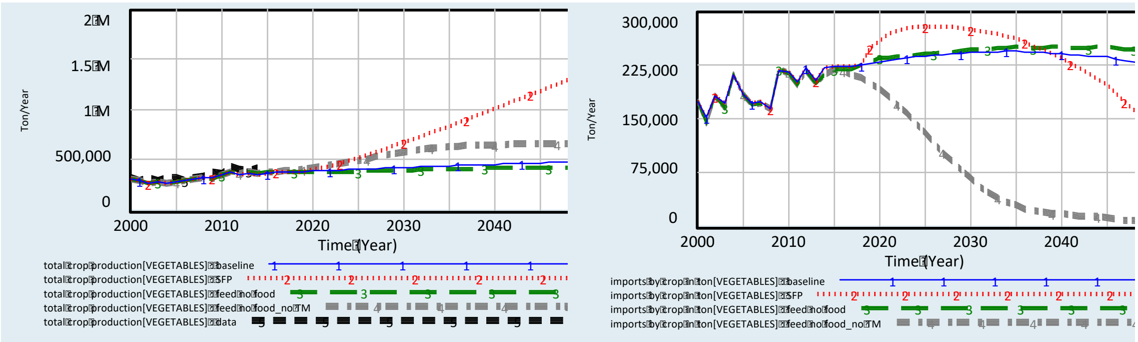


Figure 16: Domestic production and import volumes vegetables

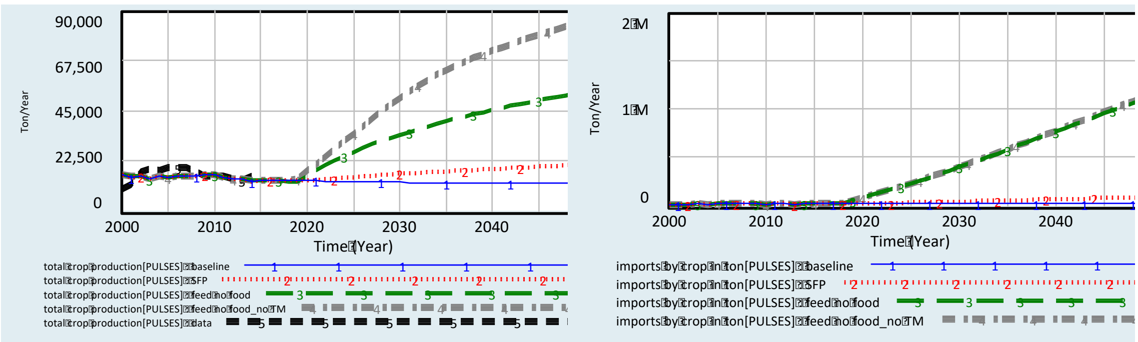


Figure 17: Domestic production and import volumes pulses

In both feed no food scenarios, the production of feed crops is reduced to zero (not shown in Figures 15 to 17). Arable land previously used for the production of feed crops becomes available for the production of other plant products, so that their production volumes tend to increase compared to reference values. This is particularly the case in the feed no food scenario without any temporary meadows that frees a considerable amount of arable land for domestic plant production. Consequently, major reductions in imports are possible.

4.4.1.3 Livestock production

Figure 18 shows the development of bovine meat and milk production over time for the four scenarios, both for the historical time period and for the time horizon of the scenarios. The figure demonstrates a good fit between statistical data and model behaviour during the historical time period. Under baseline conditions, both, milk and bovine meat production decline moderately. In the two feed no food scenarios, meat as well as milk production decline as a consequence of the restrictions imposed by the feed no food requirements. Production reductions are more substantial in the feed no food scenario where no temporary meadows are available and thus the fodder basis for bovine cattle is reduced to permanent pastures.

In the Swiss Food Pyramid scenario, milk production increases in line with an increased consumption of dairy productions. At the same time, however, and despite a 50% decline in consumption of bovine meat relative to baseline conditions, bovine meat production remains at baseline levels and even exceeds baseline levels a little. This is caused by the tight biological linkage between milk and bovine meat production.

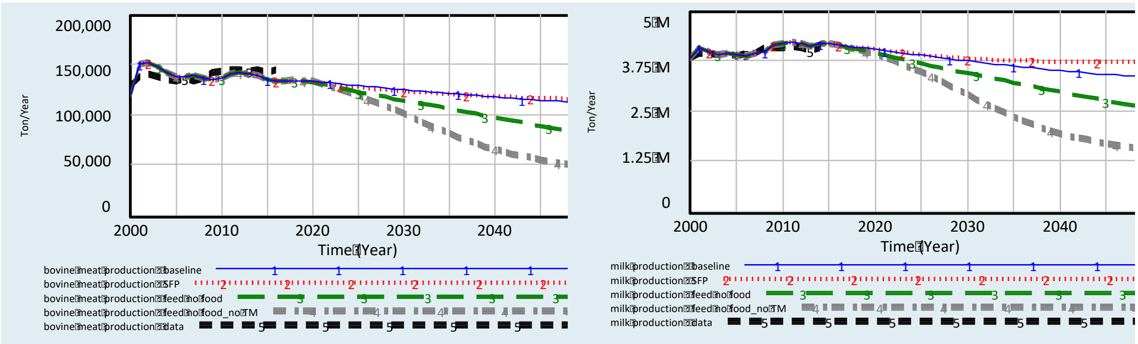


Figure 18: Bovine meat and milk production

Figure 19 describes the herd structures for bovine cattle. The Figure does not show the herd structure for suckler cattle. The number of suckler cows in Switzerland is around 15% that of dairy cows (SBV: Statistische Erhebungen und Schätzungen).

Every year, dairy cows breed a certain number of calves ("total calves"). Dairy cows need to bear one calve per year to maintain milk productivity. Once these calves are born, they either grow up into new dairy cows ("cavles to dairy cow stock") or they enter the stock of other bovine cattle ("calves to other bovine cattle stock"). Only a limited number of calves can grow into dairy cows. First, they need to be female. Second, it is only around every fifth year that a calve is needed to replace a dairy cow. All the remaining calves enter "other bovine cattle" stock and they stay in the stock until they are slaughtered.

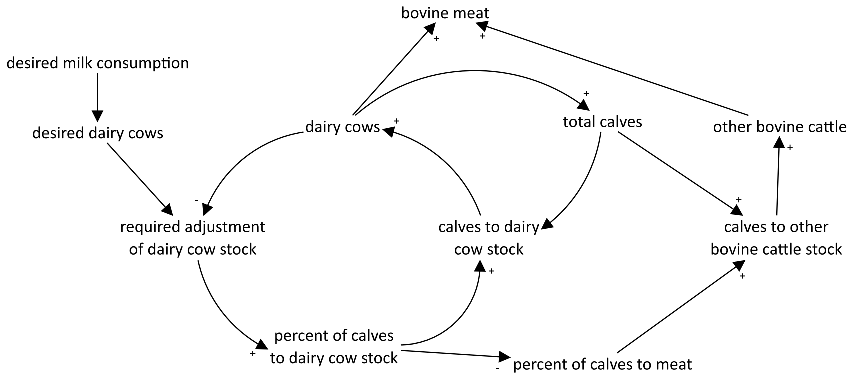


Figure 19: Link between milk and bovine meat production

The diagram in Figure 19 shows that there is a tight physical link between milk and bovine meat production. Currently, this system is approximately in balance. But this balance is lost if the demand for bovine meat goes down considerably while dairy consumption does not decrease but rather increase, as part of the reduced meat consumption is, substituted by demand for dairy products as in the case of the Swiss Food Pyramid scenario. In the short run, the reduced demand for bovine meat will drive bovine meat price down and thus lower the profitability of bovine meat production. However, because consumers start replacing some of the proteins that they previously consumed from meat by dairy products, the demand for dairy products ("desired dairy consumption") will increase. More calves now enter the dairy cow line. Once the number of dairy cows approximates the desired number of dairy cows, the counterintuitive behaviour of bovine meat production emerges. All cows in the dairy cow stock produce one calve per year to maintain their milk productivity. As no more calves are needed to increase the dairy cow stock, only one out of five calves is required to replace the existing dairy cows and to keep the number of dairy cows stable. The remaining four calves enter the other bovine cattle stock and even if they are not fattened for a long time, they still generate meat – more meat than before the shift in diets. In total, this excess of bovine meat amounts to more than 50% of the total pork and chicken meat demand or to more than 50% of the bovine meat demand in the Swiss Food Pyramid Scenario in 2050.

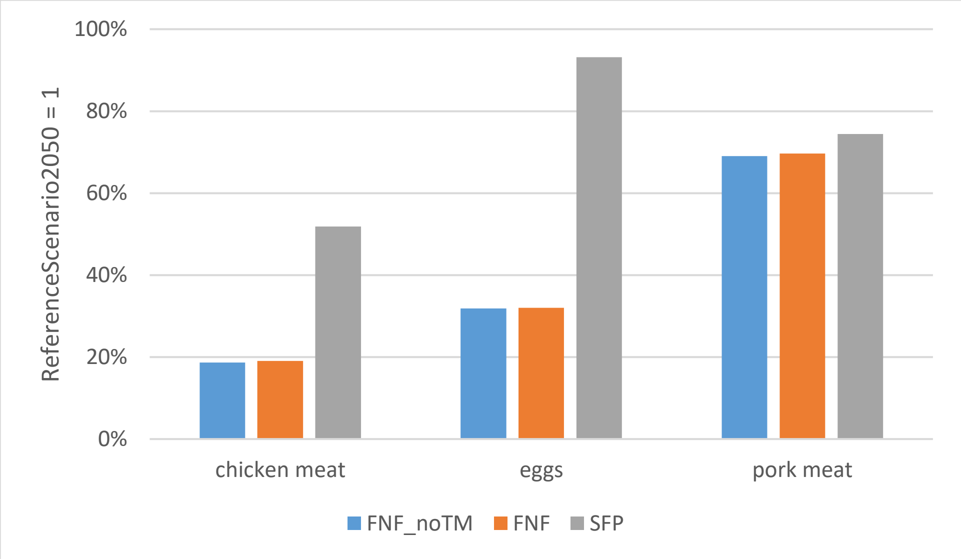


Figure 20: Summary of production changes for other animal products in the three scenarios

Pork meat production, chicken meat production as well as eggs production exhibit a similar decrease under baseline conditions as bovine meat and milk production. For the alternative scenarios, they follow the changes in consumption pattern without any scenario resistance created by biological linkages or other mechanisms in the system (Figure 20).

4.4.2 Production impacts of the alternative optimisation scenarios

Figure 21 summarizes the production impacts of one of the two optimization scenarios where environmental impacts are minimized while consumption is kept as closely as possible to the baseline diet. For each product, it compares domestic production in the year 2050 in the optimization scenario to domestic production in the year 2050 in the ReferenceScenario2050. The results are displayed as percentage deviations from the baseline 2050 domestic production volume.

The main way of minimizing environmental impacts is to exogenously determine which regions food products are produced in. Therefore, the domestic production of many animal products, for example, declines substantially. For these products, imports increase accordingly. While the production for most products changes in line with demand changes, domestic production of milk and bovine meat increase slightly beyond baseline values. Because pork and poultry production are reduced considerably, more bovine cattle can be kept without exceeding nutrient limits from manure per unit of land. Swiss production is, however, not normally competitive on international meat markets. This excess production of bovine meat and milk is therefore inconsistent from an economic point of view.

Similar patterns can be observed in the second optimization scenario where environmental impacts are minimized while consumption is kept as closely as possible to the Swiss Food Pyramid diet (not shown in Figure 21).

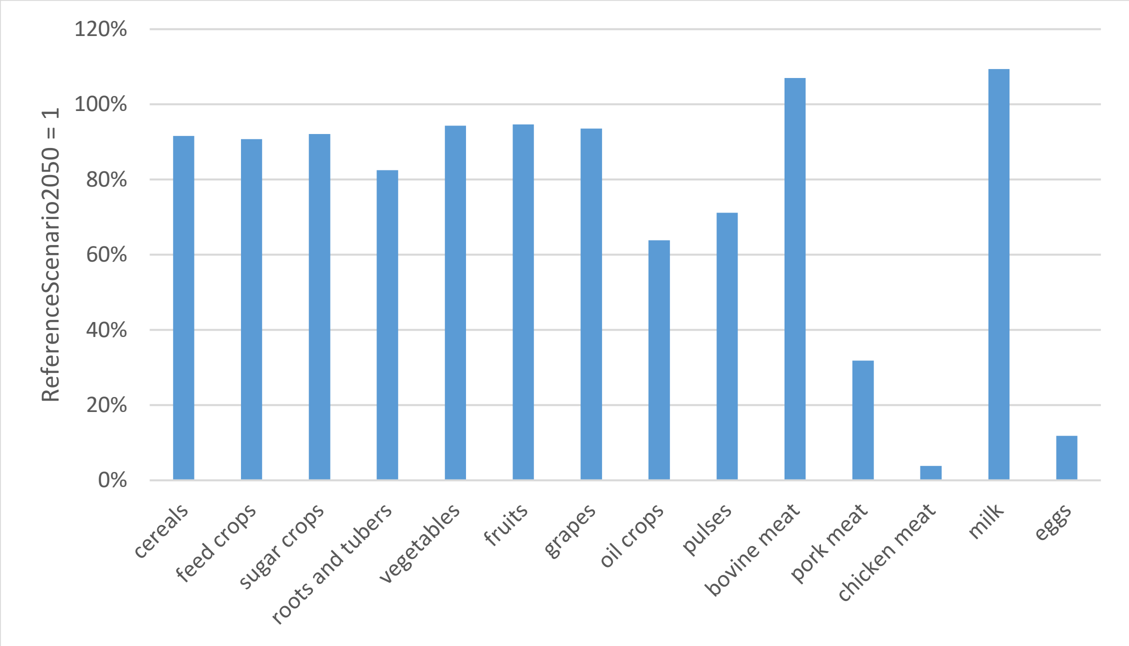


Figure 21: Summary of production changes in the optimization scenario minpenalty_2050 (minimization of environmental impacts at diets as close as possible to baseline 2050 values)

Figure 22 compares production changes to consumption changes for a scenario where 50% of household food waste is avoided. For each product, it compares changes in domestic production in the year 2050 in the food waste reduction scenario to changes in consumption with reduced food waste in the year 2050. The results are displayed as percentage deviations from the baseline 2050 domestic production/consumption volumes. The results for a scenario where 100% of household food waste is avoided are not shown in Figure 22 but follow the same trends. Overall, production changes are in the same direction as consumption changes but the extent of production changes remains below the extent of consumption changes. The only exception to this rule are the vegetables where production changes more than consumption. Changes in imports are also not shown in Figure 22. For most products, imports decline to a similar extent as domestic production so that the self-sufficiency ratio remains more or less unchanged.

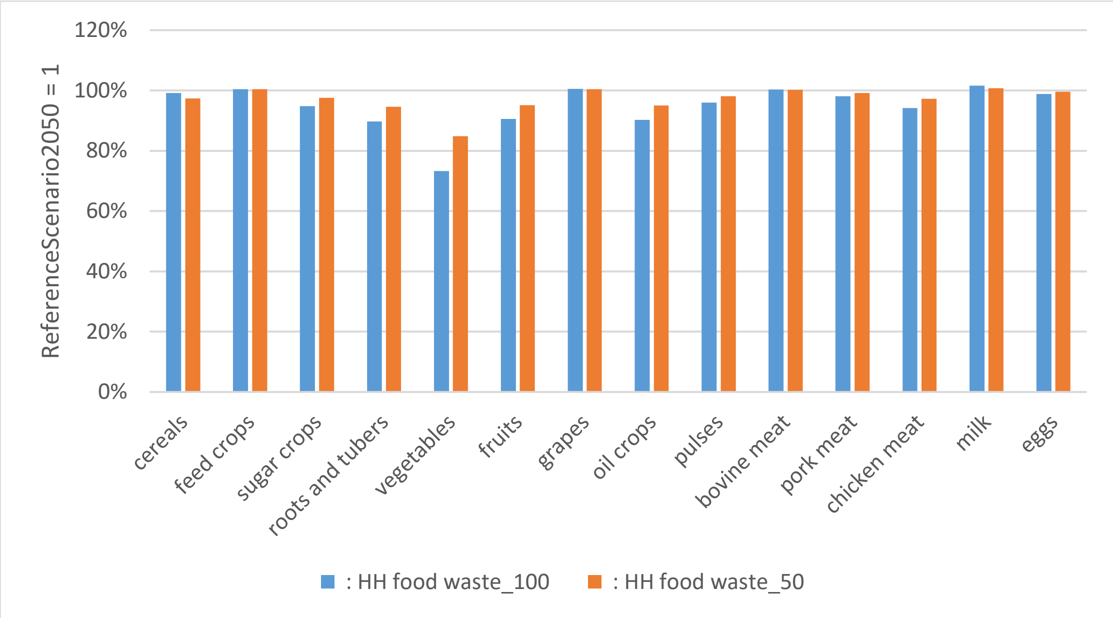


Figure 22: Summary of production and consumption changes in the scenario with 50% reduction of household food waste

Figure 23 compares the impact of alternative formulations of the feed no food strategy to the production of animal products in the ReferenceScenario2050. The ReferenceScenario2050_FNF assumes diets identical to those in the ReferenceScenario2050". The FeedNoFood2050 scenario, on the other hand, combines feed no food requirements on the production stage with substantial changes in diets on the consumption stage. While the production of milk and bovine meat do not differ from each other in the two feed no food formulations, the production of pork, chicken meat and eggs does. In both formulations of the feed no food strategy, bovine cattle is limited to the available pastureland and today's levels of temporary meadows. Pork and poultry, however, are fed with by-products from plant production. As the demand for these products is identical to baseline demand in the ReferenceScenario2050_FNF, production of these products is so profitable that more food cereals, sugar crops and oil crops are produced in order for more by-products to become available.

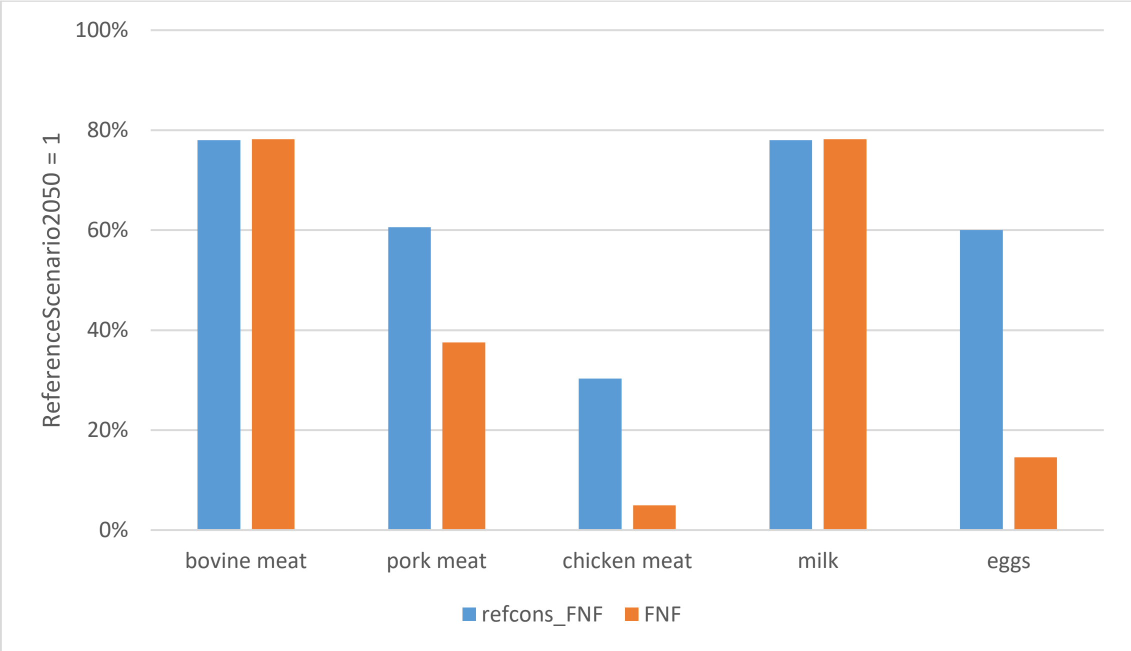


Figure 23: Summary of changes in animal production under various designs of a feed no food strategy

Figure 24 shows the feedback mechanisms responsible for the resistance of animal production in adjusting to feed no food requirements. The figure is a more detailed version of the causal loop diagram shown in Figure 6. It shows – still on an aggregated level – how the production of animal products, feed and food crops are linked by a set of mainly balancing feedback loops that counteract all attempts at limiting animal production while demand for animal products remains unchanged.

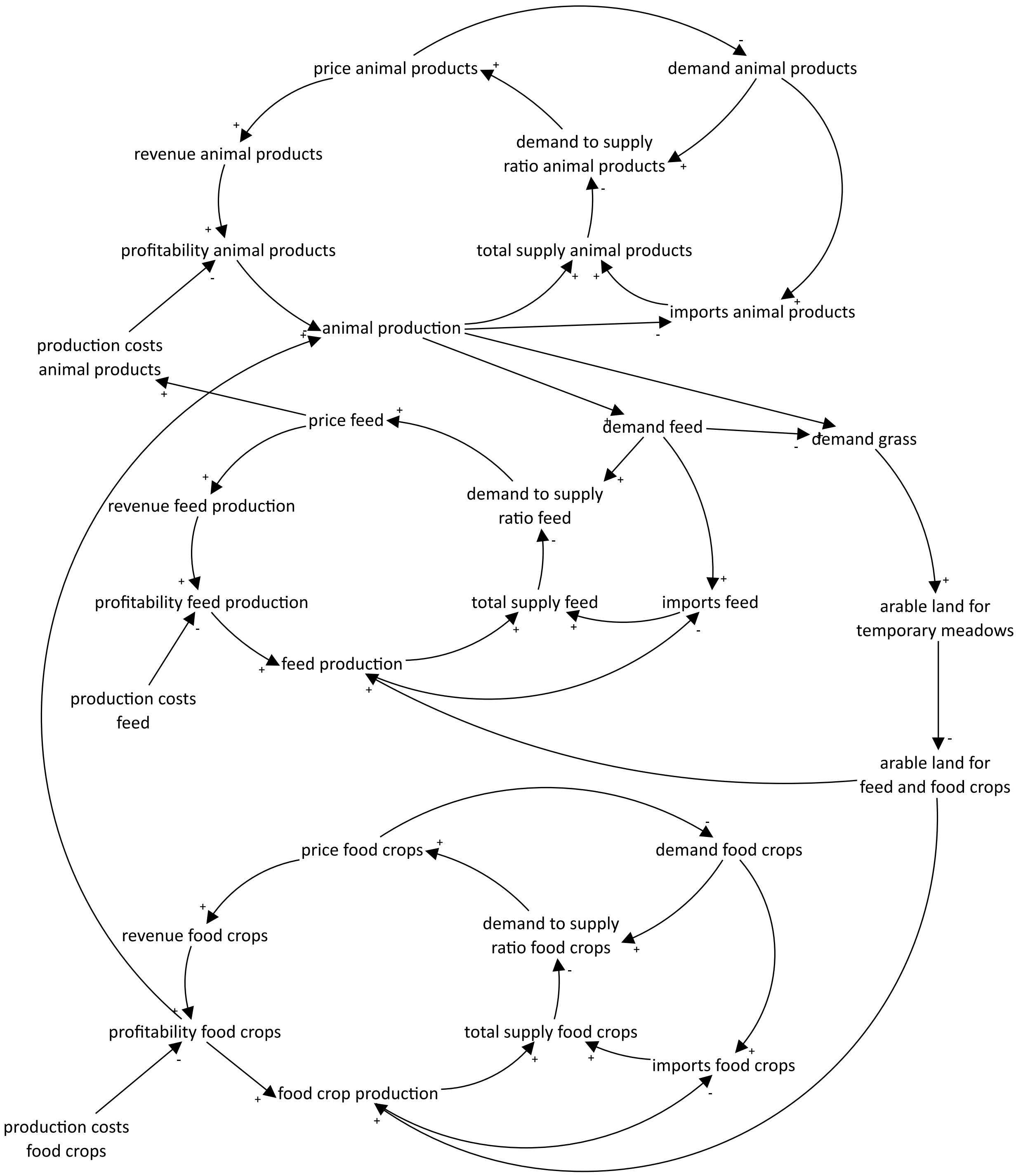


Figure 24: Feedback mechanisms underlying the unintended consequences of some variants of a feed no food strategy

4.4.3 Nutrition-related impacts on human health

Consumption-side impacts of human health have been assessed using the Alternate Healthy Eating Index (AHEI) (Chiuve *et al.*, 2006), which was also applied to assess the menuCH-data (see Section 0). Results suggest that the SFP2050 scenario clearly performs best from a health perspective (total score of 85 versus 57 in the reference). The only categories of the AHEI where the SFP2050 performs worse than the reference scenario are fish and alcohol consumption, as can be seen in Figure 25. In this figure, the difference to the reference scenario for each subcategory of the AHEI is presented. The black line thus denotes the reference scenario; if the shaded area lies outside the circle, the subcategory of this scenario performs better than the reference – and the opposite holds for shaded areas that lie within the black circle. The lower value for the category focusing on fish in the SFP2050 is a result of higher optimal intake values defined in the AHEI as compared to the SFP. Regarding alcohol consumption, recommendations in the SFP are such that maximum one small portion of alcoholic beverages should be consumed, while in the AHEI, the optimal intake level is higher, and non-drinkers are assigned a score of 2.5 (out of 10 for this subcategory). However, it has to be noted that the optimal intake values as defined in the AHEI for the category of alcoholic beverages don't reflect the current state in nutrition-related health science anymore; thus, this result is mainly driven by outdated optimal intake levels of this category in the AHEI, and therefore has to be interpreted with care. We nevertheless refrain from adapting the AHEI for this, as the AHEI as currently defined is an established and often used metric.

For the FNF-scenarios, we find that the AHEI score is higher in the categories of nuts and legumes, resulting from the increase in pulses. Further, the score is lower for the fish category, which results directly from the scenario definition, where animal-source food is limited to ruminants and monogastrics. In total, the FNF-scenarios perform similarly to the reference scenario (total score of 56.5 and 57 versus 57 in the reference).

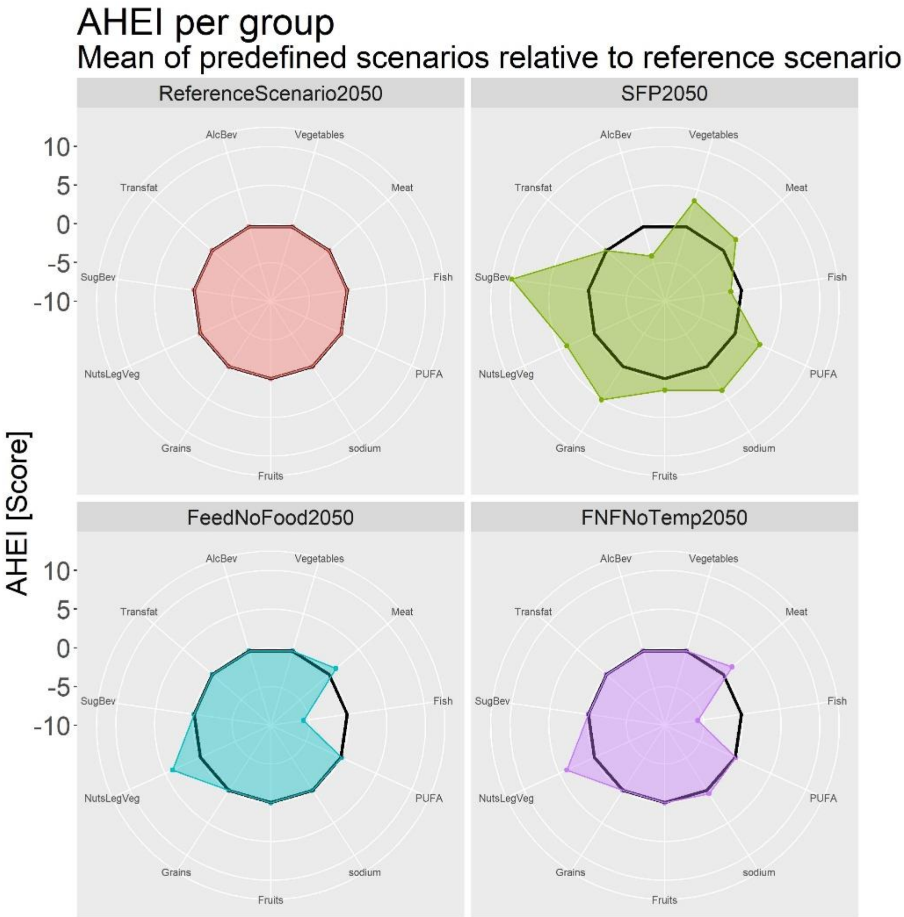


Figure 25: Values per subcategory of the Alternate Healthy Eating Index (AHEI) relative to the reference scenario, per scenario

4.4.4 Environmental impacts

The potential environmental impacts from the change in consumption and production patterns described in the FeedNoFood2050 and the Swiss Food Pyramid scenarios will be introduced in the following subchapters. In particular, the impact on climate change, land occupation, biodiversity loss potential in the agricultural sector, marine eutrophication footprint, and ecological footprint are described in detail.

The results from each scenario are presented in comparison to the ReferenceScenario2050 and split according to product groups. The product groups fall within three categories: agricultural products, food industry products and other goods and services such as basic materials, chemicals, food services, trade and transport, related to the individual household consumption of food and beverages. For the impacts on climate change and land occupation, food groups are also presented in a more disaggregated form, but without categorisation according to economic sectors. The presented percentages refer to the changes of the environmental impacts that are triggered across the value chain through household consumption. Furthermore, the potential changes are divided between domestic impacts and impacts abroad directly related to changes in Swiss dietary patterns.

4.4.4.1 Global warming potential

Climate change potential, regarded as one of the (current) main environmental threats, will be directly affected by the change in dietary consumption patterns in both scenarios.

As can be seen in Figure 26 (left), the total amount of greenhouse gas (GHG) emissions will decrease by around 8 % in the SFP2050 scenario; this is mainly due to the decrease in GHG emissions abroad (orange bar) resulting from a change of dietary patterns in Switzerland. On the other hand, domestic GHG emissions (blue bar) will actually increase by 2 %. The contributions of the individual household's food related consumption of each product group to the total percentage change in GHG emissions is measured in percentage points. Thus, the overall increase in domestic GHG emissions is mainly due to the increase in GHG emissions triggered across the value chain from household consumption of dairy products (3 percentage points). Even though GHG emissions abroad also increase in that particular product group, the significant decrease of imported meat and fish products leads to the overall reduction in GHG emissions.

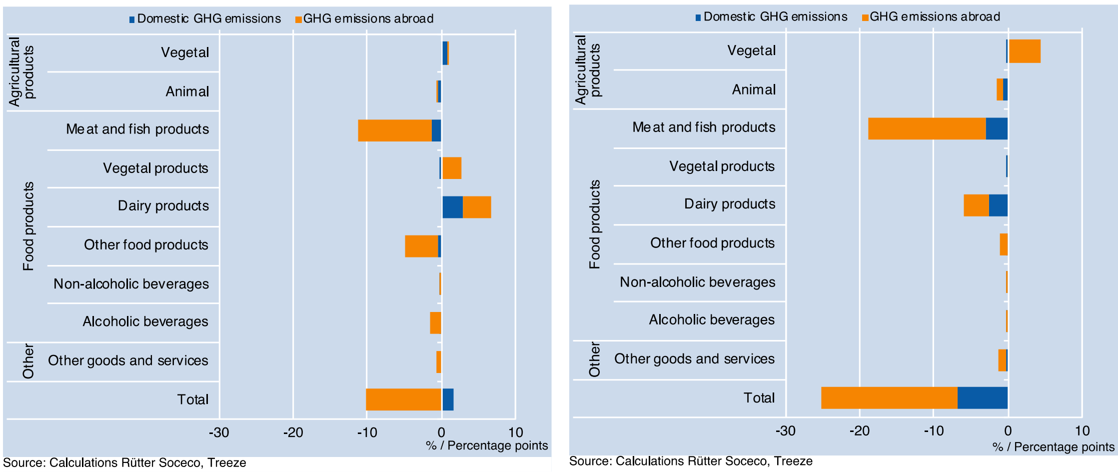


Figure 26: Deviation of GHG emissions in the SFP2050 scenario (left) and in the FeedNoFood2050 scenario (right) from the ReferenceScenario2050 (EE-IOM)

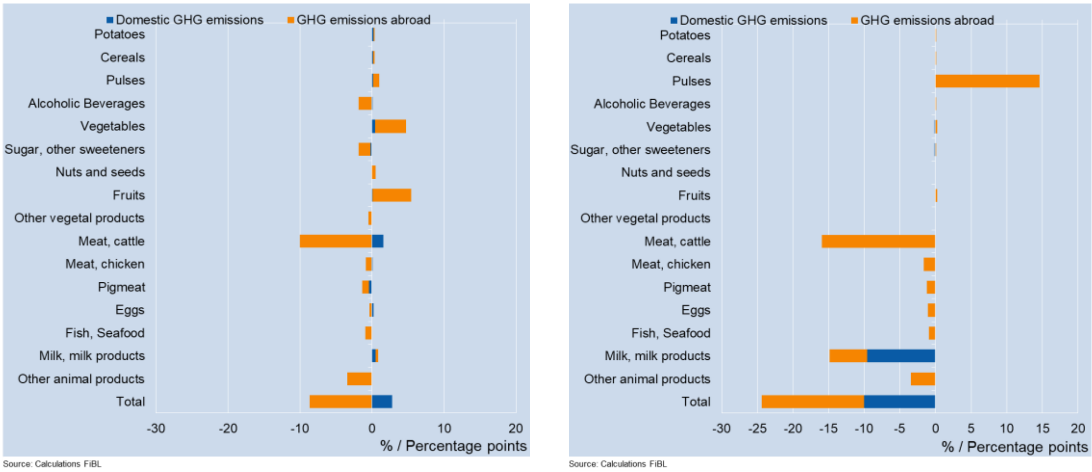


Figure 27: Deviation of GHG emissions in the SFP2050 (left) and FeedNoFood2050 (right) scenarios from the reference scenario by food group (SOLm)

In the FeedNoFood2050 (Figure 27) scenario the overall reduction in GHG emissions is even more pronounced and totals around 25 % less compared to the ReferenceScenario2050. Similar to the SFP2050 scenario the reduction of GHG emissions abroad from meat and fish products is the main contributor to the overall decline in GHG emissions. Given furthermore the domestic reduction in GHG due to the decrease in the consumption of meat and dairy products, it becomes apparent that this scenario eliminates the main dietary based contributors to GHG emissions. The increase in GHG emissions abroad from vegetal production (mainly pulses) does not seem to affect the overall reduction in a significant way.

As for GHG emissions results from two models (EE-IOM and SOLm, see figure captions) can be compared, this can serve as a consistency check between the models. Overall, the results fit quite well; the total reductions of greenhouse gas emissions derived from SOLm are slightly lower, but within an acceptable range. For the SFP2050 scenario, results from SOLm suggest not only an increase in domestic GHG emissions for milk products, but also for cattle meat – even though the consumption of cattle meat decreases. This can be explained by the different methods to calculate the GHG emissions: in SOLm, products that are coupled in their production process – such as milk and meat – cannot be decoupled and therefore, as the domestic production of milk products increases, this also affects the GHG emissions of cattle meat. One could argue that in such a case, the whole impact could be allocated to the milk products, as the meat – although it needs to be produced – will not be consumed in this scenario (it then needs to be exported, for example).

Figure 28 shows the deviation of GHG emissions in the SFP2050 and FeedNoFood2050 scenarios to the reference scenario by source of emission. For the SFP2050 scenario, we see that GHG emissions induced by animal production contribute substantially to the reduction in GHG emissions. Further, emissions induced by transport increase, which is mainly due to increased demand and thus imports for fruits and vegetables. As fruits and vegetables often belong to the category of perishable products, they need to – if imported from regions that exceed a certain threshold – be transported by aircraft. For the FeedNoFood scenario, the increase in the stages fertilised soils, deforestation emissions, and cultivation of organic soils mainly come from the substantial increase in production of pulses.

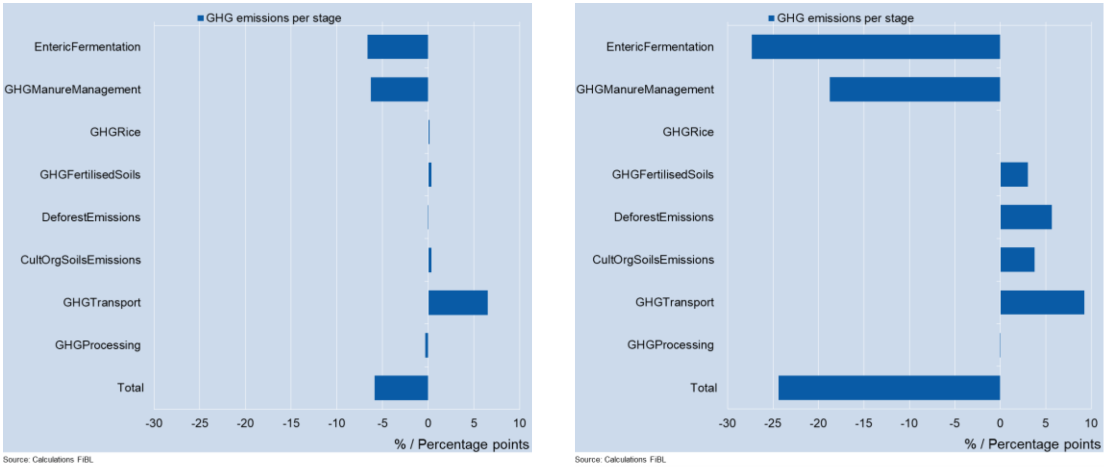


Figure 28: Deviation of GHG emissions in the SFP2050 scenario (left) and the FeedNoFood2050 Scenario (right) from the reference scenario by emission source (SOLm)

4.4.4.2 Land occupation

Land occupation denotes the total amount of land used to produce all products required in the scenarios, both under crop and grassland management. Thus, it includes different types of land, which are partly unsuitable for arable crop production. For this indicator, the sum of total area needed is calculated, irrespective of the type of land. In Figure 29, land occupation per food group for the SFP2050 relative to the reference scenario is shown. In total, land occupation is projected to decrease by around 26 %. To this, the main contributor is cattle meat. As for GHG emissions, land occupation for milk products increases. In the FeedNoFood scenario, the reduction is even higher with 35 %. The main difference here is that all animal-source food commodities – thus, including milk products – decrease.

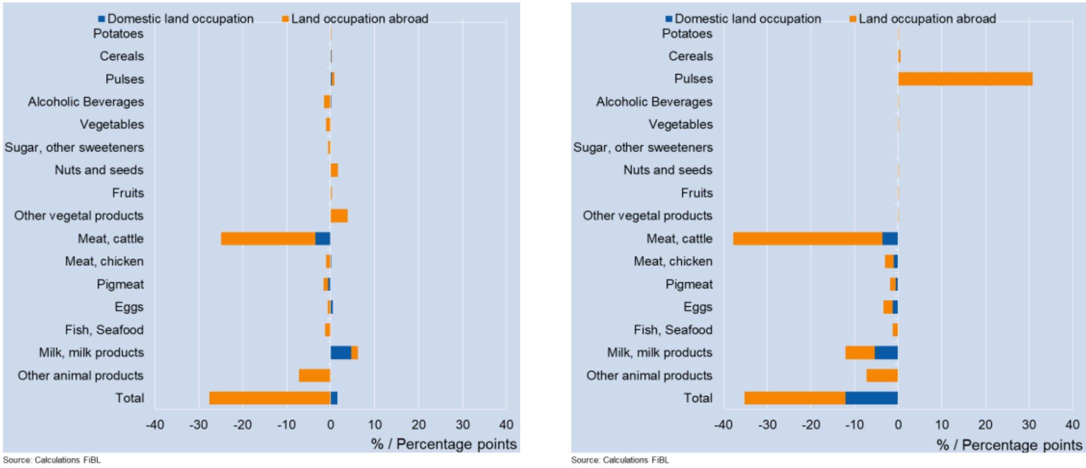


Figure 29: Deviation of land occupation in the SFP2050 (left) and FeedNoFood2050 (right) scenarios from the reference scenario by food group (SOLm)

4.4.4.3 Biodiversity loss potential

The overall reduction in biodiversity loss potential in the SFP2050 scenario is similar to the decline of GHG emissions (10 %). The greatest impact on biodiversity loss due to a change in dietary patterns according to the SFP2050 scenario is induced abroad (Figure 30, left); all food product groups, aside from dairy and vegetal products, exhibit a reduction in biodiversity loss potential abroad. The strongest contributor (slightly more than 10 percentage point) are other food products; within this product group reduction in consumption of coffee could be considered as having a substantial impact.

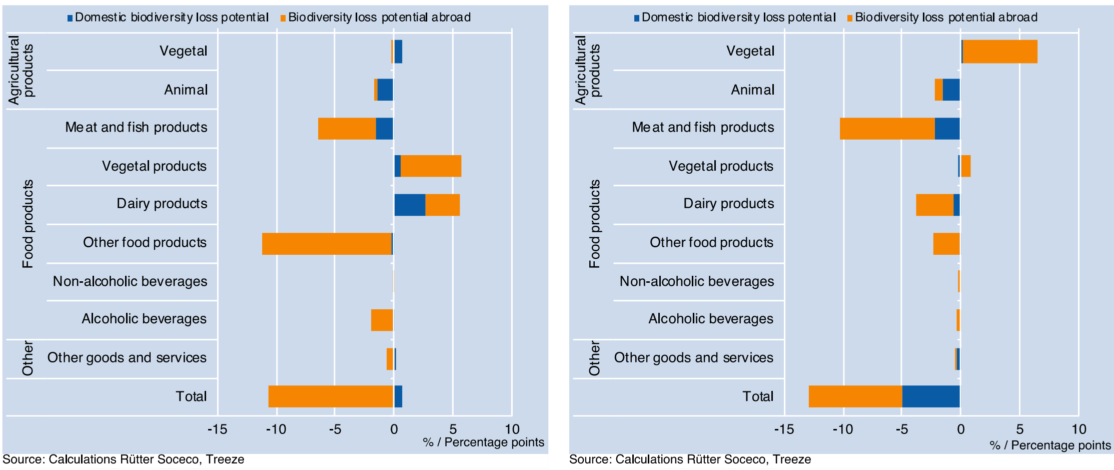


Figure 30: Deviation of biodiversity loss potential in the SFP2050 scenario (left) and in the FeedNoFood2050 scenario (right) from the ReferenceScenario2050 (EE-IOM)

In contrast, domestic reduction in biodiversity loss potential is the main driver for the 13 % overall reduction in the FeedNoFood2050 scenario (Figure 30, right). This stems mainly from the decrease in consumption of meat and dairy products. Whereas biodiversity loss potential from the meat and fish products is also reduced abroad, the increase in vegetal agricultural production because of the increase in the consumption of pulses to meet the necessary protein intake outweighs this positive development. The change in the land use pattern to meet the increased agricultural demand for land could contribute to the increase in biodiversity loss potential.

4.4.4.4 Eutrophication

In contrast to the previous environmental indicators, changes in eutrophication potential do not only deviate in the two scenarios in terms of size but also in terms of direction; in the SFP2050 scenario (Figure 31, left) the eutrophication potential largely remains unchanged (a slight increase by almost 1 %), whereas in the FeedNoFood2050 scenario it shows a strong overall decrease of nearly 24 % compared to the ReferenceScenario2050 (Figure 31, right).

In the SFP2050 scenario the reduction in meat consumption is compensated by an increase in consumption of vegetal agricultural and food products and dairy products; all of which contribute to an increase in domestic eutrophication by about 4% and thus outweigh even the additional decrease in other food products. On the other hand, eutrophication abroad decreases by about 3%; these opposite effects cancel each other out. Here it is important to emphasize that eutrophication is a local effect, though, and reporting globally aggregate impacts hide the true dynamics on the ground, different to total GHG emissions, which are a global pollutant. Thus, the net zero effect on eutrophication in the one scenario here actually means improvements in one region vs. deterioration in another.

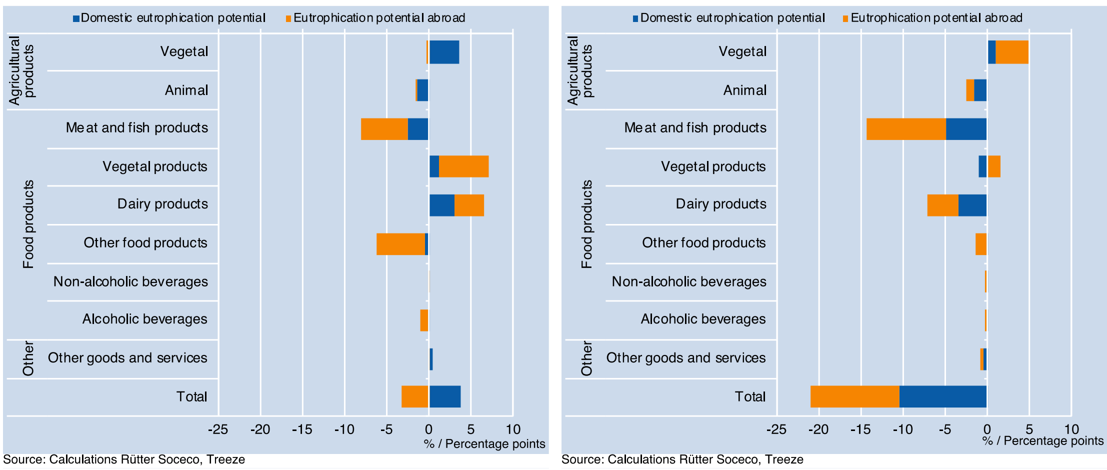


Figure 31: Deviation of eutrophication potential in the SFP2050 scenario (left) and in the FeedNoFood2050 scenario (right) from the ReferenceScenario2050 (EE-IOM)

In the FeedNoFood2050 scenario, (Figure 31) meat and dairy consumption are both decreased, thus leading to a stronger decrease in eutrophication potential. Here, an increase in eutrophication potential from vegetal agricultural production happens mainly abroad and is still outweighed by the decrease in meat and fish products, and dairy products abroad. Domestically, all food product groups exhibit a decrease in eutrophication potential (aside from vegetal within agricultural products). Clearly, the strict assumptions regarding animal feed and the resulting change in land use have a positive (decreasing) effect on eutrophication potential.

4.4.4.5 Environmental footprint

The last environmental indicator – the environmental footprint – is a composite measure, which encompasses areas such as water resources, land use, heavy metals, noise, radioactive waste and others. The more points each category gets the more damaging the overall effect to the environment. Thus, the overall 12 % reduction in eco-points in the SFP2050 scenario can be seen as a positive result of a change in dietary habits (Figure 32). Most of the changes can be attributed to changes abroad. Once again, the recommended consumption of dairy products leads to an increase of potential environmental damages; however, it is offset by significant decreases in other categories. For example, a decrease in other food products accounts for 10 percentage points of the overall decrease. Regarding the subcategories of the environmental footprint, the decrease of heavy metal emissions into the soil is the main contributor to the overall decrease of the environmental footprint.

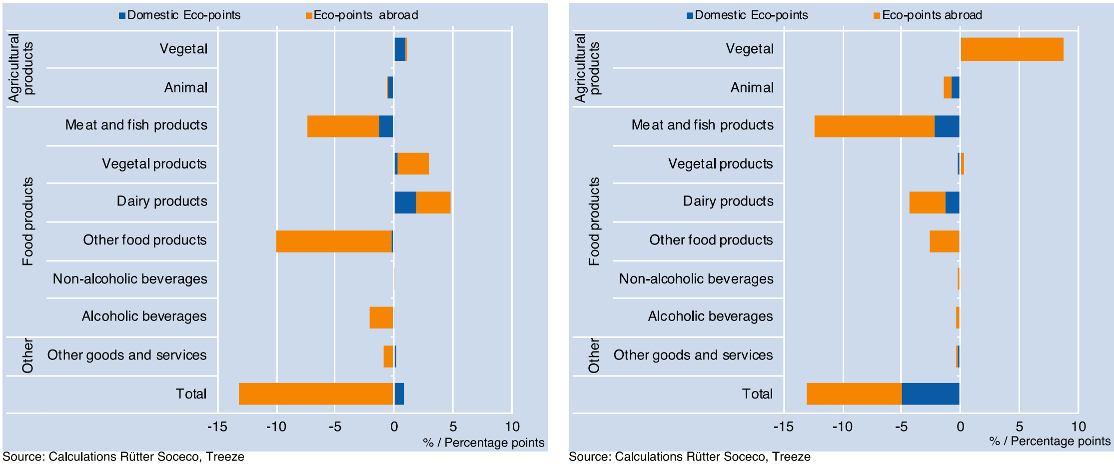


Figure 32: Deviation of environmental footprint in the SFP2050 scenario (left) and the FeedNoFood2050 scenario (right) from the ReferenceScenario2050 (EE-IOM)

The overall reduction in the environmental footprint is with not even 13 % only slightly higher in the FeedNoFood2050 scenario than in the SFP2050 scenario. Generally, the FeedNoFood2050 scenario exhibits a similar pattern as before: Meat, fish, dairy and other food products see a decrease in eco-points abroad whereas vegetal (pulses) agricultural production strongly increases to compensate the loss in protein through a decrease in meat consumption. Domestically, none of the food categories experiences an increase in eco-points, and especially meat, fish and dairy products are reduced (by up to 2.5 percentage points). The main drivers for this overall decrease in absolute terms are the decrease in main air pollutants and particulate matter and heavy metals into the soil.

4.4.5 Economic impacts

The next subchapters will describe the impacts of the changes in dietary patterns from an economic perspective. Specifically, three commonly used economic indicators – household expenditure, value added, and employment – are discussed, focussing on the changes triggered across the value chains within the different product groups due to the change in individual household consumption of food and beverages. Similar to the environmental effects, the economic impacts are presented separately for each food product group and as totals.

4.4.5.1 Household expenditure for food consumption

Household expenditure for food products decreases slightly in the SFP2050 scenario by not even 3 % (Figure 33), with an overall decrease in the value of imported goods by 2 %. Aside from the meat and fish products, the main decrease in expenditure can be contributed to the decrease of expenditure for alcoholic beverages from abroad. Even though domestic final demand also decreases, it is rather small. The domestic decrease in meat and fish products is entirely offset by an increase of expenditures in dairy products. It should also be noted that such a comparatively small decrease in household expenditure for food consumption triggers, for example, a more than 10 % reduction in the environmental footprint (Figure 32, left).

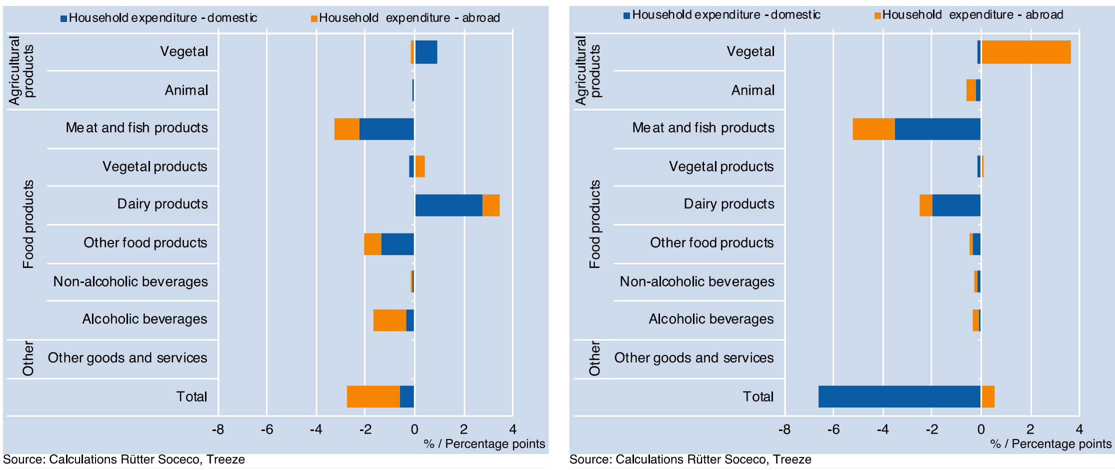
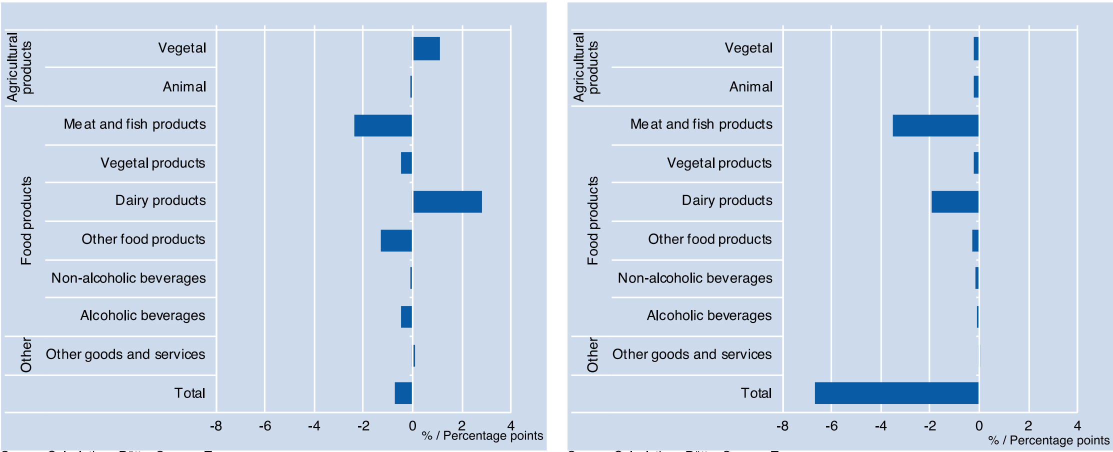


Figure 33: Deviation of household expenditure for food (including food services) in the SFP2050 scenario (left) and the FeedNoFood2050 scenario (right) from the ReferenceScenario2050 (EE-IOM)

In contrast, the changes in dietary habits have a substantial impact on the household expenditure for domestic agricultural and food products in the FeedNoFood2050 scenario (Figure 33, right). Given the dietary restrictions from the FeedNoFood2050 scenario, meat, fish and dairy products exhibit a decrease in demand; however, this is not offset by an increase in domestic demand. Instead, the demand for vegetal imports increases. It should be noted, though, that the graphs only show the impact on food consumption and not on other consumption goods. In particular, from an economic standpoint, a rebound effect would be expected – the declining demand in the food industry could be met with an increasing demand of other consumption goods. Of course, this would not only have an economic effect but also potentially change the environmental impacts described in the previous subchapters.

4.4.5.2 Gross value added

Gross value added is a productivity measure, which provides information on the value added (or lost) on a regional, national or industry level. Thus, the focus is here exclusively on the value chains within Switzerland. Gross value added triggered through the changes in dietary habits is decreased by less than 1 % overall in the SFP2050 scenario (Figure 34. left). The main areas of impact (meat and fish products on the one hand and dairy on the other) offset each other. These changes in the value added triggered by changes in consumption habits are also directly reflected in the household expenditure changes (Figure 33).



Source: Calculations Rütter Soceco, Treeze

Source: Calculations Rütter Soceco, Treeze

Figure 34: Deviation of gross value added in the SFP2050 scenario (left) and the FeedNoFood2050 scenario (right) from the ReferenceScenario2050 (EE-IOM)

Once again, the FeedNoFood2050 scenario presents a different outcome (Figure 34, right). All product groups aside from other goods and services, experience a decrease in gross value added; resulting in an overall loss of 7 %. Given that a substantial amount of demand for vegetal agricultural and vegetal food products is satisfied through imports in this scenario, the decrease in gross value added in the meat and fish as well as dairy products groups is not offset through a higher demand and thus higher value added trigger in other product groups as is at least partially the case for the SFP2050 scenario. The question remains, if potential higher demand in other consumption sectors because of a decrease in food-related expenditures could compensate the losses in the food related product groups.

4.4.5.3 Employment

Employment is another important indicator for economic impacts due to changes in dietary habits. It is commonly measure in full-time equivalents (FTE).

Figure 35 (left) shows the percentage changes of employment triggered across the value chain in each product group; overall, adjusting dietary habits to the recommended SFP causes an increase in employment in these groups by 3 %. Even though some product groups (especially meat and fish products, and alcoholic beverages) are negatively affected, both, vegetal agricultural products and the dairy food products exhibit a strong increase, contributing almost 4 percentage points each to the overall increase.

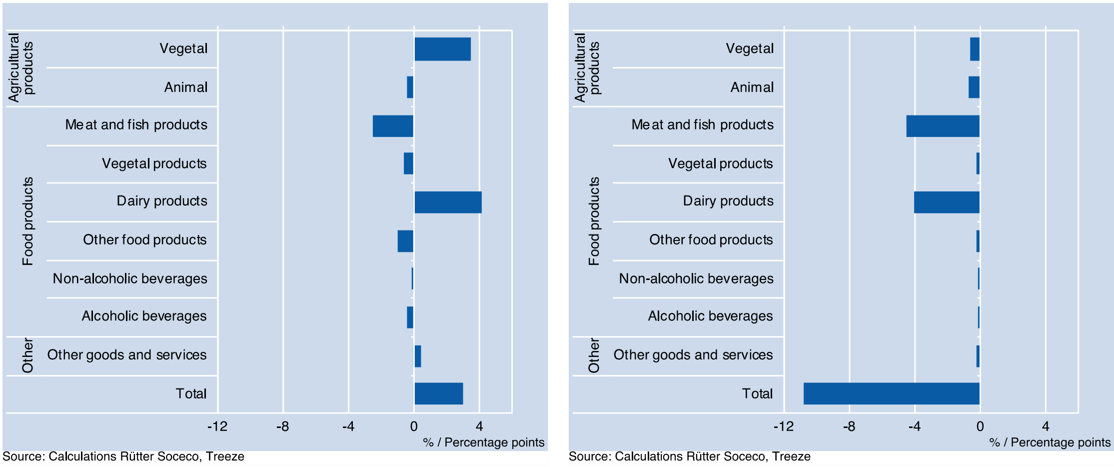


Figure 35: Deviation of employment in the SFP2050 scenario (left) and in the FeedNoFood2050 scenario (right) from the ReferenceScenario2050 (EE-IOM)

The results are less promising for the FeedNoFood2050 scenario (Figure 35, right). Overall employment decreases by 11 %. The largest (percentage points) can be found as expected in the meat and fish, and dairy products industry – each losing 4-5 percentage points. It should be noted, however, even if animal agricultural products' losses are less than half a percentage point of the overall reduction, within the sector itself, less than 10 % of the FTE remain compared to the ReferenceScenario2050.

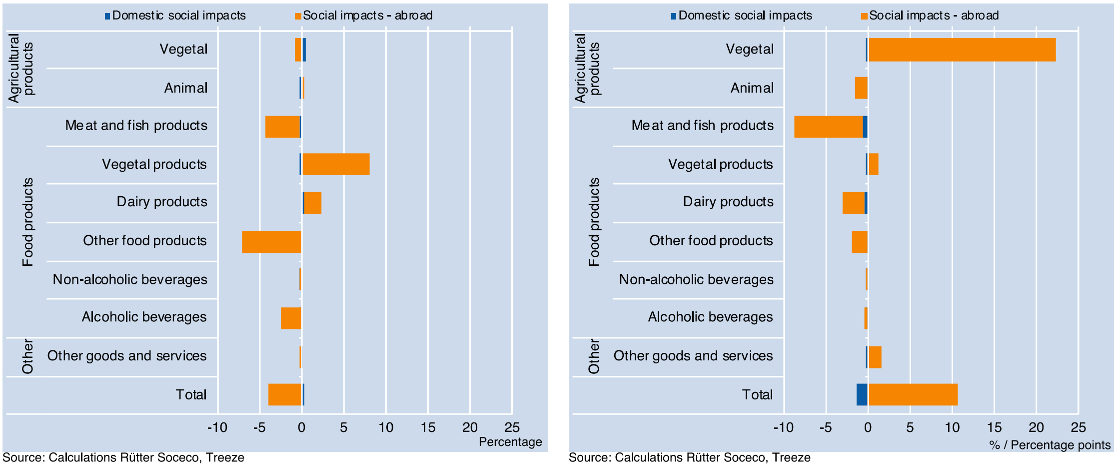
As employment is not only used as an indicator for the economic wellbeing of a country but also important for the social wellbeing, this result needs to especially be taken into consideration when evaluating the different scenarios.

4.4.6 Social impacts

Aside from employment, other social indicators should also be utilised in order to assess the overall social impact of the SFP2050 and FeedNoFood2050 scenarios compared to the ReferenceScenario2050. This chapter will describe the social impacts using two different indicators – the social hotspot index and production-related DALYs.

4.4.6.1 Social Hotspot Index

The composite social hotspot index is a weighted average based on indicators describing labour rights, health & safety, human rights, governance and community infrastructure. As can be seen in Figure 36 (left), the overall negative social impacts are reduced in the SFP2050 scenario by nearly 4 % compared to the ReferenceScenario2050, mainly because the change in consumption patterns triggers less social impact factors abroad. Especially the meat and fish products and other food product groups contribute strongly to this overall reduction. However, vegetal food products and dairy products groups contribute an increase with up to 7 percentage points. It should also be noted, that even though the total effect is negative across all groups, this is only due to the significant improvement in the health & safety indicator; all other social impact measures have deteriorated.



Source: Calculations Rütter Soceco, Treeze

Source: Calculations Rütter Soceco, Treeze

Figure 36: Deviation of social impacts in the SFP2050 scenario (left) and in the FeedNoFood2050 scenario (right) from the ReferenceScenario2050 (EE-IOM)

The results for the FeedNoFood2050 scenario appear worse from a social impact perspective (Figure 36, right): Overall, (negative) social impacts increase abroad by 10 %, even though domestic social impacts fall by 1 %. This is mainly due to an increase triggered by the changes in household demand for vegetal agricultural products, especially pulses (22 percentage points), which cannot be offset by the decrease (8 percentage points) in the meat and fish products group. Thus, vegetal products appear to have larger negative social impacts per unit of (monetary) production than meat products. Overall, all of the social impact measures have worsened in the FeedNoFood2050 scenario, even though some product groups show improvement. Changes in worker health and security mainly contribute to the overall effect. These results should be interpreted with caution due to uncertainties in method and data and should mainly serve as a hint for further in-depth analysis.

4.4.6.2 Production-related health impacts

The second indicator to measure the social impact are production-related health impacts measured as change in DALYs (disability adjusted life years). This indicator takes into account the years lost to premature death and expresses the reduced quality of life due to illness in years as well.

Figure 37 (left) presents the changes in the production-related DALYs for the SFP2050 scenario. Overall, changes in the dietary habits trigger a substantial reduction in DALYs abroad (11 %). This is once again mainly due to the reduction triggered by the consumption in the meat and fish products group. The significant impact that the other food products group had on the first social indicator (social hotspot indicator) is now smaller (less than 5 percentage points) but nonetheless still present.

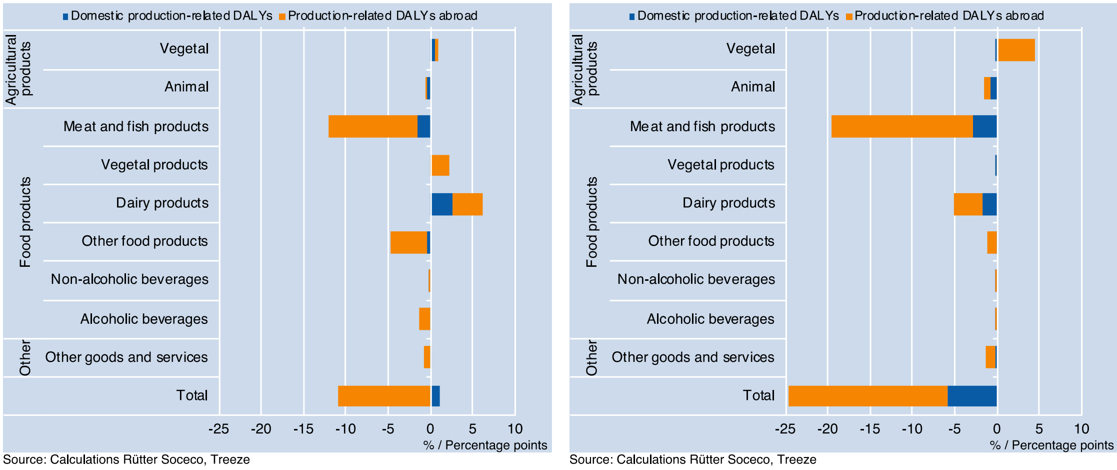


Figure 37: Deviation of production-related DALYs in the SFP2050 scenario (left) and in the FeedNoFood2050 scenario (right) from the ReferenceScenario2050 (EE-IOM)

The results for the FeedNoFood2050 scenario (Figure 37, right) show a reduction in DALYs for both domestic and abroad with a substantial overall decline of 24 %. This is mainly caused abroad by a reduction in the meat and fish products group (16 percentage points) which in contrast to the social hotspot indicator is not entirely offset by an increase in the vegetal agricultural products group. Domestically, the effect is once again much smaller (6 percentage points) mainly triggered by a decrease in the meat and fish products and dairy products group.

4.4.7 Analysis of trade-offs and synergies

Depending on the indicator chosen, the SFP2050 and FeedNoFood-scenarios perform better or worse than the reference scenario. From this, some important trade-offs and synergies arise, which will be investigated in the following sections.

4.4.7.1 Trade-offs vs. health and environmental impacts

In this section, health, environmental, social, and economic indicators are contrasted. First, environmental and health indicators are plotted together; in Figure 38, GHG emissions and the Alternate Healthy Eating Index (AHEI) are presented. In this figure, the performance of different scenarios can be compared along two dimensions, thus allowing to identify potential synergies and trade-offs. The quadrants are chosen such that for the AHEI, the ‘desired’ score lies at 2/3 of the total score or above. For GHG emissions, the threshold has been set at a reduction of one third as compared to 1990 is required, according to the Klimastrategie 2011. Only one scenario – i.e. the SFP2050 scenario – lies above the threshold for the health score. For GHG emissions, the scenarios derived via optimisation and the FeedNoFood scenario without temporary grassland lie below the set threshold. We further see that with regard to GHG emissions, all scenarios perform better than the reference scenario, but with respect to the health index, only the SFP2050 scenario, the minSFP (which minimises the distance to the SFP2050 while fulfilling certain environmental goals, see Section 4.3.4), and the scenario that minimises GHG emissions perform better than the reference. None of the scenarios investigated clearly lies in the quadrant of both environmental and health benefits, but some are close to it (minpenaltySFP2050; minGWP2050) and improving their health performance would result in such win-win scenarios.

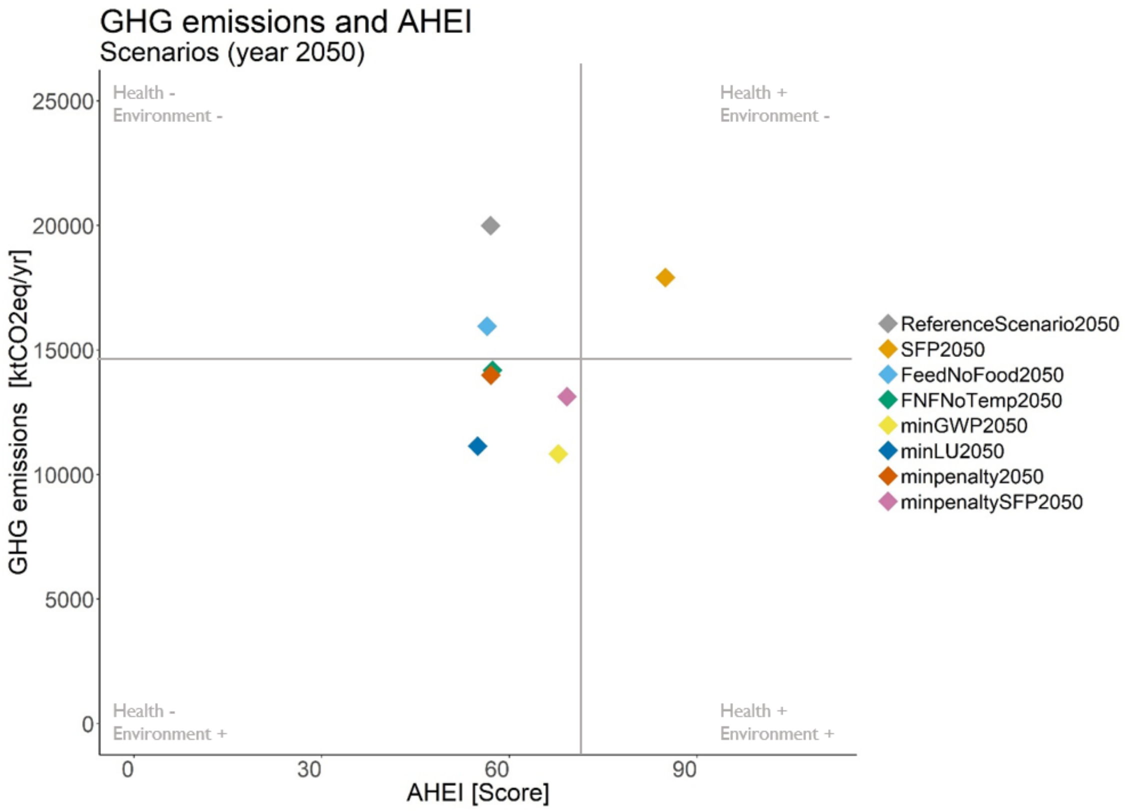


Figure 38: GHG emissions and the Alternate Healthy Eating Index of the different scenarios

Next, in Figure 39, environmental and social impacts are compared by contrasting the Eutrophication potential and the Social Hotspot Index. Here, we see clear trade-offs between the scenarios: the SFP2050 scenario performs worst from the environmental point of view but best from the social point of view, and the FeedNoFood2050 performs best from the environmental point of view, but worst from the social point of view.

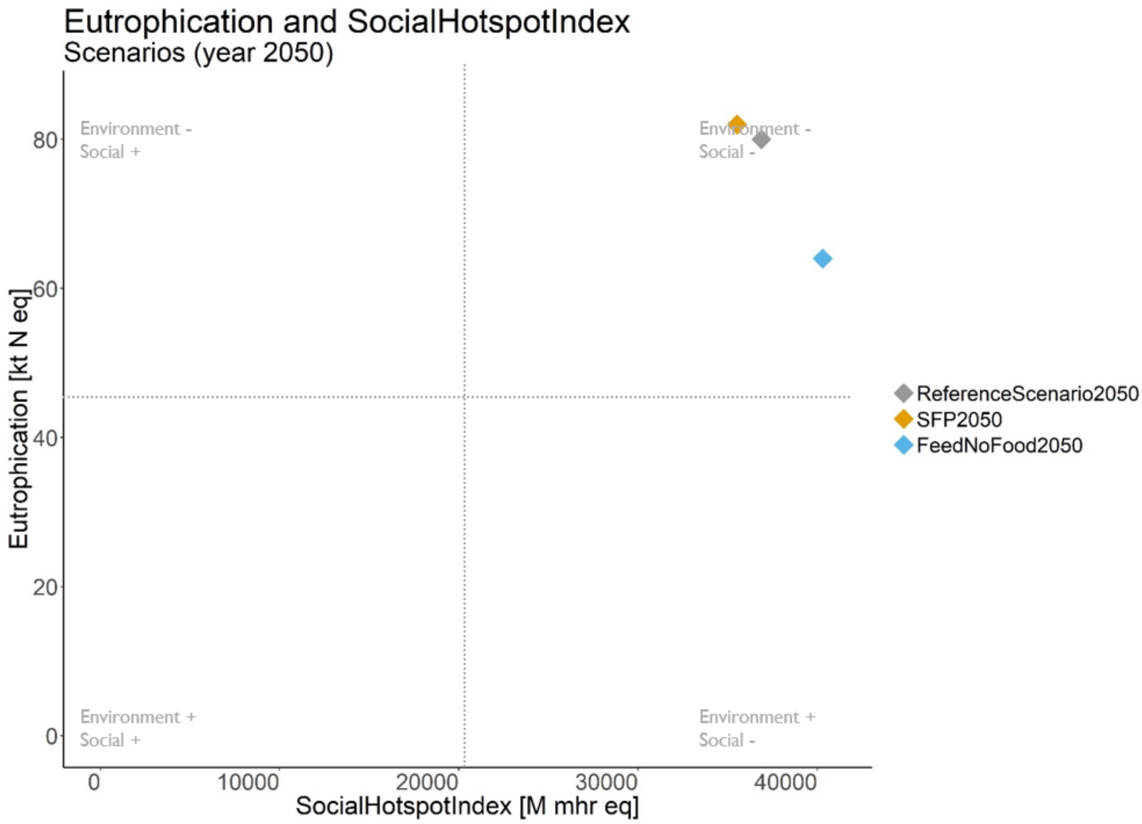


Figure 39: Eutrophication and the Social Hotspot Index of the different scenarios

Lastly, we can also contrast an environmental impact indicator with an economic measure: household expenditure (Figure 40). Individual household expenditure for food and beverage is highest in the ReferenceScenario2050 as is the biodiversity loss potential. A 3 % reduction in household expenditure already coincides with an overall decrease in biodiversity loss potential of 10 %. The FeedNoFood2050 scenario has the lowest biodiversity loss potential paired with the lowest household expenditure for food and beverages of all three scenarios. A reduction in household expenditure can be viewed as a positive result from a household perspective, as households have fewer food related expenses based on their changes in preferences. On the other hand, it can be viewed as a negative result from a production perspective, as less will be spent on food products. These expenses will most likely be shifted to other sectors, which however cannot be captured with the partial model applied here.

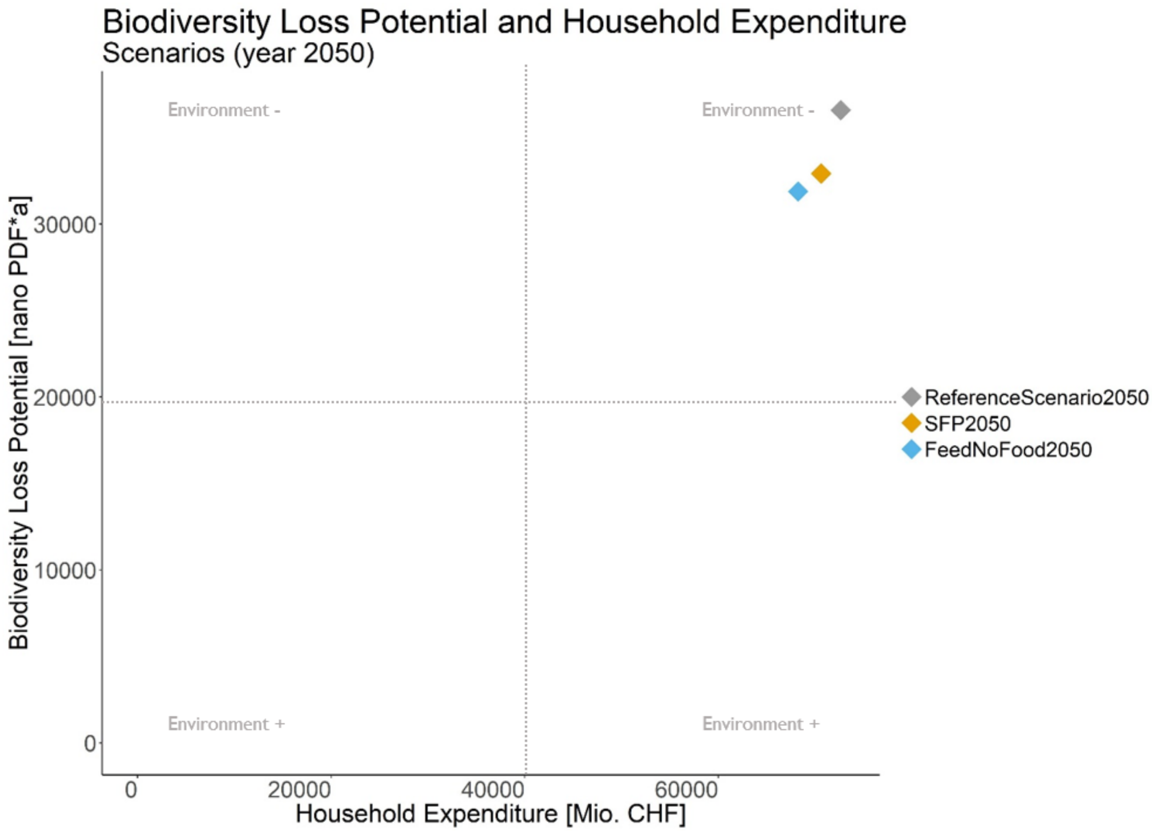


Figure 40: Biodiversity loss potential and household expenditure of the different scenarios

Figure 41 depicts health impacts at different stages: on the y-axis, production-related DALYs are presented, and on the x-axis, the consumption-related score AHEI is shown. The SFP2050 scenario performs best for the consumption-related health impacts, slightly worse than the FeedNoFood scenario for the production-related health impacts. The reference scenario, on the other hand, performs worst for the production-related health impacts, and differs only slightly from the FeedNoFood scenario for the consumption-related health impacts.

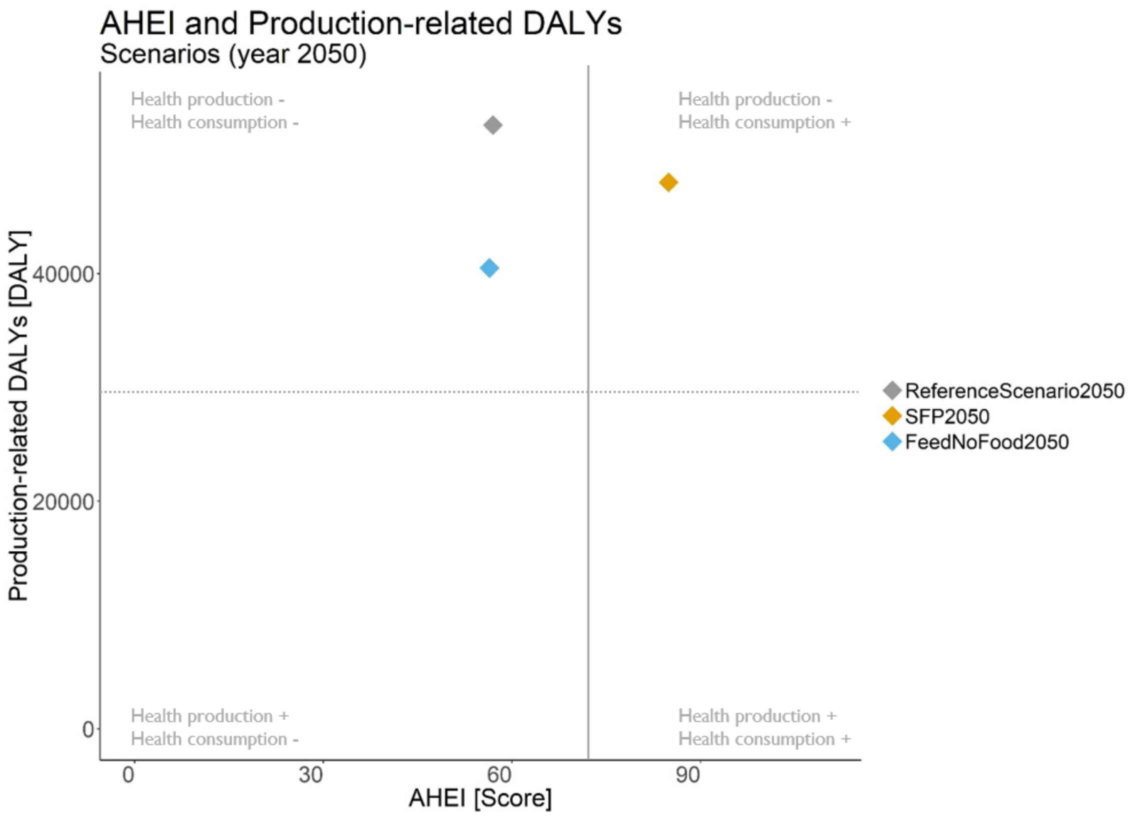


Figure 41: Production-related DALYs and the Alternate Healthy Eating Index of the different scenarios

4.4.7.2 Multi-dimensional comparison of scenarios

Below, the various relative impacts of the scenarios SFP2050 and FeedNoFood2050 compared to a ReferenceScenario2050 are compared in a multi-dimensional radar plot (Figure 42).

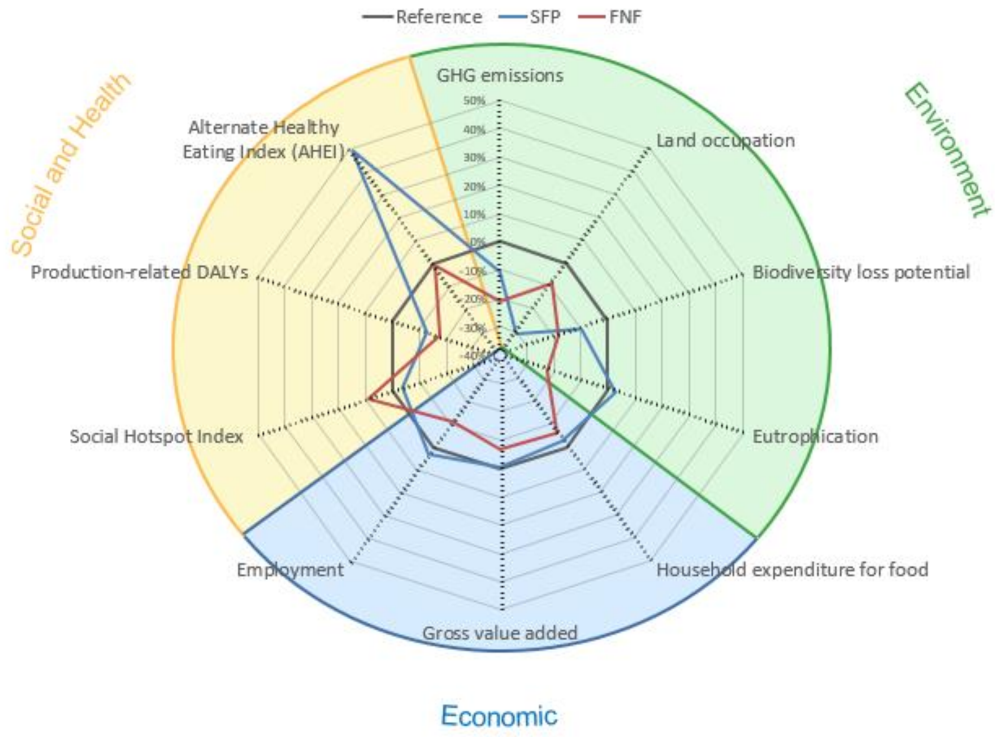


Figure 42: Comparison of the environmental, economic, and social and health performance of the SFP2050 and FeedNoFood2050 scenarios against the reference scenario. For all indicators besides AHEI: Scenario values below the reference indicate better performance, values beyond the reference indicate worse performance than the reference. For AHEI, the opposite applies.

4.4.8 Implementation challenges

The simulations with the system dynamics model identified several mechanisms that might pose challenges to the implementation of more synergies between sustainability and health impacts.

The FeedNoFood2050 scenario aligns sustainability and health impacts best. However, a transition towards such a scenario as defined in Section 4.2.2.3 requires major changes not just in agricultural production systems but also in diets. This is a challenge for farmers, food industry and consumers alike (cf. Section 6). In the FeedNoFood2050 scenario, no imports of feed or animal products are allowed. While this – in combination with substantial changes in diets – results in increased sustainability and health, it also poses the question of the feasibility in terms of, for example, trade agreements.

Reducing food waste at the household level can support a transition towards a more sustainable and healthy food system. Reducing food waste on the household level can give households a little more flexibility with regards to diets as slightly higher levels of meat consumption are possible than in the original feed no food scenario. However, this is not sufficient for realizing the necessary changes in diets as food waste reduction does not constitute a change in diets.

Additional model simulations (Section 4.4.2) showed that only partial implementation of a feed no food scenario on the production side would lead to considerable inconsistencies, that is, to mechanisms that counteract the desired shift towards sustainability. As long as diets are not aligned with production systems, production of animal products will be so competitive that every possible flexibility in the system is fully utilized. One example is that the domestic production of food crops that generate by-products for animal consumption as well as imports thereof increase and counteract the original intention of reducing production of animal goods. From these analyses, the main leverage, both for more sustainability and for more health, seems to lie in changes in diets. The extent of the required changes in diets is very challenging.

In addition, aligning agricultural production and consumption implies that optimal diets are not static but change over time. This has not been considered in the existing literature yet (e.g. Baur (2013)). In the case of a FeedNoFood strategy, the amount of available agricultural land in Switzerland will determine the amount of animal products that can be produced domestically. Agricultural land is, however, not constant but changes as a result of population and economic development.

4.4.8.1 Coupled products / interdependencies

Figure 19 showed that the production of milk is tightly linked to the production of bovine meat. As this is a biological link, it cannot be weakened by market mechanisms, policy interventions or changes in farmers' decision making. Producing the recommended amount of milk in the SFP2050 scenario while at the same time avoiding over-production of meat products can be realized in different ways, all of which pose some implementation challenges:

- Export of the excess bovine meat. The main implementation challenge is that Swiss production is not competitive on international meat markets, so that exports would have to be supported financially.
- Replacement of at least parts of milk and dairy products by calcium-enriched soymilk. The main implementation challenge here is most likely consumer acceptance.
- Substantial reduction of pork and chicken meat production to accommodate the production of bovine meat without overshooting desired consumption levels. In the current calibration of the SFP2050 scenario, the excess production of bovine meat amounts to more than 50% of the amount of pork and chicken meat produced in that scenario. Substantial reductions in the production of pork and

chicken meat most likely faces implementation challenges such as consumer acceptance and potential health implications with a shift towards more red and less white meat.

4.4.8.2 Adaptation of different operators in the food sector

Our model results show that depending on which measures are implemented, operators may react in ways, which try to bypass the desired adaptations. For instance, the results from the EE-IOM show that the value added in the agricultural sector will be negatively affected. This is particularly the case for the livestock producing farms and the businesses linked to them (e.g. slaughters). Since this is a long-term scenario, appropriate transition pathways need to be defined.

The system dynamic model shows that especially the question of temporary meadows needs to be addressed by separate policy measures in order not to make farmers bypass feed-no-food policies.

The SOL model also identifies such potential bypassing responses by consumers, which may substitute the reduced production of pig and poultry meat in Switzerland by imported meat.

4.4.8.3 Policy challenges

Swiss agricultural policy is already supported by a variety of agricultural sector models (e.g., Listorti *et al.* (2013), Möhring *et al.* (2015b) and Zimmermann *et al.* (2017)) that provide decision support at a much higher level of detail than the system dynamics model does. The specific contribution of the system dynamics model, however, is that it ensures operational consistency and coherence between agricultural production, trade, the environment and food consumption.

This became particularly obvious in the case of intervention strategies that aim at changing consumption patterns towards more plant-based diets but that result in unexpected increases in meat production. All the scenarios assuming an increase in the consumption of plant-based products, for example, involve higher consumption of dairy products. A simple herd structure for dairy cows reveals that an increase in the production of milk is biologically linked to an increase in meat production, something that is a direct contradiction to the intended consequences of the promotion of the consumption of plant-based products. In addition, the excess meat also generates serious negative environmental impacts.

This contradiction between intended consequences of dietary recommendations and system reaction is not unique to Switzerland. The literature about sustainable diets shows additional examples of proposed diets that only take health outcomes into consideration without accounting for the agronomic realities how the foods that promote health outcomes are produced (e.g. Tilman and Clark (2014)) and to some extent also Willett *et al.* (2019).

5. Recommendations for policy makers and professionals from the practice; implementation activities that were undertaken to transfer the outputs to the practice

Recommendations for policy makers

- Different dietary patterns are associated with different sociodemographic and lifestyle determinants: prevention campaigns may be more efficient if they were more targeted (by language region, or age group).
- Harmonize health/food policy and agricultural policy: Agricultural policy does not cover the aim of healthy food consumption, nor does health policy with respect to food reflect agronomic necessities. Options for solving some of the mismatches are:
  - Reduce the incentives for sugar production
  - Reduce incentives for meat production (especially for meat which is not a co-product to dairy production)
  - Adjust the recommended consumption level of dairy products (i.e. reduce this level)
- Provide incentives for retailers to promote healthy and sustainable products and impede non-healthy/non-sustainable products (e.g. via promotions).
- Consider taxation of specific foods of which the consumption induces negative externalities with respect to health. (e.g. high sugar contents)
- Consider taxation of specific inputs/practices to increase sustainability of production (e.g. a tax on external nitrogen sources).
- However, taxation of products for single environmental impacts (e.g. a CO2-tax on meat) could support intensive pig and poultry production compared to more extensive production methods. Therefore, a comprehensive policy mix, which addresses the entire set of environmental, social and health issues, needs to be formulated.
- This could also positive financial incentives (e.g. lower VAT rates) for products which are consumed to a lower extent than socially optimal (e.g. due to positive health impacts).
- Targeting at a Feed No Food Scenario would require an even more sophisticated policy mix (e.g. to avoid expansion of temporary meadows, promote suitable breeds for changed feeding rations, etc.).
- Reconsider some food quality and other regulations, which contradict sustainability aims (regulations regarding expiration dates; regulations on using food waste as feed, etc.).

- Consider a ban of ads for non-healthy and non-sustainable food items, especially of those ads, which target children and adolescents.

Recommendations for consumers

- A large part of the Swiss population consumes diets that are likely to have a negative impact both on health and on sustainability. Options for improving diets with respect to health and sustainability at the same time are:
  - Reduced sugar consumption (→ health +)
  - Increased vegetables and fruits consumption (→ health +)
  - Partly substitute animal-source foods with pulses or other potential adequate protein sources (→ environment +)
  - Consistent proportions between coupled products from a production perspective – e.g. meat and milk (→ environment +)
- However, resource efficient consumption patterns do not necessarily comply with sustainable production patterns. For instance, come co-products such as meat from dairy cows, which is often consumed as processed meat, contributes to resource efficiency, because it substitutes other sources of meat in terms of protein delivery, but is not associated with health benefits. Therefore, considering a pure resource efficiency perspective when choosing between different food items does not always lead to more sustainable food production systems.
- We may reinforce and refine the old simple rule "FDH" ("friss die Hälfte" – "eat only half of it"), as a central leverage point is reducing the total size of the food system. This applies to animal source food in particular and is refined to "buy only half of it" for supporting food wastage reduction.
- Re-thin king food, re-thinking local traditions and enhancing food literacy has to become part of all educational steps. This includes all age groups and consumer types. Such a recommendation is in line with the BLV strategy on nutrition

Recommendations for processors:

- Invest in future processing technologies for co-products for food or feed and for processing pulses (e.g. vegie-burger)
- Invest in technologies that can deal with more heterogeneous products, as sustainable production strategies with location-specific production, etc. tend to result in more heterogeneous outputs.

Recommendations for retailers and public procurement:

- Reduce promotions of non-healthy or non-sustainable diets

Recommendations for the agricultural sector:

- Invest in breeding programmes for animals with better digestion of sub-optimal feed rations to make best use of the feed available under a feed no food strategy

Recommendations all professionals in the food system:

- Improve the level of knowledge on health, sustainability and the trade-offs and synergies in the system via targeted training or information campaign. Include information in vocational training curricula.

List of References

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Appendices to this report

Flückiger, S., N. Lang and B. Klotz (2017). 'Trendstudie des Forschungsprojektes "Sustainable and healthy diets: Trade-offs and synergies". Schlussbericht', Zürich, Institut für Umwelt und natürliche Ressourcen (IUNR), ZHAW.

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Supporting information 1: Most important processes represented in the dynamic simulation model.

Model sector	**Most important processes**	**Most important inputs from other model sectors**	**Most important exogenous inputs**	**Important outputs**
Livestock – cattle	Herd structure cattle where calves are allocated either to the milk line or to the feeder cattle stock Separate herd structure for suckler cattle Adjustment of livestock numbers and allocation to the different lines according to changes in relative profitability	Change in profitability milk Change in profitability bovine meat Change in demand milk Change in demand bovine meat Limit to livestock expansion	Average lifetime milk cows; average lifetime suckler cows Supply elasticity of milk and bovine meat to profitability Meat yield per livestock category Cattle livestock adjustment time; suckler cattle livestock adjustment time	Milk production Bovine meat production Grass demand dairy cows Grass demand other bovine cattle Feed demand dairy cows Feed demand other bovine cattle
Livestock – pigs	Herd structure pigs Adjustment of breeding stock according to changes in relative profitability	Change in profitability pork production Change in demand pork meat Feed availability Limit to livestock expansion	Average lifetime breeding pigs; average fattening time mature pigs Supply elasticity of pork meat to profitability Supply elasticity of pork meat to demand Meat yield per mature pig and per breeding pig	Pork meat production Feed demand pigs

Model sector	Most important processes	Most important inputs from other model sectors	Most important exogenous inputs	Important outputs
			Adjustment time breeding pigs stock	
Livestock – poultry – eggs production	Herd structure laying hens Adjustment of laying hen stock according to changes in relative profitability	Change in profitability eggs production Change in demand eggs Feed availability Limit to livestock expansion	Average lifetime laying hens Supply elasticity of eggs production meat to profitability Supply elasticity of eggs production to demand Eggs production per hen per year Meat per slaughtered hen Adjustment time laying and breeding hens	Eggs production Feed demand laying hens
Livestock – poultry – chicken meat production	Herd structure broiler poultry Adjustment of broiler poultry stock according to changes in relative profitability	Change in profitability chicken meat production Change in demand chicken meat Feed availability Limit to livestock expansion	Average fattening time broiler poultry Supply elasticity of chicken meat to profitability Supply elasticity of chicken meat to demand Meat yield per broiler poultry	Chicken meat production Feed demand broiler poultry

Model sector	Most important processes	Most important inputs from other model sectors	Most important exogenous inputs	Important outputs
			Adjustment time broiler poultry stock	
Total livestock and land balance	Conversion of all livestock to livestock units Comparison of current livestock units to maximum allowable livestock units per ha and limit to expansion of livestock	Livestock numbers from other sectors Total agriculture land	Conversion factors animals – livestock units	Limit to livestock expansion
Animal nutrition	Total fodder demand (fodder: grass-based) Total feed demand (feed: animal feed from forage crops; concentrate feed)	Livestock numbers for the different livestock categories	Fodder demand for the different livestock categories Feed demand for the different livestock categories	Fodder (grass) demand Feed demand
Desired food consumption	Calculation of dietary patterns		Population Relative purchasing power	Target total milk products for human consumption Target total eggs consumption Target total meat consumption (bovine meat, pork, chicken)

Model sector	Most important processes	Most important inputs from other model sectors	Most important exogenous inputs	Important outputs
				Target total plant products (10 categories)
Yield and production	Calculation of yield plant products resulting from changes in water and nutrient availability	Total per ha nitrogen input arable land and temporary meadows	Nitrogen uptake efficiency Genetic yield potential plant products Impact of climate change on water availability	Yield plant products (10 categories) Production plant products (10 categories)
Nutrient dynamics	Nitrogen balance; ammonium emissions Affordability of synthetic fertilizer	Animals from different livestock categories Land in different land use categories	Per unit nitrogen input (from atmospheric deposition; manure from different livestock categories; pulses and green manure) Per unit ammonium emission factors (different livestock categories) Fertilizer unit costs Price perception adjustment time Profitability perception adjustment time	Synthetic fertilizer use

Model sector	**Most important processes**	**Most important inputs from other model sectors**	**Most important exogenous inputs**	**Important outputs**
Land use	Land use changes resulting from population growth/non-agricultural land use shifts in profitability that lead to shifts within agricultural land use categories (arable land, temporary meadows, permanent meadows and pastures) pasture abandonment	Change in profitability plant products; change in profitability milk products; change in profitability meat Change in demand plant products; change in demand milk products; change in demand meat Yield plant products	Population Elasticity of plant production to plant demand; elasticity of plant production to profitability Yield temporary meadows; Yield permanent meadows and pastures Non-agricultural land demand per person Fractional afforestation rate	Land shares in different land use categories Grass-based fodder production
Prices and imports – plant products	Calculation of price of plant products resulting from demand supply ratio; international prices; and production costs. Calculation of demand for plant products resulting from changes in price but also from changes in price of substitutes. Calculation of imports of plant products and resulting demand supply ratio of plant products	Target total plant products Production plant products Relative prices meat Relative price raw milk Relative price eggs Relative production costs plant products	Demand elasticity of price Cross price elasticities Import availability Elasticity of price to production costs; elasticity of price to international prices Price perception adjustment time	Price plant products Demand plant products Change in demand plant products Net imports plant products

Model sector	Most important processes	Most important inputs from other model sectors	Most important exogenous inputs	Important outputs
Prices and imports – milk products and eggs	Calculation of price of milk products and eggs resulting from demand supply ratio; international prices; and production costs. Calculation of demand for milk products and eggs resulting from changes in price but also from changes in price of substitutes. Calculation of imports of milk products and resulting demand supply ratio of milk products	Target total milk products and eggs for human consumption (domestic and export) Milk production; eggs production Relative prices meat Relative prices plant products Relative production costs milk products; relative production costs eggs	Demand elasticity of price Cross price elasticities Import availability Elasticity of price to production costs; elasticity of price to international prices Price perception adjustment time	Price raw milk; price eggs Demand milk products; demand eggs Change in demand milk products; change in demand eggs Net imports milk products Net imports eggs
Prices and imports – meat	Calculation of price of meat resulting from demand supply ratio; international prices; and production costs. Calculation of demand for meat resulting from changes in price but also from changes in price of substitutes.	Target total meat consumption Meat production Relative prices plant products Relative price raw milk Relative price eggs Relative production costs meat	Demand elasticity of price Cross price elasticities Import availability Elasticity of price to production costs; elasticity of price to international prices Price perception adjustment time	Price meat Demand meat Change in demand meat Net imports meat

Model sector	Most important processes	Most important inputs from other model sectors	Most important exogenous inputs	Important outputs
	Calculation of imports of meat and resulting demand supply ratio of meat			
Profitability – plant products	Calculation of changes in the relative profitability of plant products	Yield plant products Price plant products Synthetic fertilizer use	Profitability perception adjustment time Other per ha production costs Per ha direct payments	Change in profitability plant products Relative production costs plant products
Profitability – milk products and eggs	Calculation of changes in the relative profitability of milk products and eggs	Milk production per livestock unit per year; eggs production per livestock unit per year Price raw milk; price eggs Price plant products (feed)	Profitability perception adjustment time Other per ha production costs Per ha direct payments	Change in profitability milk products; change in profitability eggs Relative production costs milk products; relative production costs eggs
Profitability – meat	Calculation of changes in the relative profitability of plant products	Meat production per livestock unit Price meat Price plant products (feed) Price raw milk	Profitability perception adjustment time Other per ha production costs Per ha direct payments	Change in profitability meat Relative production costs meat