Environmental, social, and economic consequences of six food system strategies for Switzerland

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Abstract. Consumption- as well as production-side changes are needed to improve the sustainability performance of food systems. We assessed multiple impacts of six food system strategies for Switzerland. Two strategies encompassed dietary changes: following a pescetarian diet and adhering to the national dietary guidelines. Two strategies employed alternative farming systems: increasing the share of organic production and, in addition, applying the circularity principle of avoiding feed-food competition by excluding livestock feed grown on arable land. A fifth strategy reduced food waste. The sixth strategy increased the share of domestic produce. For all strategies, we assessed greenhouse gas emissions, land use, nitrogen surplus, social risks, diet quality, and diet costs. The strategies revealed trade-offs between impact categories, unless combined in a synergistic way. Combining all proposed strategies could lead to substantial improvements in all impact categories assessed, but would require a thorough transformation of the current food system.

1 Introduction

In Switzerland, as in most high-income countries, current food consumption habits and the associated food production cause substantial impacts on multiple sustainability dimensions (1,2). Dietary patterns are important factors for human health, and their roles in non-communicable diseases, such as diabetes, cardiovascular disease, stroke, and cancer, are well established (3). The transition towards diets containing more processed and refined products with a higher share of animal-source food (ASF), in combination with lower consumption of fruits, vegetables, nuts and legumes, has substantially aggravated this. Further, current food production practices contribute substantially to approaching or already transgressing multiple planetary boundaries (4–6). The latest report by the Intergovernmental Panel on Climate Change found that agriculture, including agriculturally-driven land use change, contributes 23% - 34% of global anthropogenic greenhouse gas (GHG) emissions (7,8). Moreover, agricultural production substantially altered and still alters the earth's biogeochemical cycles (9). In addition, around 40% of the earth's land surface is used as croplands and pastures (10). Of these croplands, 40% are used for feed production (11); using these for the production of direct human food would be more efficient (10).

Strategies to improve the sustainability of food systems, contributing to reach goals of for example the Paris Agreement and the SDGs, target consumption as well as production changes (1,2). On the consumption side, often-proposed strategies focus on substituting a share of ASF with plant-source foods (2,12,13). Although the reduction of meat is often particularly in focus, improving multiple dimensions of sustainability calls for a reduction of all ASF (14). Thereby, also consistent links between coupled products – such as meat and milk from dairy cattle herds – is acknowledged. For dietary shifts, dietary guidelines are a frequently employed starting point (15). Next to dietary change, also the reduction of food loss and waste is an often-considered strategy. On the production side, strategies range from sustainable intensification (16) to more extensive agricultural practices, such as organic (17). Further, a concept receiving increased attention is captured by 'circular food systems', which combines consumption- and production-related changes (18). This concept is driven by the aim to allocate resources within a food system in order to use resources for human food production first, and using only biomass unsuitable or unwanted by humans as animal feed. By this, animals can convert biomass unsuited for human consumption into valuable ASF (19). Notably, in such a system, the available ASF for human consumption would decrease as compared to current ASF intake. Moreover, many initiatives propose an increase of local produce to enhance food sustainability (20).

Although some studies combine consumption- and production-side strategies in their assessments (1), consumption-side strategies were so far not assessed together with production-side aspects such as organic and circularity principles. Furthermore, while the majority of studies assessing sustainability aspects of more sustainable dietary choices did include environmental impacts and human health, social aspects were rarely considered. In order to identify trade-offs between strategies considering both consumption and production side changes as well as multiple sustainability impacts, a combined approach is needed.

To this end, we aimed to assess multiple sustainability impacts of consumption- and production-side strategies. These strategies encompass dietary changes – reducing consumption of meat from terrestrial animals and following dietary guidelines – as well as alternative farming and food system practices, such as organic production and circularity principles, and practices such as reducing food waste and increasing the share of domestic produce. Of these strategies, we assessed multiple sustainability impacts, three environmental indicators (GHG emissions, land use, and nitrogen surplus), social risks by the Social Hotspots Index (SHI) (21), dietary costs, and diet quality by the Alternate Healthy Eating Index (AHEI) (22). In order to make results tangible, we present the assessed strategies at a consumer level. By applying this consumer strategy approach to Switzerland, we can draw conclusions with regard to effectiveness, synergies, and trade-offs of the strategies. Moreover, the proposed approach of employing consumer strategies is a promising way of engaging with stakeholders from different geographical, socio-economic, and cultural settings.

2 Methods

2.1 Consumer strategies

We developed six consumer strategies, which include a range of common strategies towards more sustainable food systems. The development of these strategies was initiated and accompanied by several stakeholder workshops with policy makers as well as representatives of different institutes and population groups within the case study country Switzerland. In the initial workshop, ideas for possible strategies were inventoried. Based on this initial inventory, we developed six potential strategies for more sustainable food systems in Switzerland. In a next step, these strategies were translated into consumer strategies, to improve their potential for communication with and adoption of different stakeholder groups.

Although all strategies related to consumers, they included changes on both the consumption (e.g., altering the composition of diet) and the production side (e.g., changing how foods are produced).

In the RM (reduced meat) strategy, meat from terrestrial animals in the human diet was reduced. We modelled this by employing three reduction levels of meat from terrestrial animals, relative to the reference diet: -25%, -50%, and -100%. The consumer of the FBDG (food-based dietary guidelines) strategy followed the Swiss nutritional guidelines (Swiss Food Pyramid). Also here, we assessed different levels of implementation: 25%, 50%, and 100%, where this part of the diet was defined according to the FBDG, and the remaining part was defined according to the reference consumption.

The consumer of the FW (food waste) strategy reduced food waste at consumption stage, at the two levels -25% and -50%. In the DOM (domestic production) strategy, we assumed an increase of domestically produced food products to a minimum of 50% over all food groups that can be produced in Switzerland. Where the current level of domestic production was currently already above 50%, this higher level was kept constant. We only assumed changes in origin of final food products, and not of input products, such as feedstuffs.

The ORG (organic) strategy represents a consumer that increased the consumption of organically certified food products, which we modelled with three different levels (over all food groups): 25%, 50%, and 100% of organic in the human diet. To represent organic agriculture in our assessment, we excluded mineral fertilizer and assumed organic yields as identified by (25).

In the ORG_CIR (organic plus circular agricultural principles) strategy, different alternative production practices were combined, by considering organic produce in combination with principles from circular agriculture. We implemented this likewise at three different levels of organic produce (25%, 50%, and 100% organic produce in the human diet), and furthermore applied the principle from circular agriculture that limits animal feed to low-opportunity-cost biomass (LCB) (28). More concretely, according to this principle, animals are only fed with products that do not compete with producing human-edible food, such as by-products, food waste, and grass resources. When applying this principle, animals can effectively upcycle LCB, and these resources can thereby be recycled into the food system (19,29). Notably, grass resources in Switzerland are currently partly grown on land that could be used for the production of human food, and not all of this is temporary grassland that has an agronomic function in crop rotations (30). This needs to be considered in opportunity costs of this land use (11). Further, since we employed consumer strategies at the level of individuals, we were able to assess this strategy without linking it to dietary changes. However, at food systems level, such a strategy would only be feasible in combination with reduced animal numbers and consequently reduced consumption of ASF, because of the limited availability of LCB.

2.2 Modeling approach and impact assessment

We assessed multiple sustainability impacts of the consumer strategies using the biophysical mass- and nutrient-flow model SOLm (17,30). SOLm encompasses all mass- and nutrient-flows that are relevant for agricultural production. Of these, resource use and emissions are calculated, and by employing characterisation factors, these were aggregated to GHG emissions, land use, and nitrogen surplus (N surplus). The different GHG emissions were converted to CO2-equivalents via the Global Warming Potential measure, assuming a 100-year time horizon (referred to as GHG emissions throughout this paper). Further, three additional indicators were calculated: the SHI on the production side, and the AHEI as well as costs of food consumption on the consumption side.

2.2.1 Environmental impact assessment

We performed an environmental impact assessment of each level of the consumer strategies using the biophysical mass-flow model SOLm (17,27,30). For the two stages in-between the farm-gate and the consumer, processing and transport, Ecoinvent 3 inventories were used (Supplementary Material, Section 2). The mass-flow model SOLm represents relevant flows of masses and nutrients that occur during agricultural production. Thereby, it allows to track resource use and emissions throughout the production processes, forming the basis for the environmental impact assessments GHG emissions, land use, and N surplus. SOLm includes 192 countries, 180 primary crop and 22 primary farmed animal activities. These activities are characterized using FAOSTAT data for production and trade, as well as food balance sheets (31,32). Considering the focus on Switzerland in this study, we employed current production in Switzerland to define whether certain products can be produced in Switzerland or not, and further used the current countries of origin per food product (23).

2.2.2 Assessment of social risks

Social risks were assessed based on the Social Hotspots Database (SHDB) (21). This database covers 156 social indicators with risk levels per country and per sector in five areas: labour rights and decent work, health and safety, human rights, governance, and community infrastructure. In the SHDB, the production of agricultural goods is represented by 22 sub-sectors, of which 18 directly relate to food production. Social risks occur directly (in the respective food-related production sectors) and indirectly (in the sectors that produce upstream resources entering the food production, such as pesticide production). Indirect social risks were estimated using an input-output table for Switzerland (33), in which the interlinkages between different industries as well as between industries and final demand of the economy are considered. By this, we capture social risks up to the final stage of production, i.e., from cradle up to but not including the retail stage. Using a weighting scheme, the social indicators were aggregated to the Social Hotspots Index (SHI) (21,34) (Supplementary Material, Section 3).

2.2.3 Diet quality assessment

Although the final human health impact of different diets depends on a multitude of factors, indices can help to assess diet quality. Here, we employed the Alternate Healthy Eating Index (AHEI), which is a dietary index that was developed based on correlations of food groups and changes in human health performance (22). It correlates well with diseases such as coronary heart disease, diabetes, and the risk of stroke and cancer (35,36). To calculate the AHEI, amounts of 11 food and nutrient categories are needed, and based on intake thresholds, a score from 1 to 10 per category is assigned. These categories include vegetables, fruits, whole grains, sugar-sweetened beverages and fruit juice, nuts and legumes, red or processed meat, trans fat, long-chain n-3 fats, polyunsaturated fatty acids, sodium, and alcohol. In total, this thus leads to a maximum achievable score of 110.

2.2.4 Dietary cost assessment

To complete an assessment of dietary costs that are associated to the consumer strategies, we collected retail price data of 94 commodities from Coop, a big retailer in Switzerland (Supplementary Material, Section 4). By this, we derived an estimation of the cost associated with the respective diet, which was driven by food group (e.g. meat vs. pulses) and production standard (e.g. organic vs. conventional). This indicator thus only captures differences in cost arising from the different diets, and not e.g. where these are consumed (at home or away from home). For the purpose at hand, this was sufficient, as we only altered food groups and production standards in the consumer strategies. Moreover, since we were interested in the differences between consumer strategies, absolute values play a minor role. Assuming that relative prices are comparable between retailers, the use of only one retailer (Coop) can be justified. To derive the cost estimates per consumer strategy, the prices per commodity were multiplied by the quantities per commodity assumed in the respective strategy, which in total yielded the estimated dietary cost.

3 Results

3.1 Required behavioral changes of the consumer strategies

Consumer strategies RM and FBDG require changes in the diet composition. Figure 1 shows the food compositions of these two strategies for their most extreme level (RM100 and FBDG100), as well as the food composition of the reference diet for comparison. The main change in the food composition of the RM strategy is characterized by a decrease of meat from terrestrial animals in the diet, which is replaced by pulses (Figure 1, middle). Notably, the remaining fraction of the food group meat originates from aquatic animals. The FBDG strategy is defined by the dietary guidelines of Switzerland (Figure 1, right). The food composition of these food-based dietary guidelines is characterized by a substantial increase in vegetables, fruits, and dairy, as compared to the reference. Moreover, sweets and alcoholic beverages are decreased, and meat both from terrestrial and aquatic animals are partly replaced by pulses and dairy. The food composition of strategies FW, DOM, ORG, and ORG_CIR is represented by the reference composition (Figure 1, left). For consumer strategies FW, DOM, ORG, and ORG_CIR, food waste and purchasing behavior are targeted. Thus, in the FW strategy, food waste at consumption stage needs to be reduced by 25% and 50% for the different levels. In strategies DOM, ORG, and ORG_CIR, purchasing behavior needs to be adapted, with alternations in the origin of the products (DOM strategy) and the production standard organic (ORG and ORG_CIR strategies).

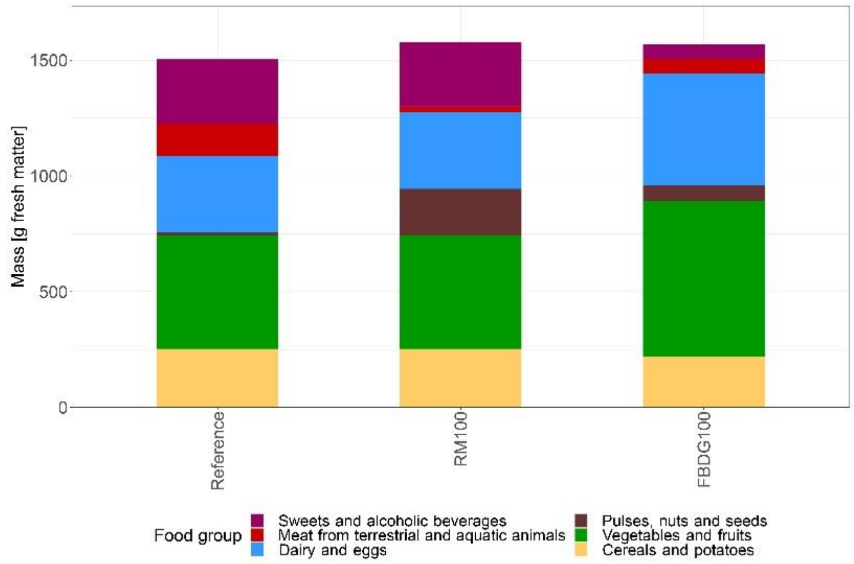

Fig. 1. Food composition of the consumer strategies. Amount per food group shown in fresh matter (weight). FBDG = food-based dietary guideline, RM = reduced meat.

3.2 Impacts of the consumer strategies

The direction of the performance per consumer strategy, level, and impact category is shown in Figure 2, relative to the reference consumer. The RM and FBDG strategies revealed a similar pattern, thus leading to a favorable performance of all impact categories, except a reduced performance of social risks (i.e. increased social risks). This was largely driven by a replacement of meat products with plant-sourced foods, such as legumes and vegetables, which for the Swiss food supply are often imported from areas with higher risk of adverse social impacts. These risks cover labour conditions in the respective countries (e.g. in worker health and security). Notably, when the RM strategy was implemented by 25% only, all impact categories performed better, but to a lesser extent than with a stricter implementation (50% and 100%). With stricter implementation, however, social risks increased compared to the reference. The FW strategy was the only strategy that had exclusively favorable effects (except for no effect on the nutritional quality index), due to its characteristic of being based on overall reduced production (as less production is wasted, less needs to be produced to allow for similar food intake levels). Further, the DOM and ORG strategies improved N surplus and the former also the SHI. They however also increased land use, and the ORG strategy moreover increased diet cost and slightly GHG emissions. Finally, the ORG_CIR strategy led to better performance of all environmental impact categories, and did not affect the SHI and AHEI. However, as the ORG strategy, it increased dietary cost. Thus, the different strategies revealed both synergies and trade-offs between the different impact categories.

Notably, N surplus was the only impact category with unambiguous signals, meaning that all strategies led to a lower N surplus than the reference consumer diet. For the other environmental indicators, land use – and partly GHG emissions – revealed trade-offs for strategies ORG and ORG_CIR, which resulted from the organic production standard employed. In fact, since organic production has been shown to come along with lower or at most comparable yields, the land used to reach the same amount of produce increases. As shown in Figure 2, land use of the ORG strategy went up by 33.3%, while increases in GHG emissions were small (up-to 1% increase). Remarkably, these trade-offs diminished when circular food system principles were employed in addition to organic production standards: in this case, all environmental impacts showed better performance. Hence, the environmental impacts of organic produce depend on whether this production standard was accompanied by additional measures regarding animal feeding regimes (ORG_CIR strategy), or not (ORG strategy). Figure 3 moreover presents the contribution per food group to the different impact categories. For GHG emissions and land use, ASF make up the largest share, while for the SHI and dietary costs, the contribution of ASF and plant-source foods was more balanced.

For the social risks (SHI), the RM and FBDG strategies showed clear trade-offs; the increase in plant-based products, such as legumes (RM and FBDG strategy) as well as vegetables and fruits (FBDG strategy), increased social risks by up-to 18.9% (RM strategy) and 10.6% (FBDG strategy). This effect was mainly driven by imports: typical importing countries of these plant-based products showed higher occurrence of social risks, which triggered this increase. Thus, while all other impact categories performed better than in the reference consumer diet, social risks increased for these strategies. For the FW and DOM strategies, social risks decreased, which was driven by a total reduction in consumed products (FW strategy) and lowered imports (DOM strategy). In the DOM strategy, the substantial decrease (-20.2%) could be linked to lower social risk pressures in Switzerland, as opposed to the countries of origin of the reference consumer diet. For the ORG and ORG_CIR strategies, it has to be noted that differences in social standards between organic and conventional production were not considered in the SHI. Therefore, potential differences in social risks could not be captured by the measure employed, and results thus suggested that no difference in social risks occurred.

The AHEI was, next to N surplus, the only impact category where no strategy led to a reduction. For the RM and FBDG strategies, the AHEI increased (up-to +17.9% for the RM strategy, and up-to +57.3% for the FBDG strategy). Especially the increase for the FBDG strategy was substantial, which was mainly driven by a decrease in red and processed meat, an increase in nuts and legumes, whole grains, and nuts and vegetables. These two strategies were the only ones with changed food composition, and the AHEI of strategies FW, DOM, ORG, and ORG_CIR was consequently not affected.

The cost of the different strategies was driven by two factors: changes in food composition, and changes in production standards (organically labelled products with a price premium, see Supplementary Material, Section 4). Hence, dietary cost was reduced (its performance thus improved) for strategies RM, FBDG, and FW – in the FW strategy, this was moreover driven by the total reduction in consumed foods. On the contrary, dietary cost was increased in the ORG and ORG_CIR strategies. Hence, also this impact category led to trade-offs for the ORG and ORG_CIR strategies; while most environmental impacts were reduced, partly even substantially, dietary cost was increased due to higher costs associated with organic produce.

In summary, all consumer strategies that revealed the highest reduction potential (RM strategy for GHG emissions: -55.3%, ORG_CIR strategy for land use; -68.9%, ORG_CIR strategy for N surplus: -75%, DOM strategy for social risks; -20.2%, FBDG strategy for the AHEI: +57.3%, FBDG strategy for cost: -27.6%) revealed trade-offs with other impact categories. These trade-offs occurred either with social risks (RM and FBDG strategies), land use (DOM strategy), or dietary cost (ORG and ORG_CIR strategies). The FW strategy was unique in the sense that it only revealed synergies; these were however of lower orders of magnitude than for the other strategies (SHI: reduction up-to 5.6%, cost: reduction up-to 4.9%, GHG emissions, N surplus, and land use: reductions up-to about 4% each).

Consumer strategy	Impact category					
	GHG emissions	Land use	N surplus	SHI	AHEI	Cost
RM25	-14.8%	-17.1%	-14.9%	-1.8%	2.1%	-6.0%
RM50	-29.1%	-32.5%	-28.7%	0.0%	13.6%	-11.0%
RM100	-55.3%	-56.0%	-51.0%	18.9%	17.9%	-17.0%
FBDG25	-8.5%	-8.3%	-8.0%	2.6%	14.3%	-6.9%
FBDG50	-17.0%	-16.1%	-16.6%	5.3%	28.6%	-13.8%
FBDG100	-34.0%	-33.2%	-32.2%	10.6%	57.3%	-27.6%
FW25	-1.9%	-1.9%	-2.0%	-2.8%	0.0%	-2.4%
FW50	-3.8%	-3.7%	-4.0%	-5.6%	0.0%	-4.9%
DOM50	-0.3%	2.0%	-0.4%	-20.2%	0.0%	0.0%
ORG25	0.3%	8.3%	-15.0%	0.0%	0.0%	10.6%
ORG50	0.5%	16.7%	-30.0%	0.0%	0.0%	21.1%
ORG100	1.0%	33.3%	-60.0%	0.0%	0.0%	42.2%
ORG25_CIR	-7.3%	-12.5%	-18.8%	0.0%	0.0%	10.6%
ORG50_CIR	-14.6%	-28.1%	-37.5%	0.0%	0.0%	21.1%
ORG100_CIR	-29.3%	-68.9%	-75.0%	0.0%	0.0%	42.2%

Improvement: <20%; 20-40%; >40%
Detriment: <20%; 20-40%; >40%
No difference

Fig. 2. Option space per strategy and level: change in performance is indicated per impact category (improved performance, detriment performance, no difference). All changes in performance are relative to the reference consumer diet. With the exception of the AHEI, improvement relates to a decrease, and detriment to an increase. AHEI = Alternate Healthy Eating Index, CIR = circular agricultural principles, DOM = domestic, FBDG = food-based dietary guideline, FW = food waste, GHG = greenhouse gas, N = nitrogen, ORG = organic, RM = reduced meat, SHI = Social Hotspots Index.

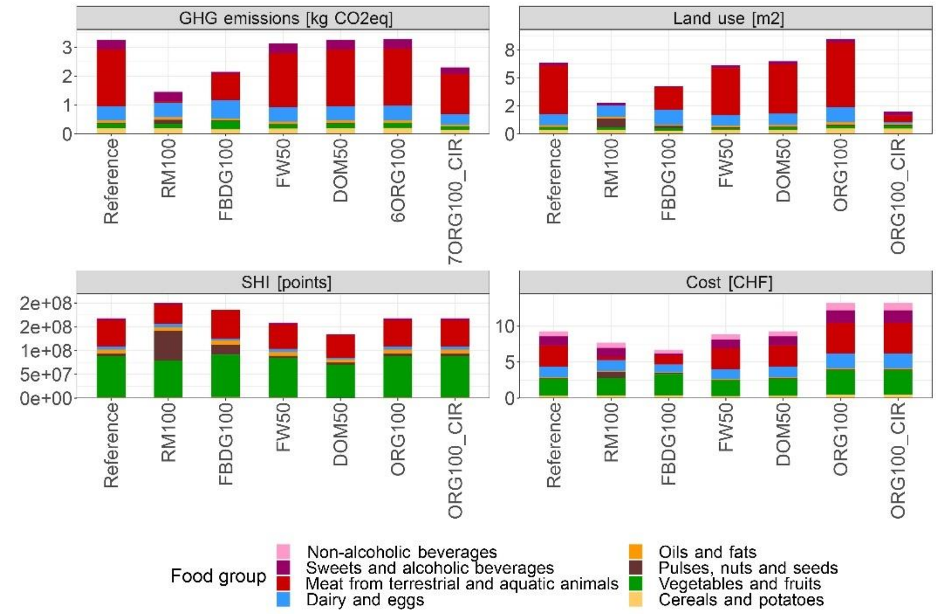

Fig. 3. Contribution per food group to the different impact categories. Results for Nitrogen surplus looked similar to GHG emissions and land use, and the Alternate Healthy Eating Index could not be displayed per food group. CIR = circular agricultural principles, DOM = domestic, FBDG = food-based dietary guideline, FW = food waste, GHG = greenhouse gas, ORG = organic, RM = reduced meat, SHI = Social Hotspots Index.

4 Discussion

Our results showed that large improvement potentials on one or more impact categories come along with trade-offs, thus detrimental performance on other impact categories. Only food waste reduction led to better – or at least constant – performance of all impact categories, but improvement potentials were of lower orders of magnitude than for the other strategies. Consequently, we found that clear priorities are needed to achieve substantial improvements. For the assessment of environmental impacts of the Swiss Food Pyramid, our results are in line with previous assessments carried out by (37). These authors found an average reduction of 36% across five different environmental impact categories for the Swiss Food Pyramid, while we found reductions between 32 and 34% for the different environmental impact categories assessed. Moreover, for cost of diets, (37) found a reduction of 35% for the Swiss Food Pyramid, while our estimates suggest a reduction of 28%, thus also in the same order of magnitude. To our knowledge, no direct comparison is available for the other impact categories and strategies for the Swiss case study.

4.1 Trade-offs in food system sustainability strategies

Our results showed that trade-offs emerge as a result of the different orientation of singular strategies towards more sustainable food systems. Examples for these trade-offs were reduced environmental impacts at the cost of increased social risks in the dietary change strategies assessed, and reduced nitrogen surplus at the cost of increased land use and dietary cost for increased organic produce. Also increasing the share of domestically-produced products would have effects on global trade of foods, which could lead to trade-offs. Measures aiming to implement such strategies therefore need to be designed carefully and accompanied by measures that hedge against these trade-offs. These accompanying measures are highly context-specific and therefore need to be designed considering the respective conditions. An open and constructive discussion about possible trade-offs is urgently needed to facilitate a fair and long-lasting transformation of the food system.

4.2 Combination of strategies

By a smart mix of strategies, it is possible to improve all impact categories assessed simultaneously. More concretely, by a combination of better performing consumption patterns (RM and FBDG strategies; less animal-source foods, healthier plant-based foods), reductions of food waste (FW strategy), and changes in production (ORG and ORG_CIR strategies; e.g. organic standards in combination with circular food system principles). By this combination, less land would be needed to produce the required food items, which would in turn allow to grow more foods domestically (DOM strategy). In this combined approach, many trade-offs could be addressed – e.g. the increase of social risks in the RM and FBDG strategies could be reduced by being able to grow more domestically (DOM strategy). Moreover, by such combinations, inconsistencies in single strategies – for example in the RM strategy, where meat is excluded completely while dairy is still consumed, whereby the meat resulting from dairy production is not consumed domestically anymore – could be addressed. While such a combination of strategies would require a thorough transformation of the current food system, smaller changes can be achieved by different consumers following different profiles. In fact, when different consumers follow one of the strategies proposed, the sum of their actions tackling different strategies can also result in an – although less strong – effect. Yet, following single strategies can have the advantage of being both easier to communicate and to implement.

4.3 Policy implications

Policy implications differ between the (combinations of) strategies. On the one hand, policies targeting at changing consumers' behaviors could do so by measures such as information campaigns, enhanced nudging, or financial mechanisms to influence relative prices (38). Alternatively, measures such as bans could be introduced, which however impair each person's freedom substantially. On the other hand, given the importance that individuals are targeted in interaction with the wider systemic environment (39), policies targeting at changed production can include information and education, financial instruments, and obligations. Further, in order to increase transparency about changes in production for consumers, labels, such as the example of organic employed here, can play an important role (40). Policies targeting at actions in between production and consumption could moreover steer allocation of resources. As an example, larger retailers can influence consumers' behavior via advertisements (41). Hence, advertisements for less sustainable products could thus be taxed higher, or even banned. Key for a transition of the food system are effective policies and policy coherence, consisting of a smart mix of above-mentioned policies. Also, adequate alternative solutions for sectors aimed to be reduced need to be considered. This would require a coordinated action plan involving all relevant stakeholders, from production, processing, retail, gastronomy, transport, and consumers.

4.4 Limitations

Our approach comes with several limitations. First, results for the organic production standard need to be interpreted with care. We modelled organic in the food systems model SOLm, which was developed to capture the essentials of this production standard. In SOLm, organic is mainly characterized by lower yields according to (25), no mineral fertilizers and consequently reduced nitrogen inputs, and prohibition of non-organic pesticide use. In our assessment, however, potential advantages of organic agriculture, such as improved biodiversity, favorable impacts of reduced pesticide use, and favorable impacts on soil health (42,43), could not be captured. Furthermore, some organic regulations also include specific social standards (44). In our assessment of social risks with the SHI, differences in production standards were not accounted for, and thus potential improvements of social risks of organic production was not captured.

Second, the indicators chosen to represent different sustainability dimensions need to be interpreted with care, since each of the dimensions is more complex than the single impact categories employed here. For example, the environmental dimension encompasses much more than land use, GHG emissions, and nitrogen surplus. Also, consequences of dietary change for human health are highly complex and depend on many factors (45,46). The AHEI indicator employed here can therefore only give a trend of a potential improvement or detriment, and not give exact estimates of these consequences (22). Moreover, with changed consumption and production patterns, costs per food item are likely to be influenced, resulting in changed prices on short-term – and vice versa, changes in prices influencing food demand (47). Also this indicator needs, therefore, to be interpreted with caution, and solely gives an indication of potential effects.

Third, the RM strategy focuses on reduction of consumption of meat from terrestrial animals solely. We acknowledge the fact that also other ASF needs to be reduced (14). While reducing meat consumption poses the advantage of being easier to convey, complexity would need to be added in order to address an improvement of multiple sustainability dimensions, as well as considering consistent links between coupled products (12).

5 Conclusion

The six consumer strategies revealed trade-offs between impact categories, unless combined in a synergistic way. While dietary changes towards more plant-based foods improved environmental impacts as well as diet quality, they could increase social risks. Further, when increasing the share of organic produce, land use and dietary costs were increased. The effect on land use could however be reversed when circularity principles were introduced in addition to the organic production standard, resulting in substantial improvements for all environmental indicators.

Our results have implications for consumers, policy makers, as well as other food system actors. We showed that consumers following individual strategies can make important contributions towards more sustainable food systems. In order to facilitate this shift, changes in food environments are needed. A coordinated action plan with coherent policies that targets a thorough redesign of the food system, including several of the proposed strategies, is needed in order to reach large systemic effects. This could encompass suitable education measures, incentives, as well as rules for production, processing, retail, gastronomy, transport, and consumption.

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