Hidden costs of the Swiss Agrifood System – Vision 2050

Appendix to the Swiss case study for the State of Food and Agriculture Report of the FAO - SOFA 2024

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Summary

This report is an appendix to the Swiss case study for the FAO SOFA 2024 report on the hidden costs of the current Swiss agrifood system (De Luca and Muller 2025). It presents and analyses the results of the hidden cost calculations for several future scenarios in 2050 as defined in the study "Zukunftsbild eines nachhaltigen Schweizer Ernährungssystems - Wirkungsanalyse von Zielvorgaben" (von Ow et al. 2026). This appendix is therefore consistent with the results of the aforementioned study. There are five scenarios: the reference development to 2050 ("Ref 2050"), assuming economic and population growth according to the public forecasts plus the implementation of currently planned climate and environmental policies on fossil fuel use, nitrogen and pesticide use. Two scenarios with additional actions on the sustainability of agricultural production, dietary patterns and food waste reduction ("ZB-T" and "ZB", the former with somewhat less technological measures than the latter), and one scenario implementing the consumption side measures only ("Nur Kon") and one only implementing the production side measures ("Nur Prd").

The results of this analysis show that the hidden costs can be reduced both in the "Ref2050"-scenario as well as in all other scenarios over a thirty-year period. In the "ZB", "ZB-T" and "Nur Kon"-scenarios the reduction in hidden costs compared to the reference scenario is significantly higher. Increasing cost differences to the "Ref 2050" scenario arise particularly during the first years because ambitious action both on the production and consumption side are launched. In subsequent years, the difference in hidden costs between the different scenarios remains at around 4 billion $2020 USD PPP. This corresponds to nearly 50 percent. Uncertainties are quite large, though and the 5 to 95-percentile range covers zero to 10 billion $2020 USD PPP. About two thirds of these reductions can be attributed to lower health costs thanks to a shift towards healthier diets, while the remaining third is due to reduced costs resulting from lower ammonia emissions and correspondingly reduced respiratory diseases. Acting on the production side only without addressing consumption ("Nur Prd") results in minor insignificant cost reductions of less than 1 billion $2020 USD PPP only.

The summed annual cost differences from 2020 through 2050 between the reference 2050 scenario and the future scenarios "ZB-T", "ZB" and "Nur Kon" indicate, that about 93 billion $2020 USD PPP could be saved over the whole period till 2050. This results in an annual average of about 3.1 billion $2020 USD PPP per year, while it is only about 15 % of this value (almost 0.5 billion) in the case of the scenario "Nur Prd" where only targets at production level are met.

It is important to keep in mind that these future cost projections do not cover the additional cost categories added to the Swiss case study on the current hidden costs of the Swiss agri-food system (De Luca and Muller 2025), most notably the considerable costs due to biodiversity loss and due to assuming higher social costs of carbon. Acting on those will thus also remain important to curb future hidden costs.

Finally, as already emphasized in the case study, it is central to avoid that costs that are low today become significant in the future. This applies to water use and antimicrobial resistances, for example. Any strategy for future hidden cost reductions must thus also address how to avoid that such costs that are relatively small today grow in the future.

DISCLAIMER

- The absolute values in this chapter should not be directly compared with those in the main report "De Luca and Muller 2025: Hidden costs of the Swiss Agrifood System - Case Study for the State of Food and Agriculture Report SOFA 2024", as the data basis and assumptions do not fully match.
- The central and most insightful comparative results in this chapter are those from comparing the various scenarios in the same year 2050.
- Comparisons of the results for 2020 (the reference situation today) and for the scenarios in 2050 compare two situations with totally different economic contexts (e.g. the 2050 situation having experienced 30 years of economic growth compared to 2020) and are thus misleading if not complemented with detailed comments and explanations (e.g. on the role of basic assumptions on economic growth and discounting).
- Do not use the numbers and graphs without explaining the context.

Résumé

Le présent rapport constitue une annexe à l'étude de cas suisse réalisée pour le rapport SOFA 2024 de la FAO sur les coûts cachés du système agroalimentaire suisse actuel (De Luca et Muller 2025). Il présente et analyse les résultats des calculs des coûts cachés pour plusieurs scénarios futurs à l'horizon 2050, tels que définis dans l'étude « Zukunftsbild eines nachhaltigen Schweizer Ernährungssystems - Wirkungsanalyse von Zielvorgaben » (von Ow et al. 2026). Cette annexe est donc cohérente avec les résultats de l'étude susmentionnée. Il existe cinq scénarios : l'évolution de référence à l'horizon 2050 (« Ref 2050 »), qui suppose une croissance économique et démographique conforme aux prévisions publiques, ainsi que la mise en œuvre des politiques climatiques et environnementales actuellement prévues concernant l'utilisation des combustibles fossiles, de l'azote et des pesticides. Deux scénarios prévoyant des mesures supplémentaires en matière de durabilité de la production agricole, d'habitudes alimentaires et de réduction du gaspillage alimentaire (« ZB-T » et « ZB », le premier comportant des mesures technologiques un peu moins importantes que le second), ainsi qu'un scénario mettant en œuvre uniquement les mesures du côté de la consommation (« Nur Kon ») et un autre mettant en œuvre uniquement les mesures du côté de la production (« Nur Prd »).

Les résultats de cette analyse montrent que les coûts cachés peuvent être réduits, tant dans le scénario « Ref2050 » que dans tous les autres scénarios, sur une période de trente ans. Dans les scénarios « ZB », « ZB-T » et « Nur Kon », la réduction des coûts cachés par rapport au scénario de référence est nettement plus importante. Les écarts de coûts par rapport au scénario « Ref 2050 » s'accentuent surtout au cours des premières années, car des mesures ambitieuses sont lancées tant du côté de la production que de la consommation. Au cours des années suivantes, la différence en termes de coûts cachés entre les différents scénarios se maintient autour de 4 milliards USD (2020, PPA). Cela correspond à près de 50 %. Les incertitudes sont toutefois assez importantes et la fourchette comprise entre les 5e et 95e centiles s'étend de zéro à 10 milliards USD (2020, PPA). Environ deux tiers de ces réductions peuvent être attribués à la baisse des coûts de santé grâce à une transition vers des régimes alimentaires plus sains, tandis que le tiers restant est dû à la réduction des coûts résultant de la baisse des émissions d'ammoniac et de la diminution correspondante des maladies respiratoires. Agir uniquement du côté de la production sans s'attaquer à la consommation (« Nur Prd ») n'entraîne que des réductions de coûts mineures et insignifiantes, inférieures à 1 milliard USD (2020, PPA).

La somme des différences de coûts annuels de 2020 à 2050 entre le scénario de référence 2050 et les scénarios futurs « ZB-T », « ZB » et « Nur Kon » indique qu'environ 93 milliards USD (2020, PPA) pourraient être économisés sur l'ensemble de la période jusqu'en 2050. Cela représente une moyenne annuelle d'environ 3,1 milliards USD(2020, PPA) par an, alors que ce chiffre n'atteint qu'environ 15 % de cette valeur (près de 0,5 milliard) dans le cas du scénario « Nur Prd », où seuls les objectifs au niveau de la production sont atteints.

Il est important de garder à l’esprit que ces projections de coûts futurs ne couvrent pas les catégories de coûts supplémentaires ajoutées à l’étude de cas suisse sur les coûts cachés actuels du système agroalimentaire suisse (De Luca et Muller 2025), notamment les coûts considérables liés à la perte de biodiversité et à la prise en compte de coûts sociaux plus élevés en raison de l'émission des gaz à effet de serre (social costs of carbon). Il restera donc également important d’agir sur ces aspects pour limiter les coûts cachés futurs.

Enfin, comme déjà souligné dans l’étude de cas, il est essentiel d’éviter que des coûts aujourd’hui faibles ne deviennent significatifs à l’avenir. Cela s’applique par exemple à l’utilisation de l’eau et aux résistances aux antimicrobiens. Toute stratégie visant à réduire les coûts cachés futurs doit donc également porter sur les moyens d'empêcher que ces coûts, relativement faibles aujourd’hui, n’augmentent à l’avenir.

AVERTISSEMENT

- Les valeurs absolues présentées dans ce chapitre ne doivent pas être comparées directement à celles du rapport principal « De Luca et Muller 2025: Hidden costs of the Swiss Agrifood System - Case Study for the State of Food and Agriculture Report SOFA 2024», car les bases de données et les hypothèses ne correspondent pas entièrement.
- Les résultats comparatifs les plus pertinents et les plus instructifs de ce chapitre sont ceux issus de la comparaison des différents scénarios pour la même année, à savoir 2050.
- Les comparaisons entre les résultats de 2020 (la situation de référence actuelle) et ceux des scénarios de 2050 opposent deux situations aux contextes économiques totalement différents (par exemple, la situation de 2050 aura connu 30 ans de croissance économique par rapport à 2020) et sont donc trompeuses si elles ne sont pas accompagnées de commentaires et d’explications détaillés (par exemple sur le rôle des hypothèses de base concernant la croissance économique et l’actualisation).
- N'utilisez pas les chiffres et les graphiques sans expliquer le contexte.

Zusammenfassung

Dieser Bericht ist ein Anhang zur Schweizer Fallstudie für den SOFA-Bericht 2024 der FAO über die versteckten Kosten des aktuellen Schweizer Land- und Ernährungssystems (De Luca und Muller 2025). Er präsentiert und analysiert die Ergebnisse der Berechnungen der versteckten Kosten für mehrere Zukunftsszenarien im Jahr 2050, wie sie in der Studie „Zukunftsbild eines nachhaltigen Schweizer Ernährungssystems – Wirkungsanalyse von Zielvorgaben“ (von Ow et al. 2026) definiert sind. Dieser Anhang steht daher im Einklang mit den Ergebnissen der oben genannten Studie. Es gibt fünf Szenarien: die Referenzentwicklung bis 2050 („Ref 2050“), die von einem Wirtschafts- und Bevölkerungswachstum gemäss den öffentlichen Prognosen sowie der Umsetzung der derzeit geplanten Klima- und Umweltmassnahmen in Bezug auf den Einsatz fossiler Brennstoffe, Stickstoff und Pestizide ausgeht. Zwei Szenarien mit zusätzlichen Massnahmen zur Nachhaltigkeit der landwirtschaftlichen Produktion, der Ernährungsgewohnheiten und der Reduktion von Lebensmittelabfällen („ZB-T“ und „ZB“, wobei das erstere weniger technologische Massnahmen vorsieht als das letztere), sowie ein Szenario, das ausschliesslich Massnahmen auf der Konsumseite („Nur Kon“), und eines, das ausschliesslich Massnahmen auf der Produktionsseite umsetzt („Nur Prd“).

Die Ergebnisse dieser Analyse zeigen, dass die versteckten Kosten sowohl im Ref2050-Szenario als auch in allen anderen Szenarien über einen Zeitraum von dreissig Jahren gesenkt werden können. In den Szenarien „ZB“, „ZB-T“ und „Nur Kon“ ist die Reduktion der versteckten Kosten im Vergleich zum Referenzszenario deutlich höher. Zunehmende Kostenreduktionen im Vergleich zum Referenzszenario werden vor allem in den ersten Jahren realisiert, da sowohl auf der Produktions- als auch auf der Konsumseite ehrgeizige Massnahmen eingeleitet werden. In den Folgejahren bleibt der Unterschied bei den versteckten Kosten zwischen den verschiedenen Szenarien bei etwa 4 Milliarden USD (Kaufkraftparität 2020). Dies entspricht fast 50 Prozent. Die Unsicherheiten sind jedoch recht gross, und der Bereich zwischen dem 5. und 95. Perzentil umfasst null bis 10 Milliarden USD (Kaufkraftparität 2020). Etwa zwei Drittel dieser Reduktionen sind auf geringere Gesundheitskosten zurückzuführen, die durch eine Umstellung auf gesündere Ernährungsweisen erzielt werden, während das verbleibende Drittel durch tiefere Kosten aufgrund niedrigerer Ammoniakemissionen und entsprechend weniger Atemwegserkrankungen resultieren. Massnahmen, die sich ausschliesslich auf die Produktionsseite beziehen, ohne den Verbrauch zu berücksichtigen („Nur Prd“), führen nur zu geringfügigen Kosteneinsparungen von weniger als 1 Milliarde USD (2020 PPP).

Die summierten jährlichen Kostendifferenzen von 2020 bis 2050 zwischen dem Referenzszenario 2050 und den Zukunftsszenarien „ZB-T“, „ZB“ und „Nur Kon“ zeigen, dass über den gesamten Zeitraum bis 2050 etwa 93 Mrd. USD (Kaufkraftparität 2020) eingespart werden könnten. Dies ergibt einen Durchschnitt von etwa 3.1 Milliarden US-Dollar (2020, PPP) pro Jahr, während es im Fall des Szenarios „Nur Prd“, bei dem nur

Ziele auf Produktionsebene erreicht werden, nur etwa 15 % dieses Wertes (fast 0.5 Milliarden) sind.

Es ist wichtig zu beachten, dass diese zukünftigen Kostenprognosen nicht die zusätzlichen Kostenkategorien abdecken, die in der Schweizer Fallstudie zu den aktuellen versteckten Kosten des Schweizer Agrar- und Ernährungssystems (De Luca und Muller 2025) hinzugefügt wurden, insbesondere die erheblichen Kosten aufgrund des Verlusts der biologischen Vielfalt und der Annahme höherer sozialer Kosten von Treibhausgasemissionen. Massnahmen in diesen Bereichen bleiben daher ebenfalls wichtig, um zukünftige versteckte Kosten einzudämmen.

Wie in der Fallstudie bereits betont, ist zu verhindern, dass Kosten, die heute noch gering sind, in Zukunft bedeutend werden. Dies gilt beispielsweise für den Wasserverbrauch und Antibiotikaresistenzen. Jede Strategie zur Verminderung künftiger versteckter Kosten muss daher auch darauf abzielen, zu verhindern, dass solche Kosten, die heute noch relativ gering sind, in Zukunft ansteigen.

HINWEIS

- Die absoluten Werte in diesem Kapitel sollten nicht direkt mit denen im Hauptbericht „De Luca und Muller 2025: Hidden costs of the Swiss Agrifood System – Case Study for the State of Food and Agriculture Report SOFA 2024“ verglichen werden, da die Datenbasis und die Annahmen nicht vollständig übereinstimmen.
- Die zentralen und aufschlussreichsten Vergleichsergebnisse in diesem Kapitel ergeben sich aus dem Vergleich der verschiedenen Szenarien im selben Jahr 2050.
- Vergleiche der Ergebnisse für 2020 (die heutige Referenzsituation) und für die Szenarien im Jahr 2050 stellen einander zwei Situationen mit völlig unterschiedlichen wirtschaftlichen Rahmenbedingungen gegenüber (z. B. hat die Situation im Jahr 2050 im Vergleich zu 2020 zusätzliche 30 Jahre mit Wirtschaftswachstum durchlaufen) und sind daher irreführend, wenn sie nicht durch detaillierte Kommentare und Erläuterungen ergänzt werden (z. B. zur Rolle der Grundannahmen bezüglich Wirtschaftswachstum und Diskontierung).
- Verwenden Sie die Zahlen und Grafiken nicht, ohne den Kontext zu erläutern.

Table of Contents

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1. Introduction

The Swiss case study for the State of Food and Agriculture Report SOFA 2024 (De Luca & Muller, 2025) provided an updated and refined estimation of the hidden costs of the current Swiss agrifood system, based on the estimates given in the context of the SOFA 2023 report (FAO, 2023; Lord, 2023) and amended in an extensive stakeholder process also described in that report.

This report here is an appendix to the case study report, presenting and analysing the results of the hidden cost calculations for several future scenarios of the Swiss agrifood system. The scenarios have been provided by Agroscope and calculated by the SWISSfoodSys-Model (Djanibekov & von Ow, 2025). Steven Lord has done the hidden cost calculations for these scenarios with the "SPIQ-FS"-model (Lord, 2022), i.e. the same model as applied for the hidden cost calculations of the FAO SOFA 2023 and 2024 reports (FAO, 2023, 2024). Steven Lord provided the data and graphics with ample explanations that were further detailed in bilateral and group exchanges.

This report first briefly explains the methods used and then presents the results, followed by some discussion and conclusions.

Section 2.3 ("How to interpret the results") provides several points that clarify aspects of the scenario outputs that may appear counter-intuitive or unexpected. Readers are advised to consult this section before interpreting the results and to return to it whenever questions about the interpretation arise.

2. Methods and data

As outlined in the introduction, the assessment is based on the SPIQ-FS model and the SWISSfoodSys scenarios. The following section briefly presents the indicators applied and the scenarios assessed and provides general guidance on how to interpret the results.

2.1 Indicators

The results cover the same impact categories as those reported in the SOFA reports, including environmental, social and health-related impacts. The differentiation of results is identical: aggregated results for each impact domain are provided, followed by intermediate and detailed levels of aggregation. As in the case study report, social impact costs are zero for Switzerland and are therefore not displayed in the graphs. For a detailed discussion of these indicators and their relevance for the Swiss context, see the case study report (De Luca & Muller, 2025). *Table 1* below reproduces the indicator set presented in De Luca & Muller (2025). We note that the cost estimates for the scenarios presented in this appendix are based on the indicators covered in the SOFA 2023 report, without any amendments and refinements as proposed in the Swiss case study.

Table 1: "Hidden cost items from agrifood production and food consumption considered in the State of Food and Agriculture 2023 study. Cost type refers to a classification of hidden cost from environmental sources (E), productivity loss from unhealthy diets (H), and cost of distributional failures (S). Capital change refers to cost bearing arising from predominately natural (N) or predominately other (O) capital changes in the impact pathway originating with the agrifood system activity. More detail on quantity and marginal cost data is in the Methodology section." (copied from the background paper on Switzerland (Lord, 2023)). For details on cost types and capitals, see the Swiss case study (De Luca & Muller, 2025).

Cost Category	Item	Impact Quantity	Cost Type	Marginal Cost	Cap -ital
GHG Emissions	GHG Emissions (CH_4): Farm-gate emissions	CH_4 metric ton	E	Social cost of CH_4 – residual damages to global future GDP PPP from agricultural losses in NPV at the optimal amount of abatement, attributed to the country of emission	N
	GHG Emissions (CH_4): Land Use change				
	GHG Emissions (CH_4): Pre- and post- production				
	GHG Emissions (CH_4): Farm-gate emissions			Social cost of CH_4 – residual damages to global future GDP PPP from mortality in NPV at the optimal amount of abatement, attributed to the country of emission	O
	GHG Emissions (CH_4): Land Use change				
	GHG Emissions (CH_4): Pre- and post- production				
	GHG Emissions (CO_2): Farm-gate emissions	CO_2 metric ton	E	Social cost of CO_2 – residual damages to global GDP PPP from agricultural losses in NPV at the optimal amount of abatement, attributed to the country of emission	N
	GHG Emissions (CO_2): Land Use change				
	GHG Emissions (CO_2): Pre- and post- production				
	GHG Emissions (CO_2): Farm-gate emissions			Social cost of CO_2 – residual damages to global future GDP PPP from mortality in NPV at the optimal amount of abatement, attributed to the country of emission	O
	GHG Emissions (CO_2): Land Use change				
	GHG Emissions (CO_2): Pre- and post- production				
	GHG Emissions (N_2O): Farm-gate emissions	N_2O metric ton	E	Social cost of N_2O – residual damages to global future GDP PPP from agricultural losses in NPV at the optimal amount of abatement, attributed to the country of emission	N
	GHG Emissions (N_2O): Land Use change				

	GHG Emissions (N_2O): Pre- and post- production				
	GHG Emissions (N_2O): Farm-gate emissions			Social cost of N_2O – residual damages to global future GDP PPP from mortality in NPV at the optimal amount of abatement, attributed to the country of emission	O
	GHG Emissions (N_2O): Land Use change				
	GHG Emissions (N_2O): Pre- and post- production				
Water use	Blue water withdrawal: Agricultural use	Cubic metre	E	Agricultural losses and productivity losses in the country of withdrawal due to burden of disease from protein energy-malnutrition, in the present and future in NPV, due to water deprived from economic use.	N
Land-use change	Land-use change: Cropland to Forest	Effective hectares of habitat returned (ha)	E	Value of equivalent hectares of present and future returned ecosystem services in NPV in the country of land-use transition due to recovery or re-establishment of ecosystem	N
	Land-use change: Cropland to Unmanaged Grassland				
	Land-use change: Pasture to Forest				
	Land-use change: Pasture to Unmanaged Grassland				
	Land-use change: Forest to Cropland	Effective hectares of habitat lost (ha)	E	Value of equivalent hectares of present and future lost ecosystem services in NPV in the country of land-use transition due to loss of natural ecosystem	N
	Land-use change: Forest to Pasture				
	Land-use change: Unmanaged Grassland to Cropland				
	Land-use change: Unmanaged Grassland to Pasture				

Nitrogen emissions	NH3 emissions to air	NH3 N-kg	E	Productivity losses in the country of emission due to burden of disease from particulate matter formation	O
				Agricultural and ecosystem services losses from nutrient imbalance and acidification of terrestrial biomes due to deposition, ecosystem services losses from nutrient imbalance, acidification and eutrophication of riverine, wetlands, and coastal systems due to deposition run-off	N
	NOx emissions to air	NOx N-kg	E	Productivity losses in the country of emission due to burden of disease from particulate matter formation	O
				Agricultural and ecosystem services losses from ozone formation, nutrient imbalance and acidification of terrestrial biomes due to deposition, ecosystem services losses from nutrient imbalance, acidification and eutrophication of riverine, wetlands, and coastal systems due to deposition run-off	N
	NO3- leached to groundwater	NO3- N-kg	E	Productivity losses in the country of emission due to burden of disease from human nitrate intake	O
	NO3- loads due to run-off from agricultural land to surface water			Ecosystem services losses from nutrient imbalance, acidification, and eutrophication riverine, wetlands, and coastal systems due to run-off	N
	NO3- loads due to effluent or human sewerage in surface water			Ecosystem services losses from nutrient imbalance, acidification, and eutrophication riverine, wetlands, and coastal systems due to run-off	N
Poverty	Agrifood system worker poverty headcount at $3.65 a day (2017 PPP)	ppl	S	Cost in PPP terms of the income shortfall below moderate poverty line of agrifood workers	O
Undernourishment	Number of Undernourished	ppl	S	Productivity losses in the country of consumption due to burden of disease from protein energy-malnutrition.	O
Dietary patterns	Burden of non-communicable diseases and high body-mass-index (BMI) attributable to dietary intake	Burden of disease in disability adjusted life years (DALYs)	H	Productivity losses in the country of consumption due to burden of disease from high body-mass index and noncommunicable diseases	O

2.2 Scenarios

The calculations cover six scenarios. These comprise the reference situation in 2019/2020 (2019 in SWISSfoodSys; in SPIQ-FS it is the average of the years 2019-2021, denoted as "2020"; in this chapter here we refer to it with the year "2020", hence using the abbreviation "**Ref 2020**"), a scenario for 2050 representing a reference development that mainly follows basic governmental projections for Switzerland, plus some additional assumptions as detailed in *Table 2* ("**Ref 2050**"), and four optimisation scenarios for 2050 defined by specific constraints and assumptions on technological progress, also detailed in

Table 2. In all optimisation scenarios, the objective function is the agricultural sector income. Constraints cover six production and three consumption targets. On the production side, these are greenhouse gas emission reductions according to the climate strategy for food and agriculture, a reduction in nitrogen surplus, an increase in biodiversity support areas, reductions in concentrate use for ruminants, an increase in the net self-sufficiency degree and a strong reduction in food losses by 75%. On the consumption side, the constraints cover a reduction of the GHG emissions related to the per capita food basket by two thirds, a reduction of consumer-side food waste by 75% and a change in dietary patterns according to the Swiss food pyramid. In addition, there are assumptions on technical improvements regarding GHG emission reductions from fossil fuel use (decarbonization of the whole economy, i.e. across all sectors, not only agriculture and food), reductions regarding direct nitrogen emissions (NH_3, NO_3, N_2O) and reductions of risks related to plant protection means. These three technical reduction assumptions apply to all scenarios. For three of the four optimisation scenarios, two additional technological improvements are assumed, namely additional reductions of direct nitrogen emissions and additional technical GHG emission reductions (

Table 2).

The references 2020 and 2050 and the four optimisation scenarios are thus

- **Ref 2020**, starting point of the reference scenario where the constraints are not yet binding
- **Ref 2050**, reference scenario with constraints regarding GHG emissions from fossil fuel use, direct nitrogen emissions and risks related to pesticides as well as the governmental assumptions on population and economic growth in terms of consumption per capita.
- **ZB-T** – Zukunftsbild ohne Technologie" (i.e. "Vision of the future without additional technological change"), where in addition to Ref 2050, all constraints on production and consumption are implemented, but no specific technological improvements beyond the reference scenario 2050 are assumed.
- **ZB**, identical to ZB-T, but in addition assuming improved technologies beyond the reference scenario 2050.
- **Nur Kon** ("only consumption"), which is identical to "ZB" except that only consumption-related constraints are applied.
- **Nur Prd** ("only production"), which is identical to "ZB" except that only production-related constraints are applied.

In general, scenario ZB is considered more realistic than ZB-T. In ZB-T, achieving all constraints requires a thorough structural change with much larger changes in production and consumption. It could be argued that it is unlikely that no additional measures would be implemented in parallel to such thorough change, hence the judgment that scenario ZB-T is less realistic and consistent. Nevertheless, the hidden cost impacts are similar between the two scenarios. The assumptions for all these scenarios are compiled in

Table 2 below.

Table 2: Scenario specifications

		Ref 2020	Ref 2050	ZB-T	ZB	Nur Kon	Nur Prd
		Reference		Targets without contributions of improved technology	Targets with contributions of improved technology	only constraints on consumer side	only constraints on production side
	Year	2019/20	2050	2050	2050	2050	2050
Targets to be met / constraints							
target function	**maximise income of the agricultural sector**	X	X	X	X	X	X
production targets	**GHG** agriculture -40% vs. 1990			X	X		X
	N-Surplus (OSPAR) -30%			X	X		X
	Biodiversity support areas ≥ 16.6% of agricultural land			X	X		X
	Net-degree of self sufficiency ≥ 50%			X	X		X
	Concentrated feed for ruminants (only upgrading)			X	X		X
	Avoidable food waste Production side -75%			X	X		X
consumption targets	**GHG** consumer -66% per capita			X	X	X	
	Avoidable food waste Consumer side -75%			X	X	X	
	Nutrition according to the food pyramid			X	X	X	
technical emission reductions	**CO_2 fossil** (decarbonization)		-40%	-40%	-40%	-40%	-40%
	GHG agriculture (technical measures)				-17%	-17%	-17%
	NH_3, NO_3, N_2O (technical measures)		-10%	-10%	-20%	-20%	-20%
	Plant protection means risk						
	surface water		-34%	-34%	-34%	-34%	-34%
	natural habitats		-29%	-29%	-29%	-29%	-29%
	groundwater		-52%	-52%	-52%	-52%	-52%

2.3 How to interpret the results

A number of aspects need to be emphasized for correctly interpreting the results. We explain them in the following sections.

2.3.1 Economic growth, discounting and purchasing power parity

The absolute values of the results may puzzle the reader, given that total hidden costs in 2050 seem only about half of those in the reference 2020 (see results section). A central aspect thereby is the fact that the reference scenario 2050 used in SWISSfoodSys is based on the government's official projections for economic and population growth for the whole Swiss economy. This is in addition to the specific assumptions regarding the development of the agricultural and food sector as additionally implemented in

SWISSfoodSys. Furthermore, specific assumptions made in SPIQ-FS regarding time preferences and marginal utility of consumption also apply. These also influence how much welfare loss and thus monetary costs are incurred due to physical damage. These are central assumptions effective in all scenarios as calculated by SWISSfoodSys and the corresponding hidden cost estimates calculated with SPIQ-FS and need to be made explicit in order to interpret the results correctly. Therefore, we provide some further details on these central aspects and their interpretation.

The cost estimates are built by multiplication of physical impacts (such as GHG emissions or DALYs lost due to unhealthy diets) with the marginal damage costs. Thus, if the quantity of physical impacts decreases, this contributes to a decrease in damage costs. In Ref 2050, many physical impacts are reduced in comparison to Ref 2020 (cf. *Figure 12* in section 3.8).

The marginal damage costs are measured in $2020 USD PPP. PPP (Purchasing Power Parity) US$ are calculated so that one unit buys the same amount of goods and services in every context at a specific point in time. PPP thus accounts in particular for exchange rates (between countries) and inflation (for different time periods for the same country). The goods represent welfare provided by their consumption. Damage costs measured in $2020 USD PPP thus represent the reduction in welfare due to a reduction of goods consumed or reduced purchasing power, and avoided damage costs represents the benefit in an avoided reduction in welfare.

Economic growth means that a society becomes richer, in the sense that the consumption of *real* goods and services per person increases. Drivers are, among other, technological progress and innovation, which increase productivity, that is how much output can be produced from a given input bundle. In welfare economics, economic growth is usually captured in a framework of decreasing marginal utility of consumption, which means that for a richer society, an additional unit of consumption results in a lower increase in utility than in a poorer society. Intuitively, this means that an "extra dollar" generates less welfare for rich people than for poor people. Formally, this is expressed as a utility change U' (in technical terms, this is "marginal utility", the first derivative of utility U). U' is proportional to consumption C raised to a *negative* power $-\eta$: $U' \propto C^{-\eta}$, where η is the elasticity of the marginal utility of consumption EMUC. This term η captures by how much one additional unit of consumption translates into additional utility. In welfare economics and related debates, the concepts "utility" and "welfare" are closely related. Generally, "utility" is used for individual wellbeing, while "welfare" is rather used for the aggregate of individual utilities over a whole society and over time. However, this is not always implemented strictly and in some contexts the concepts may be used rather interchangeably.

Determining damages costs in $2020 USD PPP for the society in 2050 thus includes accounting for this economic growth effect, i.e. that an additional unit of consumption (or one unit of consumption that is lost) results in less increase (or decrease) of welfare than in a poorer economy, such as e.g. the same economy today in 2020, before having experienced this trajectory of economic growth from 2020 to 2050. For further illustration consider Switzerland, where the economy will grow from 2020 to 2050 according to the government's assumptions, thus making society richer. Therefore, an additional unit of damage will result in a smaller decrease in welfare in Switzerland in 2050 than in 2020 in \$2020 USD PPP. This results in welfare losses from a certain physical impact (e.g. 1t of GHG emissions in CO2 equivalents) in 2050 being lower than welfare losses of the identical physical impact in 2020, both welfare losses being measured in \$2020 USD PPP (cf. *Figure 13* in section 3.8). In total, this then results in total damage costs of a certain category measured in \$2020 USD PPP being lower in Ref 2050 than in Ref 2020 as the development of physical impacts (e.g. an increase) does not outstrip the cost reducing effect of economic growth (cf. sections 3.7 and 3.8).

In the hidden costs assessments used here, the elasticity of the marginal utility of consumption EMUC is set equal to 1.5. Usually, EMUC is estimated between 1.1 and 2 and the choice of 1.5 is a generally accepted mid-level default. Section 3.7 then presents some sensitivity analysis with additional values of 1.01, 1.1 and 2. The value of 1.01 illustrates the case in which the difference in damage cost between Ref 2020 and Ref 2050 are more strongly influenced by changes in physical impacts than by the impact of economic growth (i.e. by the fact that an additional dollar lost in the future richer society results in less welfare loss); the case of EMUC = 2 then refers to the opposite case, where the weight of economic growth for determining damage costs is much larger.

In welfare economics, the full social discount rate that captures how a society values future consumption has two parts (Ramsey social discount rate, cf. (Lord, 2022)). The first part is the effect of an increasing consumption per capita (i.e. economic growth) resulting in relatively less corresponding welfare increase in richer societies, as explained above. The second part captures the so-called pure time preference, which determines by how much a society values consumption today more than consumption in the future. In the hidden costs assessments used here, this pure time preference is set to zero, so the only effect relevant for social discounting is this named effect of economies growing richer, as described above. Setting the pure time preference to zero is a moral choice and avoids that the damages of future generations are per se valued less than those of the current generation (i.e. just because they are living later than those today and not because of different economic performance levels or richness of societies).

Usually, this is formalised as follows, where social welfare W is the sum of discounted utilities over time:

$$W = \sum_t \frac{1}{(1+r)^t} U(C_t)$$

where the sum applies over time and the whole population, and

- C_t= consumption per capita in the time period t
- $U(C_t)$= utility of consumption in the time period t.
- r = Ramsey social discount rate

Thereby,

$$r = \rho + \eta * g$$

with

- ρ= rate of pure time preference
- η= elasticity of the marginal utility of consumption (EMUC)
- g= growth rate of consumption per capita (economic growth).

This formula can also help to illustrate a somewhat more intuitive approach, asking for the "present value" (i.e. in 2020) of a certain damage in 2050: a damage that has the nominal monetary value of D_{nom_2050} in 2050 has the $2020 USD PPP value D_{PPP_2020} , which is derived as follows:

$$D_{PPP\_2020} = D_{nom\_2050} * \frac{1}{(1 + r_{infl})^{(2050-2020)}} * PPPUS\$2020 * \frac{1}{(1 + r_{SDR})^{(2050-2020)}}$$

Thereby, the term with r_{infl} accounts for inflation and brings the value to the same price level across time, while PPPUS$2020 converts the national currency to $2020 USD PPP – together, they thus account for the full purchasing power adjustment. The term r_{SDR} is the Ramsey social discount rate from above, accounting for society's valuation of future consumption. For further details on these topics discussed above, see (Lord, 2022) and references therein.

For all these assessments, it has to be emphasized that the reference development from 2020 to 2050 as captured in Ref 2050 thus clearly does not imply "doing nothing". The costs between 2020 and 2050 will not be reduced as illustrated in the results section if no action is taken. Already in the Ref 2050 scenario, investments in technological innovation etc. are to be implemented form 2020 onwards to achieve the corresponding situation in 2050 with considerably reduced physical impacts in many damage categories. Furthermore, also in the reference scenario 2050 considerable efforts are undertaken to mitigate impacts, e.g. regarding GHG emissions from fossil fuels and regarding risks from the use of nitrogen and plant protection means. Without these mitigation efforts, the reduced *physical* impact estimates in Ref 2050 as compared to Ref 2020 for many impact categories would not be realised (cf. section 3.8).

In any case, comparing the costs of a scenario in 2050 and the costs of the reference situation in 2020 is not advisable. While the scenario in 2050 benefits from 30 years of economic growth, the latter does not. It is therefore crucial to compare costs of different scenarios *for the same year*, e.g. for 2050 between the ZB-T, ZB, Nur Kon and Nur Prd scenarios and the Ref 2050 development. Importantly, the reporting of all numbers in 2020 PPP allows to sum the hidden cost differences between a scenario and Ref 2050 over the whole time-period. This allows to identify the overall cost reductions from the whole trajectory from 2020 to 2050 when following a scenario instead of just realising the Ref 2050 development.

2.3.2 Further assumptions and caveats

- The projected reference development to 2050 does not account for interactions with the specific modelled impacts of the agri-food system through 2050. The economic growth rates and other developments in Ref 2050 are decoupled from the specific additional assumptions on the agricultural sector applied in SWISSfoodSys. In particular, the Ref 2050 development and all other scenarios do not consider the productivity losses from unhealthy dietary patterns on overall productivity of the economy in a feedback loop. Consequently, the reported impact values (measured as societal welfare losses, as in SOFA 2023) are likely underestimated, since such interactions could amplify some of the impacts.
- Health impacts are reported in a "joint" manner, meaning that interactions between different health impacts are taken into account. This can produce counterintuitive results: even if the overall health burden decreases, some specific impacts may increase. Consider, for example, an impact that primarily affects older age groups (e.g. certain types of cancer). As life expectancy increases due to healthier dietary patterns, the incidence rate of developing such cancer types also increases, as more people are living long enough to develop this cancer – even if for a given age group the risk to develop this cancer would be lower. However, reporting all health impacts separately, without accounting for interactions, would lead to substantial double counting (up to 25%). Therefore, the more complex "joint" assessment approach is used, despite the potential for the counterintuitive outcomes described above.
- The values reported here for the reference today, Ref 2020, are lower than those reported in the case study to the SOFA report. This is due to the different data and assumptions underlying the calculations in the two reports. While the SOFA report is based on SPIQ-FS calculations using globally available data for each country, this report here is based on SPIQ-FS calculations that use data and results from the SWISSfoodSys model. One important difference is, for example, that the productivity loss estimates used in SPIQ-FS in this report refer to the working population between 20 and 70 years only and not the whole population, as assumed for the SPIQ-FS calculations producing the SOFA 2023 estimates.
- The reference 2020 values reported for different scenarios show minor differences. These arise partly from the statistical nature of the calculations (Monte Carlo simulations) and partly from the requirement in the SPIQ-FS model that each future trajectory must have a consistent starting point in the present. This starting point varies slightly among scenarios due to their differing trajectories. These factors also explain the small non-zero differences observed between the paths of the Ref 2050 scenario and some optimisation scenarios in the reference year 2020, even though both start from essentially the same point. The differences reflect sampling noise and the slight variation in scenario starting points described above.

- The cost trajectories from the reference year 2020 to the year 2050 are not linear albeit dietary shifts are implemented linearly from now to 2050. The largest changes in costs occur between 2020 and 2030. From 2030 onwards, cost differences largely remain constant and further cost reductions between the scenarios are smaller and, in some cases, not significant. This is due to decreasing marginal returns in physical impacts of large changes, such as in dietary patterns, where initially, cost reductions are large, but when reaching a theoretical minimum risk exposure level (TMREL), further reduction of costs is not possible anymore also with these actions that have been beneficial above this TMREL (as the risk cannot be reduced below this minimal level, which is given by context variables that cannot be influenced by the measures implemented in the scenarios). Diet shifts are also implemented in such a way that the whole distribution of dietary patterns shifts without changing its form, i.e. dietary changes shift the intakes of the various food groups by mean intake shifts (every person in the population shifts by the same amount). In total, this type of shifting the whole distribution in a linear way from today to 2050 results in an increasing number of people being below the TMREL, thus lowering the beneficial impacts of a further shift later in time. This is behind this pattern of main cost reductions arising between now and 2030 and minor additional reduction only from 2030 onwards.
- The uncertainty margins generated via the Monte-Carlo-Simulations are also central for the interpretation of the results as will be seen further down in the results section. The mean values reported are indeed only an indication of the expected value of costs or cost reductions in the various scenarios, and the uncertainty information indicates in which ranges these costs come to lie with a 95% probability. These ranges are large and differences in the mean values always must be seen in the context of these ranges. There are, for example, cases, where cost reductions relative to the Ref 2050 scenario are small (in the "Nur Prd"-scenario) and the patterns are unintuitive, as cost reductions are largest in 2030 and then become smaller again in 2040, again increasing in 2050. Looking at this in the context of the uncertainty ranges provided, shows that these patterns are merely artefacts of the sampling fluctuations and not too much meaning should be given to them.

3. Results

In this results section, we first present the absolute hidden cost estimates in all scenarios for 2050 and then focus on the changes in hidden costs of the ZB-T and ZB scenario with respect to the reference scenario in 2050, Ref 2050. We then provide further details on the uncertainty of these results and the temporal trajectories from 2020 to 2050. This is followed by the results on the two other scenarios and a more detailed assessment of single indicators as well as the differentiation between domestic impacts and import-related impacts abroad. Finally, results from some sensitivity analysis on the choice of the elasticity of the marginal utility of consumption (cf. section 2.3.1) are presented as well as data on the physical impacts and the per unit damage cost values behind the cost estimates.

3.1 Hidden costs in 2050

Comparing the absolute values over all scenarios shows that “ZB-T”, “ZB” and “Nur Kon” all result in a reduction of almost 50% of hidden costs (i.e. a reduction by about 4 billion $2020 USD PPP) in comparison to the “Ref 2050” scenario (Figure 1). In these total cost reductions in relation to the reference scenario, diet-related costs are reduced by more than 50% while environmental costs are reduced by about a third. “Nur Prd” has only marginal reductions, with almost none on the level of dietary patterns, and some minor improvements for ammonia.

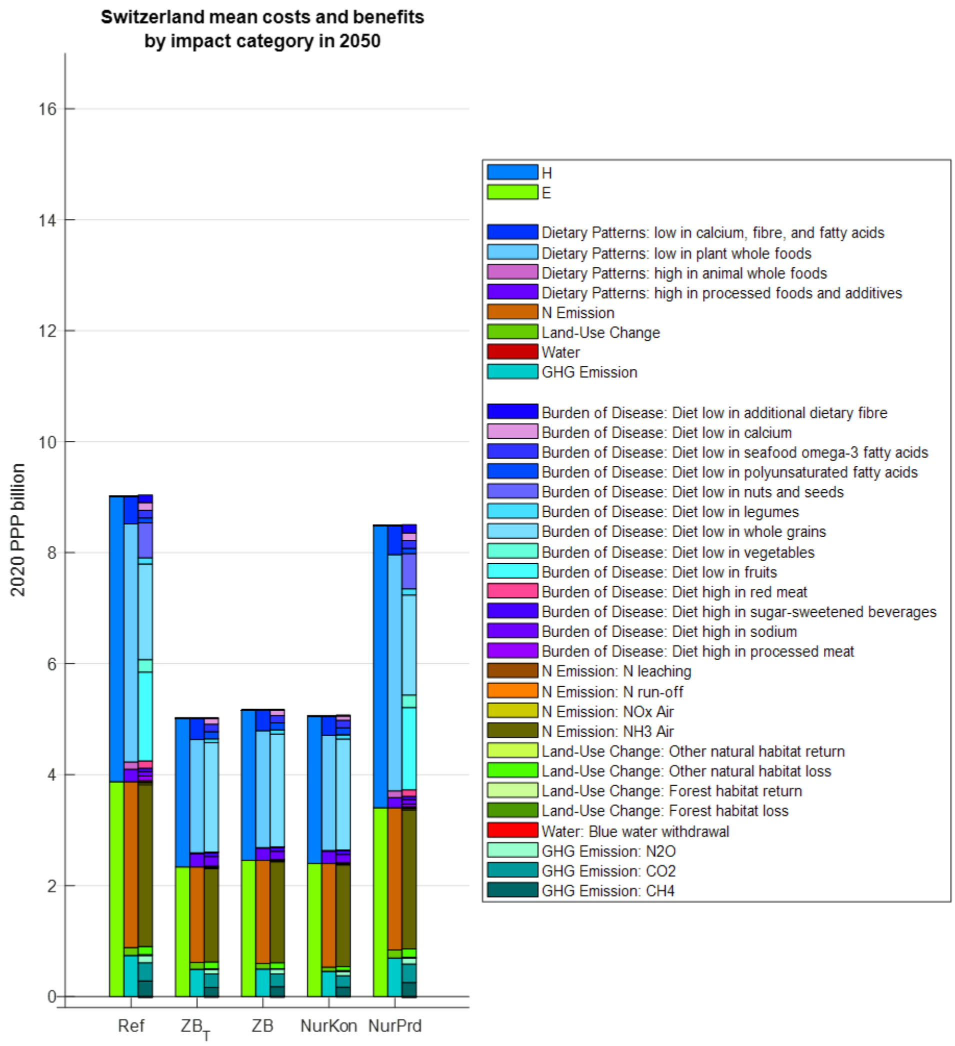


Figure 1: Comparison of absolute hidden costs for all scenarios, for the year 2050, in present purchasing power (2020 PPP); “Ref” is “Ref 2050”

3.2 Results for ZB-T and ZB

For both ZB-T and ZB, hidden costs in 2050 are reduced by about 4 billion $2020 USD PPP, i.e. by about 50 percent of the value of the hidden costs of the reference scenario Ref 2050 (Figure 2 and previous section). The main driver of this is the improved dietary patterns, mainly driven by increased fruits, vegetables and nuts and seeds intake, accounting for about two thirds of the cost reductions. The other big part is reductions of the costs related to ammonia emissions, i.e. mainly from health impacts such as respiratory diseases (albeit these are health impacts as well, they are part of the environmental cost dimension; this is due to the fact that ammonia emissions are seen as environmental pollution, the main costs of this however arise via the impact on human health), accounting for about a third of the cost reductions in comparison to the Ref 2050 scenario.

The results also show an increase in some cost components as compared to the Ref 2050 scenario (Burden of disease: diet low in whole grains, diet high in sodium, diet high in sugar-sweetened beverages). This is mainly due to diets low in whole grains. This is an effect of the joint estimation of dietary impacts (cf. methods section above). The disease burden caused by diets low in intakes of fruits, vegetables and nuts and seeds drops drastically, while the increased consumption of whole grain results in comparably lower reduction in disease burden. In consequence, proportionally, disease rates from the whole grain component in diets rise, even though the exposure to diets low in wholegrain goes down. The reason is, that now only very few people are affected by the incidents from the other diet categories, thus resulting in incidents from diets low in wholegrain being proportionally much more important. This is the counterintuitive result from the joint impact estimation.

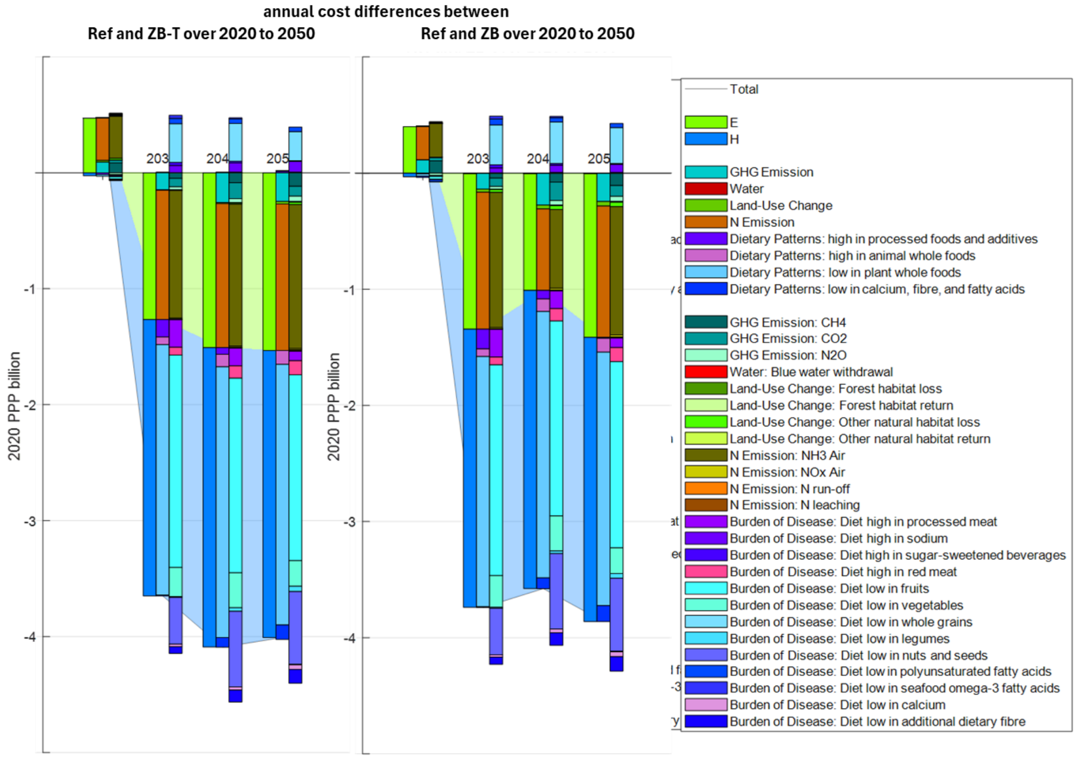


Figure 2: The bars display annual hidden costs differences between "Ref 2050" ("Ref" in the figure) and "ZB-T" (left, displaying the difference ZB-T minus Ref 2050) or "ZB" (right, displaying the difference ZB minus Ref 2050) pathways in present purchasing power (2020 PPP), for the years 2030, 2040 and 2050 (the small difference for the reference year is an artefact of the Monte-Carlo-Simulations for the scenario runs to estimate the mean values in changes displayed here). In the ZB and ZB-T scenario, costs are consistently about 4 billion lower than in the reference scenario from 2030 onwards, while the main change in costs arises during the first ten years. The shaded areas further help to illustrate how the cost differences change between the years, illustrating the larger increase in differences at the beginning and minor changes later on.

The following Figure 3 shows the hidden cost trajectories for the scenarios ZB-T and ZB from 2020 to 2050, each in comparison to the trajectory of the Ref 2050 scenario, and also providing some uncertainty estimate of these numbers. As pointed out in the methods section, this also illustrates the non-linear dynamics of cost reductions, being strongest between 2020 and 2030 and then levelling off for the subsequent years. As explained above in section 2.3.2 in more detail, this is due to decreasing marginal returns of large changes in dietary patterns, where initially, cost reductions are large, but when reaching a theoretical minimum risk exposure level (TMREL), further reduction of costs is not possible anymore also with these actions that have been beneficial above this TMREL.

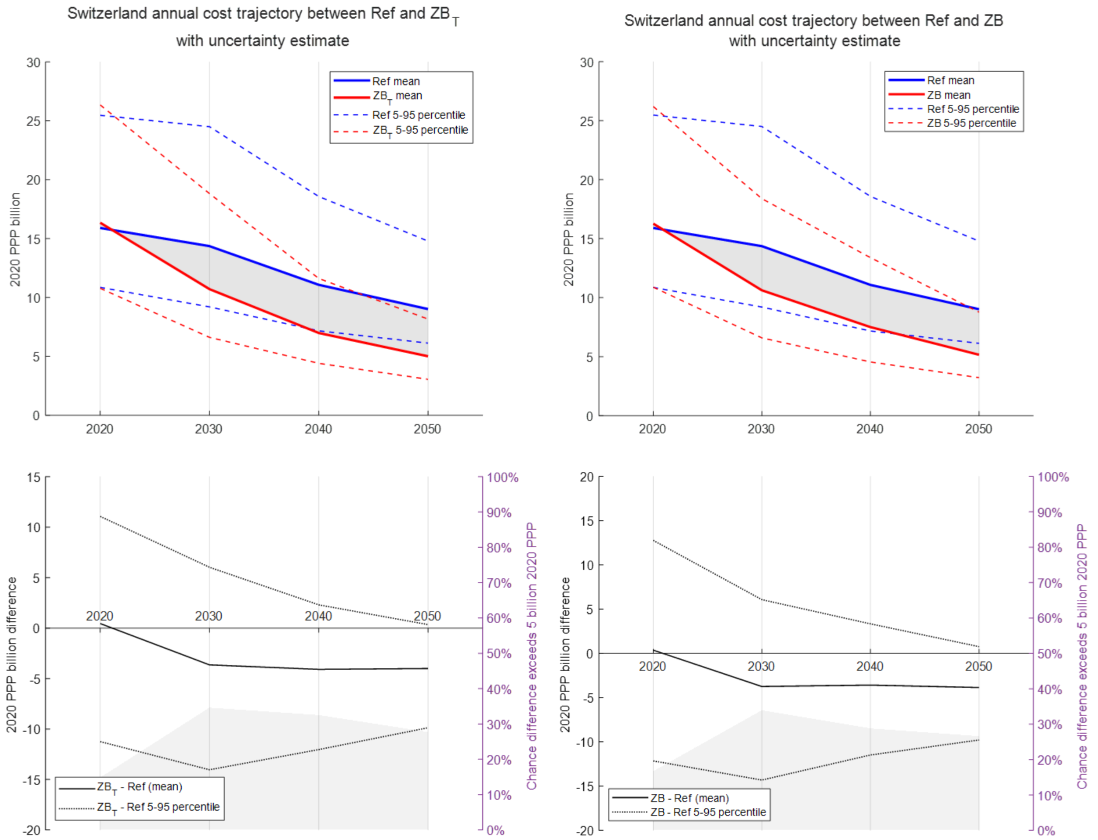


Figure 3: Comparison of trajectories of hidden costs changes for the scenarios "Ref 2050" and "ZB-T" (left) or "ZB" (right), respectively, in present purchasing power (2020 PPP). The grey area corresponds to the cumulative cost reduction over the shole time-period 2020 to 2050. The lower panels display the uncertainty of the cost differences, showing the mean difference "ZB-T minus Ref 2050" and "ZB minus Ref 2050", as well as the corresponding uncertainty interval from the 5 to 95-percentiles.

Figure 4 shows further details on the uncertainty estimates of the cost differences between the Ref 2050 scenario and the scenarios ZB-T and ZB, respectively. This and the previous figure illustrate well how important it is to not only look at the mean value of the cost estimates but also at the uncertainty range that comes with these. They indicate, for example, how large – or small – the probability is that costs between the Ref 2050 scenario and another scenario are different – where we see that this probability is quite large for both the scenarios ZB-T and ZB, thus indicating that these scenarios very likely lead to cost reductions in the range of 0 to 10 billion 2020 PPP in comparison to the Ref 2050 scenario, with an expected reduction of about 4 billion.

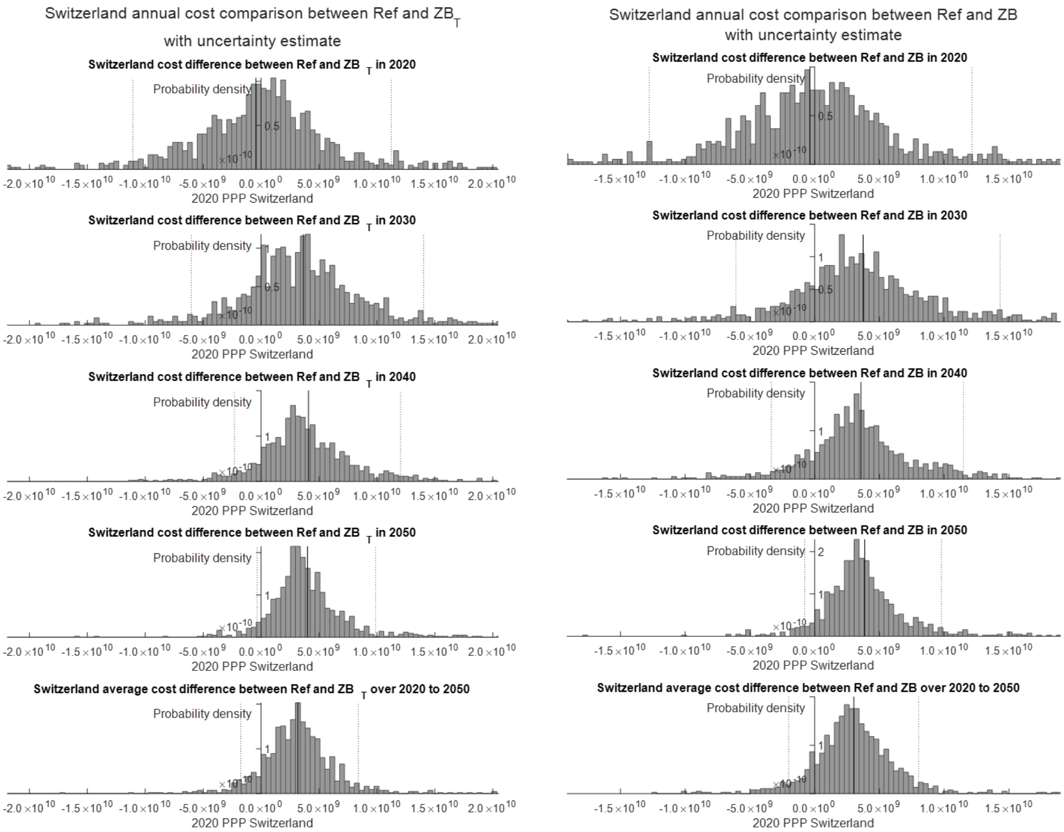


Figure 4: Uncertainty estimates for the hidden cost differences in various years between the scenarios "Ref 2050" and "ZB-T" (left) or "ZB" (right), respectively, in present purchasing power (2020 PPP).

3.3 Results for "Nur Kon" and "Nur Prd"

The patterns for "Nur Kon" are similar to those observed for "ZB-T" and "ZB", i.e. with large cost reductions from increased fruit, vegetable and nuts and seeds intakes as well as ammonia emission reductions, also showing the counterintuitive effect of increased costs for wholegrain consumption.

The pattern differs markedly for "Nur Prd", where total cost reductions are much smaller and largely within the uncertainty range, i.e., not significantly different from zero (cf. below). Nearly no cost reductions arise from dietary changes, since this scenario imposes no dietary restrictions and is thus close to the Ref 2050 scenario in terms of diets. The main cost reductions result from ammonia emission reductions, reflecting the production targets that remain in place. Ammonia contributes substantially to production-related hidden costs and therefore drives the associated cost reductions.

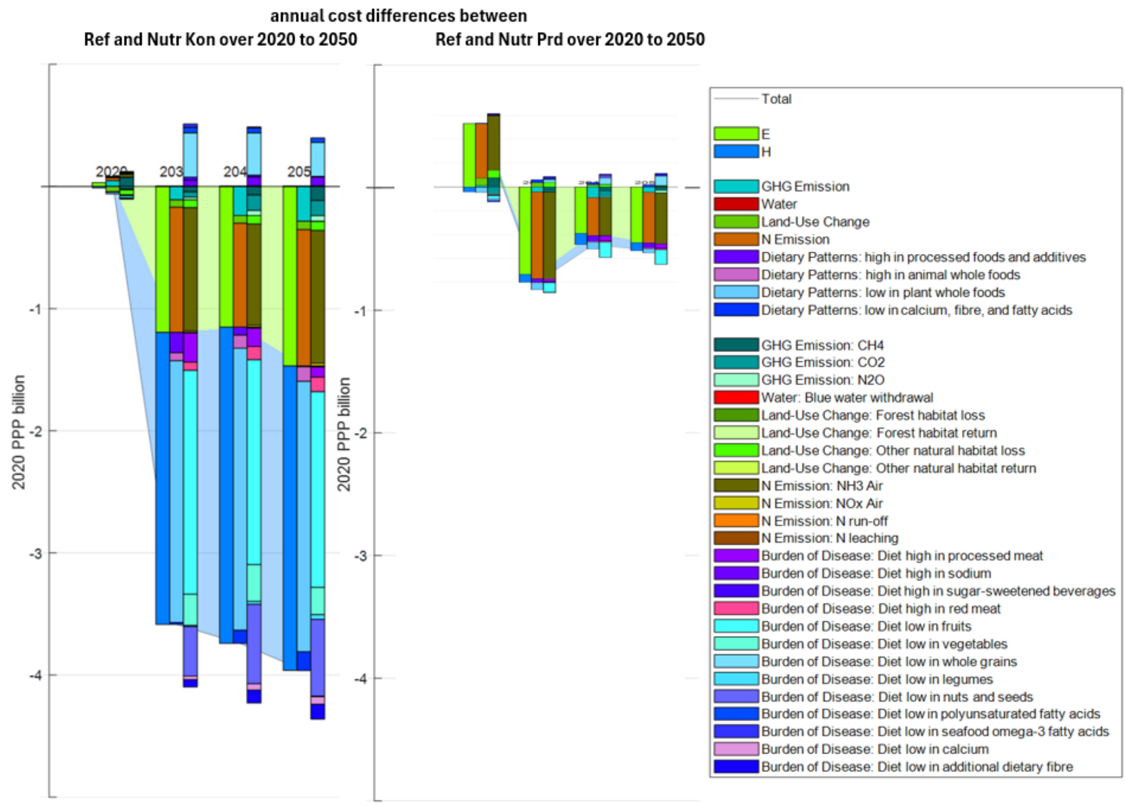


Figure 5: The bars display annual hidden costs differences between "Ref 2050" ("Ref" in the figure) and "Nur Kon" (left, displaying the difference Nur Kon minus Ref 2050) or "Nur Prd" (right, displaying the difference Nur Prd minus Ref 2050) pathways in present purchasing power (2020 PPP), for the years 2030, 2040 and 2050 (the small difference for the reference year is an artefact of the Monte-Carlo-Simulations for the scenario runs to estimate the mean values in changes displayed here). In the Nur Kon scenario, costs are consistently about 4 billion lower than in the reference scenario from 2030 onwards, while the main change in costs arises during the first ten years. A similar pattern on the time dynamics is visible for Nur Prd as well, but with larger uncertainties and absolute reductions between 0.5 and 1 billion only. The shaded areas further help to illustrate how the cost differences change between the years, illustrating the larger increase in differences at the beginning and minor changes later on.

Similar to the discussion above for ZB-T and ZB, the following two figures ***Figure 6*** and ***Figure 7*** indicate the trajectories and uncertainty estimates for the scenarios "Nur Kon" and "Nur Prd" and their differences to "Ref 2050", respectively. Here we see in particular that the cost estimates for "Nur Prd" are small in relation to the uncertainty estimates, thus indicating that the absolute values and the differences between the years should not be given too much meaning to and the focus should be on comparing relative differences between scenarios for the *same* year (e.g. 2050).

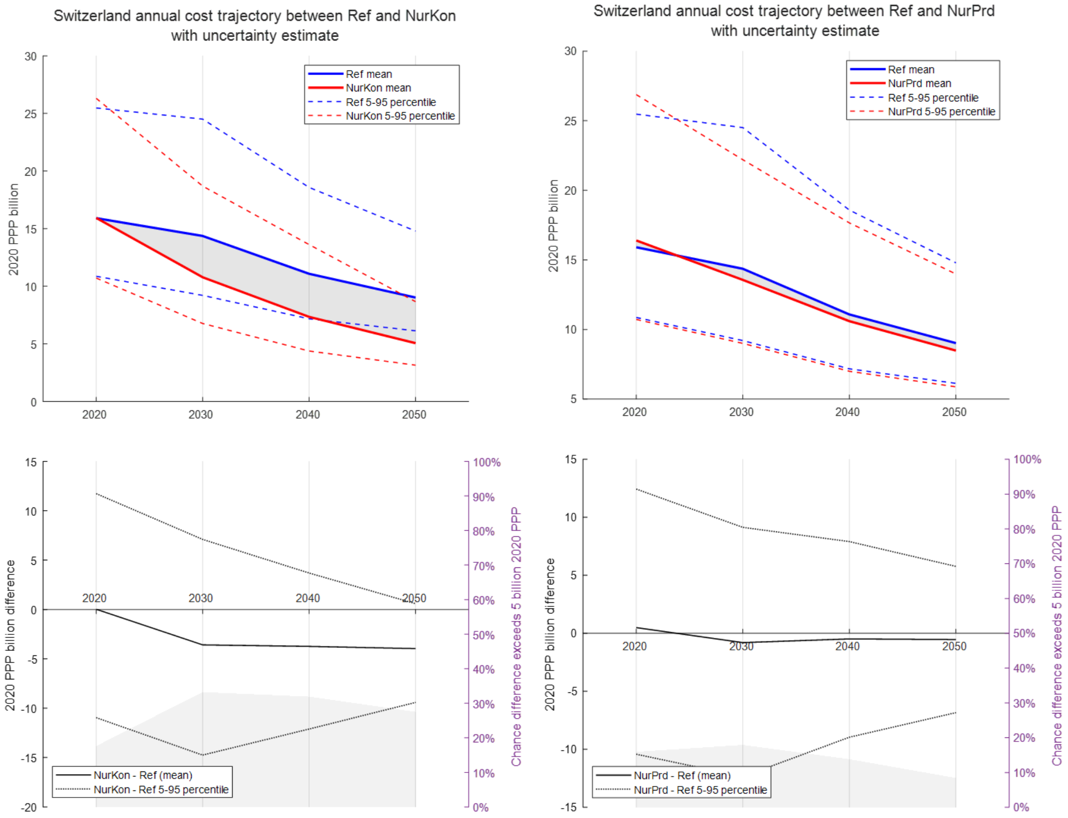


Figure 6: Comparison of trajectories of hidden costs changes for the scenarios "Ref 2050" and "Nur Kon" (left) or "Nur Prd" (right), respectively, in present purchasing power (2020 PPP). The trajectory of the "NurKon" scenario is comparable to that of the ZB and ZB-T scenarios. The development in the "Nur Prd" scenario roughly corresponds to that of the reference scenario. The grey area corresponds to the cumulative cost reduction over the whole time-period 2020 to 2050. The lower panels display the uncertainty of the cost differences, showing the mean difference "Nur Kon minus Ref 2050" and "Nur Prd minus Ref 2050", as well as the corresponding uncertainty interval from the 5 to 95-percentiles.

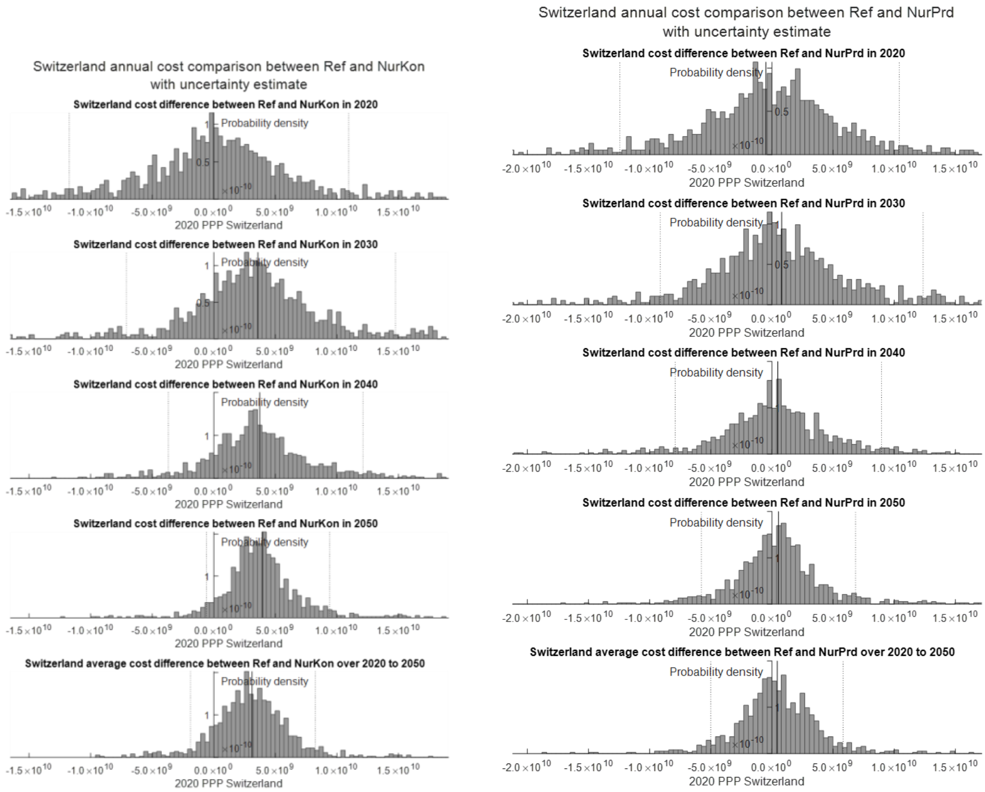


Figure 7: Uncertainty estimates for the hidden cost differences in various years between the scenarios "Ref 2050" and "Nur Kon" (left) or "Nur Prd" (right), respectively, in present purchasing power (2020 PPP).

3.4 Further Comparisons

Considering the difference between the reference 2020 and the reference 2050 scenario, the costs as reported in $2020 USD PPP drop by 45 percent, from about 16 billion to around 9 billion $2020 USD PPP. This is due to the general assumptions on economic growth and discounting underlying all scenario calculations (cf. section 2.3.1). In other words, Swiss society is expected to be richer in 2050, meaning it will place less value on a certain level of physical damage. Additionally, the emission reductions already assumed for the reference development Ref 2050 also lead to a reduction in hidden costs (cf. the methods section 2 and section 3.8). Comparing costs in 2020 and 2050 likely leads to false conclusions, as they arise from totally different economic contexts due to economic growth between these years. As already emphasised in section 2.3, comparisons are to be made between scenarios for the same year, i.e. here for 2050. Then, it is clear that the constraints as reported in the "ZB-T", "ZB" and "Nur Kons" scenarios have great potential to significantly reduce hidden costs compared to the reference 2050 development, namely by 50%. This highlights the value these actions will have to society. However, acting only on the production side will result in negligible cost reductions compared to the reference development, as shown by the results for "Nur Prd" (Figure 1).

It is also interesting to look at the cost differences between scenarios summed over the whole time period from 2020 to 2050, which is possible as all values are reported in comparable 2020 PPP (Figure 8). Results show, that between the Ref 2050 scenario and "ZB-T", "ZB" and "Nur Kon", about 93 billion could be saved over the whole period till 2050, i.e. on average about 3.1 billion per year, while it is only about 15 % of this value (almost 0.5 billion) for the scenario "Nur Prd".

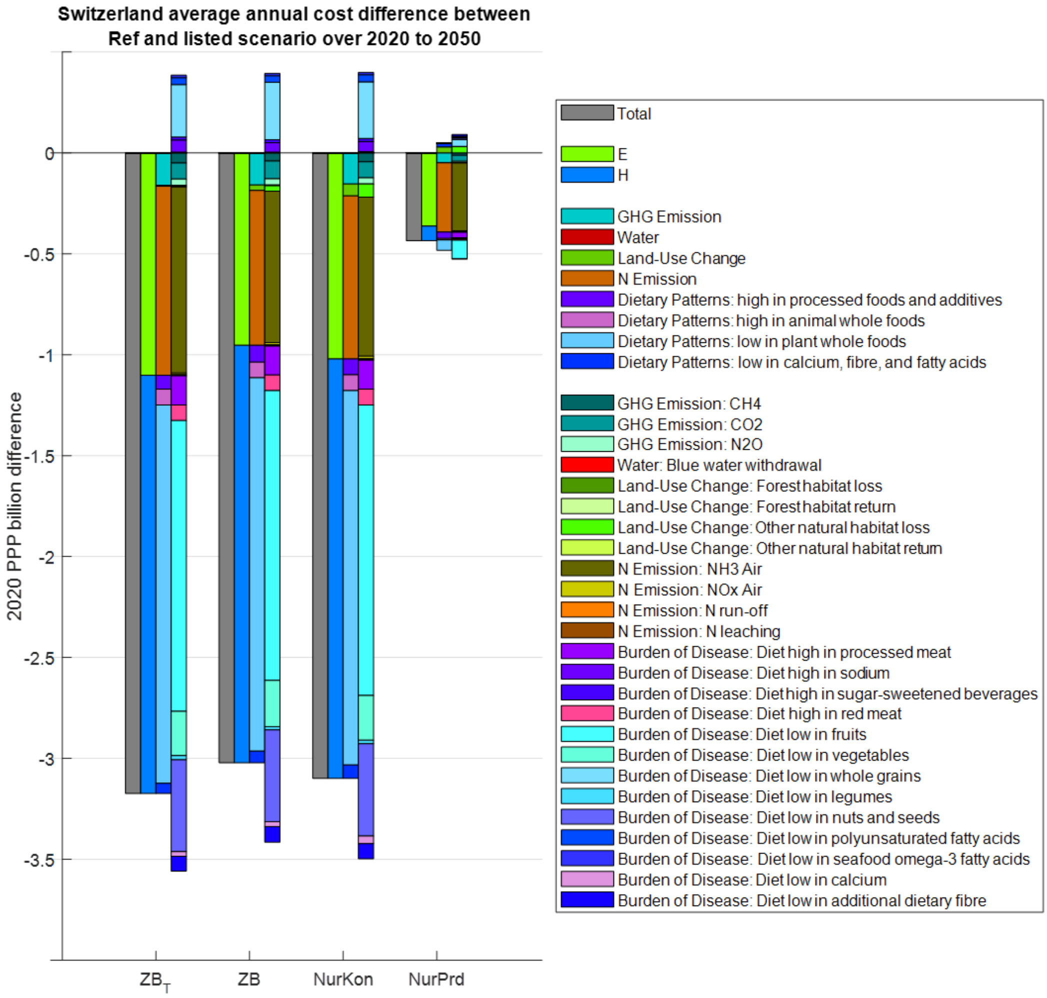


Figure 8: Comparison of average annual hidden costs avoided over 2020-2050 for each scenario in comparison to Ref 2050, in present purchasing power (2020 PPP).

Generally, one may expect that the hidden cost reductions due to improved dietary patterns in the scenarios "ZB-T", "ZB" and "Nur Kons" would be larger, given that these scenarios all assume a nutrition according to the Swiss food pyramid, i.e. a health-optimised dietary intake. Here, it is important to stress that this assumption on dietary patterns applies on average to the whole population, while the distribution of eating less or more of the various food categories than recommended by the food pyramid stays the same as in the reference situations 2020 and 2050. Thus, although the average diet is ideal, there is still a considerable amount of the population consuming not optimally. Furthermore, the largest share of diet-related health costs is caused by the small part of the population with the least-optimal dietary habits, which are reduced somewhat with these assumptions but still remain important for determining the costs. Thus, the assumptions do not reflect policies that target the part of the population that is most exposed to the adverse impacts of unhealthy dietary patterns but rather policies that aim at increasing overall average dietary health. Such a focus on the most exposed would result in a further decrease of the diet-related health costs.

3.5 Results for different impact categories

Figure 9 shows the hidden cost contribution of different impact categories. These largely follow similar patterns as the total costs, with "ZB-T", "ZB", and "Nur Kon" showing considerable reductions compared to the Ref 2050 scenario, while this is largely not the case for "Nur Prd". Several specific insights can be noted: the high water use in "ZB-T", "ZB", and "Nur Kon" relates to the high fruit and vegetable consumption, and the worse performance of "ZB" and "ZB-T" in land use change compared to "Nur Kon" is linked to the production-related boundary condition of increased biodiversity protection areas in "ZB-T" and "ZB", which is relaxed in "Nur Kon". This results in somewhat higher import needs with related adverse impacts on land use abroad (see next section).

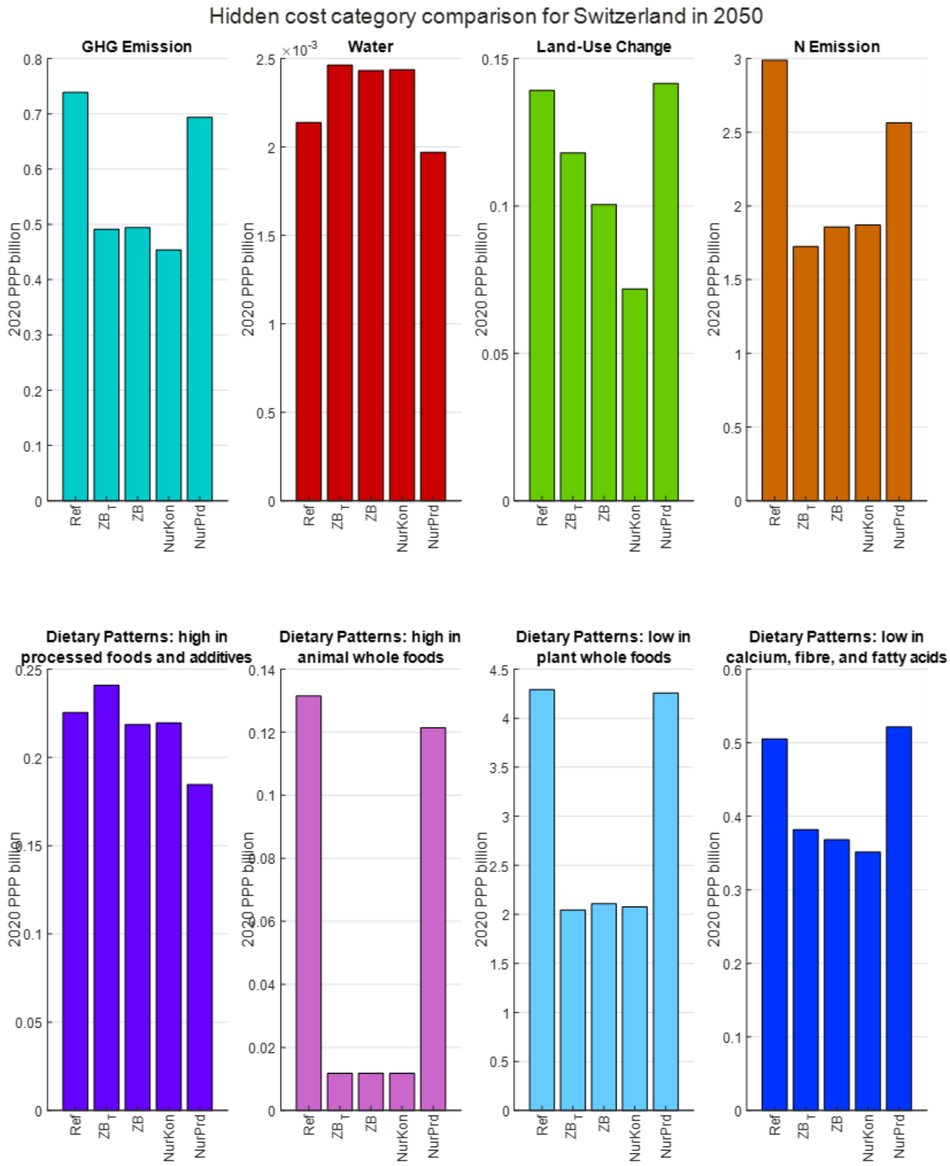


Figure 9: Comparison of absolute hidden costs for all scenarios for different impact categories, year 2050, in present purchasing power (2020 PPP)

3.6 Domestic costs and costs abroad

Finally, we shortly present the hidden costs differentiated by whether they arise domestically or abroad. This refers to the so-called "production accounting", thus separating the hidden costs by where they were generated, i.e. by domestic production (irrespective of whether the final product is consumed domestically or exported) or production abroad, i.e. for imported goods. Figure 10 shows the costs that arise domestically and abroad. Consumption-related costs arise domestically only, hence they are only reported in the panel displaying the total costs. Environmental costs arise both domestically and abroad, and the shares differ considerably between scenarios and impact categories, while largely, also here, the scenarios “ZB-T”, “ZB” and “Nur Kons” perform similarly (besides regarding land use). The same applies to the reference 2050 scenario “Ref 2050” and “Nur Prd”, illustrating the importance of dietary changes for cost reductions in these estimates. Overall, the share of hidden costs embodied in imported goods is largely similar in all scenarios (between 30-40%), which is also the value that applies today (based on the Ref 2020 results for the SPIQ-FS scenarios; not shown in the figure). In absolute terms, these hidden costs embodied in imports to Switzerland are roughly halved in the scenarios “ZB-T”, “ZB” and “Nur Kons”, the reason being the change in diets towards the food pyramid and food waste reduction.

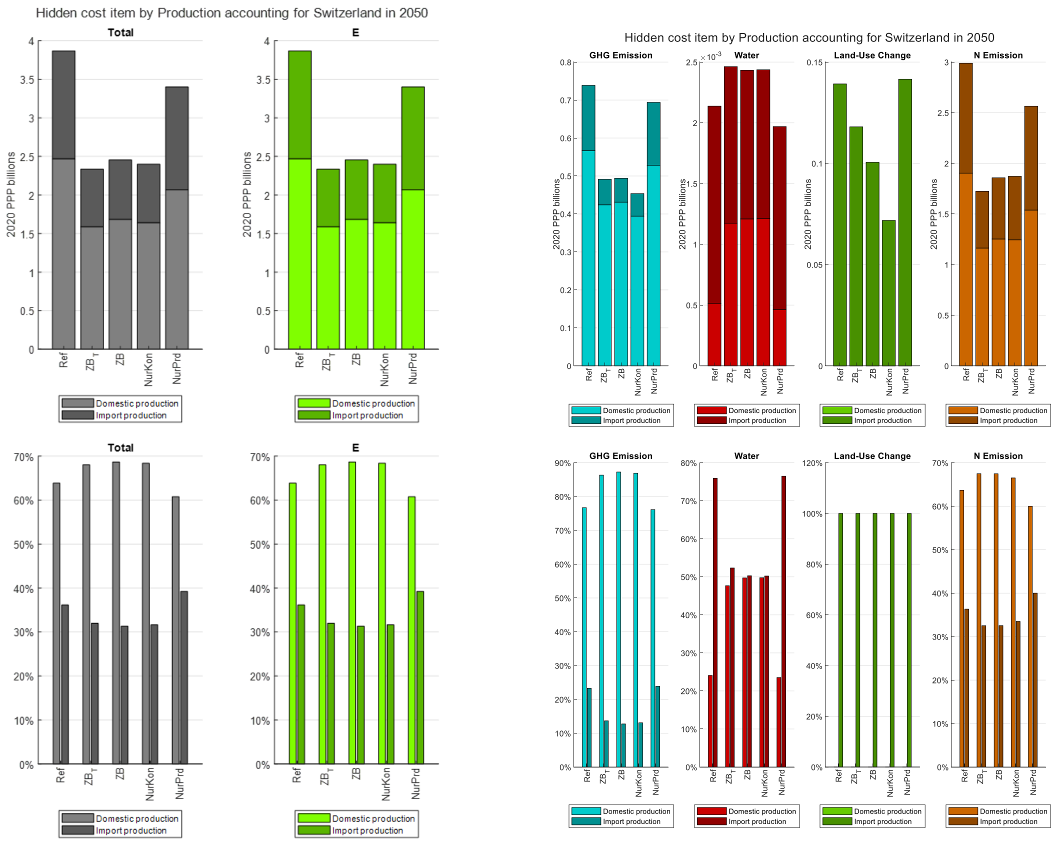


Figure 10: Comparison of absolute hidden costs that are generated domestically and abroad, differentiated by total and environmental impacts (left) and four environmental key impacts (right). The panels below show the relative shares of domestic costs and costs abroad; year 2050, in present purchasing power (2020 PPP)

3.7 Sensitivity analysis for the elasticity of the marginal utility of consumption

In this section, we present the hidden cost estimates under different assumptions on the value of the elasticity of the marginal utility of consumption EMUC that captures by how much the welfare loss of an identical physical damage is reduced when an economy grows richer (cf. section 2.3.1 for further details). *Figure 11* shows the results for EMUC 1.5 (the default choice) and 1.01, 1.1. and 2.0 for sensitivity analysis.

The choice of an EMUC close to 1 represents a low marginal elasticity of consumption and thus a lower social discounting rate *r* (cf. section 2.3.1) and results in higher damages costs. In this case, the dynamics that a dollar lost results in lower welfare losses in richer than in poorer societies is much less effective and welfare losses of a unit of physical damage are thus differing less between Ref 2020 and Ref 2050. This case then gives more weight to the influence of changes in physical damages on hidden costs, and less to the economic growth effect. But also with EMUC = 1.01, over 30 years, the factor from this discounting is still considerably lower than 1, namely about 0.55 (cf. the discounting factor in the formula in section 2.3.1, $1/(1 + \rho + EMUC * g)^t$ with ρ = 0, g = 2% and t = 30, compared to 1/2.42 = 0.41 for EMUC=1.5; for illustration for both assuming a relatively low growth rate of the economy of 2%). This is due to the fact that also with low EMUC, the growth effect is still present (cf. the formula above; the growth effect would only be significantly reduced with the growth parameter being reduced or even set equal to zero, then assuming no growth at all). This dynamic is behind the fact that also with EMUC=1.01 the welfare loss from diets low in fruits, for example, reduce from Ref 2020 to Ref 2050, albeit the physical damage increases.

The opposite applies to high values of EMUC, where economic growth is weighted much more and damage costs measured in welfare losses are thus lower.

In any case, the scenarios "ZB", "ZB-T" and "Nur Kon" allow to reduce costs by about 50% in comparison to the reference scenario Ref 2050. This is robust to these changes in assumptions on EMUC. This is also an additional reason to focus on the comparison of results within one year (e.g. 2050), as the underlying general economic growth and development assumptions are the same in all scenarios and some of the large uncertainties in these assumptions thus partly net out when assessing differences in scenarios.

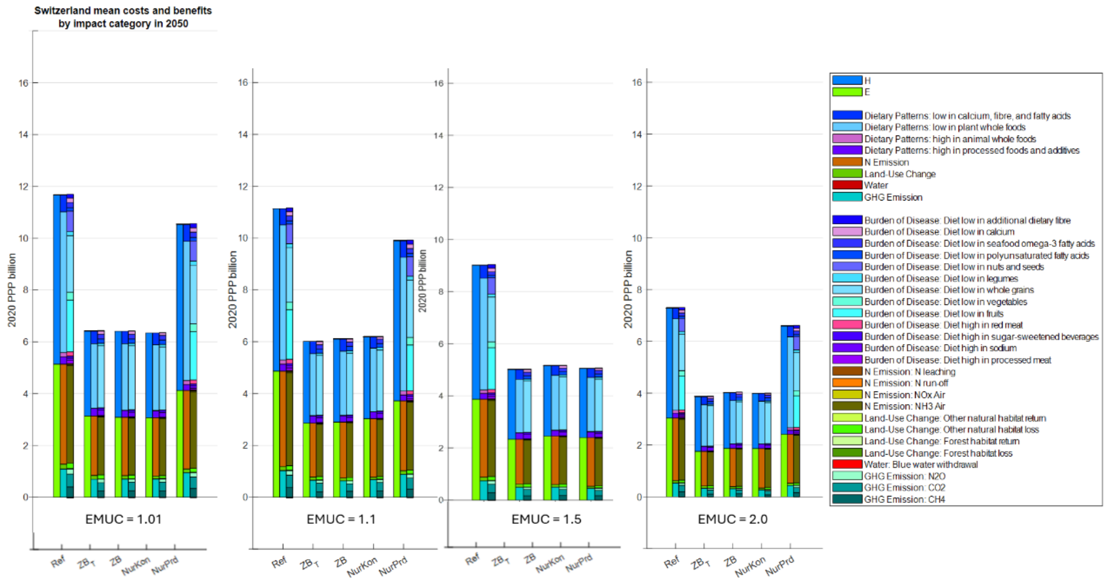
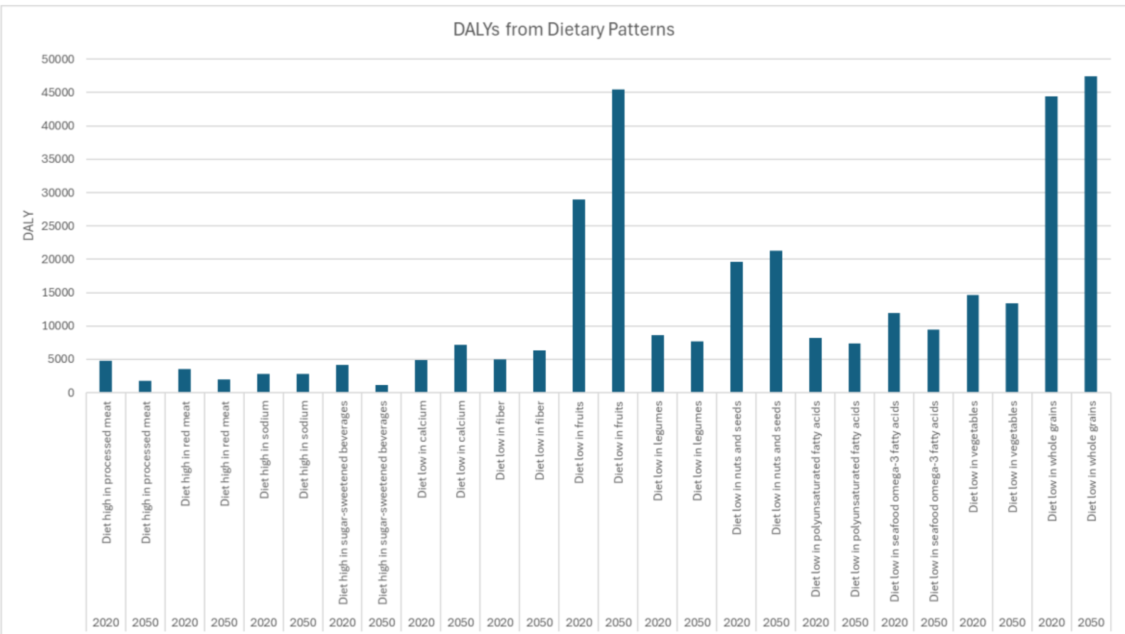
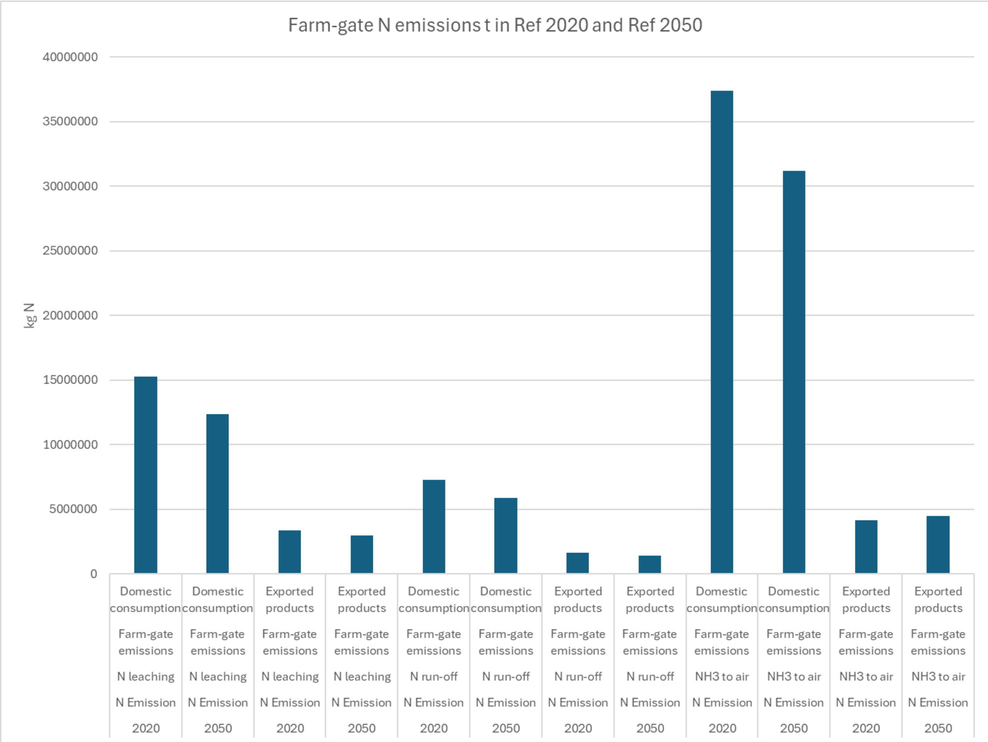


Figure 11: Comparison of absolute total hidden costs estimates under different assumptions for EMUC, covering the values 1.01, 1.1, 1.5 (default) and 2.0; year 2050, in present purchasing power (2020 PPP).

3.8 Physical impacts and unit costs

For further information, we also display how the physical damages develop between Ref 2020 and Ref 2050, as provided by the results of the SWISSfoodSys runs (for the most important cost categories), cf. *Figure 12*. This change of physical damages between Ref 2020 and Ref 2050, where in many – albeit not all - cases, physical damages are reduced from Ref 2020 to Ref 2050 is one driver of the results, in particular for EMUC = 1.01, as explained above.





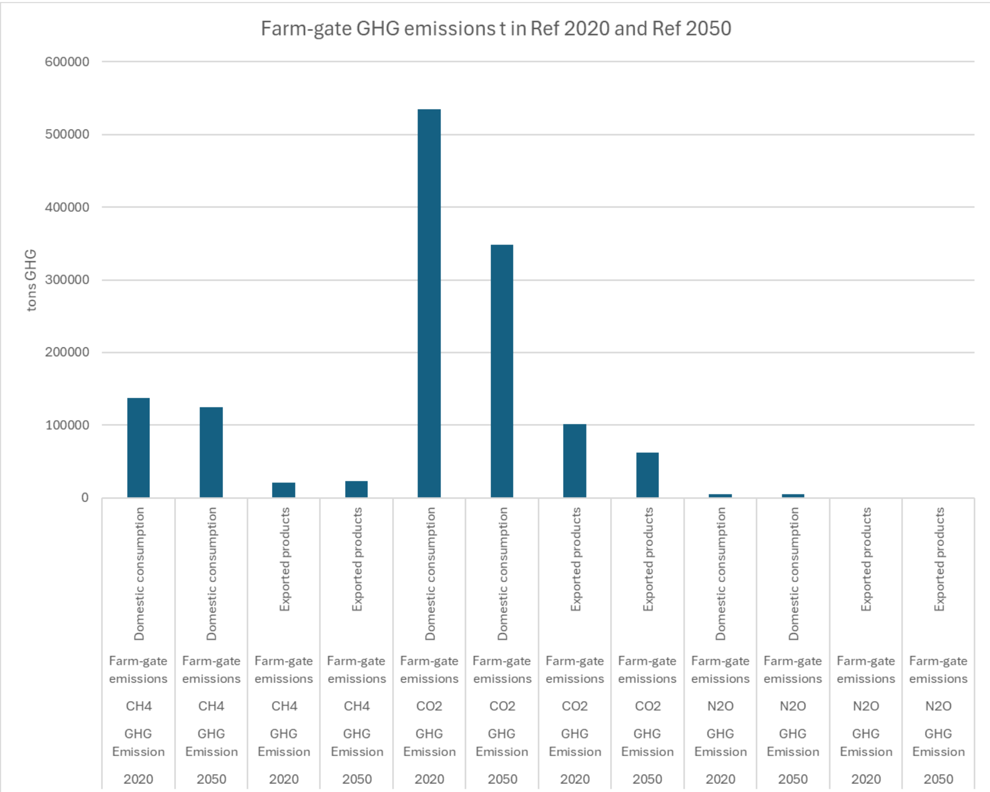
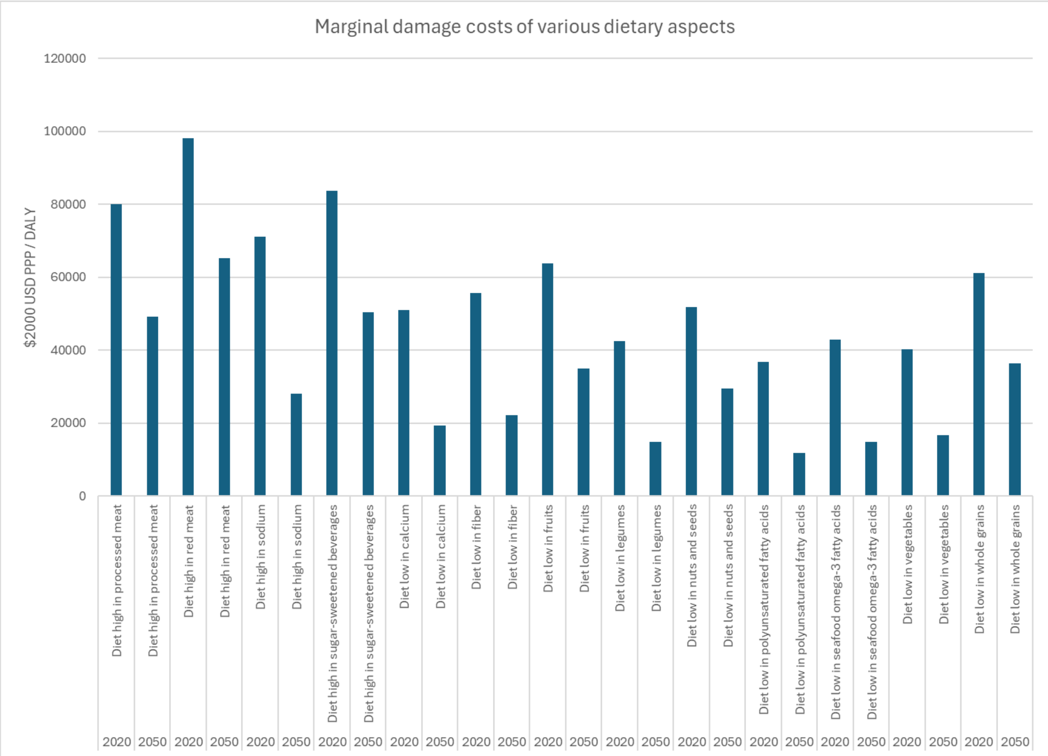
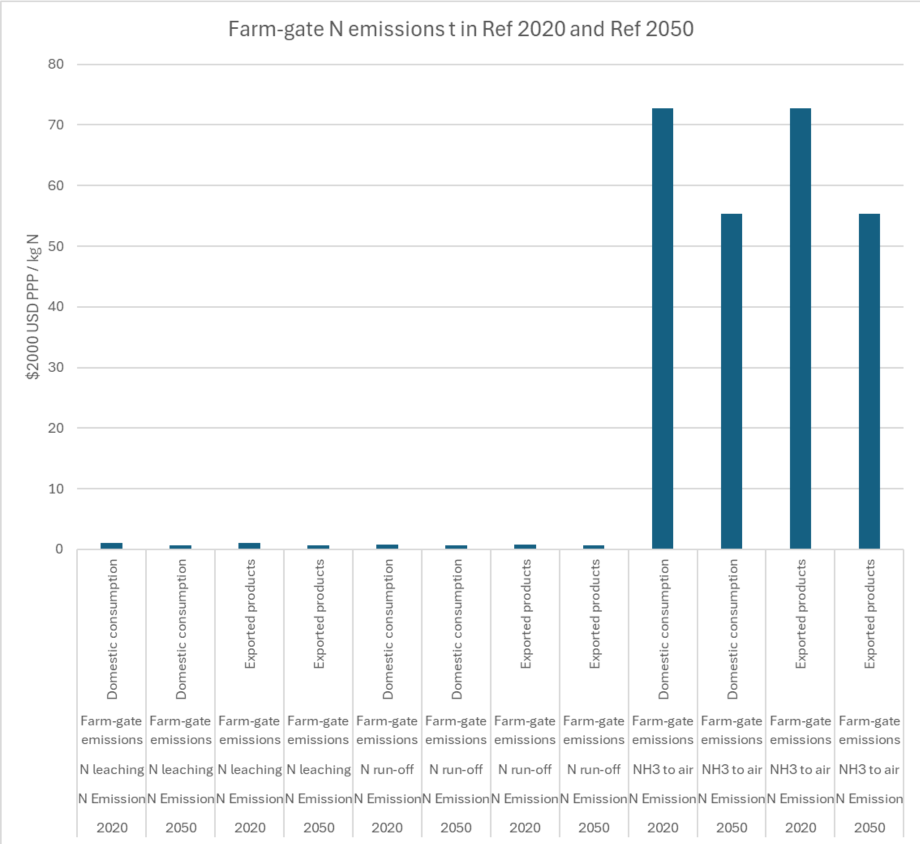


Figure 12: Physical impacts of the food system for Ref 2020 and Ref 2050, selection of most important impact categories, dietary patterns (top), Nitrogen emissions (middle), GHG emissions (bottom).

As damage costs result from the multiplication of physical damage quantities with marginal costs, we also display those unit costs for some central cost categories for Ref 2020 and Ref 2050 as provided by SPIQ-FS (assuming the default value of EMUC = 1.5), see *Figure 13*. This illustrates, for example, that the costs of diets low in fruits are much lower in Ref 2050 than in Ref 2020, thus overcompensating for the increase in physical impact from this dietary pattern that can be observed between Ref 2020 and Ref 2050.





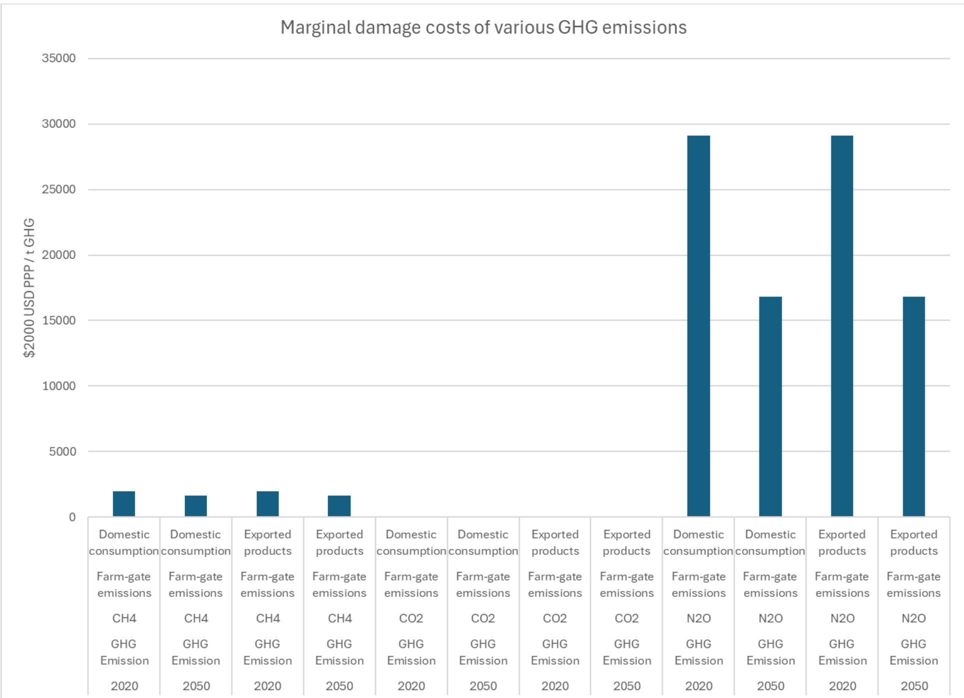


Figure 13: marginal damage costs per physical impact unit for Ref 2020 and Ref 2050, assuming EMUC = 1.5, selection of most important impact categories, dietary patterns (top), Nitrogen emissions (middle), GHG emissions (bottom).

4. Discussion

Overall important drivers of the cost estimates for 2050 are the various assumptions regarding economic growth and discounting that apply to the whole economy in all scenarios (cf. sections 2.3.1 and 3.7). Besides these general macroeconomic assumptions and effects, there is also a general decarbonisation of the economy in all scenarios, i.e. a reduction of fossil fuel-related CO_2 emissions by 40%. This is not central for agriculture, though, where CO_2 emissions are a small share of total GHG emissions only. Furthermore, specific assumptions also apply to the agricultural sector in all scenarios, captured in general reductions of N emissions (in the form of NH_3, NO_3 and N_2O) by 10% and a reduction of the risks related to plant protection means use by 30 to 50%, depending on the impact area (surface water, groundwater or natural habitats)., cf. Table 2 and section 3.8.

These assumptions drive a significant part of the cost reductions that are then relevant for all scenarios, as the reference 2050 assumptions apply to all of those. The scenario-specific, more ambitious assumptions become effective according to the respective scenario definitions. The underlying general development makes it difficult to compare the scenarios "ZB-T" etc. to the reference situation in 2020, as these refer to totally different economies with different welfare and technology levels, productivity and purchasing power, as all scenarios in 2050 have experienced a period of 30 years of economic growth, that naturally has not been experienced by the Ref 2020 scenario. Hence, for insightful comparisons, a focus should be put on the comparison between different scenarios within one year, i.e. for 2050 only.

Another point of general relevance is the high uncertainty of all cost estimates, which must be considered when comparing scenarios. As a result, the reference scenario 2050 "Ref 2050" and the production-focused scenario "Nur Prd" show similar costs, while the other three scenarios—"ZB-T", "ZB", and "Nur Kon"—also cluster together, with costs roughly half of those of the Ref 2050 scenario and "Nur Prd".

Besides these underlying developments driving the costs in all scenarios, there are the specific aspects for each scenario, allowing us to analyse which additional actions besides those incorporated in the reference development may be effective or not in hidden cost reduction and to what extent. These specific actions (cf. also Table 2) cover

- GHG emissions: 40% reduction in agricultural production in ZB-T, ZB and "Nur Prod" compared to the Ref 2050 scenario; further reductions due to technical means by 17% compared to Ref 2050 in ZB, "Nur Kon" and "Nur Prd", and a reduction of the emissions related to the consumption basket by 66% (ZB-T, ZB, "Nur Kon").
- Nitrogen: reduction of the nitrogen surplus by 30% in comparison to the Ref 2050 in ZB-T, ZB and "Nur Prd" and a reduction of direct N emissions (NH_3, NO_3, N_2O) by an additional 10% compared to the Ref 2050 scenario (i.e. 20% instead of 10% reduction as in the Ref 2050 scenario) in ZB, "Nur Kon" and "Nur Prd" (due to additional technologies, thus not effective in ZB-T, which assumes 10% reduction as the Ref 2050.

- Food waste and loss reduction compared to the Ref 2050 scenario, both on the production (ZB-T, ZB and “Nur Prd”) and consumption side (ZB-T, ZB and “Nur Kon”): each by 75%.
- Dietary consumption and food provision patterns: the population on average follows the recommendations of the Swiss Food Pyramid (ZB-T, ZB and “Nur Kon”) and domestic production reaches a self-sufficiency degree in calories of at least 50% (ZB-T, ZB and “Nur Prd”).
- Feeding rations: less concentrates for ruminants than in the Ref 2050 scenario (ZB-T, ZB and “Nur Prd”).
- Biodiversity: Increased biodiversity support areas of at least one sixth (16.6%) of agricultural land (ZB-T, ZB and “Nur Prd”).

When considering the hidden cost estimates of the various scenarios in 2050, it is important to mention the many aspects that are not covered. The scenario calculations use the indicators as provided in SOFA 2023 and do not cover the refinements and amendments as identified and added in the report on the Swiss case study (De Luca & Muller, 2025), which significantly increased the cost estimates reported there. These refinements and amendments are not covered, as they cannot easily be incorporated in the future cost projection model and gross amendments as done in the case study report for the reference year 2020 are particularly difficult, as they would not be consistent with the general scenario assumptions regarding macroeconomic and sectoral dynamics and potential interactions and feedback with these. The most important refinements and amendments cover costs of biodiversity losses, the value chosen for the social costs of carbon (that is assumed to be considerably higher in the Swiss case study than in the SOFA report), and direct and immaterial health costs (for details, see (De Luca & Muller, 2025)).

Another source of potential underestimation of the hidden costs in the scenarios stems from the missing interaction of the impacts modelled in the scenarios with the economic dynamics underlying the reference 2050 development (cf. section 2.3). Potentially, beyond a certain emission or impact level, the economic ability for mitigation may be seriously hampered, resulting in much higher costs – such “tipping-point” dynamics are not covered. This could happen for GHG emissions and related climate change impacts, for example. Furthermore, tipping points may also occur for cost drivers that are currently not that relevant according to the Swiss case study (e.g. antimicrobial resistance AMR, water use, soil health). In case such occur, hidden costs may increase dramatically. Hence it is central to avoid that these aspects that are currently not a major problem become such in the future – as already emphasized in the Swiss case study.

Finally, the results show clearly that action on the production side only, as covered in “Nur Prd”, would not result in significant cost reductions compared to scenarios that also cover consumption side measures (i.e. “ZB-T” and “ZB”). This clearly applies to the health costs related to dietary patterns, but also to the production-related hidden costs, e.g. due to ammonia emissions. Dietary change would come with a significant reduction in animal numbers with correspondingly reduced ammonia emissions, for example. This difference in significance for reaching sustainability goals between production side measures, in particular on farm level, and broader systemic approaches, also covering the consumption side measures, has also recently been emphasized in the context of climate change mitigation in agriculture (Bretscher et al., 2025), where the farm level measures are deemed to reach 10 to 20% of emission reductions only, much less than required for any climate mitigation targets that have been formulated by the sector, non-governmental bodies or the government.

5. Conclusion

This section draws some conclusions based on the results of the scenario calculations for 2050 presented above. We do this in reference to the seven conclusions drawn in the Swiss case study report (De Luca & Muller, 2025), which we quote here and then add some further considerations to each of those. In addition, we formulate four additional conclusions specifically based on the new scenario results and their discussion presented above.

1) "SOFA 2023 provides a good basis for country specific analysis of the hidden costs covered. However, important aspects need to be added, resulting for Switzerland in a total of 31.8 instead of 21.1 billion CHF annually."

The scenario results present a good basis for the assessment of which actions are promising regarding hidden costs reductions. However, also here, important aspects are missing and different to the assessment of the amended costs for the reference year 2020 in the Swiss case study to the SOFA 2024 report, these cannot directly be added to the scenario assessments. Thus, the costs reported in this appendix for the various scenarios including the reference scenario 2050 and also for the reference situation 2020 represent a lower limit. This is also relevant when focusing on entry points for action. From the cost estimates for 2050 presented here, key action is warranted on diets and ammonia emissions. The amended hidden cost estimates in the Swiss case study De Luca and Muller (2025) however suggest that acting on biodiversity loss in particular and also on GHG emissions (due to much higher values assumed for the social costs of carbon) would be central for reducing hidden costs. This must not be forgotten, albeit it is not included in these hidden cost assessments presented here.

2) "It is central to not only focus on reducing these biggest costs, but also to make sure that cost categories that are currently small do not develop into big costs in the future. Prime examples here are costs related to antimicrobial resistances and water scarcity, summing to only 0.15 billion CHF currently."

This aspect remains central also in the scenario calculations, where these additional costs are not included at all, as indicated in point 1) above. It is thus implicitly assumed that these named costs will not become relevant in the future. Thus, it is essential to ensure that this is indeed the case.

3) "True cost accounting can help giving due weight to aspects that are often neglected – but also bears the danger that aspects that are difficult to quantify are counted with zero costs."

This clearly applies to the cost estimates of the scenarios as well. Most important in this context is the fact that the cost estimates give due weight to the fact that only addressing the production side will not result in significant cost reductions – thorough change on the consumption side and thus a true food system transformation is needed to reduce the hidden costs of the agrifood system.

4) "True cost accounting has big potential as an information and communication tool."

Definitely – and the cost estimates of the scenarios complement the estimates for the reference year 2020 and related information and communication activities by an important aspect, namely, which type of future development may have the potential to significantly reduce these costs. However, as emphasized and discussed in section 2.3, most informative are comparisons between different scenarios in 2050, while it can be confusing and misleading when comparing costs between 2050 and 2020, which should thus be avoided.

5) "Reducing food waste is a central topic, as not producing something instead of producing and then wasting it results in avoiding the related hidden costs."

The results of the future scenarios confirm this observation.

6) "Accounting for interdependencies between different topics is important to build on potential synergies between them and to avoid trade-offs, where possible."

This is all the more important for the scenarios, where additional linkages arise between the general macroeconomic development, technological change and impacts of unavoidable environmental change – which is however not quantified in the cost estimates given. As said, this is a reason to take those rather as lower limits. Furthermore, specific actions must be taken to hedge against adverse effects from such interactions.

7) "Identifying the cost producers and, in particular, the drivers influencing the behaviour of cost producers is central for the development of effective policy instruments."

This clearly remains valid also in the future.

Here, we add four additional key insights, not yet provided in the Swiss case study report:

8) The scenarios illustrate the potential for cost reductions. Given that all scenarios build on the same reference development to 2050, where considerable progress is already taking place (regarding decarbonisation, direct N emissions and risks of plant protection means), it is central to ensure that at least these improvements are indeed implemented. This reference development is the minimal basis for the cost reductions reported here, but it is already very ambitious. This illustrates

that the cost reductions by 2050 are by far not self-evident and achievable without effort.

9) Given the many assumptions made for the scenario calculations, the large uncertainties and the huge changes between the economy today and in the reference scenario 2050, the focus should be on comparing different scenarios in 2050 and not on comparing some scenario from 2050 with the reference situation today. This shows the big potential of actions beyond the reference development.

10) A robust outcome of all scenario calculations is that production measures alone do not lead to significant cost reductions, neither for health nor environmental impacts. Substantial reductions are only achievable through consumption measures, i.e., significant changes in dietary patterns—particularly reductions in animal-source products, increases in fruits, vegetables, nuts, seeds, and whole grains, and strong reductions in food waste—thereby enabling a thorough transformation of the agri-food system.

11) The distribution of the costs related to health aspects of dietary patterns is biased – meaning that a relatively small share of the population with the least healthy dietary patterns causes a large share of the hidden costs. Thus, action on mitigating those extremes rather than shifting the average is most promising for reducing costs.

6. Literature

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