How to reduce agrifood systems’ future hidden costs? A multi-country case study

State of Food and Agriculture (SOFA)
2024 Background report

November, 2024

SUSTAINABLE DEVELOPMENT SOLUTIONS NETWORK
A GLOBAL INITIATIVE FOR THE UNITED NATIONS

FABLE CONSORTIUM

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The Food, Agriculture, Biodiversity, Land-Use, and Energy (FABLE) Consortium is a collaborative initiative to support the development of globally consistent mid-century national food and land-use pathways that could inform policies towards greater sustainability. The Consortium brings together teams of researchers from 24 countries and international partners from the Sustainable Development Solutions Network (SDSN), the International Institute for Applied Systems Analysis (IIASA), the Alliance of Bioversity International and CIAT, and the Potsdam Institute for Climate Impact Research. https://www.fableconsortium.org/

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Executive Summary

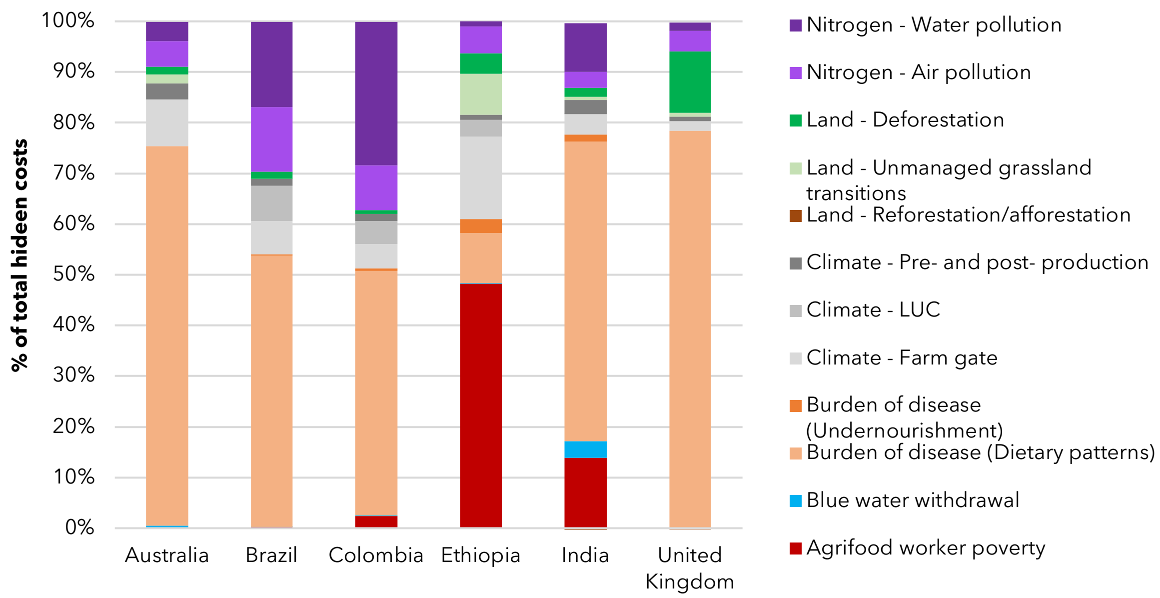
EXECUTIVE SUMMARY

True cost accounting (TCA) methods offer an opportunity to support decisions to reduce existing hidden costs instead of perpetuating them and to transition towards just and sustainable agrifood systems. For the State of Food and Agriculture (SOFA) 2023 report, annual hidden costs – including the external costs of food production on natural resources, the costs of distributional failures within agrifood systems, and productivity losses due to current dietary patterns – were computed for 154 countries over 2016–2023.

This study focuses on six countries, **Australia, Brazil, Colombia, Ethiopia, India, and the United Kingdom**, building on the TCA results from SOFA 2023, the SPIQ-FS model (Lord et al., 2023), and the network and tools of the Food, Agriculture, Biodiversity, Land-Use, and Energy (FABLE) Consortium. With input from in-country stakeholders and experts, the results on hidden costs published in SOFA 2023 have been scrutinized and future scenarios have been tested in quantitative agrifood system models to highlight the most desirable and urgent actions for reducing the hidden costs of agrifood systems.

Accounting for hidden costs in 2020 would reduce the world average PPP GDP by 10% and reduce the national PPP by 16% in Brazil, 12% in Colombia, 16% in India, 6% in Australia and 8% in the UK. In all countries but Ethiopia, the main source of the total hidden costs is the cost of burden of disease due to dietary patterns (Figure 1) and this has been steadily increasing from 13% in 2016 to 33% in 2023. In Ethiopia, with a high share of rural population living below the poverty line, poverty among agrifood workers emerges as the most significant contributor (48%).

Figure 1: *Comparison of agrifood systems' hidden costs for the six countries in % of total hidden costs in 2020*



It was not always possible to compare the data used in the global hidden costs analysis with national statistics because the categories used were inconsistent. For a tailored country analysis of hidden costs, the main recommendation is that national data should replace the by-default data used in SOFA 2023. This is especially important for land use change (as the global HILDA+ land use data does not match currently observed trends in

Australia, Brazil, Colombia, and the UK), greenhouse gas (GHG) emissions, the national poverty line, and undernourishment.

In this study, the FABLE Calculator is used in Australia, Brazil, Colombia, Ethiopia, and the UK, building on the FABLE Scenathon 2023 results, and the MAgPIE model is used in India building on the FSEC results. Both models focus on the agricultural sector and rely on the assumption of equilibrium between demand and supply quantities. The main difference is that the FABLE Calculator is a stepwise model where, except for the first step which sets up the demand, all steps are dependent on one (or several) variable(s) that is (are) estimated in the previous steps, with one feedback loop in case of land scarcity. MAgPIE is a global partial equilibrium model that optimizes food, material, and bioenergy demand through a cost-minimization approach. These tools have been adapted to fit the different national contexts.

Future hidden costs are projected by substituting some of the impact quantity indicators in the TCA model with some of the outputs of the FABLE Calculator or MAgPIE. An intermediate step was required to convert average food consumption by food groups into DALYs (disability-adjusted life years). This conversion was done for MAgPIE by Marco Springmann (2020) while the FABLE Calculator used the machine learning model which has been built to estimate the health hidden costs linking food availability to food intake for the SOFA 2024 (see Box 7 in FAO 2024).

All countries featured in this study assume some changes in crop and livestock productivity to increase the sustainability of their agricultural production. Dietary changes are also considered as a key element to increase the sustainability of the agrifood systems in all countries except Ethiopia. The UK derives the dietary change scenario from the UK Balanced Net Zero (BNZ) pathway of the Climate Change Committee (CCC) and the other countries use a transition towards the average EAT-Lancet planetary diet. In most case studies, deforestation is prevented beyond 2030, and afforestation is increased.

For the UK and Brazil, changing diets is the most important factor for six of the eleven modelled indicators which are used to compute hidden costs, including CO_2 and N_2O emissions, and nitrogen application (Table 1). Increasing productivity reduces cropland and pasture area and avoids some conversion of natural land; crop productivity gains have a significant positive impact on forest area in Brazil, Colombia, and Ethiopia, and on other natural land area, particularly in Ethiopia. Higher productivity per animal and ruminant stocking rate on pasture (ruminant density) have large impacts particularly in countries with large livestock herds such as Australia, Brazil, and Ethiopia. Effective deforestation control avoids about 7 million hectares of deforestation between 2045 and 2050 in Brazil, close to 5 million hectares in Ethiopia, and 0.5 million hectares in Colombia. Finally, afforestation is important to reduce net GHG emissions through carbon sequestration.

The dietary change assumed in Australia is the most effective to reduce the DALYs compared to current trends by 2050 (-27% DALYs) as it reduced almost all the dietary risk categories (Table 1). The most important changes are a higher consumption of nuts, fruits, vegetables, and legumes, and a lower consumption of processed meat, red meat, and sugar-sweetened beverages. In Brazil, Colombia, and the UK, the focus of dietary change is on reduced consumption of processed and red meat and sugar-sweetened beverages, with higher legumes and nuts consumption in Colombia and the UK. Moreover, all countries have assumed a reduction in the consumption of ultra-processed food compared to current trends. To further reduce the DALYs, a more significant increase in fruits, vegetables and wholegrains consumption should be envisaged compared to the diets that have been tested in this study.

However, the analysis reveals some risks of trade-offs if policies are implemented in isolation: a) Dietary changes assumed in Brazil and the UK emphasize environmental benefits, but adjustments could be made to ensure larger health benefits and a better consideration of local preferences; b) Dietary changes could increase water demand (e.g., to grow more fruits and vegetables) and reduce on-farm employment (e.g., in the livestock sector), showing that this type of transition needs to be carefully managed at local level; c) In some cases, productivity gain could increase demand further, which could offset some of the environmental benefits; d) Deforestation control could have negative effects on food consumption and displace agricultural expansion to non-forest natural land; e) Afforestation can lead to indirect deforestation or reduction of other natural land while benefits from afforestation for ecosystem services strongly depends on how afforestation is done. Managing these trade-offs requires an integrated strategy.

Table 1: *Scenarios that are most effective in decreasing the hidden cost subcategories by country, 2050*

Sub-categories	Australia	Brazil	Colombia	Ethiopia	India	United Kingdom
CO_2 emissions	Afforestation	Dietary changes	Crop productivity	Constraints on agricultural expansion	Afforestation and expansion of protected areas	Dietary changes
CH_4 emissions	Dietary changes	Dietary changes	Food waste	Livestock productivity*	Dietary changes	Dietary changes
N_2O emissions	Crop productivity	Dietary changes	Dietary changes	Livestock productivity*	Nitrogen efficiency	Dietary changes
Total N	Dietary changes	Dietary changes	Crop productivity	Livestock productivity*	Nitrogen efficiency	Dietary changes
Cropland	Crop productivity	Crop productivity	Crop productivity	Crop productivity*	Livestock management	Crop productivity
Forest	*No change*	Crop productivity	Constraints on agricultural expansion	Constraints on agricultural expansion	*No change*	*No change*
Pasture	Dietary changes	Dietary changes	Ruminant density	Ruminant density	Dietary changes	Dietary changes
Other land	Dietary changes	Dietary changes	Crop productivity	Afforestation	Livestock management	Dietary changes
Water irrigation requirements	Crop productivity	Irrigation	Trade	Crop productivity *	Dietary changes	Food waste
Farm labour	Crop productivity	Crop productivity	Crop productivity	Crop productivity *	Dietary changes	Food waste
DALYs	Dietary changes	Dietary changes	Dietary changes	*No change*	Dietary changes	Dietary changes

Frequency

1	2	3	7	16	31

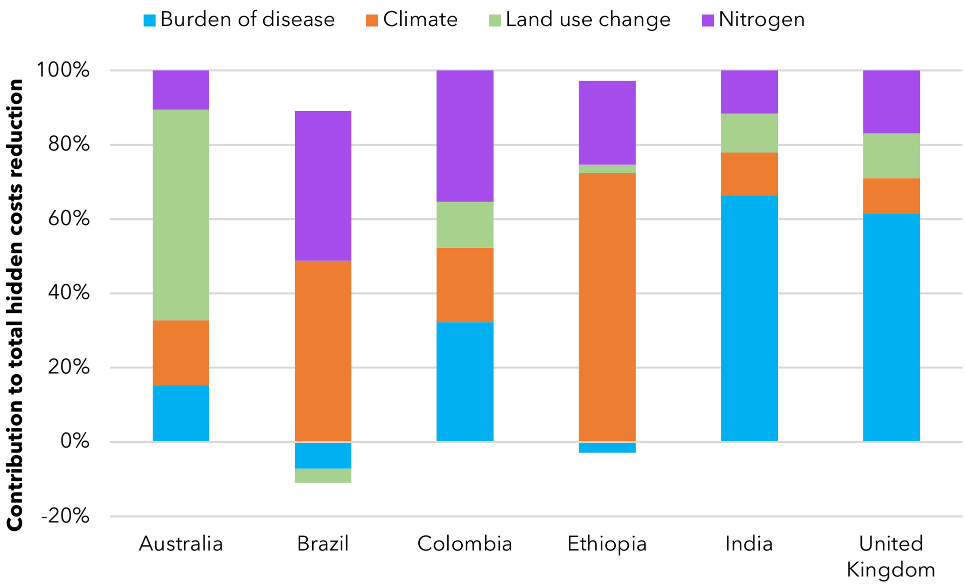
NOTES: CO2 = carbon dioxide; CH4 = methane; N2O = nitrous oxide; N = nitrogen; DALY = disability-adjusted life year; SSB = sugar-sweetened beverage. Dietary changes modelled include the following for each country: Australia – Higher intake of nuts and seeds, fruits, vegetables, legumes; lower intake of processed and red meat, and SSBs; Brazil – Lower intake of processed and red meat, and SSBs; Colombia – Lower intake of processed meat and SSBs; higher intake of legumes; India – Lower intake of sugars, salt, and processed foods; United Kingdom – Lower intake of processed meat; higher intake of legumes.

**The Global Sustainability scenario in Ethiopia includes a lower population assumption in line with the Ethiopian National Statistical Office's projections. While the largest decrease in hidden costs in these subcategories is attributable to this assumption, we show the most impactful outcome related to agrifood systems transformation – namely, livestock and crop productivity improvements – in this table.*

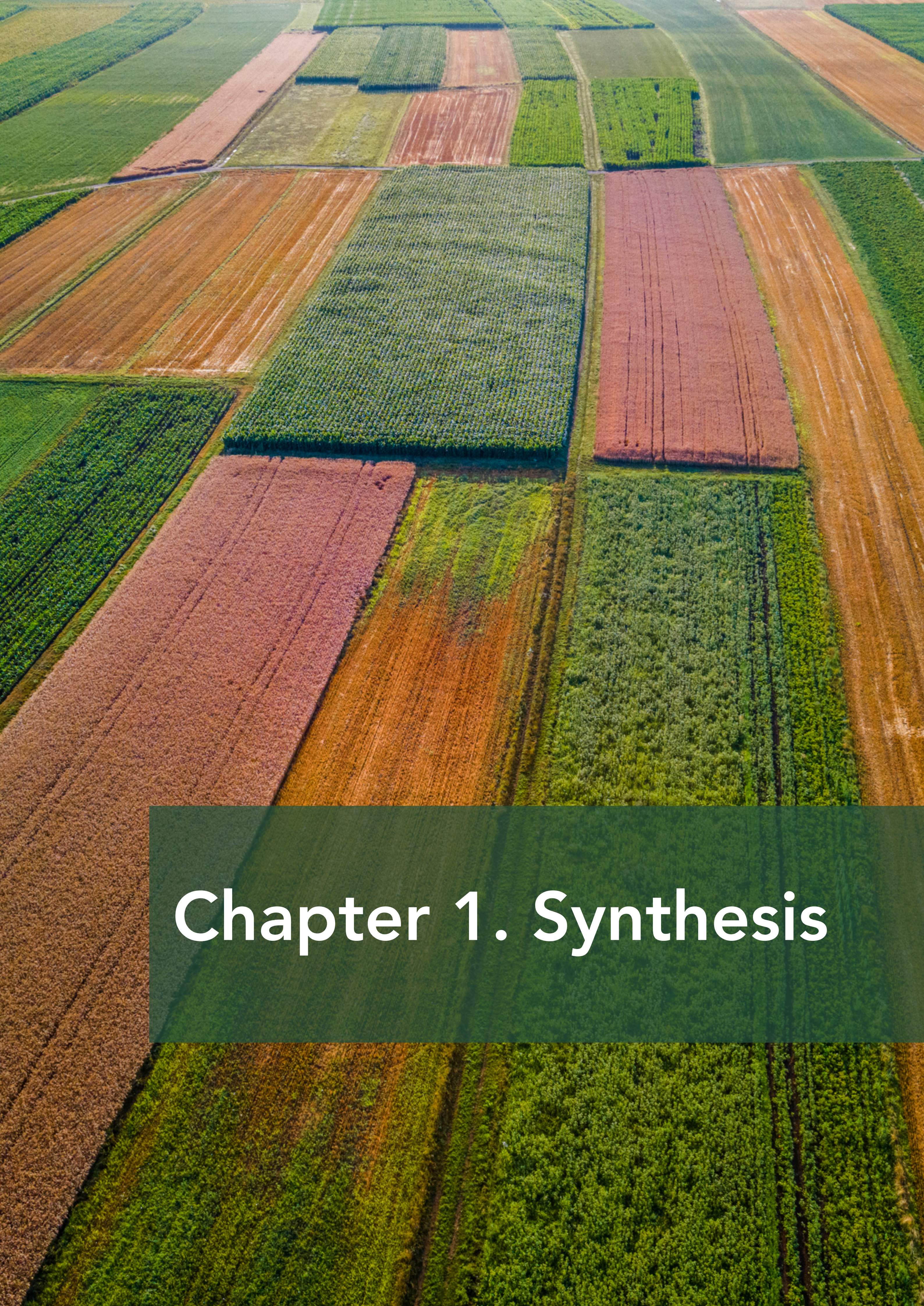
The combination of several factors at the same time (i.e., the global sustainability pathway) leads to the best outcome compared to a path following current trends (CT): between 2020 and 2050 our results show a reduction in accumulated hidden costs compared to the CT scenario by 32% in Brazil, 24% in Colombia, 25% in Ethiopia, 57% in India, and 15% in the UK[1] (in 2020 PPP). In Australia, the reduction is 140%, i.e., the hidden deficit of current trends that would have accumulated over 2020–2050 is eliminated and benefits of the order of 40% of the CT hidden deficit are accumulated. Here, the agrifood system transitions from net hidden costs to net hidden benefits, but this is subject to large uncertainty.

In Figure 2 we can see that despite the dominant contribution of unhealthy diets to current hidden costs in all countries but Ethiopia, dietary change is only the main component of total hidden cost reductions for India and the UK. Although the number of DALYs decreases in the sustainable pathway, the hidden costs related to diets increase because each DALY is more expensive, due to higher GDP per capita, Human Development Index, and labor productivity.

Figure 2: *Source of the computed reduction in the hidden costs of agrifood systems in the sustainable pathway compared to current trends in 2050 by country*



[1] This does not account for the hidden costs that are not computed based on the model's outputs, e.g., agri-food worker poverty.



Chapter 1. Synthesis

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Highlights

- This chapter summarizes the main findings about hidden costs in agrifood systems across six countries, Australia, Brazil, Colombia, Ethiopia, India, and the United Kingdom building on the results from SOFA 2023, the FABLE Consortium, and the Food System Economic Commission (FSEC) initiative.

- While the fact that unhealthy diets currently trigger the biggest hidden costs in most countries was a surprise for some stakeholders, there was a consensus that this is an important and growing issue that urgently needs to be addressed.

- Changing diets and increasing agricultural productivity have the largest impact on reducing the agrifood system's hidden costs in the future, but implementing an integrated strategy that can also target environmental protection has the largest benefits.

- Some hidden costs related to undernourishment are covered in the analysis, but they do not accurately reflect the size of the problem, particularly in low-income and lower-middle-income countries.

- Better local datasets should be used in hidden costs computation for GHG emissions and land cover change, and thresholds for poverty and undernourishment should be aligned with national statistics.

- There are challenges to communicating the complexity of the hidden costs method, but this topic is gaining momentum for policy planning, and several governments are already either utilizing or planning to develop similar metrics, so this analysis was a timely exercise.

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1.1 Introduction

True cost accounting (TCA) methods can support decisions to reduce existing hidden costs instead of perpetuating them and to transition towards just and sustainable agrifood systems. The State of Food and Agriculture (SOFA) report 2023 showed that while agrifood systems generate significant benefits, they generate hidden costs around 12 trillion 2020 PPP (purchasing power parity) dollars, equivalent to 10% of global GDP. Three types of hidden costs are included in the analysis: external costs of agricultural production on natural resources, the costs of distributional failures within agrifood systems, and labor productivity losses due to current dietary patterns (SOFA 2023). These costs are generated by markets, and institutional and policy failures: **they are not included in private costs but are absorbed by society and the environment. They are usually ignored in decision-making, leading to unfair impacts**. The impacts of air and water pollution and losses of ecosystem services, for example, are borne by third parties that are not directly involved in the production or consumption of the goods. Similarly, poverty among agrifood workers results from unequal distribution of the value added generated by the agrifood systems. Unhealthy food leads to disabilities and premature mortality, but consumers may not be aware of these risks, or healthy food might be out of reach.

For the SOFA 2023 report, annual hidden costs were computed for 154 countries over 2016 to 2023 using readily available and comparable data across many countries (Lord et al., 2023). They are expressed in 2020 PPP dollars to allow comparability across different capital flows, impacts and countries and allow aggregation to regional and global levels. Quantification of hidden costs requires combining impact modeling with monetary estimates. Monetary valuation of the hidden costs of agrifood systems focused on the economic component, e.g., measures of losses attributable to declines in labor or land productivity. Flows and impacts are numerous and many of them are difficult to quantify, while others are qualitative in nature (cf. Figure 2 in SOFA 2023). The impacts which have been included are volatilization and run-off of nitrogen applied on agricultural land and sewerage, GHG emissions along the entire value chain, conversion of natural ecosystems to agriculture, water withdrawals for irrigation, poverty of agrifood workers, the prevalence of undernourishment, and non-communicable diseases from food consumption choices converted into disability-adjusted life years (DALYs).

The focus of the SOFA 2024 report is on targeted assessments of TCA (FAO 2024). The initial assessments are incomplete and suffer from uncertainty but are a useful starting point for raising awareness and initiating a dialogue within countries. With input from in-country stakeholders and experts, country-specific information can be used to improve the initial preliminary quantification and analysis, leading to more in-depth assessments. Moreover, quantitative models can help to prioritize investments and policies by showing the magnitude of the change induced by each factor through scenario analysis. Comparing the outcomes from different scenarios highlights which actions might be the most desirable and urgent to implement. The research community can develop these models to foster collaboration between political, economic, and social actors through a common understanding of the underlying mechanisms of the system.

The Food, Agriculture, Biodiversity, Land-Use, and Energy (FABLE) Consortium is a collaborative initiative created in 2017 to support the development and transfer of quantitative models for integrated long-term analysis of food and land use systems by researchers and experts from local knowledge institutes. The tools developed by FABLE provide a framework for engaging stakeholders to anticipate and manage trade-offs between different land-use pressures, align shorter-term strategies with long-term ambitions, and avoid locking themselves into unsustainable land use systems. FABLE has built a decentralized framework to foster the availability of models for national food and land systems that can account for feedback between the national and global scales through so-called Scenathons (scenario marathons) (Mosnier et al., 2023). Research teams from 24 developed and developing countries spanning all continents are currently represented in the Consortium.

This study focuses on six countries, Australia, Brazil, Colombia, Ethiopia, India, and the United Kingdom, building on the TCA results from SOFA 2023, the SPIQ-FS true cost accounting model (Lord et al., 2023), and the network and tools of the FABLE Consortium. The objectives are: 1) to assess the plausibility of the SOFA 2023 results for these countries; 2) to highlight the opportunities and needs for a tailored assessment of TCA by country; and 3) to identify recommendations of potential entry points for reducing hidden costs through the simulation of different scenarios of agrifood system transformation. The first step of the analysis was to communicate the complex hidden costs concept and methodology to a wide range of stakeholders so that they can provide useful feedback. Then, we developed scenarios in an agrifood system model, the FABLE Calculator was used in five countries and MAgPIE was used in India, to highlight and prioritize entry points for reducing hidden costs and increase the overall sustainability of agrifood systems by 2030 and 2050. Finally, we soft-linked the FABLE Calculator and the MAgPIE models to the SPIQ-FS model to assess the most impactful scenarios for reducing hidden costs.

We first present the context of the country case studies and the stakeholder engagement process that occurred in each country. Then we present and compare the hidden costs computed in SOFA 2023 with available national data, and finally we compute the evolution of the hidden costs in alternative scenarios to identify the most promising entry points to reduce them.

1.2 Presentation of the case studies

1.2.1 Context of the country case studies

***Table 1-1**: Important characteristics of the six countries included in this analysis*

	Australia	Brazil	Colombia	Ethiopia	India	UK
Classifications						
Marshall agrifood system	Industrialized	Formalizing	Formalizing	Protracted crisis[a]	Traditional /rural	Industrialized
Income group	High income	Upper middle income	Upper middle income	Low income	Lower middle income	High income
National priorities for agrifood systems						
Land	Livestock grazing on native vegetation > 50% of the land	Reduce illegal deforestation, restore degraded pasture, high intensity large-scale cropland.	Reduce illegal deforestation and illegal crops, increase productivity of pasture and silvopastoral systems.	High rates of deforestation and land degradation.	High rates of land degradation through the high application of nitrogen.	Almost half grassland, high population density, some peatland.
Water	Highly variable rainfall and temperature pose risks to rain-fed production; soil salinity problem related to irrigation.	Abundant water resources but high heterogeneity in availability; irrigation mostly for rice and sugarcane.	Water protection (increasing vulnerability due to climate variability).	Water scarcity, exacerbated by climate change.	Water scarcity, exacerbated by climate change.	Mainly rainfed, but climate variability becoming problematic. Groundwater resources declining, and poor water quality.
Trade	>70% of the food produced is exported.	Large exporter of beef, sugar, soybean, and corn.	Exports of coffee	Self-sufficiency in staples and higher exports is the objective.	Large exports of staple crops, imports of pulses, oils	Proportion of imports grew from 30% to 50% since 2020.
AFOLU GHG	17% of total emissions, mainly from livestock.	48% of total emissions from deforestation, 27% from agriculture.	66% of total emissions.	Largest livestock herd in Africa; major source of GHG.	6% of total emissions.	12% of total emissions.
Nitrogen and phosphorous		80% of the nitrogen fertilizers are imported; phosphate is key for crop production.	Low average use of synthetic fertilizers with high concentration of use in a few crops.	Need to increase nitrogen use.	Extensive use of nitrogen and phosphorous, resulting in high nutrient deposition in soils.	High synthetic fertilizer use causes nitrogen pollution in water, but declining due to precision agriculture.
Food and nutrition	Meat consumption 24% higher than the Australian Dietary Guidelines.	32% of the population faced moderate or severe food insecurity between 2020 and 2022.	42% rural poverty rate and high prevalence of under-nourishment in rural areas	Under-nourishment persists, with 62% employed in agriculture, many trapped in poverty.	High prevalence of underweight, micronutrient-deficiency, and obesity.	High obesity rates (30% adults, 15% children).

Note: The agrifood systems typology presented in SOFA 2024 based on Marshall et al. (2021) captures the challenges countries face in delivering nutritious and healthy diets in an environmentally sustainable way using four variables: 1) the value added per worker in agricultural production; 2) the number of supermarkets per 100,000 people; 3) the share of calories from staples; and 4) urbanization. A sixth category was introduced to address the significant distortions caused by medium to long-term conflicts and fragilities in agrifood systems.

[a] The "protracted crisis" category includes countries listed by the FAO as being in protracted crisis as of September 2023 (FSIN and Global Network Against Food Crises, 2022). It encompasses countries that meet all of the following conditions: i) humanitarian assistance from official development assistance is greater than 10% of the country's GDP; ii) inclusion in the list of low-income food-deficit countries; and iii) assistance required for food in four consecutive years (2018–2021) or eight of the ten previous years (2012–2021). The list includes the following countries: Afghanistan, Burundi, Central African Republic, Chad, Democratic People's Republic of Korea, Democratic Republic of Congo, Eritrea, Ethiopia, Haiti, Liberia, Mali, Mauritania, Niger, Sierra Leone, Somalia, South Sudan, Sudan, Syrian Arab Republic, Yemen and Zimbabwe. In addition, Palestine is included in the category of countries/territories in protracted crisis in the typology. Note that this list does not include all countries in the world, and it is not necessarily endorsed by country governments.

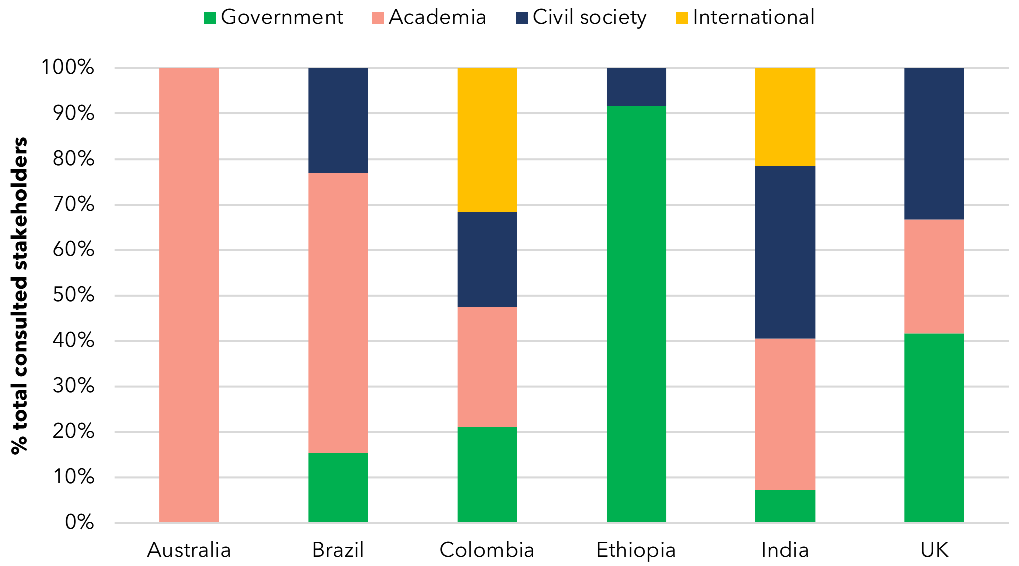
1.2.2 Stakeholder consultation

Feedback was collected from key stakeholders of the agricultural sector, including from academia, government, and civil society (Table 1-2). Some countries had already consulted on the underlying scenario assumptions prior to this study, for the 2023 Scenathon. With limited time and financial resources, the approach for stakeholder consultation on TCA was pragmatic: depending on the country, the consultations were in-person or online, with a large group, several small groups or bilaterally, and through online surveys. One significant constraint for stakeholder consultation was the overlap of the time of the study and the summer holiday in the Southern hemisphere. The response rate was 46% on average, with the lowest response rate among government institutes (28%) and the highest among international organizations (75%).

- In **Australia**, consultation focused on CSIRO staff who cover a broad range of expertise and are in regular contact with farming communities, government and industry representatives, and other stakeholders.
- In the case of **India**, more than 50 participants from all sectors —policy, academia, think tanks, and civil society— were represented. Most of the participants were from think tanks and the academia (51 and 25% respectively).
- In **Brazil**, the consultation was online, including a survey and a workshop. Of 51 stakeholders invited, 13 participants—primarily from academia—responded.
- **The UK** consultation included a range of highly relevant stakeholders and experts across business, research, civil society, and public administrations. Feedback was obtained directly in workshops, with an online survey for people to provide further feedback after the workshops.
- Stakeholder engagement in **Colombia** included consultation with 19 experts split between the private sector (representatives of growers' associations), government, and academia. The consultation process had support from the Centre of Studies on Production and Sectoral Trade of the Colombian Central Bank and the Colombia Office of the FAO, who were instrumental in calling participants to the meetings.
- Feedback on hidden costs in **Ethiopia's** agrifood system was collected through in-person meetings and phone interviews of experts, including policymakers, farmers and researchers. The total of 11 respondents participated in Ethiopia's stakeholder consultation.

Consequently, this consultation does not claim to be representative of all stakeholders in the country. Even if there was a good balance between representatives from government institutes, academia, civil society, and international organizations, most of the individuals who provided feedback are better characterized as experts rather than decision-makers. Some individuals were reluctant to participate in the consultation due to the complexity of the TCA methods and a feeling of insufficient knowledge on the topic.

Figure 1-1: *Origin of the stakeholders consulted on average across all six case studies*



Note: the frontier between these different groups is sometimes slim, e.g., in Australia, CSIRO is a government research entity so the staff who were consulted could be considered both government and academia.

Table 1-2: *Summary of the stakeholder consultation process for this analysis*

	Who was consulted?		How and when?	
Australia	CSIRO staff, broad range of expertise informed by industry and other stakeholders (cf. Chapter 2)		Small workshop in December 2023 with selected CSIRO experts and Steven Lord and bilateral consultations in February	
Brazil	51 stakeholders invited incl. recommendations from the FAO representative and from the Science Panel for the Amazon	13 respondents (cf. Chapter 3)	Via online survey and 1 virtual workshop on 3 April 2024.	
Colombia		19 respondents (cf. Chapter 4)	3 virtual and 1 in-person meetings	
Ethiopia	15 persons invited	11 respondents (cf. Chapter 5)	In-person workshop: 2 December 2024.	Follow-up online bilateral meetings with people who could not attend
India	42 participants incl. 2 representatives from the FAO country office (cf. Chapter 6)		2 in-person workshops: 23 December 2023 and 23 January 2024	
UK	12 respondents (cf. Chapter 7)		3 online workshops with a follow-up survey and emails	

1.3 Validation of the SOFA 2023 results for the current hidden costs of the agrifood systems

1.3.1 Overview of the SOFA 2023 method

Hidden costs in the SOFA 2023 report include those due to labor productivity loss, loss of ecosystem services, loss of environmental flows, the economic damages of poverty, higher mortality, and agricultural production losses. These costs are clustered into three categories: 1) **Health (H)**: productivity losses from the burden of disease due to dietary choices; 2) **Social (S)**: productivity losses from distributional failure (undernourishment), reflecting the amount society would pay for eliminating the economic damages of poverty; and 3) **Environment (E)** which includes the external costs of environmental damage caused by agriculture, i.e., labor productivity loss due to air pollution, loss of ecosystem services due to land conversion and water pollution by nitrogen, loss of environmental flows due to irrigation water withdrawal and losses of agricultural production due to climate and soil leaching. In addition, it should be noted that only 75% of the costs related to unhealthy diets were attributed to the agrifood system since other factors contribute, for instance, to obesity. The productivity losses considered are those associated with forgone labor and informal care.

The impact on well-being is measured as the overall economic losses of GDP in 2020 PPP dollars. The hidden costs are computed as the impact quantities multiplied by the marginal costs (Table 1-3). The global database for impact quantities uses different sources as shown in brackets while most of the marginal costs come from the SPIQ-FS database (Lord et al., 2023). This uses a discount rate of 3% that assumes a business-as-usual socioeconomic pathway (SSP2) for discounting the hidden costs that future generations will bear. Shadow prices are used for the marginal valuation of hidden costs (cf. marginal cost indicator column in Table 1-3) and are then compared with GDP. Shadow prices reflect the change in the value of an economic activity associated with one more unit of resource. The model used relies on shared assumptions about national growth rates, costs of burden of disease, future economic and demographic conditions, and ecosystem service values, allowing for better consistency and an ability to perform sensitivity analyses at different discount rates and diseases costs. Nitrogen costs have the highest uncertainty due to a gap in knowledge concerning the value of ecosystem services, the absence of spatially explicit data on the damage to ecosystem productivity from nitrogen loading, and the compounding uncertainty along the nitrogen cascade. Marginal costs of agricultural blue water use are underestimated due to a lack of cost data on the loss of environmental flows.

Table 1-3: *Computation of the hidden costs by category as the impact quantities multiplied by marginal costs to GDP*

	Total cost to GDP	Impact quantity indicator	Marginal cost indicator
H	**Costs of burden of disease due to dietary patterns**	Number of years lived with disability and years of life lost compared to expected life years (NCD) (DALYs) (Global Studies of Diseases, 2014–2019)	**Labor productivity** losses in the country of consumption due to burden of non-communicable diseases and high BMI in 2020 PPP dollars/DALY (ILO)
S	**Costs of undernourishment**	Number of people within a national population with food intake below minimum energy requirements (FAOSTAT, 2014–2020) transformed into DALYs using SPIQ-FS model	**Labor productivity** losses in the country of consumption due to burden of disease from protein-energy malnutrition in 2020 PPP dollars/undernourished person (SPIQ-FS, ILO, WHO)

S	**Cost of eliminating poverty among agrifood systems workers**	The share of agrifood systems workers in total employment is used as a proxy for the share of agrifood systems workers under the poverty line of $3.65 a day 2017 PPP (World Bank)	Conversion of poverty gaps into **income shortfall** per annum, i.e., financial transfers that would be needed to avoid moderate poverty
E	**Costs from agricultural production losses due to climate**	GHG emissions in tCO_2e (CO_2, CH_4 and N_2O) from on-farm production, pre- and post-production, land use and land use change (Tier 1 - FAOSTAT 2014–2020)	**Agricultural production losses** (Interagency working group on the social cost of Greenhouse Gases IWG-SCGHG, 2020)
E	**Costs from higher mortality due to climate**		From **higher human mortality** due to heat stress
E	**Net costs from loss of ecosystem services after conversion of natural ecosystems to agriculture**	Effective hectares of lost ecosystem services. Area of temperate and tropical forest converted to cropland and pasture and forest regrowth on cropland and pasture. Area of unmanaged grassland converted to cropland and pasture and unmanaged grassland recovery. (HIstoric Land Dynamics Assessment HILDA+, 2014–2019)	Marginal cost from **loss of provision of natural ecosystems** (Ecosystem Services Valuation Database ESVD and SPIQ-FS)
E	**Costs from loss of environmental flows due to irrigation withdrawal**	Blue water withdrawal for agricultural use in cubic meters (AQUASTAT 2014–2020)	**Agricultural production losses** **Labor productivity** losses in the country of withdrawal due to burden of disease from protein-energy malnutrition due to water deprived from economic use
E	**Costs from air pollution related to nitrogen application**	Volatilization of NH_3 (ammonia) and NOx (nitrous oxide) to air (European Commission's Emissions Database for Global Atmospheric research EDGAR v5.0, 2015)	**Labor productivity** losses due to air pollution **Agricultural production losses** **Ecosystem services losses** - from ozone formation, nutrient imbalance, and acidification of terrestrial biomes due to deposition - from nutrient imbalance, acidification, and eutrophication of riverine, wetlands, and coastal systems due to deposition run-off (Ecosystem Services Valuation Database ESVD) **Labor productivity** losses in the country of emission due to burden of disease from particulate matter formation
E	**Costs from water pollution related to nitrogen application**	NO_3- leached to groundwater, NO_3- due to run-off from agricultural land to surface water and effluent or human sewerage in surface water. (Calculated from Integrated Model to Assess the Global Environment – Global Nutrient model IMAGE-GNM spatial datasets)	**Labor productivity** losses in the country of emission due to burden of disease from human nitrate intake **Ecosystem services losses** from nutrient imbalance, acidification, and eutrophication of riverine, wetlands, and coastal systems due to run-off (Ecosystem Services Valuation Database ESVD)
E	**Costs from crop losses due to soil leaching**	Run-off of reactive nitrogen into surface waters and soil leaching, predominately soluble nitrate (European Nitrogen Assessment; IMAGE-GNM spatial datasets)	**Agricultural production losses** (crop)

E	**Costs from water pollution due to nitrogen run-off**	Run-off of reactive nitrogen into surface waters and soil leaching, predominately soluble NO_{3-} (nitrate) (IMAGE-GNM spatial datasets)	**Ecosystem services losses**

Note: H: Health, S: Social, E: Environment; source of the data indicated in brackets.

1.3.2 Main sources of hidden costs in country case studies between 2016 and 2023

According to SOFA 2023 estimates, as the average income by country increases: a) the country's share of total global hidden costs tends to increase, b) the share of hidden costs in its national GDP tends to decrease, and c) the contribution of social hidden costs in national hidden costs decreases while the contribution of health hidden costs increases. Most of the total quantified hidden costs are generated in upper-middle-income countries (39%) and high-income countries (36%) with low-income countries only making up 3%. However, the share of total hidden costs in national GDP is highest in low-income countries (27%) and lowest in high-income countries (8%). Overall quantified hidden costs show an upward trend mostly driven by increasing health-related hidden costs from unhealthy diets. This is the only cost category that is on the rise across all income groups.

Accounting for hidden costs would reduce global GDP PPP by 10% in 2020, and national GDP PPP by 16% in Brazil, 12% in Colombia, 16% in India, 6% in Australia and 8% in the UK. In all countries but Ethiopia, the main hidden cost is the burden of disease due to dietary patterns (Figure 1-2) and this has been steadily increasing from 13% in 2016 to 33% in 2023. The estimated share of hidden costs related to the burden of disease due to undernourishment is low in all countries (less than 5%). These results show that countries face different challenges related to economic development (e.g., poverty), intensity and efficiency of production inputs (e.g., utilization of nitrogen and water for irrigation), and land use.

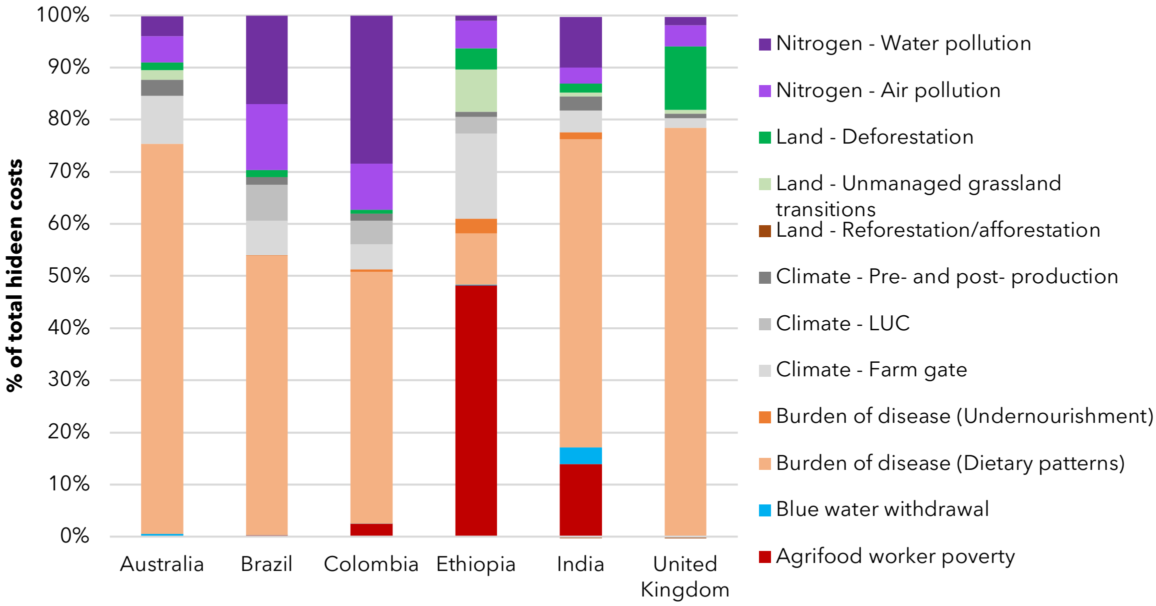
Brazil and Colombia share quite similar patterns, with half of the hidden costs coming from the burden of disease due to dietary choices, 30 to 37% coming from nitrogen (but with the highest share due to water pollution in Colombia), 11 to 15% coming from GHG emissions (split almost equally between land-use change and on-farm emissions), and a very small portion (1%) from the costs of deforestation (Figure 1-2). The costs from the burden of disease due to dietary choices and nitrogen have been steadily increasing from 2016 to 2023 (+14% and +23% respectively in Colombia).

Both in Australia and the UK, the cost of burden of disease due to dietary patterns represents more than the two thirds of the total (positive) costs, and land use change appears to be the second most important source of costs (positive in the UK and negative in Australia) (Figure 1-2). For land use change, the data appears to fluctuate considerably between 2016 and 2019, before the extrapolated period to 2023 where it stays constant, and there has been a gradual decline in the costs related to nitrogen (-11% for Australia and -14% for UK).

In Ethiopia, the pattern of hidden costs aligns with the observed cost structure in many low-income countries, where the social sector often bears the brunt of hidden costs associated with food production. Poverty among agrifood workers emerges as the most significant contributor (48%). This reflects the high concentration of rural populations living below the poverty line in Ethiopia. Climate and land-related costs from the environmental sector in Ethiopia follow closely representing 20% and 12% of the total average cost. GHG emissions primarily stem from livestock since Ethiopia has the largest livestock population in Africa with 65 million cattle and 90 million small ruminants in 2020 (Mekuriaw and Harris-Coble, 2021). All these costs have risen between 2016 and 2020.

In India, after the cost of the burden of disease from dietary patterns, the costs related to nitrogen flows (especially water pollution) and poverty among agrifood workers contribute the most to total hidden costs (˜14% each). India reports hidden costs to the extent of 0.73 trillion PPP dollars 2020 due to health outcomes of agrifood systems in India. This is driven by the double burden of malnutrition and obesity that currently plagues India's population. Between 2016 and 2020, costs related to the burden of disease from dietary patterns and to nitrogen flows have risen (14% and 16% respectively) but costs related to poverty have reduced. India is the only country among the six country case studies where the hidden costs related to blue water withdrawal plays a role (3%).

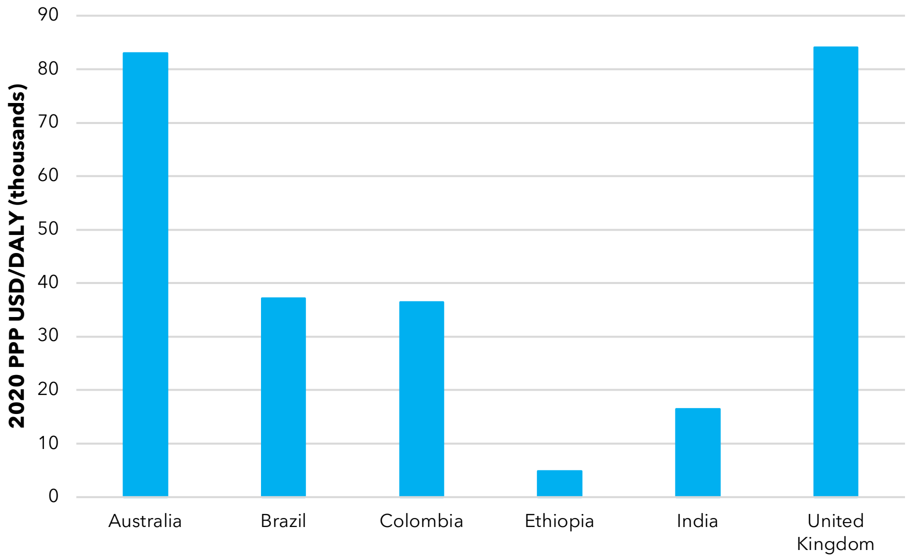
Figure 1-2: *Comparison of agrifood system hidden costs for the six countries as % of total hidden costs in 2020*



Source: Authors based on SOFA 2023

The contribution of impact quantities and marginal costs to the total cost estimates varies between countries. Labor productivity loss is a major marginal cost indicator used to compute the hidden costs and can arise from health, social, or environmental impacts (Table 1-3), including: 1) burden of non-communicable diseases and high BMI due to dietary patterns; 2) burden of disease from protein-energy malnutrition; 3) burden of disease from protein-energy malnutrition due to water deprived from economic use; 4) air pollution; 5) burden of disease from particulate matter formation (NH_3 and NOx); and 6) burden of disease from human nitrate intake. Consequently, the assumption on labor productivity has a large impact on the resulting hidden costs and can partly explain the differences across countries (Figure 1-3). Other marginal costs include income shortfall, agricultural production losses, higher human mortality, and reduced provision of ecosystem services (Table 1-3).

Figure 1-3: *Comparison of the marginal cost of a DALY across countries*



In the high-income countries of the current report (Australia and United Kingdom), the hidden cost of dietary patterns in 2020 was driven by the high marginal cost of productivity losses (>80,000 2020 PPP dollars per DALY) while the estimated number of DALYs are moderate relative to the size of the population (0.7 and 2.3 million years respectively). In contrast, in Brazil and India the hidden costs of dietary patterns are driven by a high number of DALYs (7.3 and 40.7 million years) whereas the marginal costs are much smaller than the high-income countries (~37,000 and ~16,000 PPP dollars 2020 per DALY respectively). Colombia and Ethiopia have similar number of DALYs but total costs for Colombia are much larger because the marginal cost is seven times higher than in Ethiopia. In Ethiopia, the hidden cost estimate is dominated by poverty, driven mainly by the large number of people below the poverty line (54.4 million) rather than the marginal cost (453 PPP dollars 2020 per person). Poverty headcount is also large in India (358 million people), but the marginal cost is quite low (440 PPP dollars 2020 per person).

Regarding environmental costs, the UK features the highest marginal costs of land among the six countries with ~100 thousand PPP dollars 2020 per hectare compared to 27.8 and 13.6 marginal cost of forest and unmanaged grassland in Ethiopia. Environment costs in Brazil, Colombia and India relate predominantly to nitrogen flows (NH_3 emissions to air). The highest impact quantities are estimated for India (5.4 Mt of N) and this contributes the most to the cost estimate given the comparatively low marginal cost (1.4 and 3.6 PPP dollars 2020 per N kg for air pollution and deposition respectively). In contrast, the marginal costs seem to contribute the most to the estimates in Colombia and Brazil (13.2 and 11.9 PPP dollars 2020 per N kg), although Brazil also features a significant amount of NH_3 emissions to air (3.7 Mt of N).

1.3.3 Comparison with national datasets

Direct comparisons between the global datasets used in the hidden costs analysis and national statistics were in some cases not possible as they used inconsistent categories. To allow comparisons, we have combined subcategories among different datasets and highlight higher, lower, or similar levels of estimates (Table 1-4). The impact quantities indicators that have been used for land use change, poverty, undernourishment, nitrogen, water and GHG in SOFA 2023 tend to diverge from national datasets in almost all countries studied here, while other impact indicators such as dietary patterns tend to be mostly in line with national statistics.

Table 1-4: *Comparison of SOFA 2023 hidden cost data with national statistics for the main cost components of the analysis (impact quantities)*

	Land use	GHG	Nitrogen	Poverty	Dietary patterns	Under-nourishment	Water
Australia	Higher	Higher		Lower	Similar levels	Lower	Higher
Brazil	Lower		Similar levels		Similar levels		Lower
Colombia	Higher / Lower	Higher	Higher		Similar levels		Higher
Ethiopia		Higher		Higher		Lower	
India		Higher			Similar levels		Similar levels
UK	Higher	Higher	Higher		Similar levels		Similar levels

SOFA 2023 data compared to national statistics

Higher | Similar levels | Lower | No reported differences / or missing information

Notes: This table does not show consistency of categories or units between the SOFA 2023 data and national statistics but simply highlights observed differences and similarities in the magnitude of impact quantities. Land use comparison refers to differences on distinctive land use changes by country with the dataset HILDA+ which has been used in SOFA 2023 (cf. paragraph on land use change). In cases where datasets were inconsistent or missing information, no comparison was made, and no differences are identified (white cells).

Land use change

The land use change patterns from 2016 to 2019 described by HILDA+ do not seem to match currently observed trends in many countries (Australia, Brazil, Colombia, and the UK). For the UK, many land use transitions assumed, including shifts between grassland, pasture, forest, and cropland, are not supported by UK-level datasets (UNFCCC, 2022a), potentially due to misclassifications of forest plantations that have been felled prior to restocking as land that has been deforested. Some land use transitions are not included, suggesting that certain important changes may be overlooked. For Brazil, while HILDA+ shows a decrease of forest conversion to agricultural land between 2017 and 2018, national data (Mapbiomas time series, Souza et al., 2020) show an increasing trend in natural vegetation loss during the same period. In Colombia, HILDA+ transitions of cropland and pasture to forests are considerably overestimated while conversions of forests to pasture are grossly underestimated (Second and Third Biennial Update Reports (BUR); UNFCCC, 2022). In Australia, the HILDA+ values of conversion of forest to cropland are three orders of magnitude different to the National Greenhouse Gas Inventory (NGGI) (Australian Government Department of Climate, Energy, the Environment and Water, 2021) and land clearing for grazing on native vegetation could be overestimated by two orders of magnitude.

Greenhouse gas emissions

In the UK, Colombia, and Australia, GHG emissions from FAOSTAT are higher than emissions from national sources: the UK Greenhouse Gas Inventory (GHGI) (UNFCCC, 2022a), the Colombia Biennial Update Report (58% higher) (UNFCCC, 2022) and Australia's National GHG Inventory (7 to 65% higher) (as reported to the UNFCCC, DCCEEW, 2021). For Australia, this is mainly due to the use of more detailed Tier 2 and 3 methods in the national inventory compared to the basic Tier 1 approach in FAOSTAT. In Ethiopia, it is the opposite: the national-level assessment (FDRE, 2022) estimates higher CO_2 emissions than FAOSTAT (+54%) but total CH_4 and N_2O emissions appear broadly comparable in both reports, though inconsistencies are observed for N_2O manure management and land use-induced emissions. In India, discrepancies emerge due to CO_2 emissions from land use change, which are estimated to be zero, while data from the GHG platform indicate that there are negative emissions of approximately 180 million tonnes (UNFCCC, 2021). CH_4 emissions are also underestimated compared to official data.

Nitrogen-related costs

Estimated nitrogen-related costs compare reasonably well in the case of Brazil where costs are in line with past trends in nitrogen fertilizer use due to uptake of precision farming techniques. Specifically, nitrogen run-off in Brazil is associated with the increased application of fertilizer related to robust growth in agricultural production in the last decades, coupled with a lack of improvement in nitrogen use efficiency, which even shows signs of worsening according to a few studies (Pires et al., 2015; Santos et al., 2023). In the UK case study, the estimates of NH_3 emissions to air from agriculture appear to be larger than those in the National Atmospheric Emissions Inventory but smaller than those in the UK Environmental Accounts (the "Blue Book", Office for National Statistics, 2021). In the case of Colombia, the impact quantities are considerably larger than those corresponding to national historical data, although the latter also show an upward trend.

Poverty

Differences between the poverty estimates used in SOFA 2023 and official poverty estimates mainly come from the use of different poverty lines: in SOFA 2023, USD 3.65 per day corresponding to moderate poverty is used while a poverty line of USD 1.90 per day is used in Ethiopia (FDRE, 2012) and India (Panagariya and More, 2023). The method to compute poverty has limited applicability in Australia because it overlooks disparities in affordability across the country, particularly in remote areas, since the national metric does not account for heterogeneity in costs of essential products within the country (Davis et al., 2023; Box 1).

Dietary patterns

The cost of the burden of disease due to unhealthy diets is in line with the high and growing prevalence of obesity and levels of overweight currently observed in Brazil and the UK (Ferrari et al., 2022; National Statistics, 2015; Rocha et al., 2023). In India, the poor dietary patterns and corresponding burden of disease are supported by India's State of Health Report (ICMR et al., 2017a). Similarly, hidden costs due to unhealthy diets in Australia are in line with currently reported high prevalence of obesity and overweight levels (Lal et al., 2020; Australian Institute of Health and Welfare, 2019). Data on dietary patterns for Colombia used in the TCA method are sourced from the National Health Observatory from the Ministry of Health and Social Care and specifically the Global Burden of Disease, Injuries, and Risk Factors study (Forouzanfar et al., 2015) thereby no differences between national statistics and SOFA 2023 data are identified.

Undernourishment

Ethiopian official statistics define undernourishment as the income shortfall required to meet a predetermined minimum caloric intake (2,200 kilocalories per adult equivalent per day) ("food poverty"). Based on this definition, 24.8% of households, i.e., 22 million individuals, were considered undernourished in 2016, which is higher than the 14 million individuals used in SOFA 2023. This discrepancy persists even if we account for the higher caloric threshold for defining undernourishment in the national data. While it is not visible in the SOFA 2023 results because of the FAO definition of undernourishment, multiple sources and studies have highlighted the extent of food insecurity in Australia over the last few years (Foodbank, 2023).

Water

Quantities related to water compare reasonably for countries like India and the UK. Discrepancies are identified for Colombia, where national statistics (IDEAM, 2023) indicate that total water demand is much lower than SOFA 2023 data. In Brazil, where agriculture is mainly rainfed, the increase of water withdrawals for irrigation is questionable (only about 10% of the agricultural area is irrigated). In Australia, water use data used for the hidden costs estimation is 21–35% higher (during 2019 and 2020) than the national reported value (Water Use on Australian Farms (ABS, 2022).

1.3.4 Gaps in the SOFA 2023 analysis and suggestions for improvements

Replacement of impact quantities data by national datasets: As highlighted in the previous section, we recommend that for a tailored country analysis, the land-use change and GHG emissions data are systematically replaced by national datasets. Using different thresholds for poverty and calorie needs would make the comparison across countries more difficult but would increase the relevance of the hidden costs' computation to the national contexts. All countries highlighted that using sub-national statistics would also increase the relevance of the hidden costs' computation (Box 1).

Suggestions for improvements to compute hidden costs related to agrifood systems include extending the analysis to cover:

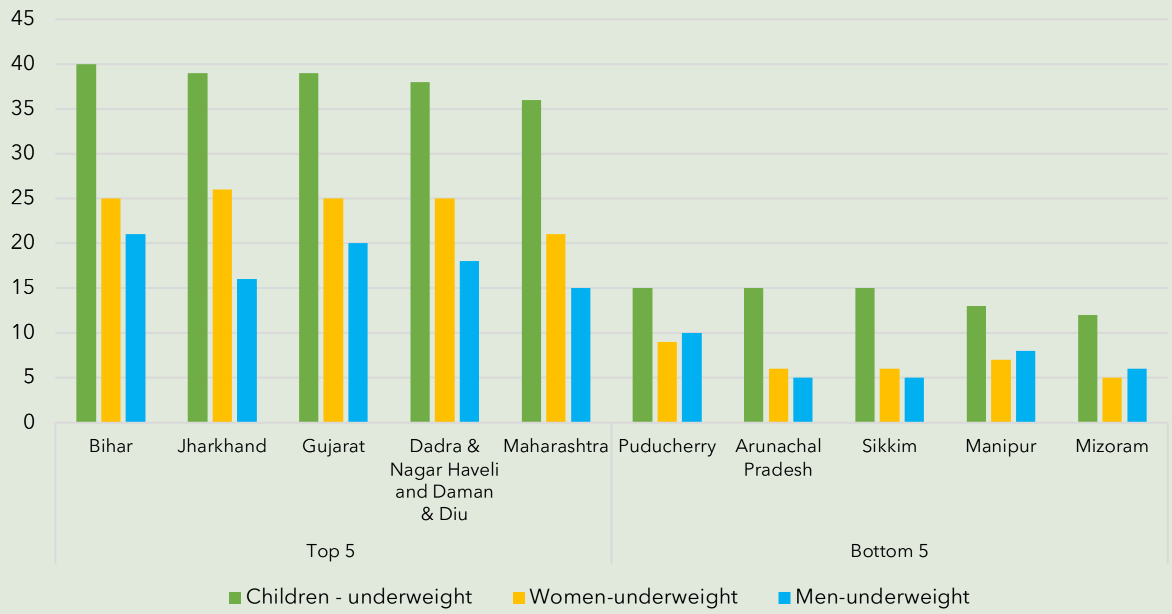
- Biodiversity losses and land degradation (e.g., soil erosion, desertification, salinization) and the potential benefits of certain practices or crops (e.g., enset) to ecosystem services, including pest and erosion control.
- GHG emissions and air pollution from household cooking.
- Other transitions to or from agricultural land (e.g., from cropland to pasture, or from unmanaged grassland to improved pasture or cropland).
- Alternative computation of the hidden costs related to food consumption taking place in the country instead of production. For example, the UK imports 50% of its food, and the impact of the imported food could be attributed to the choices of UK consumers.
- Water scarcity impacts on the loss of drinking water and the environmental cost for biodiversity, such as streams and wetlands drying out, or salinization of groundwater due to over-abstraction in coastal areas.
- Extending water use to processing (e.g., rice and sugar mills in India) and fertilizer production (e.g., in India CSE, 2019).
- Impacts of type 2 diabetes and hypertension on productivity loss (e.g., in Australia and India).
- Impacts of pesticides on human health and ecosystem services.
- Year-to-year fluctuations in undernourishment levels, particularly in response to climate anomalies like rainfall deviations and droughts. These events often trigger year-on crop failures and price fluctuations, potentially leading to significant increases in undernourishment. Accounting for this hidden cost would provide a more comprehensive understanding of the economic consequences and food insecurity because of climate variability.
- Lasting consequences of undernourishment during childhood on human capital and consequently on labor productivity.
- In specific country contexts (such as Australia) most malnutrition is due to micronutrient deficiencies, particularly calcium, magnesium and zinc (ABS, 2015) and thus, the method could better capture the respective hidden costs for health by further disaggregating undernourishment to a micronutrient intake basis.
- Improve the accuracy of health data as in specific contexts like Ethiopia where the traditional cereal-based diet and active rural lifestyles are likely to contribute to lower dietary-related costs compared to other countries. Relying solely on hospital records might underestimate the true burden of such illnesses, as many people may not seek medical care.

Box 1: *The need to go to sub-national level for tailored country-level hidden costs assessments*

The possibility of transforming the food and land systems towards greater sustainability is constrained by biophysical characteristics and the spatial organization of territory. National results based on national average values are likely to overestimate or undermine the magnitude of the impacts on hidden costs. Sometimes, a problem becomes even invisible at the national level as it can be offset by the other regions of the country. Thus, depending on data and resource availability, national level data should be complemented by spatial analyses, which will enable the heterogeneity of the main impacts and drivers of agrifood systems to be captured:

- *For national GHG inventories, several countries use a Tier 3 approach that reflects the heterogeneity of carbon stocks in the country instead of a national average value in the Tier 1 approach which is used in the FAOSTAT database.*
- *In SPIQ-FS, marginal costs of ecosystem services are currently differentiated for temperate vs tropical forests, but a single value is used for unmanaged grassland which can encompass a wide range of ecosystems.*
- *When diverse agroecological zones in the country offer different opportunities and challenges to reduce hidden costs, e.g., highland area, very arid areas, different agricultural systems should be distinguished. This might be particularly topical for countries such as Ethiopia where small-scale farmers constitute 75% of the population.*
- *Dietary shifts should take account of affordability in remote areas, e.g., in remote Australian stores food baskets cost 39% more than in major supermarkets in capital cities (Davis et al., 2023), and population in those areas can be impacted more by higher commodity prices (National Indigenous Australians Agency, 2020).*
- *In India, while the hidden costs of undernourishment only represent a small share of the total hidden costs, the extent of the issue varies greatly from one state to another requiring different levels of prioritization by state (Figure 1-4).*

Figure 1-4 *– Share of undernourished children, women and men across top and bottom five states in India*



Source: NFHS 5

1.4 Evolution of hidden costs by 2030 and 2050

1.4.1 The agrifood system models and link with the TCA model

In this study, the FABLE Calculator (Mosnier et al., 2020) is used in Australia, Brazil, Colombia, Ethiopia, and the UK, building on the FABLE Scenathon 2023 results (FABLE, 2024). The MAgPIE partial equilibrium model (Dietrich et al., 2019) is used in India, building on the FSEC results (Bodirsky et al., 2023). Both the FABLE Calculator and MAgPIE focus on agriculture as the main driver of land use and land use change. They both rely on the assumption of equilibrium between demand and supply quantities in each region and country, for each commodity and each five-year time step (cf. 1.8.2 and Mosnier et al., 2023 for a detailed comparison of the two models). The FABLE Calculator is an Excel-based non-optimization model. It is a stepwise process where, except for the first step, all steps are dependent on variables that are estimated in the previous steps (cf. 1.8.1). MAgPIE is a global partial equilibrium model that optimizes food, material, and bioenergy demand through a cost-minimization approach accounting for biophysical, technological, and socioeconomic constraints. The MAgPIE model is integrated with two different health and poverty models that evaluate the impact of agricultural production and consumption decisions on health and poverty outcomes for all regions (Dietrich et al., 2023).

These tools have been adapted to fit the local contexts: e.g., through the replacement of the input data from global datasets with country datasets in Australia and the UK (Smith et al., 2022) (Navarro Garcia et al., 2022); the implementation of new features, e.g., representation of locally important crops such as teff, a cereal used as a staple food in Ethiopia (Molla and Woldeyes, 2020); the calibration of key parameters to align models' results with historical statistics over 2000–2015, e.g., Brazil for historical deforestation (Costa et al., 2020); and the improvement of the scenarios to better represent domestic policies or policy ambitions (cf. Annexes). These adaptations are documented in each country chapter. The FABLE Calculator is an open tool and can be downloaded here. The version which is used in this study is v44. The code of the MAgPIE model is available on GitHub. Version 4.7.3 has been used for this analysis (Dietrich et al., 2023).

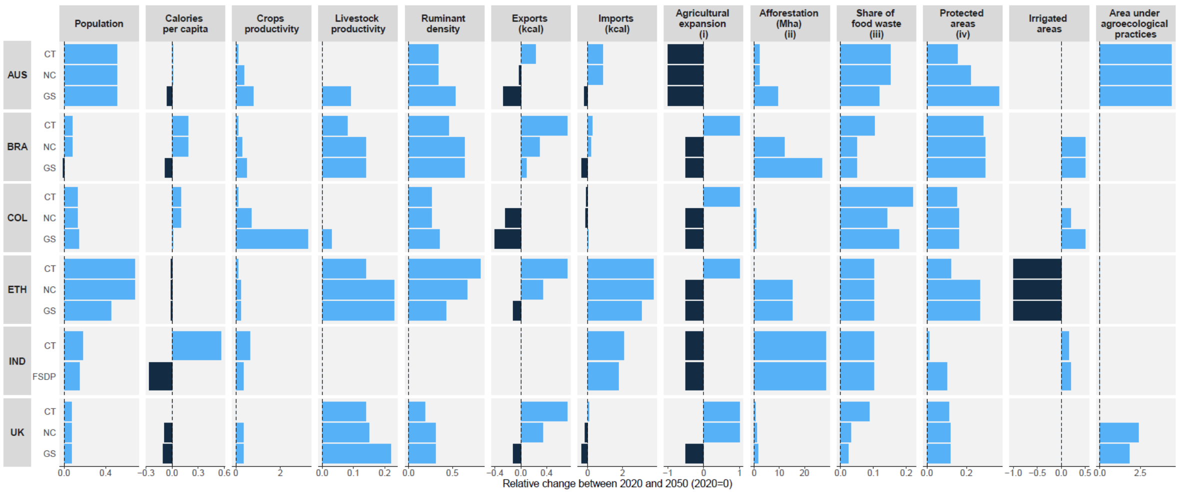
Hidden costs are projected into the future by using some of the outputs of FABLE Calculator or MAgPIE as inputs in the TCA model (cf. 1.8.3). This can be done for GHG emissions (excluding GHG from pre- and post-production), conversion of forest and unmanaged grassland to farmland, and blue water withdrawals for irrigation. For nitrogen, the FABLE Calculator only provides the quantities of nitrogen applied to soils (organic and inorganic) and nitrogen from manure left on pasture, while MAgPIE provides a more comprehensive set of outputs that are more compatible with the SPIQ-FS model. Both the FABLE Calculator and MAgPIE project the evolution of food consumption by food group (and at commodity level for the FABLE Calculator) but not the associated health impacts. An intermediate step was required to convert average food consumption by food groups into DALYs (disability-adjusted life years). This conversion was done for MAgPIE by Marco Springmann (Springmann et al., 2020) while the FABLE Calculator used the machine learning model built to estimate the health hidden costs linking food availability to food intake for the SOFA 2024 (see Box 7 in FAO 2024) and to DALYs using an emulator of the University of Washington 2017 global burden of disease (GBD) model.

1.4.2 Scenarios

The Australian, Brazilian, Colombian, Ethiopian, and UK case studies presented in this paper use the FABLE Scenathon 2023 framework with three pathways: 1) the *current trends* (CT) pathway represents a low ambition of feasible action towards environmental sustainability with a future strongly dependent on current policy; 2) the *national commitments* (NC) pathway reflects the actions that would be necessary to meet national commitments and targets; 3) the *global sustainability* (GS) pathway corresponds to efforts that would be compatible with the achievement of global sustainability targets. The Indian case study relies on the work which has been done in the framework of the FSEC commission. The business-as-usual (BAU) pathway aligns with the "middle-of-the-road scenario" of the shared socioeconomic pathways (SSP2) (Riahi et al., 2017; O Neill, 2017; Popp, 2017), where the plausible future state of the food system continues in line with current trends. The full sustainable development pathway (FSDP) represents a transformative pathway that integrates 23 individual food system measures (FSMs)[2]. The scope of the FSDP is very close to the global sustainability pathway.

Figure 1-5 shows the magnitude of the changes which have been assumed by each country for each scenario parameter and Table 1-5 lists all the assumptions which have been used to differentiate NC and GS from current trends in each country.

Figure 1-5: *Overview of the underlying model assumptions in each pathway*



Notes: 0.3 means a 30% increase in 2050 compared to 2020. Countries represented are AUS – Australia, BRA – Brazil, COL – Colombia, ETH – Ethiopia, IND – India, and the UK. Exports and imports reported here are calculated after the global trade equilibrium is computed in the FABLE-C. (i) Agricultural expansion: 1 corresponds to free expansion of agricultural land, -0.5 corresponds to no deforestation after 2030, and -1 corresponds to no expansion of agricultural land beyond the 2020 area; (ii) Afforestation is in absolute change (Mha); (iii) Food waste: results are expressed in % of consumption which is wasted; (iv) Protected areas: results are expressed in % of total land in 2050. For India: the relative change of exports and imports is computed using Mt dry matter; the unit for crop productivity is metric tonne dry matter per hectare; livestock productivity is endogenously computed in MAgPIE and ruminant density is not explicitly represented in MAgPIE; irrigated area is expressed in % of harvest area in 2050; no explicit agroecological module in the model.

[2] The 28 transformation domains (comprising both within and outside food systems) are represented by five distinct packages or policy measure bundles: healthy diets and sustainable consumption patterns (Diets), nature-positive agricultural transition (Agriculture), biodiversity protection (Biodiversity), equitable livelihoods (Livelihood), and a broader socioeconomic development external to the food system (CrossSector).

Table 1-5: *Number of scenario parameters activated in NC and GS compared to CT by country*

Country	#	Scenario parameters tested separately
Australia	11	Diet, Food waste, Livestock productivity, Crop productivity (2 levels), Afforestation, Ruminant density on pasture, Protected areas expansion (2 levels), Post-harvest losses, Urban area expansion
Brazil	14	Population, Diet, Food waste, Livestock productivity, Crop productivity (2 levels), Constraints on the expansion of agricultural land, Afforestation (2 levels), Ruminant density on pasture, Protected areas expansion, Post-harvest losses, Biofuel demand, Irrigated area
Colombia	21	Population, Diet, Food waste (2 levels), Livestock productivity, Share of the consumption which is imported (2 levels), exports of main commodities, Crop productivity (2 levels), Livestock productivity (2), Constraints on the expansion of agricultural land, Afforestation, Ruminant density on pasture, Protected areas expansion, Post-harvest losses, Urbanization, Irrigated area (2 levels), Agroecological practices
Ethiopia	11	Population, Share of consumption, which is imported, Export of main commodities, Crop productivity, Livestock productivity, Constraints on the expansion of agricultural land, Afforestation, Protected areas expansion, Post-harvest losses, Urbanization, Irrigated area
India	10	Population, Diet (3 levels), Food waste, Livestock productivity and Feed efficiency, Yield increasing technologies, Manure management, Nitrogen efficiency, Water use efficiency and protection of environmental flows
UK	21	Diet (2 levels), Food waste (2 levels), Livestock productivity (2 levels), Crop productivity (2 levels), Constraints on the expansion of agricultural land, Afforestation (2 levels), Ruminant density on pasture, Protected areas expansion (2 levels), Post-harvest losses (2 levels), Biofuel demand, Urbanization (2 levels), Agroecological practices (2 levels)

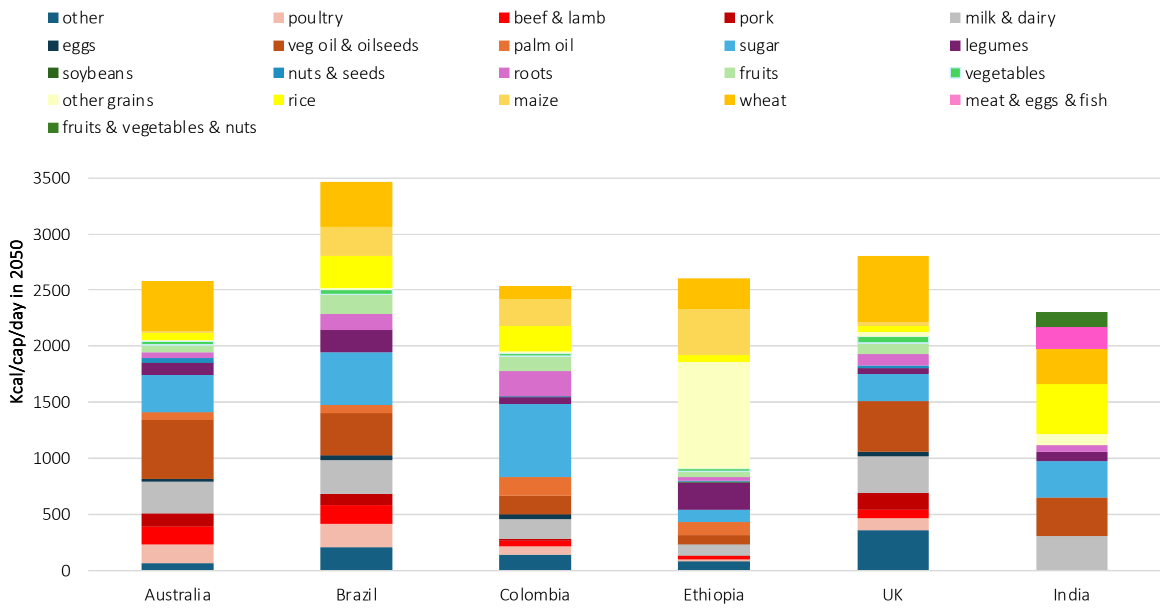
Note: for India, afforestation and protected areas expansion, and trade liberalization scenarios have been included in the sustainable pathway but not included in the decomposition analysis as their impacts on the results were small.

Assumptions under Current Trends

Medium levels of **economic growth** and **population growth** are assumed in most countries in line with the global SSP2 scenario (India) or UN-DESA medium population scenario that corresponds to the median of several thousand distinct population trajectories. Australia integrates a country-specific target in line with the Australian Intergeneration report. This leads to strong population growth in Australia and Ethiopia (>50% increase between 2020 and 2050), a moderate increase in India (23%) and a low increase in Brazil, Colombia, and the UK (<13%).

The average calorie intake per capita is assumed to remain stable in Australia, Ethiopia and the UK and increases slightly in the other countries (Figure 1-5). In Brazil, the diet transition includes an overall increase of calorific consumption for both plant and animal calories (20% and 19% respectively compared to 2020). Australia assumes some small increases in consumption of legumes, vegetable oils, soybeans and pork, decreases of similar magnitude in consumption of fruits, vegetables, roots, and milk, and small reduction in beef and lamb consumption (-6%). In India, the composition of all food products uniformly increases by about 3%, except eggs and lamb that each increase by about 1%. Colombia assumes a reduction in animal-based calories consumption (-19%) while plant-based calories overall increase (+17%). Ethiopia assumes increases in animal calories consumption (+57%), mainly driven by poultry, eggs and milk consumption and a slight reduction in cereals and roots consumption, but in 2050, cereals still represent more than half of the calorie intake, with a large contribution of teff (Figure 1-6).

Figure 1-6: *Composition of the average daily kilocalorie intake per capita per country by 2050*



Note: the category "other" includes animal fat, alcoholic and non-alcoholic beverages, spices; oil – veg includes both oilseeds and vegetable oils except oil from palm which is in palm – oil; other grains include other cereals. MAgPIE has different product groups that could not always be matched with the group aggregation from the FABLE-C: meats, eggs and fish are grouped together as well as fruits, vegetables, and nuts, maize is included in other cereals, palm oil is included in veg. oil & oilseeds.

Crop productivity follows a low- to medium-growth path (closing the yield gap by 30% to 50% by 2050) whereas **livestock productivity** reflects either current trends or business-as-usual improvements (same productivity growth as in the 2000–2010 period). In MAgPIE, crop yields growth is endogenous based on levels of claimed investments in R&D and infrastructure.

Afforestation is low or zero in most countries, but targets in India are in line with their Nationally Determined Contribution (NDC) to the Paris Agreement, to create an additional carbon sink of 2.5 to 3 billion tonnes of CO_2 equivalent through afforestation and reforestation by 2030. No change is assumed in **protected areas**. **Expansion of agricultural land** is prohibited only in Australia and India. As for **the evolution of trade**, exports for key commodities are assumed to increase by 50% between 2020 and 2050 in Colombia, Ethiopia, and India, and to double in Brazil, whereas Australia and the UK assume stable exported volumes. Shares of imports are assumed to be stable for most countries except Colombia and Ethiopia where they are assumed to increase.

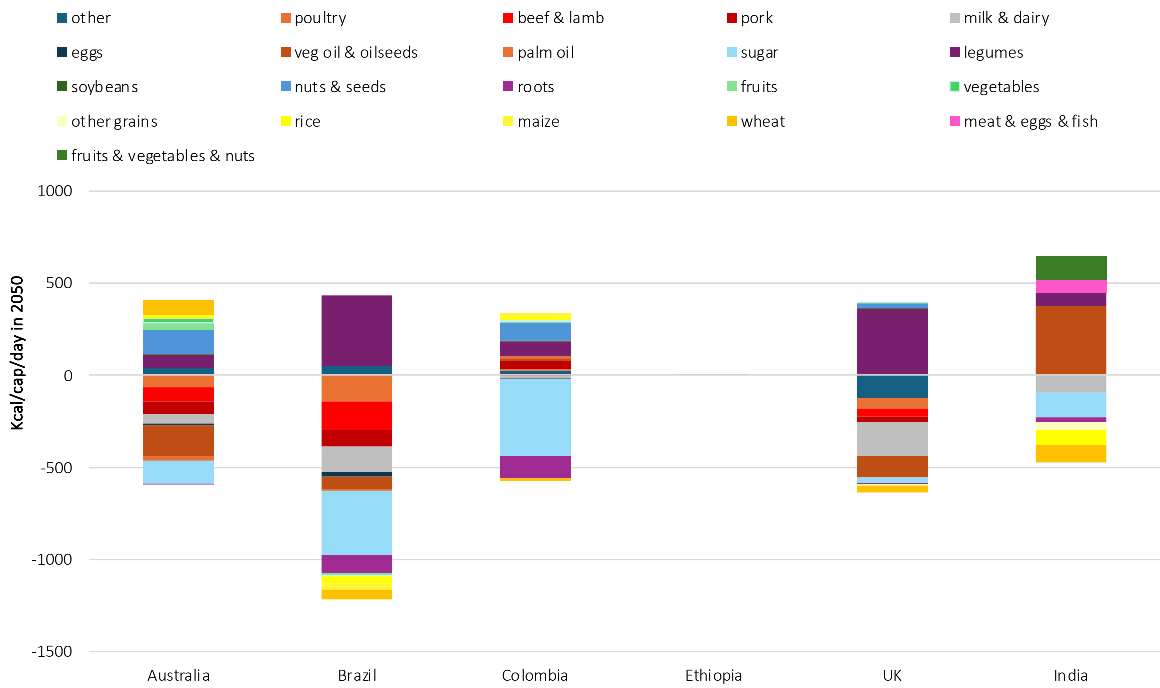
How to increase sustainability in NC and GS pathways?

To increase the sustainability of agricultural production, all countries featured in this study assume some changes in **crop and livestock productivity**, **stocking rate (ruminant density) on pasture**, and **post-harvest losses** (Table 1-5). Higher agricultural productivity is used to increase sustainability of the agrifood system of the country, although it is recognized that this could involve trade-offs with other environmental impacts such as nitrogen pollution from fertilizers.

Dietary changes are also seen as a key factor in increasing the sustainability of the agrifood systems in five countries. The UK derives the dietary change scenario from the UK Balanced Net Zero (BNZ) pathway of the Climate Change Committee (CCC) resulting in a 20% cut in meat and dairy calorie consumption by 2030 and a 35% cut by 2050 for meat, or a more ambitious target of a 50% cut in meat and dairy consumption by 2050. The other countries use a transition towards the average EAT-Lancet diet with the most dramatic changes being assumed for Brazil. Ethiopia is the only country that did not implement dietary change compared to current trends.

In most case studies, **deforestation is prevented beyond 2030** in the NC and GS pathways. **Afforestation** scenarios are used in most countries to increase carbon sequestration on land, assuming realization of official commitments to the Bonn challenge (Brazil, Colombia, Ethiopia, India) or other national targets (Australia, India, and the UK). Other scenario parameters such as changes in food waste, agroecological practices, and irrigation areas have been activated in some countries.

Figure 1-7: *Assumed changes of per capita kilocalorie consumption by food group and country in 2050 in NC and GS compared to CT*



Note: the category "other" includes animal fat, alcoholic and non-alcoholic beverages, spices; "oil – veg" includes both oilseeds and vegetable oils except oil from palm which is in "oil – palm"; "other grain" includes other cereals. MAgPIE has different product groups that could not always be matched with the group aggregation from the FABLE-C: meats, eggs and fish are grouped together as well as fruits, vegetables, and nuts, maize is included in other cereals, palm oil is included in veg. oil & oilseeds.

1.4.3 Changes between 2020 and 2050 in Current Trends

Australia

The cropland area increases are accompanied by a reduction of grassland areas which potentially indicates that dietary changes reduce the demand for livestock production leading to the freeing up of pastureland. Marginal increases of forest area by 2050 are attributed to afforestation efforts targeted in Australia, (approximately 2 million hectares of new forest). Agricultural production CO_2 is estimated to increase marginally by about 4%. Methane emissions increase by 2%, which results primarily from livestock production related emissions. Nitrous oxide emissions increase slightly in Australia, by 5%.

Brazil

Cropland areas increase which is accompanied by a reduction of grassland areas indicating that cattle ranching intensification is sparing land for cropland expansion (mostly relevant in Brazil) and also that dietary changes reduce the demand for livestock production leading to freeing up pastureland. Forest area in the Current Trends pathway decreases in Brazil by 26%. CO_2 emissions from agricultural production in Brazil are estimated to increase by approximately 18%. Deforestation-related CO_2 emissions are estimated to increase by 24% between 2030 and 2050. Also, Brazil shows a substantial increase in other land use CO_2 emissions (OtherLUCCO2) that increase from -48 to 2 Mt CO_2e. Moderate increases in methane emissions are shown (8%) which mainly result from livestock production related emissions. Nitrous oxide emissions increase by 13%.

Colombia

Marginal increases of forest area are estimated by 2050 which are attributed to afforestation efforts of approximately 1 million hectares of new forest. Colombia is estimated to have a notable decrease of agricultural CO_2 emissions in the order of magnitude of 10%. Reductions are estimated for CH_4 emissions (-5%) which are driven by decreases in both livestock and crop related emissions. Nitrous oxide emissions remain stable in Colombia.

Ethiopia

Increases of agricultural land are estimated for Ethiopia (16%), primarily driven by increased cropland area (30%) and stable pastureland extent. As a result, agricultural CO_2 emissions increase by nearly half by 2050 (47%). Deforestation-related CO_2 emissions are estimated to decrease by 15%. An increase in methane emissions is estimated (47%) which is predominantly driven by increases in livestock production. Estimates show an increase of nitrous oxide emissions almost by half (increase by 47%) in 2050, compared to 2030 levels.

India

Cropland area increases are accompanied by a reduction of grassland areas which indicates that dietary changes reduce the demand for livestock production leading to freeing up pastureland. Forest area increases by 7%. Increases in agricultural production of CO_2 are estimated to be low (about 4%) while nitrous oxide emissions increase slightly through 2050, by 12%. Methane emissions remain at similar levels between 2030 and 2050.

United Kingdom

Both cropland and grassland increase until 2050, when no more unprotected land is available for conversion to farmland. Further urban expansion and tree planting therefore leads to a slight decrease in pasture in 2050, meaning that food production targets are not met. Forest area marginally increases by 2050 due to afforestation targets in the UK (approximately 1 million hectares of new forest). Agricultural production of CO_2 increases by about 21% while CH_4 and nitrous oxide emissions are estimated to increase by 10% and 12%, driven by increases in both livestock and crop production.

1.4.4 What are the most influential factors to reduce the hidden costs of agrifood systems?

As well as presenting the overall results from the combination of actions in each pathway, we also compute the individual impact of each action through a decomposition analysis (1.8.4), to help inform the prioritization of actions in each country. To do that, we fixed all the scenario parameters to the same value as in the CT pathway and then set individual parameters to the value used in the alternative pathways, recording the key output variables before moving on to the next parameter (Table 1-5). Results are shown in Figure 1-8.

1. Managing demand

The decomposition analysis highlights the important role of **changing diets** in reducing the impact quantities of several indicators that lead to hidden costs of the agrifood systems (Figure 1-8 a). Dietary change provides the largest reduction in DALYs, and in four out of the six countries a reduction of ruminant meat consumption provides the largest reduction in CH_4 emissions and pasture area compared to CT (Table 1-6).

For the UK and Brazil, changing diets is the most important factor for six of the eleven output indicators which are used for the hidden costs analysis, including nitrogen application and CO_2 and N_2O emissions. The strong impact of dietary changes on environmental variables for these two countries is not surprising: Brazil uses the EAT-Lancet planetary diet, which partly builds on limiting climate change impacts, and the UK uses the Balanced Net Zero pathway of the UK Climate Change Committee which focuses on reducing consumption of animal produce to cut GHG emissions, leaving total calories, fat, and sugar consumption unchanged.

The dietary change assumed in Australia is the most effective for reducing DALYs compared to current trends by 2050 (-27% DALYs) as it reduced almost all the dietary risk categories. The most important changes are a higher consumption of nuts, fruits, vegetables, and legumes, and a lower consumption of processed meat, red meat, and sugar-sweetened beverages. In Brazil, Colombia, and the UK, the focus of dietary change is on reduced consumption of processed and red meat and sugar-sweetened beverages, with higher legumes and nuts consumption in Colombia and the UK. Moreover, all countries assumed reduced consumption of ultra-processed food compared to current trends. To further reduce the DALYs, a more significant increase of fruits, vegetables, and wholegrains consumption should be envisaged compared to the diets that have been tested here. In the UK, the Eatwell healthy diet recommended by the UK government could be used for a more holistic approach (Smith, Harrison et al., 2022).

In Ethiopia, lower **population** growth reduces demand in GS compared to CT. This projection aligns with the Ethiopian National Statistical Office's estimates, which forecast a reduced population growth rate due to increased contraceptive use (from 29% to 65% by 2050), delayed marriages, and higher school enrolment (CSA, 2013) and national policies aimed at reducing fertility rates, including the National Reproductive Health Strategy (FMoH, 2016), National Adolescents and Youth Health Strategy (FMoH, 2021), and the National Guideline on Family Planning (FMoH, 2011).

Food waste at the retail and household level is estimated at 26% and 27% respectively for cereals and fruits and vegetables in Europe. In the NC and GS pathways, the UK assumes a reduction of food waste share by 60% and 70% respectively which explains the significant impacts that this scenario has on the results. The reduction of demand due to lower food waste translates to lower cropland and pasture area by 2030 and is the main reason for reduced on-farm labor in 2030 and 2050 (revealing a potential trade-off with socio-economic goals). This is due to the high labor requirements per hectare to produce fruits and vegetables, which currently form a relatively large proportion of food waste.

2. *Increasing productivity*

Increasing **crop productivity** is the most important factor that reduces cropland area compared to CT (Figure 1-8 c). This also reduces the number of full-time equivalent workers in the agricultural sector, since labor intensity per hectare is assumed to be fixed over time in the FABLE Calculator. The reduction of cropland area avoids expansion onto natural land, with a significant positive impact on forest area in Brazil, Colombia, and Ethiopia, and on the area of other natural land particularly in Ethiopia. Increased crop productivity reduces GHG emissions due to lower CO_2 emissions from land use change, increased CO_2 sequestration on abandoned agricultural land, less CH_4 from rice cultivation (since a smaller area of flooded rice is needed), and a reduction in N_2O emissions from application of synthetic nitrogen on cropland. In the FABLE Calculator, part of the increase of the crop productivity is achieved by higher nitrogen application but this is offset by the reduction of the cropland area since nitrogen application rates are computed per hectare of cropland.

Higher productivity per animal and higher ruminant stocking rate on pasture (ruminant density) have large impacts, particularly in countries with large livestock herds such as Australia, Brazil, and Ethiopia. These productivity gains reduce the required pasture area but not the cropland area (Figure 1-8 c) since it is assumed in the Calculator that livestock productivity gains will require higher feed ratios. As for crop productivity, the reduction of pasture expansion resulting from productivity gains in the livestock sector is beneficial for natural (mostly non-forest) land, mainly through the abandonment of pasture which is assumed to revert to other natural land with slightly higher carbon stocks. Reduction of GHG emissions is also achieved through lower CH_4 and N_2O emissions per animal head. Ruminant density does not contribute significantly to the reduction of agrifood systems' hidden costs in Ethiopia in the decomposition analysis. This can be misleading as ruminant density is an important determinant of the future sustainability of livestock production, but in the Ethiopian model, it adjusts automatically to the demand to ensure that the total natural pasture area remains stable.

In the case of the UK, productivity gains lead to a slight increase in food consumption compared to CT. This is because targeted consumption could not be met under CT, as not enough unprotected natural land was available for the expansion of agricultural land. By increasing the possible production within the same land limits, productivity increase allows higher consumption, leading also to slightly higher GHG emissions. Another mechanism which is not represented in our model, but which could lead to similar patterns, is the rebound effect of increased demand following productivity increases due to lower prices. This has been widely documented in economic literature.

3. *Effective deforestation control*

Deforestation control has been assumed in Brazil, Colombia, and Ethiopia. The model does not say which incentives and policies need to be put in place to achieve this outcome, but our findings highlight the amount of avoided deforestation that could result from such actions: about 7 million hectares between 2045 and 2050 in Brazil, close to 5 million hectares in Ethiopia, and 0.5 million hectares in Colombia. There are potential trade-offs when this measure is implemented in isolation as it reduces the average level of food consumption in Brazil (Figure 1-8 a) and displaces agricultural expansion to non-forest natural land (Figure 1-8 c). This highlights the need of combining deforestation control with either changing diets and reduction of food loss and waste to reduce the demand, or with productivity gains to release the pressure on other land, as highlighted by the overall impact of the GS pathway.

4. *Afforestation*

Afforestation allows significant reduction of hidden costs related to GHG emissions through carbon sequestration (+ 10 million hectares in Australia, + 15 million hectares in Ethiopia, + 1.4 million hectares in the UK by 2050) (Figure 1-8 b). However, we can see that trade-offs can arise with other objectives. Afforestation reduces the area of non-forest natural land, either directly when this land is afforested, or indirectly when afforestation takes place on cropland or pasture but displaces cropland and pasture expansion onto other natural land (Australia, Brazil, Colombia, Ethiopia). This indirect effect can be observed in Brazil with additional deforestation resulting from afforestation when deforestation control is not implemented (Figure 1-8 c). Afforestation could also increase the delivery of ecosystem services, but this strongly depends on how afforestation is done, e.g., if it is through monoculture commercial plantations or assisted natural regeneration.

5. *Changing demand in the rest of the world*

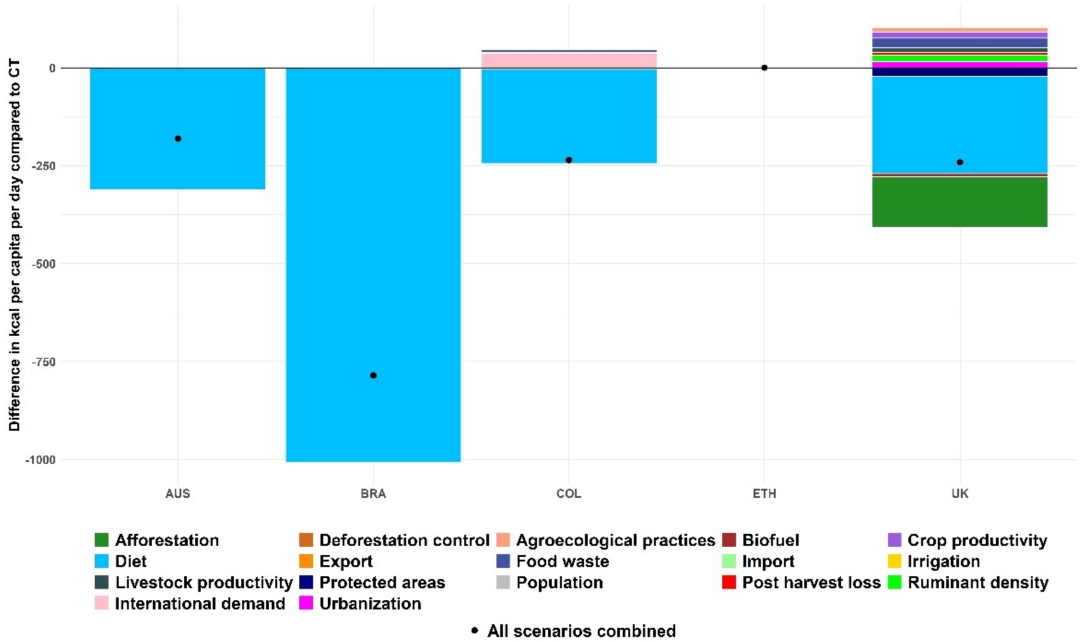
During the Scenathon, exports from each country are adjusted to meet the total aggregated imports from all countries and rest of the world regions for each product in each pathway. Changes in imports outside the country of interest affect hidden costs across the three pathways. Impacts are significant for major exporters like Australia and Brazil, where the impact of changes in international demand on cropland area is almost as important as domestic dietary change (Figure 1-8 c). In Australia, cropland reduction is driven by reduced exports of wheat (-17% in GS compared to CT in 2050), barley (-27%), and rapeseed (-38%) due to decreased global consumption of animal-based products and the resulting lower demand for cereals for animal feed, along with reduction of sugar exports (-25%). In Brazil, it is driven by the reduction of corn (-32%) and soybean exports (-11%) for animal feed, and sugar (-23%). These trade shifts significantly affect total nitrogen application in these two countries (Figure 1-8 d) because synthetic nitrogen application per hectare for corn and soybean in Brazil is above the average application rate for other crops. For Colombia, the evolution of international demand tends to increase hidden costs of agrifood systems in the GS pathway compared to CT because of higher Colombian exports of banana (+100% in 2050 in GS compared to CT) and coffee (+56%).

6. *Other impactful factors*

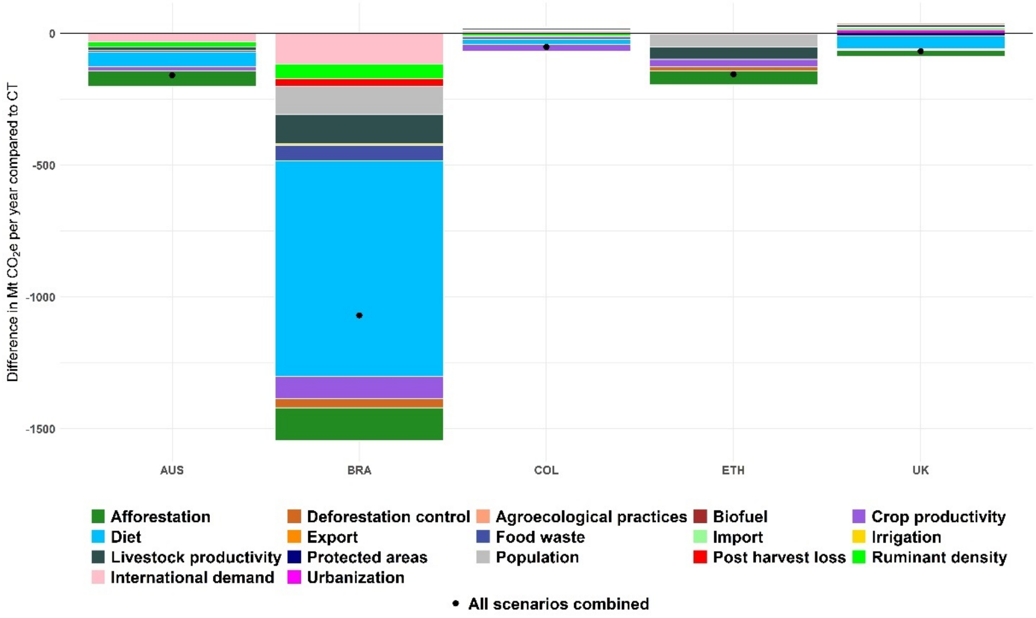
Agroecological practices play a major role in the UK for reducing nitrogen application and nitrogen emissions to air and water, with a target of 50% of cropland area under organic farming by 2050 in GS. This leads to a substitution of synthetic fertilizer with organic fertilizer and significantly reduces the amount of manure not applied to cropland (-84% in GS in 2050 compared to NC). Adoption of agroecological practices under GS also includes a large increase in cover crops and embedded natural land in agricultural land, but the resulting impacts on fertilizer use, CO_2 sequestration, and ecosystem services are not yet quantified in the FABLE Calculator. Through increases in nitrogen efficiency uptake rates in India, nitrogen surplus on land and manure is reduced by 61% by 2050.

Figure 1-8*: Impacts of each scenario parameter on the main hidden costs impact quantities when implemented alone, i.e., results of the decomposition analysis*

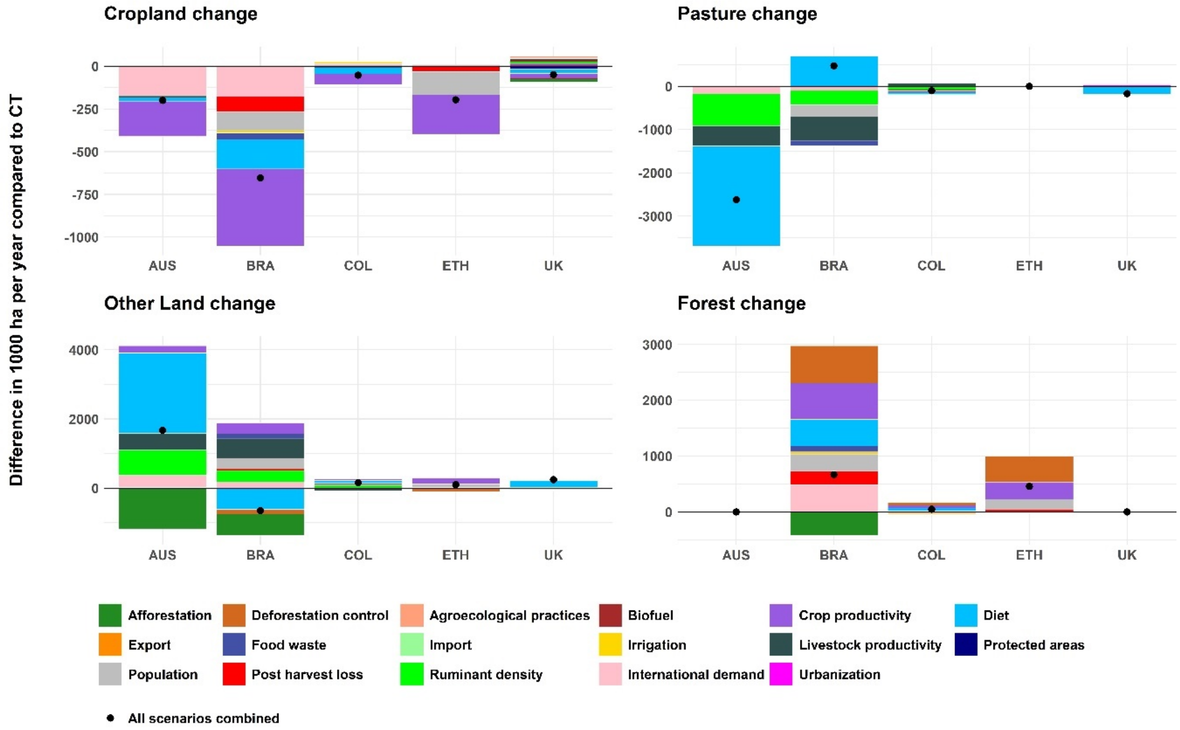
a) Average daily per capita kilocalorie consumption



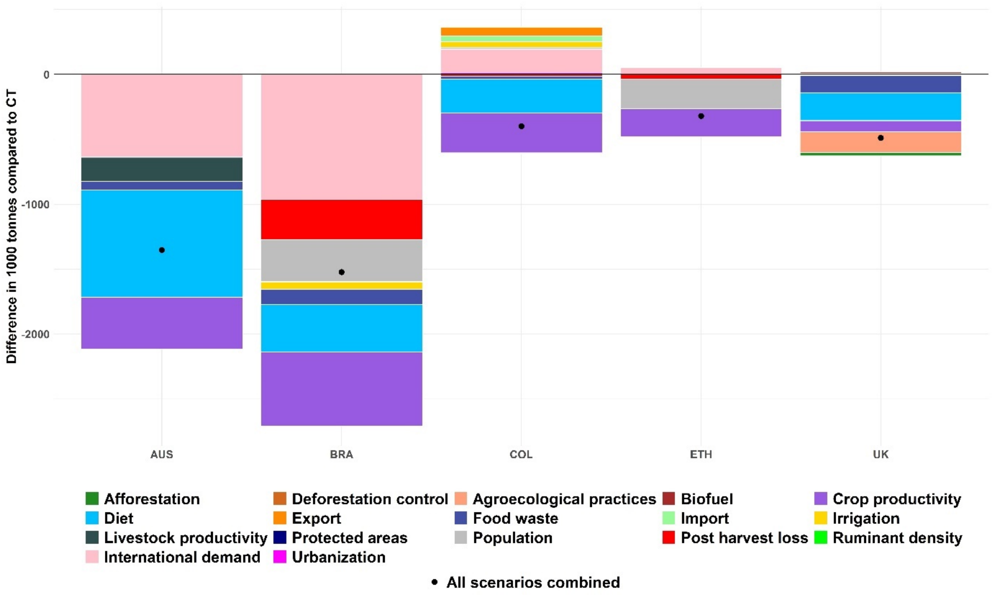
b) AFOLU GHG emissions



c) Area by land cover type



d) Nitrogen application



Note: India is not represented in these figures because the scenarios are different than in the FABLE-C. See Chapter 6 for the decomposition analysis of the MAgPIE-India results.

However, we can see some risks of trade-offs if these actions are taken in isolation: a) Dietary changes assumed in Brazil and the UK emphasize environmental benefits, but adjustments could be made to ensure larger health benefits and a better consideration of local preferences; b) Dietary changes could increase water demand (e.g., to grow more fruits and vegetables) and reduce on-farm employment (e.g., in the livestock sector), showing that this type of transition needs to be carefully managed at the local level; c) In some cases, productivity gain could increase demand further, which could offset some of the environmental benefits; d) Deforestation control could have negative effects on food consumption and displace agricultural expansion to non-forest natural land; e) Afforestation can lead to indirect deforestation or reduction of other natural land, while benefits from afforestation for ecosystem services strongly depends on how afforestation is done. To manage these trade-offs, an integrated strategy is required.

The Global Sustainability pathway leads to the best outcome compared to a path following current trends: between 2020 and 2050 our results show a reduction in accumulated hidden costs by 32% in Brazil, 24% in Colombia, 25% in Ethiopia, 57% in India, and 15% in the UK[3] (in 2020 PPP). In Australia, the reduction is 140%, i.e., the hidden deficit of current trends that would have accumulated over 2020–2050 is eliminated and benefits of the order of 40% of the CT hidden deficit are accumulated. Here, the agrifood system transitions from net hidden costs to net hidden benefits.

[3] This does not account for the hidden costs that are not computed based on the model's outputs, e.g., agri-food worker poverty.

Table 1-6: *Most impactful scenarios affecting each of the model outputs used for the hidden cost computation by country in 2050*

Sub-categories	Australia	Brazil	Colombia	Ethiopia	India	United Kingdom
CO_2 emissions	Afforestation	Dietary changes	Crop productivity	Constraints on agricultural expansion	Afforestation and expansion of protected areas	Dietary changes
CH_4 emissions	Dietary changes	Dietary changes	Food waste	Livestock productivity*	Dietary changes	Dietary changes
N_2O emissions	Crop productivity	Dietary changes	Dietary changes	Livestock productivity*	Nitrogen efficiency	Dietary changes
Total N	Dietary changes	Dietary changes	Crop productivity	Livestock productivity*	Nitrogen efficiency	Dietary changes
Cropland	Crop productivity	Crop productivity	Crop productivity	Crop productivity*	Livestock management	Crop productivity
Forest	*No change*	Crop productivity	Constraints on agricultural expansion	Constraints on agricultural expansion	*No change*	*No change*
Pasture	Dietary changes	Dietary changes	Ruminant density	Ruminant density	Dietary changes	Dietary changes
Other land	Dietary changes	Dietary changes	Crop productivity	Afforestation	Livestock management	Dietary changes
Water irrigation requirements	Crop productivity	Irrigation	Trade	Crop productivity *	Dietary changes	Food waste
Farm labour	Crop productivity	Crop productivity	Crop productivity	Crop productivity *	Dietary changes	Food waste
DALYs	Dietary changes	Dietary changes	Dietary changes	*No change*	Dietary changes	Dietary changes

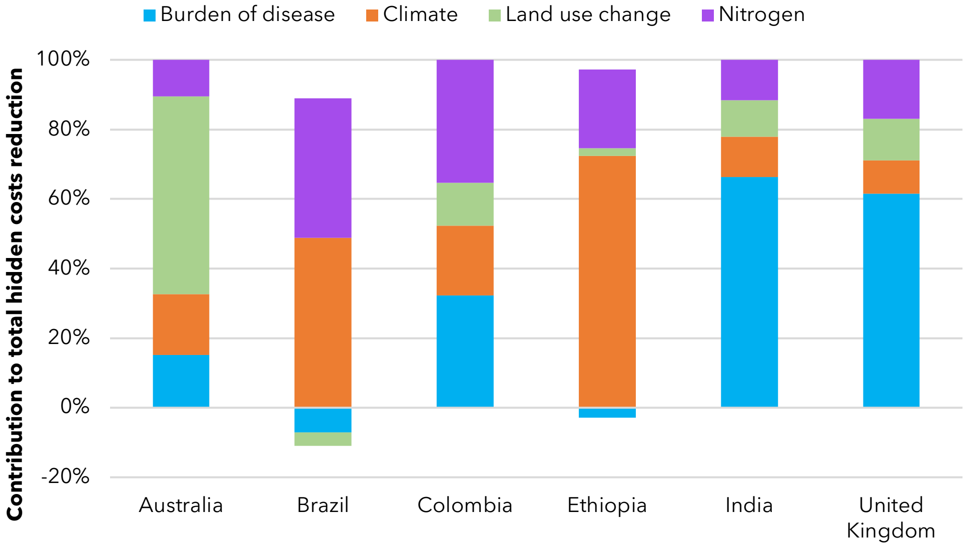
Frequency

1		2	3			7	16	31

NOTES: CO_2 = carbon dioxide; CH_4 = methane; N_2O = nitrous oxide; N = nitrogen; DALY = disability-adjusted life year; SSB = sugar-sweetened beverage. Dietary changes modelled include the following for each country: Australia – Higher intake of nuts and seeds, fruits, vegetables, legumes; lower intake of processed and red meat, and SSBs; Brazil – Lower intake of processed and red meat, and SSBs; Colombia – Lower intake of processed meat and SSBs; higher intake of legumes; India – Lower intake of sugars, salt, and processed foods; United Kingdom – Lower intake of processed meat; higher intake of legumes.

**The Global Sustainability scenario in Ethiopia includes a lower population assumption in line with the Ethiopian National Statistical Office's projections. While the largest decrease in hidden costs in these subcategories is attributable to this assumption, we show the most impactful outcome related to agrifood systems transformation – namely, livestock and crop productivity improvements – in this table.*

Figure 1-9: *Source of the computed reduction of hidden agrifood system costs in the sustainable pathway compared to current trends in 2050, by country*



In Figure 1-9, we can see that despite the dominant contribution of unhealthy diets to current hidden costs in all countries but Ethiopia, dietary change is only the first contributor for reducing hidden costs in India and the UK. Although the number of DALYs decreases in the GS pathway, the costs related to diets increase because each DALY is more expensive due to assumptions of higher GDP per capita, Human Development Index, and labor productivity in the SPIQ model (cf. Brazil and Ethiopia).

In Australia, most of the reduction in hidden costs comes from the afforestation program and natural regeneration of vegetation on abandoned agricultural land (land use change on Figure 1-9). In Brazil, demand-induced changes such as the assumed reductions in red meat intake in Brazil and globally contribute the bulk of the avoided costs savings from GHG emissions and nitrogen reduction. The increase of the hidden costs related to the global burden of disease in Brazil is due to lower intake of fruits and vegetables in GS that also resulted in a lower intake of wholegrains (correlation from the machine learning model, cf. 1.8.5). In Colombia, the reduction of hidden costs come mainly from the combination of dietary change and large productivity improvements that reduces overall nitrogen pollution from manure and feed production. In Ethiopia, the main source of the reduction of hidden costs is the reduction in GHG emissions achieved through the improvement in crop and livestock productivity, and reduced demand pressure.

The calculation of hidden costs involves significant uncertainty in the value of ecosystem services, the exposure and damage caused by nitrogen loading to ecosystem services and human health, and the long-term future economic conditions under climate change. Moreover, the disease burden from dietary risks from the GBD modeling also provides uncertainty. When these sources of uncertainty are included, this results in wide variance in the marginal costs of GHG emissions, reactive nitrogen pathways to air and soil, habitat loss, and productivity loss from food intake. In Australia, the scenarios used in the GS pathway magnify key uncertainties and shifts were not sufficient to provide robust conclusions given large uncertainty in hidden costs. To improve the sharpness and robustness of our results additional information in the ecosystem services of Australia's arid and semi-arid rangelands would be particularly needed.

1.5 Discussion and recommendations

How do the estimates of hidden costs overlap with countries' priorities for agrifood systems?

In all the case study countries of this report except Ethiopia, **unhealthy diets** trigger the biggest hidden costs (FAO, 2023). While some stakeholders in the five countries were surprised by the proportion of hidden costs related to unhealthy diets, there was a consensus that this is a significant and growing issue that urgently needs to be addressed.

Some hidden costs related to **undernourishment** are covered in the analysis but there was a feeling that they do not accurately reflect the size of the problem, particularly in low-income and lower-middle-income countries such as Ethiopia and India, but also in middle- and high-income countries where it might particularly affect some groups of the population and locations but not be visible at the aggregated national level. For future improvements of the hidden costs' methodology, it would be important to account for the lasting consequences of undernourishment during childhood on human capital and consequently on labor productivity, also to include the impacts of micronutrient deficiencies, and better consider the sub-national heterogeneity of undernourishment.

Environmental costs tend to be the second most important source of hidden costs, and thus, addressing them is the next most important priority. This coincides well with countries' commitments to halt deforestation, reduce GHG emissions (Paris Climate Agreement), and enhance biodiversity (Kunming-Montreal Global Biodiversity Framework). Environmental costs are likely underestimated as highlighted in SOFA 2023. Accounting for pesticide impacts on biodiversity would be a great improvement in the future. The hidden costs of GHG emissions and air pollution related to household traditional cooking could also be included in some countries where statistics are available, such as India, but this might be more difficult at the global level.

How to ensure dietary shifts towards healthy food for all?

In Australia, some recent trends towards more plant-based eating are encouraging and in India, there are current efforts such as the National Food Security and Nutrition Mission, to promote a higher consumption of legumes, fruits, vegetables, and nuts, but improvements are still limited. In the UK, stakeholders highlighted the need for more research on how to achieve dietary change. Potential actions include a carbon tax on food; a sugar tax; education about healthy food; warning labels on ultra-processed and high-sugar food and other properties related to high-risk health externalities (obesity, type 2 diabetes, etc.); emphasizing the benefits of a healthy diet; a reduction in the working week so people have more time to cook healthy food; free school meals; and a less unequal society. Education alone is not enough, as consumers live in an environment full of unhealthy food choices and marketing, so it needs to be backed by strong policy in other areas. For instance, the Welsh Government is working on a dietary-shift systems map which will identify key policy instruments.

Public procurement of healthy food with lower environmental impacts (e.g., in schools and hospitals) plays an important role. In Ethiopia, healthier diets require both incomes to be increased and the cost of healthy food to be reduced. The increase in income could be achieved by diversifying livelihood options, in which farmers can increase their income through non-agricultural employment (e.g., in industry and services), that will ultimately help them get out of poverty. The affordability of food could be increased by shifting the production focus from increasing food quantity to prioritizing nutritious food production. Several country profiles (including Ethiopia and Colombia) would potentially benefit from the establishment of better connections between producers and consumers, and the creation of cooperatives offering better infrastructure and market data, that can boost incomes and decrease costs due to more efficient marketing processes.

Which policy instruments can be mobilized to reduce negative externalities of agricultural production?

To mitigate negative environmental externalities resulting from agricultural production, governments might also utilize regulations imposing a carbon tax. For countries like Colombia, in which sustainable agricultural intensification is an ongoing effort, policies could enhance this process by facilitating technical assistance for producers to apply best practice and meet the demand while reducing GHG emissions, soil degradation, and water pollution. In the UK, agri-environment schemes including ELMS in England and similar schemes emerging in the other UK nations have a key role to play in reducing the hidden costs of agriculture, if uptake is significant. Extra support would be required for farmers who want to adopt certain agroecology practices to compensate for a possible reduction in production for the first few years. Pollution regulations are important and could improve nitrogen management around storage and application of manure and slurry. Schemes could potentially incentivize greater uptake of innovation through precision farming, which can limit the use of synthetic fertilizers and agro-chemicals and ultimately reduce negative agricultural impacts.

How to protect and enhance ecosystem services?

Actions for protecting and enhancing ecosystem services are key to several countries in the current report. Halting illegal deforestation in Brazil and Colombia is an ongoing effort. Deforestation-related restrictions could be also implemented in countries of consumption such as the EU regulation currently promoting the consumption of "deforestation-free" products. It should be noted that the link between reduction of ruminant meat consumption and pasture area might be more complex than modeled here. Some pasture expansion in the tropics is not directly related to meat production but more to land speculation, i.e., it is barely correlated with the demand for beef, milk or other cattle products. This type of deforestation can only be curbed by deforestation control measures and changes in the rules to claim land property rights. Additionally, the restoration of degraded areas, especially Brazilian pastures, has high potential to spare land that can be dedicated to other uses such as afforestation. National policies and programs towards those practices have the capacity to conserve water, sequester carbon and maintain and improve soil quality. As far as soil health and quality is concerned, many countries of the current report acknowledge its pivotal role (Brazil, UK and India) calling for further investments to enhance soil conservation, as this remains relatively underrepresented in policy and regulations. Finally, habitat protection is not just about creating more protected areas, but also about providing the resources needed to improve the condition of existing protected areas and manage them properly.

Recommendations for modelling hidden costs

- There remains a great need for comparison between the different iterations of the Global Burden of Disease assessment and other models such as Marco Springmann's since they use very different relative diet risk factors for different food groups, and more particularly meat. Transparency in this aspect is particularly needed in a context where a strong pushback against recommendations to change diets is observed across the world.
- Neither the FABLE Calculator nor the MAgPIE model can yet estimate the impacts of dietary changes on health. They need to be coupled with other models to translate consumption by food group to DALYs, and DALYs are then used as input to the SPIQ-FS model to compute the impact on labor productivity (cf. 1.8.5). It would be important to include an assessment of health impacts directly in the agrifood system models to help experts design and test dietary change scenarios better suited to health requirements and

cultural preferences. That would lead to better outcomes on total hidden costs.

- Improvements are needed to better include the factors that affect the evolution of undernourishment such as scenarios on the evolution of income distribution, the impact of extreme climate events, the evolution of stocks, and connectedness of rural areas to the rest of the country.
- Both the MAgPIE model and the FABLE Calculator have shortcomings to assess the evolution of agrifood workers' poverty. Productivity increases which are included in our models could improve farmers' income, but the final income effects will depend on the evolution of the quantity and prices of inputs used to reach higher productivity, and prices of the crops and livestock products which are sold by the different agents of the agrifood value chain. For instance, overproduction can cause prices to collapse and a degradation of farmers' income. Moreover, adoption of some practices might reduce employment needs in the agricultural sector but people might not have better employment alternatives. A Computable General Equilibrium model that covers the whole economy would be better suited to do this type of assessment. To assess the impacts of a more equal distribution of the value added generated within the whole chain of agrifood on workers' poverty, other models such as agent-based models would be more appropriate to represent the interactions between different agents.
- To facilitate the estimate of future hidden costs related to nitrogen in SPIQ-FS, the FABLE Calculator would need to be improved to compute the nitrogen balance in addition to nitrogen application.
- Different techniques are currently used to ensure models reproduce historical deforestation, often using an exogenous component that is calibrated as the difference between the historical deforestation and the computed commodity-driven deforestation. Improvements are needed in our agrifood system models to better represent the non-demand drivers of deforestation and consequently, provide more robust estimates of this deforestation and the impact of different policies on it.

1.6 Conclusion

Applying a national perspective to first review the hidden costs computed in SOFA 2023 and then model the impacts of context-specific scenarios on the evolution of the hidden costs by 2050 in Australia, Brazil, Colombia, Ethiopia, India, and the UK, was a very constructive process. First, both the authors of this study and stakeholders who have been consulted were able to gain a deeper awareness and understanding of the hidden costs generated by agrifood systems. There are challenges to communicate the complexity of the method, and the marginal costs are particularly hard to sense-check for non-experts on hidden costs. However, it was noticed that this topic is gaining momentum, including for policy planning, and several governments (e.g. the UK, Australia, India) are already either utilizing or planning to develop similar metrics so it was a timely exercise. Second, while it was not possible in the scope of this study to adapt the hidden costs model to specific countries, better local datasets have been identified that will improve the quality of hidden costs estimates in the six countries if a tailored assessment is envisaged. Third, important data gaps have been identified in countries, highlighting the need to invest in data collection, for instance for nitrogen application or the value of ecosystem services in different locations. Fourth, some improvements would be needed in the suite of models which have been used, particularly to increase the transparency and the number of iterations with stakeholders.

1.7 References

ABS, 2022. Water Use on Australian Farms [WWW Document]. URL https://www.abs.gov.au/statistics/industry/agriculture/water-use-australian-farms/latest-release (accessed 2.27.24).

ABS, 2015. Australian Health Survey: Usual Nutrient Intakes [WWW Document]. URL https://www.abs.gov.au/statistics/health/health-conditions-and-risks/australian-health-survey-usual-nutrient-intakes/latest-release (accessed 2.27.24).

Australian Government Department of Climate Change, Energy, the Environment and Water, 2021. Australian National Greenhouse Gas Inventory (NGGI) [WWW Document]. URL https://www.dcceew.gov.au/climate-change/publications/national-greenhouse-gas-inventory-quarterly-updates (accessed 2.23.24).

Australian Institute of Health and Welfare, 2019. Overweight & obesity Overview [WWW Document]. Australian Institute of Health and Welfare. URL https://www.aihw.gov.au/reports-data/behaviours-risk-factors/overweight-obesity/overview (accessed 3.1.24).

Bank, W., 2018. Ethiopia Economic Update: The Inescapable Manufacturing-Services Nexus. World Bank.

Bodirsky, B. L., Beier, F., Humpenöder, F., Leip, D., Crawford, M., Chen, D., von Jeetze, P., Springmann, M., Soergel, B., Nicholls, Z., Strefler, J., Lewis, J., Heinke, J., Müller, C., Karstens, K., Weindl, I., Führlich, P., Mishra, A., Molina Bacca, E., Stevanovic, M., Koberle, A., Wank, X., Singh, V., et al., 2023. A food system transformation can enhance global health, environmental conditions and social inclusion. https://doi.org/10.21203/rs.3.rs-2928708/v1

Béné, C., Fanzo, J., Achicanoy, H.A., Lundy, M., 2022. Can economic development be a driver of food system sustainability? Empirical evidence from a global sustainability index and a multi-country analysis. PLOS Sustainability and Transformation 1, e0000013. https://doi.org/10.1371/journal.pstr.0000013

Bizikova, L., De Brauw, A., Rose, M.E., Laborde, D., et al., 2022. IISD.org ii Achieving Sustainable Food Systems in a Global Crisis: Ethiopia International Institute for Sustainable Development Achieving Sustainable Food Systems in a Global Crisis: Ethiopia Ceres2030 Deep Dives into the Nexus of Food Systems, Climate Ch.

Bodirsky, B., Beier, F., Humpenoder, F., Singh, V., 2023. A food system transformation can enhance global health, environmental conditions and social inclusion. preprint. https://doi.org/10.21203/rs.3.rs-2928708/v1

Bukhman, G., Mocumbi, A.O., Atun, R., et al., 2020. The Lancet NCDI Poverty Commission: bridging a gap in universal health coverage for the poorest billion. The Lancet 396, 991–1044. https://doi.org/10.1016/S0140-6736(20)31907-3

Costa, W., Scarabello, M., Soterroni, A.C., Ramos, F., 2020. Pathways to Sustainable Land-Use and Food Systems in Brazil by 2050, in: FABLE 2020, Pathways to Sustainable Land-Use and Food Systems. International Institute for Applied Systems Analysis (IIASA) and Sustainable Development Solutions Network (SDSN), pp. 130–160.

CSA, 2013. Population projections for Ethiopia 2007–2037. Federal Democratic Republic of Ethiopia, Population Census Commission Addis.

CSE, 2019. Grain by grain: Green rating of the fertiliser sector.

Davis, B., Mane, E., Gurbuzer, L.Y., et al., 2023. Estimating global and country-level employment in agrifood systems, FAO Statistics Working Paper Series. FAO, Rome, Italy. https://doi.org/10.4060/cc4337en

DCCEEW, 2021. National Inventory Report 2021. Commonwealth of Australia.

Diao, X., Pauw, K., Thurlow, J., Ellis, M., 2023. Ethiopia's agrifood system structure and drivers of transformation.

Dietrich, J.P., Bodirsky, B.L., Humpenöder, F., et al., 2019. MAgPIE 4 – a modular open-source framework for modeling global land systems. Geoscientific Model Development 12, 1299–1317. https://doi.org/10.5194/gmd-12-1299-2019

Dietrich, J.P., Bodirsky, B.L., Weindl, I., et al., 2023. MAgPIE - An Open Source land-use modeling framework. https://doi.org/10.5281/ZENODO.7920802

Fanzo, J., Haddad, L., McLaren, R., et al., 2020. The Food Systems Dashboard is a new tool to inform better food policy. Nature Food 1, 243–246. https://doi.org/10.1038/s43016-020-0077-y

FABLE, 2024. Transforming food and land systems to achieve the SDGs. In Sachs et al. (2024) The Sustainable Development Report 2024. SDSN, New York and Paris.

FAO, 2024. The State of Food and Agriculture 2024: Value driven transformation of agrifood systems. Rome.

FAO, 2023. The State of Food and Agriculture 2023: Revealing the true cost of food to transform agrifood systems. FAO, Rome. https://doi.org/10.4060/cc7724en

FDRE, 2022. Third National Communication (NC3) of the Federal Republic of Ethiopia 1–349.

FDRE, 2021. Vision 2030: Transforming Ethiopian Food Systems.

FDRE, 2012. Federal Democratic Republic of Ethiopia Ethiopia ' s Progress Towards Eradicating Poverty :

FDRE, 1986. Food and Nutrition Policy. Food and Nutrition Bulletin 8, 1–6. https://doi.org/10.1177/156482658600800310

FDRE, F.D.R. of E., 2011. Ethiopia's Climate Resilient Green Economy (CRGE) Strategy. Federal Democratic Republic of Ethiopia 200.

Ferrari, G., Giannichi, B., Resende, B., Paiva, L., Rocha, R., Falbel, F., Rache, B., Adami, F., Rezende, L.F.M., 2022. The economic burden of overweight and obesity in Brazil: perspectives for the Brazilian Unified Health System. Public Health 207, 82–87. https://doi.org/10.1016/j.puhe.2022.03.015

FMoH, 2021. National Adolescents and Youth Health Strategy.

FMoH, 2016. National Reproductive Health Strategy. FMoH 1–49.

FMoH, 2011. National Guideline for Family Planning Services In Ethiopia.

Foodbank, 2023. Foodbank Hunger Report 2023 - Foodbank Reports.

Forouzanfar, M.H., Alexander, L., Anderson, et al., 2015. Global, regional, and national comparative risk assessment of 79 behavioural, environmental and occupational, and metabolic risks or clusters of risks in 188 countries, 1990–2013: a systematic analysis for the Global Burden of Disease Study 2013. The Lancet 386, 2287–2323. https://doi.org/10.1016/S0140-6736(15)00128-2

Guendehou, G.H.S., 2006. IPCC NGGIP Technical Support Unit Inventory Internship Land-Use Changes and Greenhouse Gas Fluxes : Scientific Understanding and Contribution to Improving Methodologies for Greenhouse Gas Inventory in BENIN. Strategies 2005–2006.

ICMR, PHFI, IHME, 2017a. India: Health of the Nation's States - The India State-Level Disease Burden Initiative. Indian Council Of Medical Research Public Health Foundation Of India, Institute For Health Metrics And Evaluation.

ICMR, PHFI, IHME, 2017b. India: Health of the Nation's States. Indian Council for Medical Research.

IDEAM, 2023. Estudio Nacional del Agua 2022.

Jha, C.K., Singh, V., Stevanović, M., Dietrich, J.P., Mosnier, A., Weindl, I., Popp, A., Traub, G.S., Ghosh, R.K., Lotze-Campen, H., 2022. The role of food and land use systems in achieving India's sustainability targets. Environ. Res. Lett. 17, 074022. https://doi.org/10.1088/1748-9326/ac788a

Lal, A., Peeters, A., Brown, V., et al., 2020. The Modelled Population Obesity-Related Health Benefits of Reducing Consumption of Discretionary Foods in Australia. Nutrients 12, 649. https://doi.org/10.3390/nu12030649

Lord, S., 2023a. Hidden costs of agrifood systems and recent trends from 2016 to 2023 – Background paper for The State of Food and Agriculture 2023 (FAO Agricultural Development Economics Technical Study No. 13). Food and Agricultural Organization, Rome.

Lord, S., 2023b. Regional analysis of hidden costs of the Food System Economic Commission current trends and food system transformation pathways to 2050: India Key Figures.

Mekuriaw, Z., Harris-Coble, L., 2021. Ethiopia's livestock systems: Overview and areas of inquiry.

Minten, B., Dereje, M., Bachewe, F., Tamru, S., 2018. Evolving food systems in Ethiopia : Past , present and future.

MoA, ATI, 2024. Rural Connectivity to Support Food Security Project (P176303) Appraisal Federal Democratic Republic of Ethiopia Ministry of Agriculture (MoA) and Agricultural Transformation Institute (ATI) 1–11.
MoANR and MoLF, 2017. Federal Democratic Republic of Ethiopia National Nutrition Sensitive Agriculture Strategy 1–35.
MoE, 2024. The National Potato and Sweetpotato Development Strategy(NSPSDS) 2024-2030.
MoEFCC, 2021. India. Third Biennial update report to the United Nations Framework Convention on Climate Change. Government of India.
Molla, K.G., Woldeyes, F.B., 2020. "Pathways to Sustainable Land-Use and Food Systems in Ethiopia by 2050" In: FABLE 2020, Pathways to Sustainable Land-Use and Food Systems, 2020 Report of the FABLE Consortium. 262–291. https://doi.org/10.22022/ESM/12-2020.16896
Mosnier, A., Javalera-Rincon, V., Jones, S.K., et al., 2023. A decentralized approach to model national and global food and land use systems. Environ. Res. Lett. 18, 045001. https://doi.org/10.1088/1748-9326/acc044
Mosnier, A., Penescu, L., Perez-Guzman, K., Steinhauser, J., Thomson, M., Douzal, C., Poncet, J., 2020. FABLE Calculator documentation- 2020 update. IIASA (Laxenburg) and SDSN (Paris).
MoSPI, G. of I., 2024. Household Consumption Expenditure Survey:2022-23 Factsheet.
National Indigenous Australians Agency, 2020. Food prices and accessibility in remote communities: 'simple basket of goods' snapshot.
National Statistics, 2015. Health Survey for England.
Navarro Garcia, J., Marcos-Martinez, R., et al., 2022. Multi-target scenario discovery to plan for sustainable food and land systems in Australia. Sustain Sci. https://doi.org/10.1007/s11625-022-01202-2
Nguyen, H., 2018. Sustainable food systems: Concept and framework. FAO, Rome, Italy.
Niti Aayog, 2023. MULTIDIMENSIONAL POVERTY IN INDIA SINCE 2005-06 (No. A Discussion Paper). UNDP, New Delhi, India.
NSSO, 2023. Key Employment Unemployment Indicators (Jan 2023-Dec 2023). Ministry of Statistics and Program Implementation, Government of India, New Delhi, India.
O'Neill, B.C., Kriegler, E., Ebi, K.L., et al., 2017. The roads ahead: Narratives for shared socioeconomic pathways describing world futures in the 21st century. Global Environmental Change 42, 169–180. https://doi.org/10.1016/j.gloenvcha.2015.01.004
Panagariya, A., More, V., 2023. Poverty and Inequality in India: Before and After Covid-19.
Pires, M.V., Cunha, D.A. da, Carlos, S. de M., Costa, M.H., 2015. Nitrogen-Use Efficiency, Nitrous Oxide Emissions, and Cereal Production in Brazil: Current Trends and Forecasts. PLOS ONE 10, e0135234. https://doi.org/10.1371/journal.pone.0135234
Popp, A., Calvin, K., Fujimori, S., Havlik, P., Humpenoder, F., Stehfest, E., Bodirsky, B.L., 2017. Land-use features in the shared socio-economic pathways. Global Environmental Change 42, 331–345.
Raghunathan, K., Headey, D., Herforth, A., 2021. Affordability of nutritious diets in rural India. Food Policy 99, 101982. https://doi.org/10.1016/j.foodpol.2020.101982
Reardon, T., Echeverria, R., Berdegué, J., et al., 2019. Rapid transformation of food systems in developing regions: Highlighting the role of agricultural research & innovations. Agricultural Systems 172, 47–59. https://doi.org/10.1016/j.agsy.2018.01.022
Riahi, K., Van Vuuren, D.P., Kriegler, E., et al., 2017. The shared socioeconomic pathways and their energy, land use, and greenhouse gas emissions implications: an overview. Global environmental change 42, 153–168.
Rocha, C.E.F., Parajára, M. do C., Machado, Í.E., Vegi, A.S.F., Menezes, M.C. de, Meireles, A.L., 2023. Chronic diseases attributable to a diet rich in processed meat in Brazil: Burden and financial impact on the healthcare system. Frontiers in Nutrition 10.
Rudolph, S., Aydos, E., 2021. Lessons learned from the implementation of ETS. Carbon Markets Around the Globe 1–7. https://doi.org/10.4337/9781839109096.00013
Santos, E.A., Cunha, D.A., Travassos, G.F., 2023. Nitrogen demand and agro-environmental efficiency in Brazilian cereal production. Braz J Biol 83, e268927. https://doi.org/10.1590/1519-6984.268927
Sharma, M., Kishore, A., Roy, D., Joshi, K., 2020. A comparison of the Indian Diet with the EAT-Lancet Reference Diet. BMC Public Health. https://doi.org/10.21203/rs.2.19833/v2

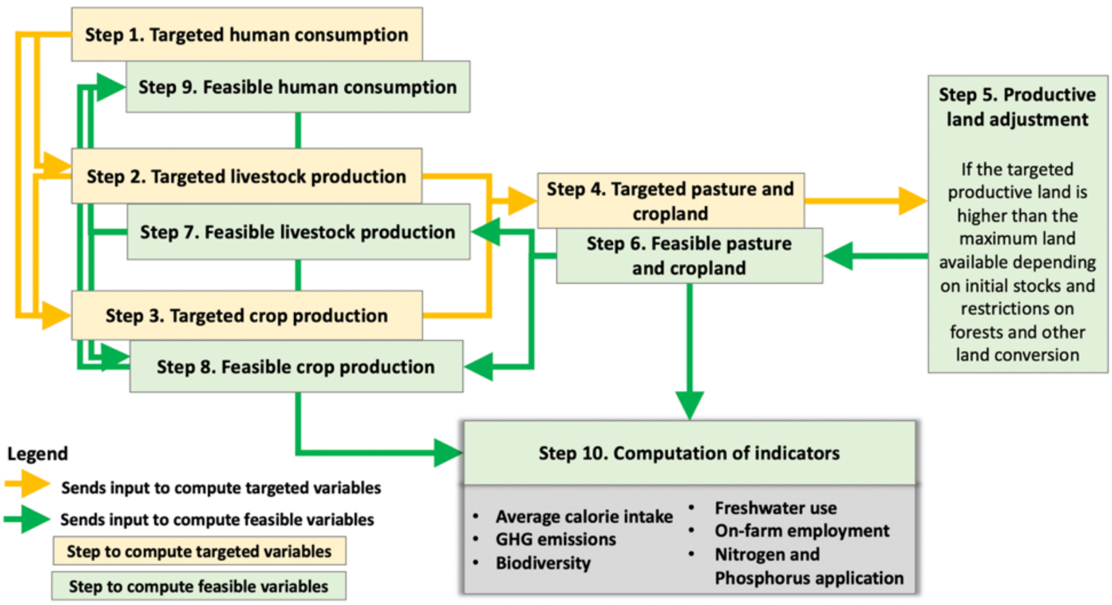
Singh, V., Das, P., Stevanovic, M., Jha, C., et al., 2024. An Inclusive agri-food systems transformation pathway for India. https://doi.org/10.21203/rs.3.rs-4767324/v1
Singh, V., Stevanovic, M., Jha, C.K., Beier, F., Ghosh, R.K., Lotze-Campen, H., Popp, A., 2023. Assessing policy options for sustainable water use in India's cereal production system - IOPscience. Environmental Research Letters. https://doi.org/10.1088/1748-9326/acf9b6
Smith, A.C., Harrison, P.A., Leach, N.J., et al., 2022. Sustainable pathways towards climate and biodiversity goals in the UK: the importance of managing land-use synergies and trade-offs. Sustain Sci. https://doi.org/10.1007/s11625-022-01242-8
Soergel, B., Kriegler, E., Bodirsky, B.L., Bauer, N., Leimbach, M., Popp, A., 2021. Combining ambitious climate policies with efforts to eradicate poverty. Nat Commun 12, 2342. https://doi.org/10.1038/s41467-021-22315-9
Solanki, S., Chakraborty, M., Gupta, S., K.P., R., Dutt, R., Mehta, 2022. GHG Platform India 200-5-2018 National Esimates - 2005-18 Series.
Souza, C.M., Z. Shimbo, J., Rosa, M.R., et al., 2020. Reconstructing Three Decades of Land Use and Land Cover Changes in Brazilian Biomes with Landsat Archive and Earth Engine. Remote Sensing 12, 2735. https://doi.org/10.3390/rs12172735
UK National Accounts, The Blue Book: 2021, 2021.
UNFCCC, 2022a. UK Greenhouse Gas Inventory, 1990 to 2020.
UNFCCC, 2022b. Colombia. Biennial update report (BUR). BUR3.
UNFCCC, 2021. India. Biennial update report (BUR). BUR3. [WWW Document]. URL https://unfccc.int/documents/268470 (accessed 2.23.24).
van Vuuren, D.P., Edmonds, J., et al., 2011. The representative concentration pathways: an overview. Climatic Change 109, 5–31. https://doi.org/10.1007/s10584-011-0148-z
Von Bloh, W., Schaphoff, S., et al., 2018. Implementing the nitrogen cycle into the dynamic global vegetation, hydrology, and crop growth model LPJmL (version 5.0). Geoscientific Model Development 11, 2789–2812.
WB, 2020. Ethiopia poverty assessment: Harnessing continued growth for accelerated poverty reduction.
World Bank, 2024. Poverty and Inequality Platform.

1.8 Annexes

1.8.1 FABLE Calculator

The FABLE Calculator represents the evolution of 88 agricultural raw and processed products, from both crop and livestock sectors, building on the FAOSTAT database. The integration of national and global scales in FABLE is done through Scenathons. National quantitative pathways are developed individually by country-level research teams while regional quantitative pathways are developed by the FABLE Secretariat for countries not currently represented in the Consortium. Export volumes from each exporting country and region are proportionally adjusted to match global imports for each product and time step and national and regional pathways are bound by trade volumes that align globally (Mosnier et al. 2013).

Figure A1: *Computation steps in the FABLE Calculator*



The first step of computation includes the annual human demand for food consumption and non-food consumption. This step consists of three components: food, biofuels, and other non-food consumption. Food and non-food demand per product and capita for the historical years (2000–2020) is estimated using information on commodity balance derived from FAOSTAT (information on sources available in Table A1). The patterns of food consumption per capita depend on the selected scenario relevant to the evolution of the average kilocalorie consumption per food group and capita, per time step. By default, the other non-food demand per capita is fixed at the last historical year available (2020) level, a value that can be easily modified by the user. The final demand per capita, year, and product is estimated as the sum of a) non-food consumption per capita and b) food consumption per capita, adjusted by the share of consumption that is wasted at the retail and household level. Total demand is calculated by multiplying the average demand per capita by the total population and adding the demand for biofuels production. Targeted production is computed as human consumption that includes waste, increased by the post-harvest losses (accounted as a share). The demand for animal feed is added to human consumption of crop products. Imports depend on computed internal demand and the assumption about the share of this consumption that needs to be imported. Exports are exogenously driven.

The second step of the FABLE Calculator computes production from the livestock sector. This sector both supplies animal food products and consumes other agricultural products in the form of animal feed. For that reason, the livestock production calculations precede the crop sector calculations. This step calculates the evolution of the livestock herd which then determines the feed demand and the pasture area, which are used in the calculation steps that follow. The livestock herd comprises the livestock categories dairy cattle, other cattle, dairy sheep and goats, other sheep and goats, laying hens, chicken broilers, mixed poultry, and pigs. The number of animals is computed as the projected domestic production volume, multiplied by the contribution of each animal type and production system in the total production per animal product in 2000 as reported by Herrero et al. (2013). Animal numbers are reported in a tropical livestock unit (TLU) basis, which is computed by dividing the animal type and production system by the corresponding average productivity rate in the year 2000. Animal productivity until the year 2020 corresponds to calibrated productivity from FAOSTAT, and from 2020 onwards it depends on the selected animal productivity scenario.

Feeding requirements per TLU derived from Herrero et al. (2013) include corn, wheat, sorghum, rice, barley, other cereals, and soybean, for each animal type and production system. Feed requirements here are assumed to vary proportionally in connection with assumed changes in animal productivity. This assumption might lead to an overestimation of the increase in animal feed demand over time when productivity gains are high while improvements in breeding and animal health could also play a significant role in lowering the rate of increase in feed demand. The number of ruminants is then divided by the average ruminant density per hectare to estimate the targeted pasture area. Historical ruminant density is computed using FAOSTAT's ruminant numbers divided by the grassland area for 2000 to 2020 and kept constant at 2020 levels over the 2025–2050 period. An optional update package for implementing alternative scenarios on the evolution of ruminant density is available.

For estimating targeted crop production, the initial inputs are human consumption and feed demand which were computed in the previous steps. The volumes of imports are then estimated by multiplying the sum of human and feed demand by the share of the consumption that is imported, according to the selected import scenario. Exported quantity is taken from the selected export scenario.

Additional demand for crops comes from processing. This is related to the human and feed demand for processed commodities such as vegetable oils or refined sugar. Targeted production of processed commodities is computed similarly to the estimation of targeted crop production, with the addition of a computation step that is required to calculate the quantity of raw product (crop) that is needed to produce the targeted production of the final (processed) product. The processing coefficient is introduced, calculated as the reported production level of a processed product divided by the reported processed quantity of the raw product used as input in 2020 according to the FAO Commodity Balance (e.g., the production of sunflower oil divided by the sunflower quantity which is reported as processed). Targeted production is the sum of the targeted production of a crop which is used as the final product and the targeted production of a crop which is used for processing. Multiple products can stem from processing the same initial input. For example, after extracting oil from oilseeds, the remaining oilseed cakes can serve as animal feed. To accurately determine the harvested areas corresponding to specific production, it is vital to choose the primary input production that leads to a singular final processed product, preventing any double counting.

Harvested area is estimated as the total targeted production divided by the average annual yield on a tonne per hectare basis. Productivity levels (yield) are derived from FAOSTAT for the years 2000 to 2020, and for the period 2025–2050 yields vary depending on the productivity scenario that is selected. In some countries, multiple harvest rounds are possible during the same year, which results in estimates of lower cropland area than the total harvested area per year. The planted area is estimated by dividing the harvested area by the harvesting coefficient. The average harvesting coefficient is computed as the sum of the harvested area per crop divided by the total cropland area using historical FAO data. Where the total harvested area is lower than the cropland area, the harvesting coefficient is set to 1. This can be explained by missing crops in the FAO database but also because arable land includes "temporary meadows for mowing or pasture, land under market and kitchen gardens and land temporarily fallow (less than five years)" (FAOSTAT, 2020), which are not yet explicitly considered in the FABLE Calculator. The difference is allocated to "other crops" and this area is set constant at 2000 levels for the whole period of the simulation.

The Calculator incorporates six distinct land cover categories: pasture, cropland, urban areas, forests, new forests, and other natural lands. The category “other natural land” in 2000 was derived by computing the difference between the total land area of a country or region and the combined area occupied by pasture for livestock, cropland, forests, and urban areas. As a result, this category can potentially include a range of diverse land types and varying levels of wilderness. Changes in pasture, cropland, urban, and new forest areas subsequently influence alterations in forest and other natural land as the overall land area remains constant. To determine the initial area for each land cover type at the beginning of a given period, historical data from 2000 is used as a baseline, while the computed feasible area from the previous period is used for following time steps. If the intended expansion exceeds the maximum allowable expansion due to scenario constraints or limited land availability, the maximum value is utilized to calculate the feasible productive land area. The adjustment factor for pasture and cropland is calculated by comparing the maximum feasible area for pasture and cropland with the targeted areas. Urban and afforested areas are excluded from this adjustment process.

Any disparity between the targeted and feasible areas for pasture or cropland is traced back to the cause-and-effect pathway to the consumption level. As a starting point, adjustments are made within the livestock sector. The targeted pasture area is first multiplied by the pasture adjustment ratio, determining the count of ruminant herds. The updated herd number is determined by re-estimating the feasible pasture area in relation to ruminant density. For feed, the demand for all crops and their processed products is initially multiplied by the cropland adjustment ratio. Subsequently, the adjusted feed demand, based on the feasible ruminant herd count, is computed according to feed requirements. The feasible feed demand is established as the minimum of the new feed demand derived from the adjusted herd and the adjusted feed demand from the cropland adjustment ratio. The feasible herd count is then calculated by dividing the feasible feed by the feed requirement. For both exports and final human consumption of livestock products, reductions are proportionally applied based on the ratio of the feasible herd to the targeted herd. In scenarios where “Fixed trade” is chosen, exports are not adjusted proportionally to compensate for production reduction caused by land constraints. Instead, the reduction is allocated exclusively between feed demand and final human consumption.

For crops, the targeted planted area for all crop products is adjusted by multiplying it with the cropland adjustment factor. This factor ensures a proportional reduction in the planted area, by crop, in line with the overall cropland reduction. The calculation of feasible production is based on multiplying the feasible planted area per crop by the average number of harvests per year and then by the productivity per hectare. Feasible feed, already determined in the previous step, remains unchanged, while imports are held constant. To maintain market equilibrium, feasible final human demand, feasible exports, and feasible processed demand are adjusted to compensate for the residual reduction in crop production.

Table A1: *Main input data sources to the FABLE Calculator*

	FABLE Calculator
Demand	FAOSTAT: Food, Feed, Process, Non-Food Demand, Post-harvest Losses, Imports, Export quantities
Bioenergy	OECD-FAO
Crop production	FAOSTAT: Production, Harvested area, yields
	(Mekonnen and Hoekstra, 2011): green, blue, and grey water footprint of crops;
Livestock production	FAOSTAT: milk, meat, and eggs production
	FAOSTAT: livestock herd number (Herrero et al., 2013): feed requirements and output per production system and animal category
Food	FAOSTAT: Food Balance Sheets caloric, protein, and fat supply, dietary composition
	(Institute of Medicine, 2002): for minimum calorie requirements per day by age, sex and activity level (Gustavsson et al., 2011): assumed waste per commodity group and region
Land cover	FAOSTAT: cropland, forest, pasture, other natural vegetation, and urban area
	ESA-CCI land cover map
Prices, expenditures and costs	FAOSTAT: producer prices
Protected areas	UNEP-WCMC and IUCN: Protected Areas
Population	SSP database
GDP	World Development Indicators: GDP between 2000 and 2010
GHG	FAOSTAT: emissions factors for agriculture, average forest carbon stock (Herrero et al., 2013): emission factors for livestock.

1.8.2 Comparison between the FABLE Calculator and MAgPIE

Table A2: *Main characteristics of the FABLE Calculator and MAgPIE*

<table>
<tr><th></th><th>FABLE Calculator</th><th>MAgPIE</th></tr>
<tr><td>FABLE Countries / Regions using this model in this study</td><td>Argentina, Australia, Brazil, Canada, China, Colombia, Ethiopia, Finland, Germany, Indonesia, Malaysia, Mexico, Norway, Russia, Rwanda, South Africa, Sweden, United Kingdom, United States, Rest of Asia and Pacific (ASP), Rest of Central and South America (CSA), Rest of European Union (ROEU), Rest of Europe non EU27 (NEU), Rest of North Africa, Middle East and Central Asia (NMC), Rest of Sub-Saharan Africa (SSA)</td><td>India

(MAgPIE is a global model solved for 12 regions in this exercise -but results are only used for India)</td></tr>
<tr><td>Model type</td><td>Agricultural and land use accounting model</td><td>Agricultural and land use sector equilibrium economic model</td></tr>
<tr><td>Objective function</td><td>No objective function (no optimization)</td><td>Minimization of global production costs (large-scale nonlinear optimization)

(Costs include agriculture production, land use change, yield-increasing technology, transport, trade, processing, irrigation expansion, and GHG emissions abatement costs in case of mitigation policy)</td></tr>
<tr><td>Software</td><td>Microsoft Excel</td><td>Written in R and GAMS; Solved in GAMS using the CONOPT solver</td></tr>
<tr><td rowspan="2">Main constraints</td><td colspan="2">National or regional market balance:
Food +Food waste+ Feed + Process + Bioenergy + Other Non-Food = Production –Losses - Imports + Exports
Cropland balance:
$\sum_{i=1}^{N}$ planted area crop$_i$ = cropland area
Land balance:
Cropland + pasture + primary forest + secondary forest + other land area + urban area = total land area (fixed)</td></tr>
<tr><td>Other land balances:
harvested area crop$_i$ / harvesting intensity= planted area crop$_i$
ruminant number x ruminant density per ha = pasture area</td><td>Global market balance:
Global supply ≥ Global demand
Other land balance:
pasture area x pasture yield = animal product x feed basket for pasture
Water balance:
Water availability = irrigated area x water requirements x irrigation efficiency + livestock production x water requirements</td></tr>
<tr><td rowspan="2">Model outputs</td><td colspan="2">Harvested area by crop, Area by land cover class, Land use change (incl. deforestation), GHG emissions, Food consumption, Blue water use, Net trade with the rest of the world per product, Land where natural processes predominate (LNPP)</td></tr>
<tr><td>Planted area by crop (1000ha), Number of livestock units (1000 TLUs)</td><td>Irrigated and rainfed crop specific area (1000ha), Crop Prices in USD of 2005 Market Exchange Rate, per ton of dry matter</td></tr>
<tr><td>Products</td><td>Crops: abaca, apple, banana, barley, beans, cassava, other cereals, other citrus, clove, cocoa, coconut, coffee, corn, cotton, date, other fruits, grape, grapefruit, groundnut, jute, lemon, millet, nuts, oats, oil palm fruit, other oilseeds, olive, onion, orange, peas, pepper, piment, pineapple, plantain, potato, other pulses, rapeseed, rice, rubber, rye, sesame, sisal, sorghum, soyabean, other spices, sugar beet, sugarcane, sunflower, sweet potato, tea, tobacco, tomato, other tubers, other vegetables, wheat, yams
Processed products: cotton lint, vegetable oils (11 types), oilseed cakes (7 types), sugar raw
Livestock products: chicken, eggs, milk, pork, mutton-goat, pork, beef, other meat
Bioenergy: first generation biofuels</td><td>Crops: Temperate cereals (wheat), maize, tropical cereals (sorghum, millet), rice, soy, rapeseed, groundnut, sunflower, pulses, potato, cassava, sugar cane, sugar beet fruits and vegetables, cotton
Processed products: oils, oilcakes, sugar, molasses, alcohol, ethanol, grain distillers, brans, single cell protein, fibers
Livestock products: ruminant meat, pork, chicken, eggs, milk, fish
Bioenergy: first generation bioenergy, second generation bioenergy (bioenergy grasses, bioenergy trees)
Feed roughage: fodder, grass</td></tr>
<tr><td rowspan="2">Scenario parameters</td><td colspan="2">population, diets, biofuel use, food waste at the consumer level, livestock and crop productivity, agricultural land expansion restrictions including protected areas, afforestation, climate change impacts on crops</td></tr>
<tr><td>share of domestic consumption that is imported, export quantity, share of the production lost during storage and transportation (i.e., post-harvest losses), ruminant density per hectare of pasture</td><td>GDP, nitrogen use efficiency, irrigation of bioenergy crops, protection of environmental flows, animal waste management systems, GHG price</td></tr>
</table>

Source: Mosnier et al. (2023), Environmental Research Letters

1.8.3 Outputs of the FABLE Calculator and MAgPIE used as input in SPIQ

Table A3: *Comparison of agrifood models' outputs that can be used in TCA to compute the evolution of hidden costs in the future and across alternative scenarios and comparison with the original impact indicators used in SOFA 2023*

Cost to GDP	How the output from the agrifood system models (the FABLE calculator (FC) and MAgPie) correspond to the impact quantity indicators used in SOFA 2023
Burden of disease due to dietary choices	• SOFA 2023: number of DALYs • FC: DALYs computed on the basis of average food availability by capita in g/day by MIRAGRODEP food groups using the machine learning model developed for SOFA 2024 • MAgPIE: for FSEC, Marco Springmann computed DALYs using dietary intake output to compare with eight diet and weight-related risk factors of five diseases.
Undernourishment	• SOFA 2023, FC and MAgPIE: Number of people with food intake below minimum energy requirements
Eliminating poverty among agrifood systems workers	• SOFA 2023: Number of workers in the agrifood system under poverty line of 3.65 PPP dollars 2017 a day • FC: number of full-time equivalent on-farm workers – not compatible with TCA model • MAgPIE: Translation of "Expenditure on Agricultural Products" from MAgPIE in average real incomes and inequality levels (Soergel 2021)
Due to climate change (agricultural production losses and higher mortality)	• SOFA 2023: GHG emissions (CO_2, CH_4 and N_2O) from on-farm production, pre- and post-production, land use and land use change (FAOSTAT) • FC and MAgPIE: GHG emissions (CO_2, CH_4 and N_2O) from on-farm and land use change related GHG emissions – pre- and post-production not computed
From loss of ecosystem services after conversion of natural ecosystems to agriculture	• SOFA 2023: Temperate forest to cropland, temperate forest to pasture, tropical forest to cropland, tropical forest to pasture, cropland to forest regrowth, pasture to forest regrowth, unmanaged grassland to cropland and pasture, managed grassland to unmanaged grassland (HILDA) • FC: land transitions endogenous (cf. Annex for all possible land transitions) • MAgPIE: The different land uses represented are cropland, pasture, built-up land, forestry, forest, other land
From loss of environmental flows due to irrigation withdrawal	• SOFA 2023, FC, and MAgPIE: Blue water withdrawal for agricultural use in cubic meters
Related to nitrogen application	• SOFA 2023: Volatilization of NH_3 (ammonia) and NOx (nitrous oxide) to air and NO_{3-} leached to groundwater, NO_{3-} due to run-off from agricultural land to surface water and effluent or human sewerage in surface water (SPIQ-FS) • FC: nitrogen application on cropland and nitrogen left in pasture – not compatible with TCA model • MAgPIE: Nitrous oxide (N_2O) emissions from soils and manure management are calculated using IPCC (2006) emission factors, adjusting for nitrogen budgets. The rescaling of emission factors considers variations in regional soil nitrogen uptake efficiencies, ensuring proportional representation to total cropland nitrogen surplus and adjusting for changes in emissions with improved management practices and nitrogen uptake efficiencies.
Costs from crop losses due to soil leaching	• SOFA 2023: Run-off of reactive nitrogen into surface waters and soil leaching, predominately soluble nitrate (European Nitrogen Assessment) • FC: nitrogen application in cropland and nitrogen left in pasture – not compatible with TCA model • MAgPIE: Nitrogen surpluses from agricultural soils are estimated as the difference between nitrogen inputs in the form of organic and inorganic fertilizers, and the withdrawals in the form of harvested biomass. This budget approach provides the total quantity of reactive nitrogen leached, volatilized or denitrified.
Costs from water pollution due to nitrogen run-off	• SOFA 2023: Run-off of reactive nitrogen into surface waters and soil leaching, predominately soluble NO_{3-} (nitrate) • FC: nitrogen application in cropland and nitrogen left in pasture – not compatible with TCA model • MAgPIE: Nitrogen application

1.8.4 Explanation of the decomposition analysis

The decomposition analysis shows the **absolute change in the value of an output of the model for a specific year (2030 or 2050) after we change <u>only one scenario parameter</u>** from its value under current trends (CT) to its value under the national commitment (NC) pathway or the global sustainability (GS) pathway.

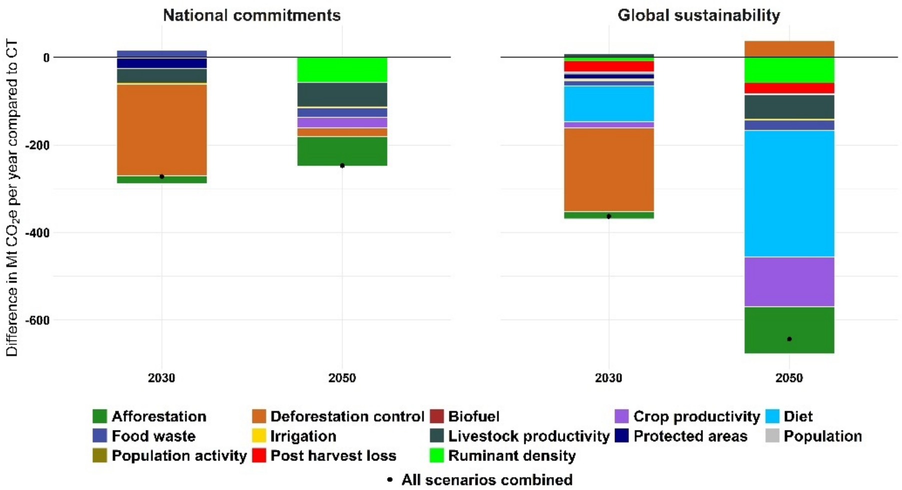
No change means that this specific parameter change assumption does not have an impact on this specific model output compared to current trends. In some cases, none of the scenarios change the output value compared to current trends. This can happen when there is a strong constraint that does not allow this output variable to change value across scenarios. For example, if deforestation is prohibited and afforestation does not vary across the three pathways (CT, NC and GS), it is expected that forest cover will be the same in all pathways, independent of the other parameters (cf. country annex for Australia). Alternatively, if none of the selected parameters are used in the computation of a certain model output then no change will result.

The **black dots** on the figures show the total impact of the national commitments (NC) pathway, or the global sustainability (GS) pathway compared to current trends, i.e., **when all the selected scenario changes are implemented simultaneously in the model**. The individual impact of each scenario change is represented as one item of stacked bars, e.g., the impact of the crop productivity change which is assumed in the NC pathway on CO_2e emissions from agriculture. In most cases, the sum of the items in the stacked bar is not expected to be equal to the value shown by the black dot. This is because, when combined, some scenario changes reduce the impact of others. For instance, if we reduce the consumption of animal-based products in the diet scenario, this reduces the domestic production of livestock, and livestock productivity gains will apply to a smaller number of animals leading to lower benefits than when implemented alone. And if we increase agricultural productivity and prevent deforestation, benefits of dietary changes will be slightly reduced compared to when implemented alone.

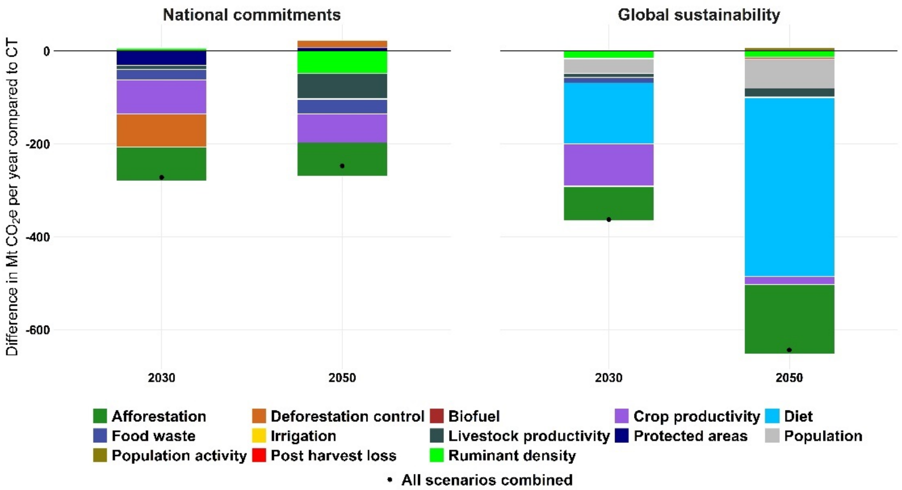
This is illustrated in the figures below for Brazil, which compares two different sequences for progressively changing the scenario parameters, in which sequence a is the reverse of sequence b (Figure A2). While the total impact – i.e., when all the scenarios are combined – is the same, the attribution of the different scenarios to the total varies depending on the sequence in which they are introduced. For instance, when deforestation control is introduced before dietary change (Figure A1 – a), it is attributed a big share of the total reduction of CO_2 emissions by 2030 compared to current trends, while when it is introduced after diet and crop productivity change (Figure A1 – b), this share is reduced because these other factors have already reduced much of the deforestation.

Figure A2: *Comparison of the contribution of each scenario to CO_2 emissions when implemented cumulatively and depending on the sequence of implementation of the scenarios*

a) Implementation of scenarios such as: 1- Irrigation 2-Biofuels 3-Post-harvest loss 4-Protected areas 5-Ruminant density 6-Afforestation 7-Deforestation control 8-Crop productivity 9-Livestock productivity 10-Food waste 11-Diet 12-Population



b) Implementation of scenarios as 1- Population 2- Diet 3- Food waste 4- Livestock productivity 5- Crop productivity 6- Deforestation control 7- Afforestation 8- Ruminant density 9-Protected areas 10- Post-harvest loss 11- Biofuels 12- Irrigation



On the level of calorie availability: Scenario parameters can affect food consumption only if the desired consumption level cannot be achieved because of land scarcity. In this case, selecting scenario parameters that produce more food with the same amount of land (e.g. by increasing productivity or reducing waste) could increase the level of consumption to the desired level (e.g. see UK results). An alternative, which is not modelled in the FABLE Calculator, is that food imports could be increased to supply the deficit. Also, other scenario parameters could indirectly affect consumption through changes in prices, but the Calculator does not model this as it is not an economic/optimization model.

Non linearities of the impacts: Some impacts may be significant in 2030 but not in 2050, for different reasons. One reason is that population growth is often slower in 2030–2050 than in 2020–2030, i.e., there is a lower increase in food demand, thus reducing land use change and related emissions.

Trade: The trade adjustment in the FABLE Calculator is driven by the evolution of the international demand for goods. The exports of each country are proportionally adjusted to their computed market share so that total global exports match total global imports. Total imports depend on the assumptions of all other countries and rest of the world regions about the evolution of population, diet, animal feed composition, and the share of domestic consumption satisfied by imports.

1.8.5 Computation of the hidden costs related to dietary patterns

First, results from **the FABLE Calculator** on the average consumption per capita by product and by five-year time step are extracted from the Scenathon 2023 database (FABLE 2024) and aggregated by food group used in the machine learning model (Table A4).

Second, **the Machine Learning (ML) model** developed and run at the FAO to link food availability to food intake and DALYs is also used to convert the results of the FABLE Calculator into intakes for the seven processed food groups used to compute DALYs: processed meat, sodium, sugar-sweetened beverages (SSB), trans fatty acids, polyunsaturated fatty acids, seafood omega-3 fatty acids, and wholegrains. Intake is directly taken from the FABLE Calculator's results for the following food groups: red meat, fruits, legumes, milk, nuts and seeds, and vegetables.[4]

Table A4: *Mapping between product groups used in the machine learning model to compute DALYs and the products for which consumption is computed in the FABLE Calculator*

Food group used for DALYs computation	Products in the FABLE Calculator
beef	beef
eggs	eggs
fish	fish
pork	pork
poultry	chicken
lamb	mutton & goat
rice	rice
maize	corn
milk	milk
wheat	wheat
soybean	soybean
other grains	barley, millet, oats, rye, sorghum, other cereals
fruits	apple, banana, coconut, date, grape, grapefruit, lemon, orange, pineapple, plantain, other citrus, other fruits
legumes	beans, groundnut, peas, other pulses
nuts and seeds	nuts, sunflower

[4] We know from the poor performance of linear regression amongst the ML models this direct proportionality from supply to intake is historically questionable, as supply to intake is not that linear or simple. However, using the 1-1- match for the categories we can use it for, though quite inaccurate, is more transparent and easier to understand.

oil palm	palm oil, palm kernel oil
other vegetable oil	coconut oil, cotton oil, groundnut oil, olive oil, rapeseed oil, sesame oil, soybean oil, sunflower oil, other oil, cotton, rapeseed, sesame, olive, other oilseed
roots	cassava, potato, sweet potato, yams, other tuber
sugar	sugarbeet, sugarcane, sugar raw
vegetables	onion, tomato, other vegetables
other	clove, cocoa, coffee, pepper, piment, other spices, tea, tobacco

The ML model is trained in historical data which shows that per capita intake of processed foods increases with higher HDI in most countries and to a lower extent with higher Gross National Income (GNI). It can reflect the historical fact that some high HDI countries have higher intake in fruits and vegetables and lower levels of processed foods (e.g., in Mediterranean diet countries), but it cannot observe or reflect planetary-health diets at high HDI for many countries as this is not seen in historical data. This cannot be changed because the ML was originally designed to estimate partial derivatives of cost versus intake for current dietary patterns, not hypothetical futures. Broad macroeconomic patterns combined with supply changes can lead to slight increases in processed meat and sugar-sweetened beverages under GS even though red meat and sugar intake goes down. This is reasonable if we assume the association between increased wealth and increased consumption of processed foods continues in line with historical trends, but it becomes less reasonable if GS assumes high HDI and dietary patterns that are breaking with historical trends. Therefore, for this study, we decided to make direct exogenous assumptions on the evolution of UPF (Table A5) entered into the ML.

Table A5: *Assumptions on ultra-processed food consumption under the GS pathway*

Country	UPF 2002 (kg/capita)	UPF 2016 (kg/capita)	Relative change between 2002 and 2016	Assumed relative change between 2020 and 2050	Implementation rate
UK	156	141	-10%	-50%	Linear
Australia	109	109	-1%	-67%	Linear
Brazil	26	37	39%	-22%	Linear
Colombia	15	21	37%	-20%	Linear

Source: for historical data: Euromonitor 2002 and 2016; for assumed relative change between 2020 and 2050: authors from each country. Note: for Ethiopia, we use the HDI-forced UPF projections, as the assumed dietary change is a continuation of historical trends.

Third, **the global burden of disease (GBD) emulator** run at the Oxford University was used to estimate the DALYs from various diseases and 15 food groups and age brackets 15–70 and 70+. The emulator has been validated to reproduce the original 2017 GBD population attributable fractions (PAFs) per disease outcome and risk group and overall dietary risks (not 15 individual risks) in DALYs per disease outcome. The GBD relative risk factors vary across the years. For instance, red meat was not as high a risk factor in GBD 2017 as in 2019 and 2021. The risk factor for trans fats was also corrected due to a possible unit error in the GBD 2017. GBD 2021 and GBD 2019 use a different model to GBD 2017 and according to our validation of some of the data, the 2019 model is less reliable than in 2017. GBD 2021 could not be used for this study as it was just recently released. DALYs are not directly proportional to food intake because they are also impacted by life expectancy, variance in intake around mean intake, and demographic structure (intake and disease outcomes by age brackets).

Some effects cannot be calculated, due to the scope chosen for SOFA 2024 or the design of the GBD model. For example, in our emulator sodium affects the disease burden of stomach cancer but not the DALYs resulting from high systolic blood pressure, for which the full GBD model is needed. As systolic blood pressure DALYS are larger than the stomach cancer component (e.g., up to 17% of the overall dietary risk DALYS in China), 0–17% of the disease burden is missing (for most countries it is between 5–8%) because the effect on high systolic blood pressure of sodium is missing. However, this missing component is likely not playing a large role in our results as the relative change in disease burden between CT and GS due to change in sodium intake predicted by the ML model is small.

Sugar-sweetened beverages contribute directly to DALYS and indirectly through a higher Body Mass Index (BMI), which impact is larger according to the GBD. However, although the BMI impact is included in the hidden costs computation made with MAgPIE (FSEC 2024), it is not included for the FABLE Calculator outputs.

Finally, **the SPIQ model** (run by Steven Lord from Oxford University) computes the hidden costs of the DALYs based on labor productivity losses. The evolution of the marginal cost of labor productivity depends on the population trajectory (e.g., old age dependency), GDP per capita, and HDI. GBD modeling provides uncertainty estimates for the disease burden from dietary risks. Some epistemological uncertainty in benefit transfer methods is also included in the hidden costs model used, as indicated in the references cited in the SOFA 2023 and SOFA 2024 hidden cost methodology.

Chapter 2. Australia

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Highlights

- We put together a team of experts in agriculture, land use modelling, environmental sustainability, resource economics, food systems transformation, and nutrition from Australia's national science agency to undertake a detailed assessment of the SOFA 2023 methodology and underlying data's accuracy and reliability.
- In general, the sources of impact quantity data used for SOFA 2023 overestimate impact quantities relative to official national statistics. We found potential overestimations of GHG emissions, blue water use, and land clearing. On the other extreme, we think the estimates of undernourishment and poverty in SOFA 2023 do not adequately reflect the reality of many Australians which has been exacerbated through the post-covid cost of living crisis.
- The results of the assessment and FABLE modelling identify opportunities for improvement of further hidden costs analyses and subsequent stakeholder consultation. Incorporating national statistics datasets into hidden costs calculations is imperative as is fine-tuning aspects of the methodology. For example, we show that understanding the economic value of natural grasslands and how this is impacted by grazing has a massive effect on hidden cost estimates.

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2.1 Introduction

CSIRO has been a long-standing member of the FABLE Consortium, leading development and assessment of food system pathways for Australia (e.g. Navarro et al., 2023). This chapter features the contribution of the FABLE Australia team to FAO's 2024 State of Food and Agriculture (SOFA) report (FAO, 2024), with a review of the applicability of the hidden cost estimates of the SOFA 2023 (FAO, 2023a) results for Australia, making recommendations for possible improvements and further research. Then we couple the TCA approach with the 2023 results of the FABLE Scenathon to allow for comparison between development pathways of Australia.

The feedback presented here was collected and produced via internal expert consultation within CSIRO where experts have access to a broad range of expertise in the Australian agriculture, food and land use system and strong relationships with stakeholders in industry, government, academia and other stakeholders. The consulted experts have expertise spanning the areas of economics, large scale agricultural and food systems modeling, agricultural, food and land use systems, low carbon and climate resilient development, and sustainability transformations.

The hidden cost estimates for the SOFA report are derived from the product of the impact units and associated marginal cost function. The impact units cover categories across the environmental, health and social dimensions of the agrifood systems. It is important to recognize that hidden costs for each category are distributed in time and space. While some impacts will accrue now, others will only materialize later. The selection of discount rates to account for the intertemporal welfare implications of hidden costs is discussed in Lord (2023). Our feedback focuses on the impact units used for the assessment, which together with the application of marginal cost functions determine the hidden cost estimates. We conclude with some suggestions for further research.

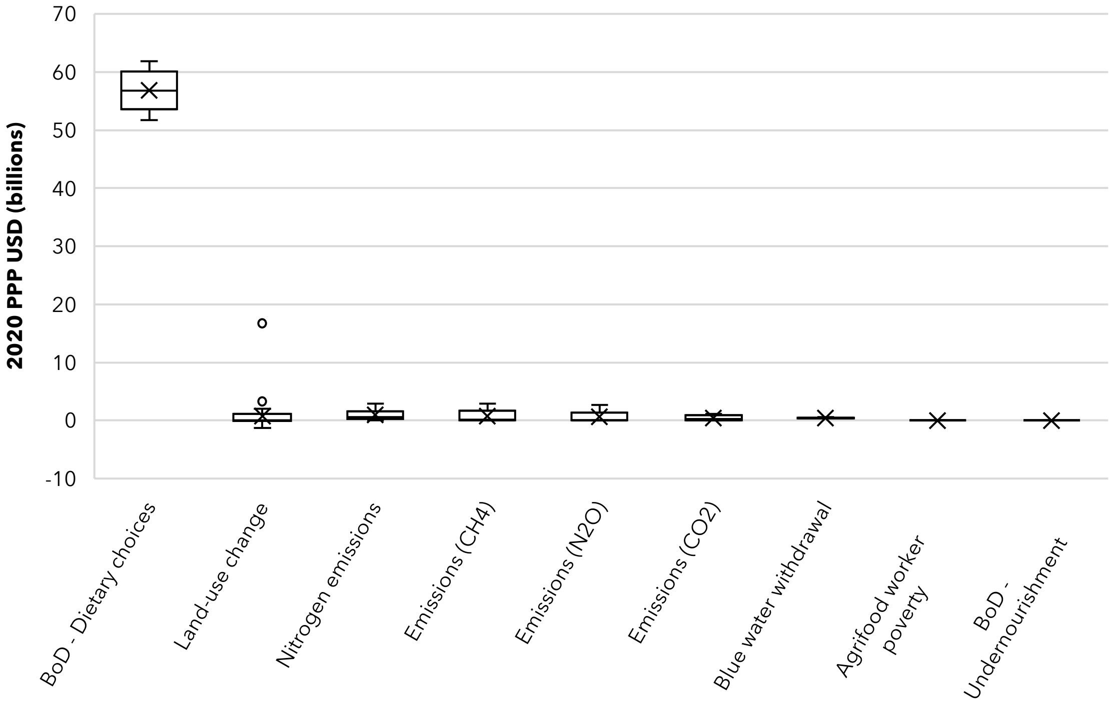
2.2 SOFA 2023 hidden costs analysis

2.2.1 Main cost components and explanations of the results

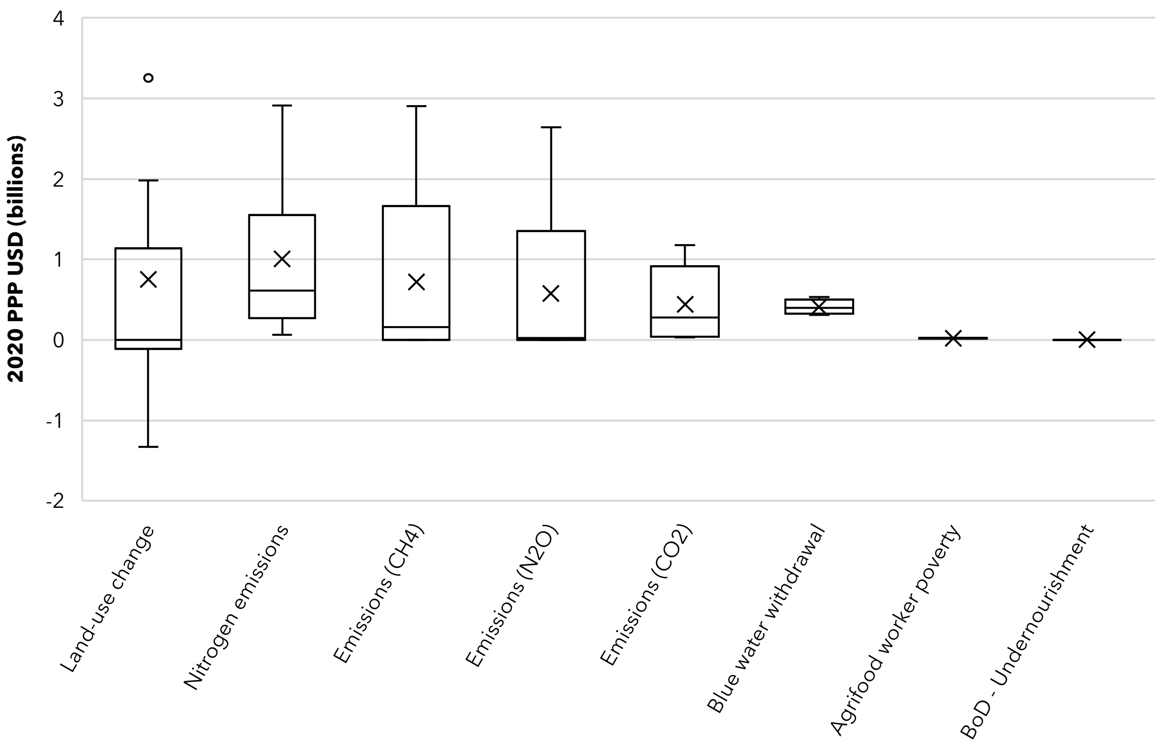
The two main sources of hidden costs in the Australian food system found by Lord (2023) are land use change and burden of disease associated with dietary choices (Figure 2-1, Panel a). Land use change hidden costs in the study period range from -1.3 billion 2020 PPP dollars to 16.7 billion 2020 PPP dollars and burden of disease (dietary choices) costs range between 52–62 billion 2020 PPP dollars per year. Other sources of hidden costs are not insignificant according to Lord (2023) but their magnitudes are far less. Emissions of nitrogen, methane and nitrous oxide are associated with hidden costs up to nearly 3 billion 2020 PPP dollars per year (each) whereas emissions of carbon dioxide and blue water withdrawal costs top at 1.2 billion and 0.5 billion 2020 PPP dollars per year respectively (Figure 2-1, Panel b). Added together, the hidden costs of GHG emissions were highest in 2017 at 13 billion 2020 PPP dollars and lowest in 2023 at 8.6 billion 2020 PPP dollars; this makes GHG emissions the second costliest in terms of hidden costs. Hidden costs of poverty and undernourishment are relatively small in the SOFA 2023 results. The accuracy of the SOFA 2023 assessment for Australia will hence be mostly affected by how accurately the categories of land use change and burden of disease (diets) are represented. However, in the feedback below we will also comment on issues around the possible underrepresentation of poverty and undernourishment in Australia.

Figure 2-1: *Boxplot of hidden cost estimates for Australia*

(a)



(b)



Source: Lord, 2023. BoD stands for burden of disease. Panel a displays all sources of hidden costs and Panel b focuses on sources with maximum below 20 billion 2020 PPP dollars. Comparison of SPIQ data with national datasets

Environment

The environmental dimension of the hidden cost estimates covers greenhouse gas (GHG) emissions, nitrogen pollution, land use transitions, and blue water withdrawals.

GHG emissions: Lord (2023) used FAO Tier 1 GHG emissions value for Australia to assess the annual total impacts (FAO, 2023a). The impact units and marginal cost are given for each greenhouse gas (CO_2, CH_4, N_2O) individually and are not expressed as CO_2 equivalent. The IPCC Fifth Assessment report (AR5) global warming potentials (GWP100) are used both in FAOSTAT (Please see FAOSTAT Domain Emissions Totals. Methodological note, release October 2023), the National Inventory Report 2021 and National Inventory Report 2022 (published in April 2024).

Comparing the FAO Tier 1 GHG values reveals discrepancies with the values of Australia's National GHG Inventory as reported to the UNFCCC (DCCEEW 2021; see also Table 2-1). Considering the data reported for the year 2020, the values are, depending on GHG considered, between 7 to 65% higher than those in the National GHG Inventory. In addition, the National GHG Inventory does not have emissions from *prescribed burning of savannas* under the agriculture category reported to UNFCCC inventory, but instead is a specific category under LULUCF in the Kyoto inventory.

Overall, total GHG emissions under the agriculture sector from the FAO Tier 1 GHG emissions dataset for 2020 are 30% higher than the value reported in the National GHG Inventory. For the years 2014–2019, total GHG emissions under the agriculture sector as reported in FAO Tier 1 GHG emissions are 32–51% higher than the Australian National GHG Inventory (2021) reported value. This is mainly due to the use of Tier 2 and 3 methods in the Australian inventory.

This example highlights how differences in the impact quantities can considerably influence the hidden costs, leading to a potential over- or underestimation. With regards to hidden costs associated with GHG emissions, it may be worthwhile adjusting the figures in line with the National GHG Inventory. Direct comparisons between the inventories are imperfect as some of the categories are different and uncertainties apply to each inventory. However, we expect these uncertainties to be smaller when using the national inventory data.

Chemical inputs: The aforementioned climate characteristics of Australia coupled with lower fertility soils than their European or North American counterparts means that Australian dryland agriculture employs very low stocking rates and nitrogen fertilizer application by global standards. Levels of pesticide application (kg/ha) are slightly lower than UK or USA average application rates (ABARES, 2023). On the point of agrichemical use though, we must keep in mind that overall metrics of pesticide application such as average kg/ha or number of sprays would be too crude for environmental assessment purposes due to the heterogeneity in physico-chemical properties of individual active ingredients (Navarro et al., 2021).

NH_3 and NOx emissions to air for the hidden cost estimation are obtained from Global Atmospheric Research version 5.0 (EDGARv5.0). The source categories included in EDGARv5.0 for the NH_3 and NOx are detailed in Table 2-2.

***Table 2-1**: Difference in GHG emissions values for Australia used in report compared to the National GHG Inventory value used for the agriculture sector*

GHG emissions Category	2020 FAO TIER 1 value reported in FAOSTAT	2020 value reported in National GHG Inventory (2021)	Comments
Agricultural soils	31,680	10,997	FAO TIER 1 value is around 2.9 times the National reported value.
Rice cultivation	44	23	FAO TIER 1 value is around 1.9 times the National reported value.
Burning crop residues	398	224	FAO TIER 1 value is around 1.8 times the National reported value.
Enteric fermentation	55,645	51,796	FAO TIER 1 value is around 1.1 times the National reported value.
Manure management	5,197	6,806	FAO TIER 1 value is around 0.75 times the National reported value.
Prescribed burning of savannas	13,277	--	This category is included in the Kyoto Protocol Inventory rather than in the inventories of the UNFCCC or Paris Agreement. Australia classifies this category as a net carbon sink within LULUCF emissions, instead of attributing it to the agriculture sector.
Liming	Not reported as the same item.	1,318	Perhaps included under Synthetic Fertilizers (Item Code 5061)
Urea application	Not reported as the same item.	1,478	
IPCC Agriculture sector (total)	106,241	72,642	FAO TIER 1 total Agriculture sector GHG emission is around 1.45 times the National reported value.

Note: Units are in Gg CO_2-e, gigagrams of emissions in carbon dioxide equivalent using AR5 GWPs

***Table 2-2:** Sources of NH3 and NOx*

Source categories for NH_3	Source categories for NOx
Main activity electricity and heat production	Main activity electricity and heat production
Petroleum refining – manufacture of solid fuels and other energy industries	Petroleum refining – manufacture of solid fuels and other energy industries
Manufacturing industries and construction	Manufacturing industries and construction
Civil aviation	Civil aviation
Road transportation no resuspension	Road transportation no resuspension
Railways	Railways
Water-borne navigation	Water-borne navigation
Other transportation	Other transportation
Other sectors	Other sectors
Non-specified	Non-specified
Solid fuels	Oil and natural gas
Other process-uses of carbonates	Chemical industry
Chemical industry	Metal industry
Non-energy products from fuels and solvent use	Other
Manure management	Manure management
Emissions from biomass burning	Emissions from biomass burning
Urea application	Direct N_2O emissions from managed soils
Direct N_2O emissions from managed soils	Incineration and open burning of waste
Biological treatment of solid waste	Other
Incineration and open burning of waste	
Wastewater treatment and discharge	

Building on Lord (2023), it would be helpful to specify the source categories of agricultural production and energy use that contribute to NH_3 and NOx emissions, and whether energy use is included only for the food system. If so, specifying how the food system-related energy is disaggregated from the above source categories would facilitate the comparison with national data, as the current reporting makes such comparisons challenging.

The accuracy of NH_3 and NOx emissions estimates based on EDGARv5.0 is limited. Nitrogen emissions in the form of N_2O, NH_3 or NOx are calculated based on total nitrogen applied (just as the Australian NGGI does). In reality, farm management practices play a big role in regard to the proportion of nitrogen applied that can become volatilized. Much effort has been dedicated in recent decades in Australia to improving nitrogen use efficiency, although past studies also indicate that the biggest predictor of dissolved inorganic nitrogen (DIN) in watersheds is nitrogen surplus – the difference between nitrogen applied and nitrogen uptake by crops or plants (Howarth, 2006; Thorburn, 2013). This means that, for the same nitrogen applied, areas yielding higher will emit lower levels of N_2O, NH_3, NOx or DIN because the rest was taken up by the crop. This is a critical piece of the puzzle that needs to be explored in the future.

Land use conversion: Figure 2-2 shows the estimated land conversion by category for Australia between 2016 and 2023 based on Lord (2023) and a comparison with the Australian National Greenhouse Gas Inventory (NGGI) figures on primary and regrowth clearing over a similar period. The HILDA+ values for 2016 seem to be inconsistent with LUC values from the same dataset from 2017 onwards. Conversion of pasture to forest equals or exceed ~1.5Mha per year for most years, which is about ten times the net vegetation gain that the NGGI indicates (Figure 2-3). HILDA+ also estimates ~0.14Mha of forest clearing for pastures but does not quantify conversion of forest to unmanaged grassland. The NGGI shows a decline in clearing for native grazing from 0.35Mha in 2016 to about 0.1Mha in 2020.

The conversion of forests to cropland in HILDA+ vary between ~12,000 and ~30,000 ha per year between 2016 and 2023 but the corresponding cumulative change reported in the NGGI is only about 3,000 ha. Hence the estimated conversion of forests to cropland are much higher than official Australian estimates indicate. There are therefore significant differences between HILDA+ and the Australian NGGI that require further investigation should HILDA+ be relied on as an accurate source of land use change information for TCA in Australia.

In addition, it is important to understand the makeup of grazing as a land use in Australia. Native grasslands or lands under permanent meadows and pastures (broadly defined as rangelands) occupy 81% of the total landmass. In comparison, the HILDA+ dataset significantly overestimates the extent of modified pastures and maps the entire Simpson desert to grazing which underlines the limited suitability of the dataset for land use change in Australia (Figure 2-4).

The Australian rangelands are composed or relatively undisturbed environments including grasslands, shrublands, savannas and open woodlands (DCCEW, 2024) and hence form an important part of Australia's natural heritage. This heterogeneity in landscape features and temporal variability of precipitation present substantial challenges to accurately assess the extent of rangelands in Australia using remote sensing techniques, including Copernicus LC100 Global Land Cover map, the source of HILDA+ dataset.

Based on the land use categories used in the SOFA 2023 report, we would posit that Australian rangelands are closer to unmanaged grasslands than they would be to pastures in Europe or Brazil. Most of the management of rangelands focuses on stocking rates (for grazing intensity), fire management and cattle supplementation. Pasture improvement is possible at small scales but not widespread, therefore the livestock production systems occurring in rangelands are primarily considered low input systems.

Figure 2-2: *Hectares of land conversion from HILDA+ (left panel) vs. hectares of vegetation clearing (primary + regrowth) used in the Australian National Greenhouse Gas Inventory activity data (right panel)*

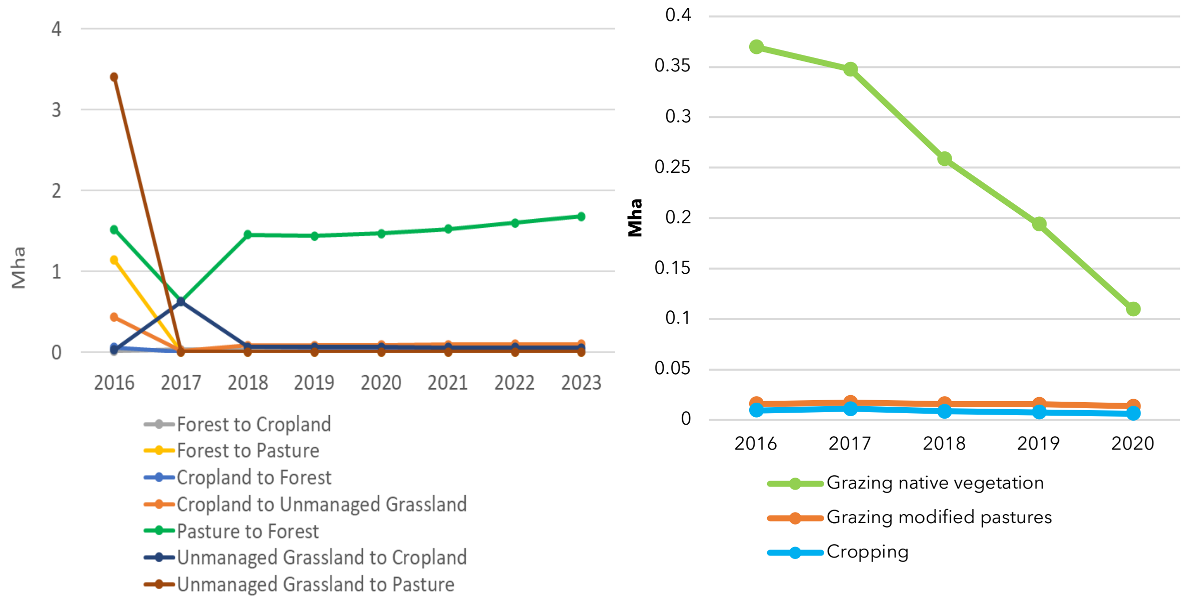
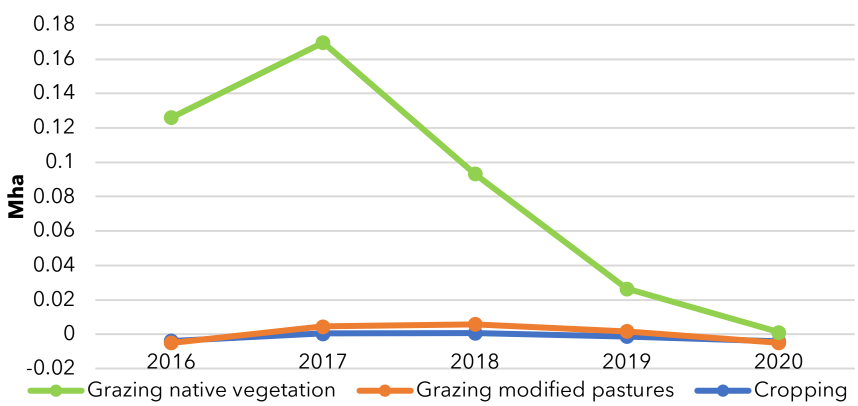


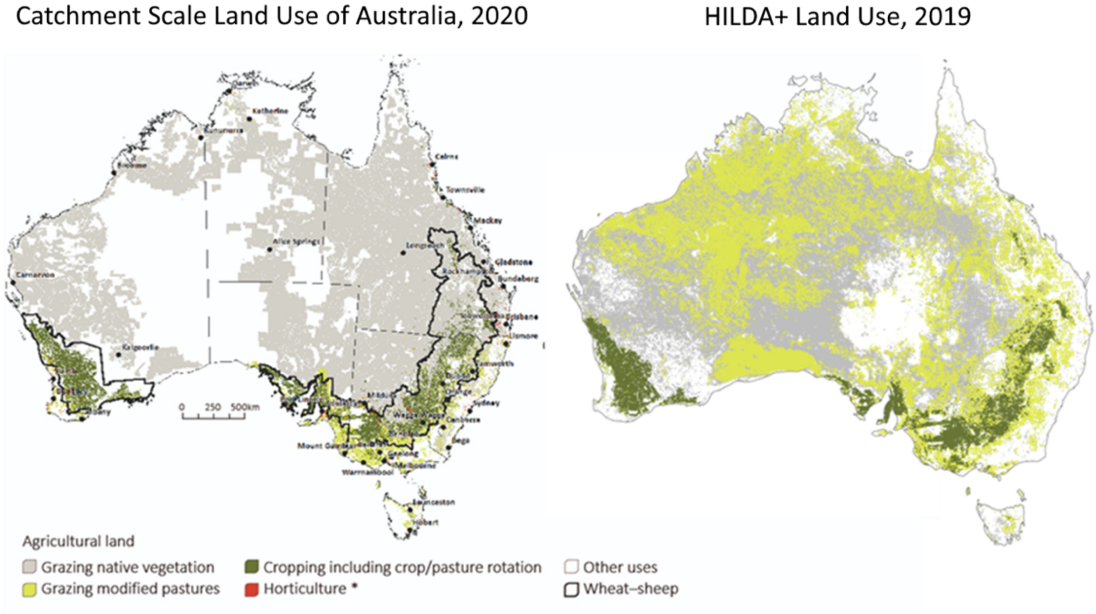
Figure 2-3: *Net vegetation gain reported in the Australian National Greenhouse Gas Inventory 2020*



Source: DCEEW, 2023

Note: Focusing specifically on the year 2020, some of the categories included for the hidden cost estimates are not in alignment with the national land use change categories reported by the NGGI (Table 2-3) which makes it difficult to compare and validate SOFA 2023 results. The data used in Lord (2023) shows no land use change for the year 2018–2020 under the cropland to forest land use change category, whereas the NGGI reported land use change under this category for that period.

Figure 2-4: *Comparison of the land use map used in hidden costs analysis with the national land use map for Australia*



Source: ABARES, 2023 (left) and HILDA+ (right)

To improve the hidden cost estimates arising from land use change, a different source that is consistent with the Australian NGGI should be adopted (or simply to use the values reported in the NGGI). The mapping of pastures in 2019 from HILDA+ is a major concern (Figure 2-4). Figure 2-3 shows how the amount of land clearing for grazing on modified pastures is negligible compared to land clearing for grazing on native pastures. The ecological value of rangelands compared to intensively managed pastures should be considered in the marginal costs in the future.

Blue water use: Blue water withdrawals for agricultural use (m^3) are based on data from AQUASTAT from 2014 to 2020. AQUASTAT has data categories on "agricultural water withdrawal" and "irrigation water withdrawal." The definition used for irrigation water withdrawal is "the volume of water extracted from rivers, lakes, and aquifers for irrigation purposes," which is consistent with the definition of blue water in AQUASTAT. Assuming that this category is used as blue water withdrawal, the data used in hidden cost estimation is compared in Table 2-3 with the national data.

Australian water use for the agriculture sector is reported by the Australian Bureau of Statistics (ABS) every year through the reporting on *Water Use on Australian Farms* (ABS, 2021). The categories "irrigation channels or pipelines," "on-farm dams or tanks," "water sourced from rivers, creeks and lakes," and "groundwater" of ABS *Water Use on Australian Farms* are consistent with the definition used in AQUASTAT for irrigation water withdrawal.

A summation of these four categories is shown in Table 2-3 to compare with the data used as a basis for estimating associated hidden costs. Considering the years 2019 and 2020, the agricultural water use data used for the hidden costs estimation is 21–35% higher than the national reported value.

Table 2-3: *Comparison categories for estimating blue water withdrawals for 2019 and 2020*

Year	AQUASTAT - Irrigation water withdrawal (m³)	ABS Water Account (m³)	Comments
2019	9,413,428,536	7,797,000,000	The AQUASTAT value used in the hidden costs estimation is 1.21 times the national reported value.
2020	8,471,011,250	6,292,000,000	The AQUASTAT value used in the hidden costs estimation is 1.35 times the national reported value.

Health

Undernourishment: The results for undernourishment used in SOFA 2023 come from FAOSTAT, and these suggest that Australia as a whole does not suffer from undernourishment based on the FAO's definition. As a result, the SOFA 2023 results do not present any hidden costs from undernourishment. In reality, over the last few years, multiple sources and studies have quantified the extent of food insecurity in Australia (e.g., see Foodbank 2023 for some recent estimates). Malnutrition is an issue for some areas and income groups, pointing to inequities embedded in the existing food system in Australia.

Most malnutrition in Australia is due to micronutrient deficiencies, particularly calcium, magnesium and zinc (ABS, 2015). Certain groups are more at risk (including First Nations People). Specifically, up to 50% of older Australians are at risk of malnutrition or malnourished (Healthdirect 2019), and up to 40% of all hospital admissions result in hospital-acquired malnutrition (Australian Commission on Safety and Quality in Health Care, 2019). In 2016, 9.1% of women of reproductive age and 20.1% of pregnant women suffered from anemia, which can lead to maternal death; 14% of children also suffered (WHO, 2020). In 2017, 3% of children under five years suffered nutritional deficiencies (range 2.2–4%) (The Lancet, 2017). Furthermore, although reported prevalence of undernourishment is low in Australia, other FAOSTAT indicators of malnutrition indicate that food insecurity is present in the country. For instance, the indicator *prevalence of moderate or severe food insecurity in the population* in Australia was 11.4% in 2021. This places Australia forty-fourth among 148 countries surveyed, with higher food insecurity than countries such as Kuwait (10.9%), Sri Lanka (10.9%) and Azerbaijan (10.1%) (FAO, 2023c).

Dietary patterns and non-communicable diseases: The SOFA 2023 estimates of impacts from dietary patterns and non-communicable diseases are based on the Global Burden of Disease Study (The Lancet, 2017), which is one of the major sources of quantitative data available. Hence, we don't have any major recommendations for improvements in this space.

In Australia most children are not eating enough fruit and vegetables, and most older girls (9–16) are not drinking enough milk (Australian Institute of Health and Welfare, 2012). There are still major concerns around the very low intake of fresh fruit and vegetables. Most Australians adults (91%) do not meet their recommended minimum number of servings of vegetables, while only 50% consume enough fruit (NHMRC, 2013[5]). The key dietary risks for Australians hence are underconsumption of fruit and vegetables coupled with overconsumption of discretionary foods high in saturated fat, sodium and sugar, which are associated with increased risk of weight gain (Lal et al., 2020):

[5] Different methodology to the National Nutrition Survey but more recent data from the ABS further supports this (Dietary behaviour, 2022 | Australian Bureau of Statistics (abs.gov.au))

36% of adults were overweight, and 31% of adults were obese in 2017–18. Obesity shares have increased from 19% since 1995. In 2017–18, 25% of children were overweight or obese (Australian Institute of Health and Welfare, 2019).

An estimated 15% of premature deaths are attributable to dietary risks (13.4–16.7%), or 106 deaths per 100,000 people per year (92–123) (The Lancet, 2017). Dietary risks are also estimated to lead/ to cause 420 (364–490) thousand disability-adjusted life years (DALYs), or 342 (296–397) thousand years of healthy life lost (YLL) due to an inadequate diet (The Lancet, 2017). This equates to 0.02 DALYs or 0.013 YLLs per capita. An estimated 0.06% (0.05–0.07%) of the population (14,760 people) suffers from type 2 diabetes, and 0.29% (0.27–0.31%) (71,300 people) from cardiovascular diseases; both are associated with lifestyle risk factors such as diet, but also have strong genetic risk factors (The Lancet, 2017).

Social

Poverty: The above data around undernourishment and non-communicable diseases linked to diets do not reflect the disparity between the population average and disadvantaged groups like First Nations People and low socioeconomic groups. McKay et al. (2019) found a prevalence of food insecurity is significantly affected by the type of question being asked when surveying insecurity, and also varied greatly between the general population and other disadvantaged groups such as First Nations People. For example, while the prevalence of food insecurity in the general population can vary between 1.6–8% using the single-item measure, other methodologies such as the USDA Household Food Security Survey Module measure (USDA, 2019) or the Kleve et al. (2018) Household Food and Nutrition Security Survey (HFNSS) measure observe the prevalence of 29% and 57% respectively. Disadvantaged groups (including First Nations People) in urban locations have an estimated food insecurity of 16–25% using the single-item measure (that is on average 4.3 times greater than the general population), whereas food insecurity amongst remote First Nations People has been estimated at 76% using the single-item measure (on average 18 times greater than the general population (McKay et al., 2019). The 2016 Australian Burden of Disease Study (Australian Institute of Health and Welfare, 2019) shows First Nations People experience a burden of disease 2.3 times greater than that of non-First Nations People, and that about 37% of this burden was preventable by modifying risk factors including tobacco/alcohol use (20% of burden), and high BMI/physical inactivity/diet (24%).

Moderate poverty is defined in this exercise as the population living with 3.65 or less per day in 2017 PPP dollars, combined with estimates of the share of agrifood systems workers in total employment (Davis et al. 2023). This definition and metric have limited applicability in Australia. It overlooks disparities in affordability across the country, particularly in remote areas since the national metric does not account for heterogeneity in costs of essential products within the country. Remote areas of Australia where the population relies on extensive cattle farming or subsistence fisheries can be more affected by higher commodity prices. For instance, the average price of a representative "basket of goods" across 47 remote stores in Queensland, the Northern Territory, South Australia and Western Australia was found to be 39% higher compared with major supermarkets in capital cities (National First Nations People Agency, 2020). Therefore, there is a need to better account for affordability to more accurately estimate moderate poverty among agrifood systems workers across the country. For future estimates it may be worthwhile drawing on definitions of relative poverty within the country instead or other more contextualized indicators.

2.2.2 Recommendations for tailored country hidden costs analysis

The advances made in highlighting and identifying the hidden cost estimates by FAO and others will be an important step in guiding the debate on how and where we need to transform our food systems towards greater sustainability. By offering a comprehensive global estimate, SOFA 2023 provides first insights into the scale of the challenge. However, as also noted in the comprehensive methodology description by Lord (2023) several constraints apply. In assessing the impact units for hidden cost estimation, we have identified several areas for future improvement.

A key challenge constitutes striking the balance between international comparability and context specific detail. It underscores the importance of considering countries like Australia's unique environmental conditions and spatial heterogeneity, particularly in areas like GHG emissions, nitrogen pollution, land use conversions, and blue water withdrawals.

We have noted discrepancies between national data sources and FAO estimates. This highlights the necessity for refining methodologies and enhancing data accuracy. Additionally, our assessment suggests adjustments to account for specific factors such as pesticide-related GHG emissions and the ecological value of rangelands in Australia.

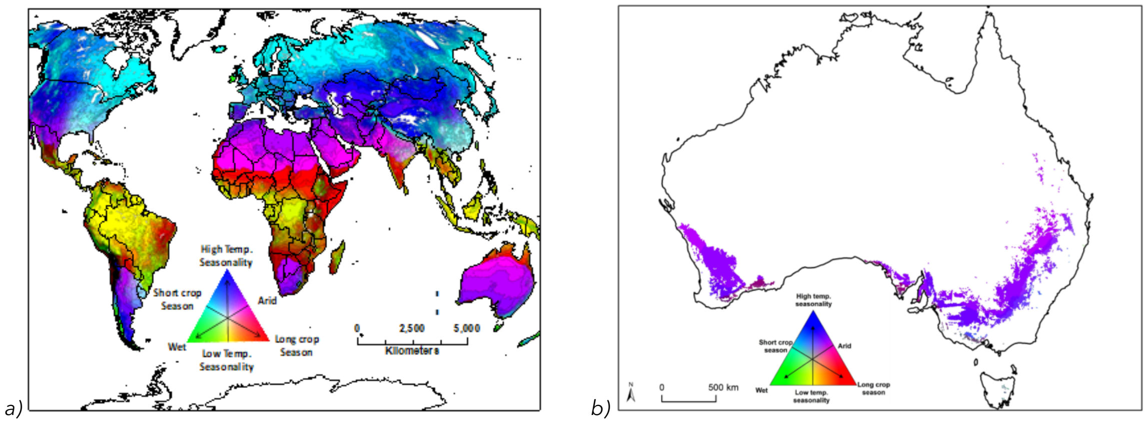
We also suggest a more comprehensive approach to assessing food insecurity and nutritional challenges, particularly among disadvantaged groups like First Nations People and those in remote areas. Furthermore, we recommend refining poverty measures to better reflect the affordability disparities across different regions.

In addition to refining the global estimates, following on from SOFA 2023 it may be worthwhile for Australia and countries with similar characteristics to deepen investments in data collection and conduct more detailed and regionally differentiated assessments, which over time would help to remove existing caveats to policy decisions and practical implementation.

The environmental conditions and geographic characteristics of Australia have shaped an agricultural production system that in several instances differs considerably from those of other major food producing countries (Figure 2-5). When it comes to rainfed broadacre and livestock production, Australia is known for a highly variable climate and rainfall which are difficult to forecast. Data generated by Van Wart et al. (2013) shows how the Australian cropping zone displays high temperature seasonality, aridity and lower growing degree days, which means that the climatic conditions for the majority of broadacre crop and livestock production in mainland Australia is akin to southern USA, northern Mexico, north Africa or the Punjab.

Improving the accuracy of hidden cost estimates for Australia could be achieved by recognizing the spatial heterogeneity of the Australian landscape more thoroughly and understanding its influence on the management practices available to farmers. This would require shifting from country-level to more spatially explicit datasets. The sections below summarize feedback on specific impact quantities for the key categories for assessing the environmental, health and social dimensions of the hidden costs of Australia's agrifood systems.

Figure 2-5: *Global agro-climatic zones*



Source: developed for the Global Yield Gap Atlas (GYGA) by (a) van Wart et al. (2013) and (b) GYGA agroclimatic zones in the Australian cropping zone (Hochman et al. 2016). Note the color similarity between Australia and other world regions (highlighted in the text). The cropping zone is where agricultural experts agree the majority of broadacre production occurs. Marginal land tends to lie inland of the cropping zone and is hence mostly native grazing (Figure 2 4).

2.3 Evolution of hidden costs by 2030 and 2050

2.3.1 FABLE Calculator for Australia

Multiple components of the FABLE Calculator (Mosnier et al., 2020) were modified to adapt the analysis to Australian conditions. In addition, we generated scenarios grounded on expert consultation and peer-reviewed projections of plausible Australian futures, e.g., the Australian National Outlook (Brinsmead et al., 2019).

Some changes include:

- Projections of crop and livestock productivity (including livestock density) based on historical spatiotemporal data, statistical models, and literature review.
- Inclusion of Australian-specific Gross Domestic Product (GDP), trade, and population projections to improve the representation of domestic food demand, based on econometric analysis of historical data and results from integrated assessment models published in peer-reviewed studies.
- Changes in implementation rates for multiple variables, e.g., defining expected time when carbon plantings become profitable due to global climate abatement efforts impacting carbon offset prices.
- Modification of default AFOLU carbon coefficients to make them representative of Australian conditions.

2.3.2 Scenathon 2023 pathway assumptions

Among possible futures, the 2023 Scenathon assessed three alternative pathways in their ability to reach sustainable objectives, in line with the FABLE targets, for food and land use systems in Australia: Current Trends (CT), based on a thorough analysis of existing Australian agricultural statistics and trends; National Commitments (NC), based on the Current Trends pathway but incorporating changes where specific government targets have been announced; and global sustainability (GS), representing the adoption of ambitious policies around achieving higher productivity and sustainability targets and at the upper level of feasibility.

Please note that the description of the pathways and results provided here are based on previous modeling undertaken by the authors for the FABLE Consortium and are consistent with the FABLE 2023 Scenathon (FABLE, 2024). Descriptions and results have been adapted for this document where necessary.

The CT pathway corresponds to the continuation of trends observed over the last 20 years and assumes little change in the policy environment. It is characterized by high population growth (from 26 million in 2020 to 38 million in 2050), strong constraints on agricultural expansion, a low afforestation target, on-trend productivity increases in the agricultural sector, and no change in diets.

These and other important assumptions are justified using historical data, experts' advice, and results from integrated science assessment models. The CT pathway is embedded in a global GHG concentration trajectory that would lead to a radiative forcing level of 6 W/m^2 (RCP 6), or a mean global warming increase likely between 2°C and 3°C above pre-industrial temperatures, by 2100.

The National Commitments pathway is an extension of the CT pathway. It follows CT except where specific commitments to actions have been made by the Australian Government that relate to input parameters of the FABLE Calculator or where the authors consider that there is already a substantial push underway to dial up improvements beyond past (current) trends. The current commitments from the Australian Government are:

- Protected areas: Protecting 30% of Australian land and sea area by 2030. In the NC pathway we reach 21% of the total terrestrial area in protected areas and OECMs.
- Yield gap: From 54% to 40% yield gap. It is implemented in the Calculator, as halfway between the Current Trends pathway and the Global Sustainability pathway for NC.
- Evolution of exports for key exported products: From no changes by 2050 to doubling export tonnage by 2050. No change implemented in the Calculator compared to CT.
- Climate change mitigation: Net zero emissions by 2050; 43% lower GHG emissions by 2030 (relative to 2005 levels). Not implemented as input to the FABLE Calculator because there is no clarity around what the entry points in the land system are (or what the target for the land system is).

The Global Sustainability pathway represents a future in which significant efforts are made to adopt sustainable policies and practices that are consistent with higher-than-trend productivity growth and corresponds to an upper boundary of feasible action. Similar to the NC pathway, we assume that this future would result in high population growth and no agricultural expansion. However, the GS pathway assumes higher agricultural productivity growth, higher carbon sequestration via afforestation and regrowth, adoption of more sustainable diets, and increased water use efficiency than under the CT pathway. This corresponds to a future based on the adoption and implementation of new ambitious policies that support farmers in achieving greater yields at lower environmental costs and which enable the development of negative-carbon technologies to bridge the gap between what industry can achieve in terms of emission reductions and the net zero emissions target. This pathway is embedded in a global GHG concentration trajectory that would lead to a lower radiative forcing level of 2.6 W/m^2 by 2100 (RCP 2.6), in line with limiting warming to 2°C.

Under the GS pathway, we assume that domestic diets would transition towards an overall healthy and sustainable diet (based on the EAT-Lancet report (Willett et al., 2019) but adapted to Australian conditions). The average calorie intake is 28% and 22% higher than the MDER in 2030 and 2050 respectively, which equates to a 2% and 8% reduction relative to the CT pathway. Compared to the EAT-Lancet healthy diet recommendations, by 2050, under the GS pathway, only fish consumption is above the recommended range. However, fish is not explicitly represented in the FABLE Calculator. All other crops and animal commodities are within the recommended range of a healthy diet.

2.3.3 Results across the three pathways

Table 2-4: *Selected FABLE 2023 Scenathon results across the three pathways*

Pathway	Baseline	Current Trends		National Commitments		Global Sustainability	
Year	2020	2030	2050	2030	2050	2030	2050
Pasture (Mha)	325	▼ -13	▼ -39	▼ -18	▼ -73	▼ -56	▼ -191
Cropland (Mha)	31	▲ 3	▲ 4	▲ 1	▼ -2	▼ -2	▼ -7
Abandoned (Mha)	107	▲ 8	▲ 33	▲ 16	▲ 72	▲ 56	▲ 188
Crop GHG Mt	19	▲ 3	▲ 5	▲ 2	▼ 0	▼ -1	▼ -4
Livestock GHG Mt	69	▲ 5	▲ 12	▲ 4	▲ 3	▼ -2	▼ -24
Ag. GHG Mt	88	▲ 8	▲ 16	▲ 6	▲ 3	▼ -3	▼ -29
Land GHG Mt	-40	▼ -34	▼ -60	▼ -41	▼ -86	▼ -67	▼ -227
Net GHG Mt	47	▼ -25	▼ -44	▼ -35	▼ -83	▼ -70	▼ -255
Blue Water Footprint (km^3)	637	▲ 122	▲ 146	▲ 79	▲ 47	▲ 31	▼ -40
Abandoned seq. Mt	-62	▼ -5	▼ -21	▼ -10	▼ -45	▼ -35	▼ -118
Affor. Seq. Mt	0	▼ -9	▼ -18	▼ -9	▼ -18	▼ -10	▼ -87
N manure applied to cropland	132	▲ 22	▲ 27	▲ 8	▼ -10	▼ -8	▼ -38
N manure left on pastures	2683	▲ 228	▲ 705	▲ 140	▲ 312	▼ -84	▼ -928
Kcal consumed per capita per day (% over MDER)	30	▲ 1	▲ 2	▲ 1	▲ 2	▼ -2	▼ -8

Note: All pathway values are relative to the 2020 baseline (e.g. +3 means 3 units more than the baseline). Conversion into CO_2 equivalents based on the IPCC AR6 GWP factors.

Current Trends pathway

Projected land use in the CT pathway is based on several assumptions, including no productive land expansion beyond its 2010 value, and 2 million hectares of carbon and environmental tree plantings by 2050. By 2030, the FABLE Calculator projects that the main changes in land cover in the CT pathway could result from an increase in abandoned agricultural area and a decrease in pasture area. This trend remains stable over the period 2030–2050: pasture area further decreases at an average rate of 1 million hectares per year. By 2050 this pathway projects an expansion of croplands of 4.1 million hectares (21%) relative to 2020: the expansion of the planted areas for pulses, cereals, sugar, and fruit and vegetables, explains 50%, 32%, 8% and 2% respectively of total cropland expansion between 2015 and 2030. For all crops, area growth is due to the combination of a growing population with little change in domestic diets and moderate growth in crop yields on-trend with historical increases. To meet demand, area sown for crops must grow. Pasture decrease is mainly driven by increases in livestock productivity per head and ruminant density per hectare of pasture over the period 2020–2030. Abandoned pastureland is subject to vegetation regrowth, which contributes to an expansion of land where natural processes predominate by 1% by 2030 and by 3% by 2050, compared to 2010. Net GHG emissions under current trends decrease from 47 Mt CO_2e/yr in 2020 to 22 Mt CO_2e/yr in 2030 and 3 Mt CO_2e/yr in 2050, driven by regrowth and carbon sequestration in abandoned land (-83 Mt CO_2e/yr) and new afforestation (-18 Mt CO_2e/yr).

National Commitments pathway

Under the NC pathway, annual GHG emissions from AFOLU (net GHG) decrease from 47 Mt CO_2e/yr in 2020 to 12 Mt CO_2e/yr in 2030 (46% less than CT), before declining to -36 Mt CO_2e/yr in 2050 (1200% less than CT). In 2050, livestock remains the largest source of emissions (72 Mt CO_2e/yr, 11% less than CT) while the carbon sink of vegetation regrowth in abandoned land becomes -107 Mt CO_2e/yr (29% greater than CT). Over the period 2020–2050, the increase in GHG emissions for livestock is four times less than under CT. Crop GHG emissions register a modest reduction of less than 0.5% (about five times fewer emissions than under CT). These reductions are driven entirely by reductions in crop yield gaps and the compounded effect of national commitments globally on trade (see decomposition analysis, Figure 2-12).

Under the CT and NC pathways, the average calorie intake is 31% and 32% higher in 2030 and 2050, respectively, than the average minimum dietary energy requirement (MDER). The average calorie intake in 2010 was mainly composed of oil and animal fat (24%), cereals (19%), sugars (14%), and red meats (6%) for an aggregated 63% of the total calorie intake. Projected diet changes indicate that the consumption of animal products could increase by about 20% between 2010 and 2050. Average diet estimates indicate per capita overconsumption of red meat, poultry, roots, sugars, fish, and eggs by 2050; other food categories are within the EAT-Lancet healthy diet recommended ranges.

Global Sustainability pathway

In the GS pathway, we assume stronger productivity growth, extensive, increased resource-use efficiency, maximum attainable yield gap closure (80% of yield potential) and overall reductions in environmental impacts.

These conditions could support the Australian agriculture sector to maintain and anticipate changes in social license and enhance the resilience and competitiveness of the sector in international markets. The main difference in assumptions compared to the NC pathway includes 9.4 million hectares of carbon and environmental plantations by 2050. The afforestation scenario corresponds to the lower bound of a multi-model ensemble that assessed potential Australian land use futures under ambitious economic and environmental sustainability settings (Brinsmead et al., 2019).

Compared to the NC pathway, we observe the following changes regarding the evolution of land cover in Australia in the GS pathway: (i) a decline of crop and pasture areas, and (ii) an increase in forest, urban and other land areas. In addition to the changes in assumptions regarding land use planning, these changes compared to the National Commitments are explained by increased productivity growth in crops, increased livestock density growth and global changes in diets impacting the configuration of Australian landscapes. This leads to an increase in the share of the Australian landmass that can support biodiversity conservation from 54% in 2020 to 79% by 2050 for the GS pathway.

The AFOLU GHG emissions in 2050 in the GS pathway are 160 Mt CO_2e/yr lower than in National Commitments (25 Mt CO_2e/yr in NC, -135 Mt CO_2e/yr in GS pathway). The potential emissions reductions under the GS pathway are dominated by a reduction in GHG emissions from livestock and crops (25% reduction on both) resulting from increasing crop and livestock productivity, increasing livestock density, and international shifts in diets. Compared to national commitments under UNFCCC, our results show that AFOLU could contribute 26–43% of Australia's total GHG emissions reduction objective by 2030.

2.3.4 What are the most influential factors to reduce the hidden costs by 2030 and 2050?

Navarro, Marcos-Martinez et al. (2023) conducted a scenario discovery analysis using the Scenathon 2020 FABLE Calculator for Australia. Scenario Discovery is an exploration of the FABLE Calculator using hundreds of thousands of input parameter combinations (this is called the parameter space) to understand the limits of each input parameter. This allows the analysis of a single goal or combinations of them.

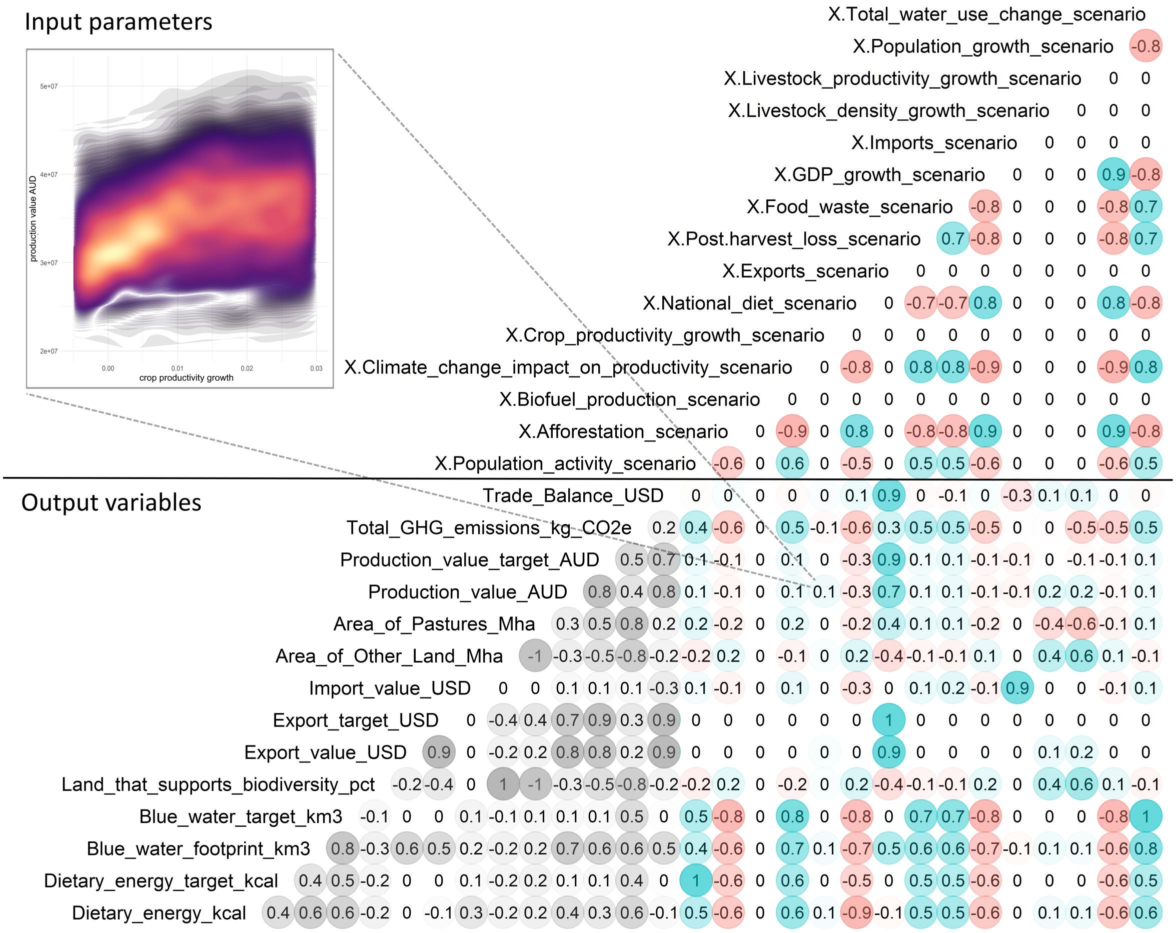
Figure 2-6 shows the correlation between FABLE Calculator input and output variables in the stochastic analysis by Navarro, Marcos-Martinez et al. (2023). There is a high correlation between input "X.Livestock_productivity_growth_scenario" and outputs

"Total_GHG_emissions_kg_CO2e" (r^2 -0.5), "Area_of_Pastures_Mha" (r^2 0.6), and "Land_that_supports_biodiversity_pct" (r^2 0.6). Input "X.Livestock_density_growth_scenario" exhibits a strong correlation to these outcomes too but less so (r^2 0.4 compared to 0.6 in the previous example), and livestock density growth bears no correlation with "Total_GHG_emission_kg_CO2e" (r^2 0). This means the hidden costs for Australia are strongly correlated with future changes in livestock productivity per head and pasture stocking rate, the amount of afforestation to 2050, and adoption of healthy diets. Note that here we say that a r2 of 0.6 or 0.8 are strong correlations because in the analysis performed by Navarro, Marcos-Martinez et al. (2023) there are many input variables which makes it difficult for anyone variable to influence the output more strongly.

The reason for the strong correlations outlined is variables like total land required for grazing or total livestock GHG emissions are proportional to the number of heads in the national herd. Reductions in the demand for meat due to adoption of diets such as EAT-*Lancet* would mean that the national herd required would be less; similarly increases in productivity would mean a smaller herd could meet the same demand for meat and hence result in smaller grazing footprint and GHG emissions. The area that is no longer regularly grazed or managed becomes part of the FABLE Calculator's "Other Land" pool where vegetation regeneration takes place and contributes significantly to carbon sequestration. Increase in livestock productivity has a significant but weak correlation with "Blue_water_footprint_km3" which makes sense because as productivity goes up fewer heads are required to meet the same demand and hence some reduction in water used for drinking will be observed. Dietary patterns ("X.National_diet_scenario") are strongly correlated with total GHG emissions (r2 0.6) and "Blue_water_footprint_km3" (r2 0.8), but its correlation with area of pastures and land that can support biodiversity is moderately weak (r2 0.2), reflecting the notion that Australian meat exports have a very strong influence on production.

The results from Navarro, Marcos-Martinez et al. (2023) revealed which factors of Australia's food and land system are in relation to FABLE targets and provided a quantitative assessment of their importance using the Pearson correlation coefficient (r). Hence those results are directly applicable to this assessment on how to reduce hidden costs from the Australian food and land system, with one exception: while in Navarro, Marcos-Martinez et al. (2023) all six targets were deemed equally important, in the TCA method (Lord, 2023) the marginal costs provide de-facto weighting of these disparate economic, food, and environmental targets and expresses them all in 2020 PPP dollar value. The result is a much higher emphasis on the impact of burden of disease due to poor diets than on all other sources of hidden costs (52–62 billion 2020 PPP dollars hidden cost due to dietary choices vs 20–40 billion 2020 PPP dollars of all other items combined). Therefore, according to the SOFA 2023 results dietary change is by far the single biggest contributor to the reduction of hidden costs of the food and land system, but this dietary change would have to be comparable to widespread adoption of the EAT-*Lancet* diet.

Figure 2-6: *Correlation matrix of FABLE Calculator inputs (inputs indicated with an X at the start) and outputs*



Source: Navarro, Marcos-Martinez et al. (2023).

The results of the decomposition analysis (Figure 2-7 to Figure 2-12) are consistent with the above analysis. Reduction in yield gap (from 46% yield potential achieved to 60%) in the NC pathway have a small effect on on-farm labor requirements and net GHG emissions (Figure 2-7 and Figure 2-12). Reducing labor requirements is important to government and industry due to recent labor shortages, particularly in the horticultural sector, and the prospect of increased labor shortages in the coming decades. The NC pathway leads to significant reductions in cropland area requirements, blue water use for irrigation, and nitrogen application required to meet demand (Figure 2-8, Figure 2-10, Figure 2-11).

In the GS pathway, greater substantial improvements in yield gap (80% of yield potential achieved), greater growth in livestock productivity and density, reduced post-harvest losses and food waste, and adoption of the EAT-*Lancet* diet led to big improvements in most areas. A notable exception is that widespread adoption of an EAT-*Lancet* like diet (heavy in fruits, vegetables, grains, light on livestock products) would lead to an increase in blue water used for irrigation but this would be outweighed by the improvements in crop productivity and reductions in food waste considered in the GS pathway (Figure 2-10). Afforestation plays a significant role in achieving and surpassing net zero CO_2 emissions in the GS pathway (with 10 million hectares afforested by 2050). Under the NC pathway, net zero emissions are also expected by 2050 and could potentially be achieved in the CT pathway (though surpassing this target is unlikely, according to FABLE modelling) (Figure 2-12).

Figure 2-7: *Isolated impacts of single scenarios on on-farm labor using the FABLE-C*

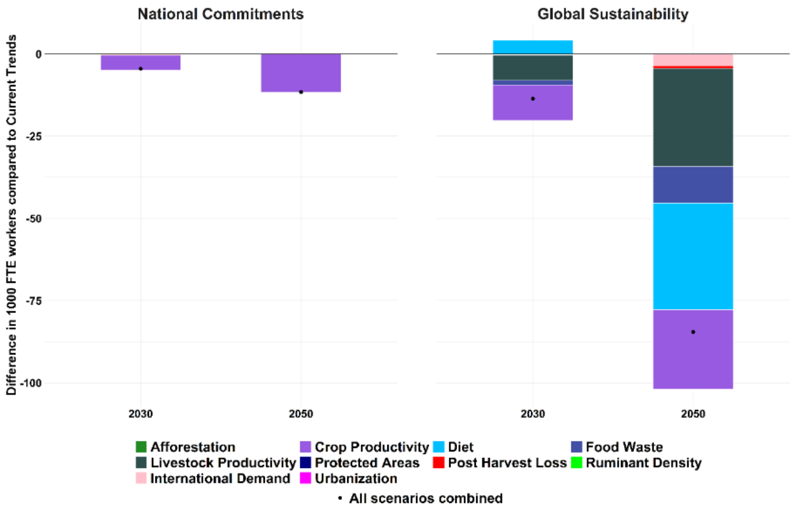


Figure 2-8: *Isolated impacts of single scenarios on cropland area using the FABLE-C*

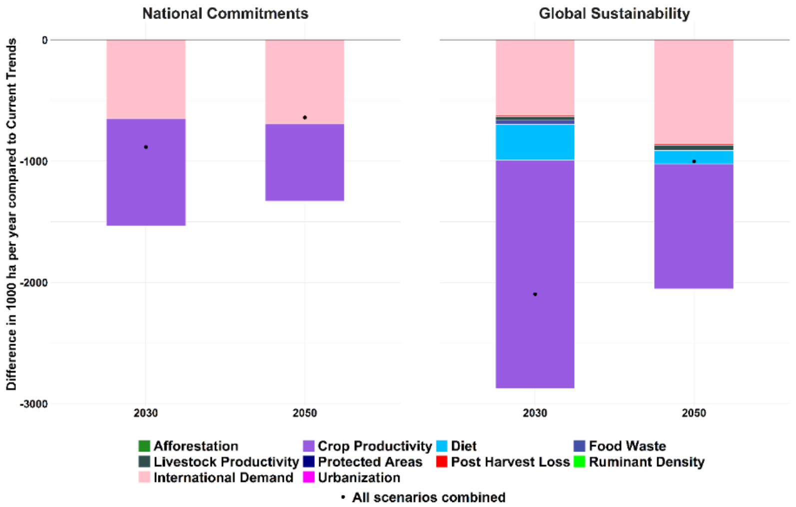


Figure 2-9: *Isolated impacts of single scenarios on pasture area using the FABLE-C*

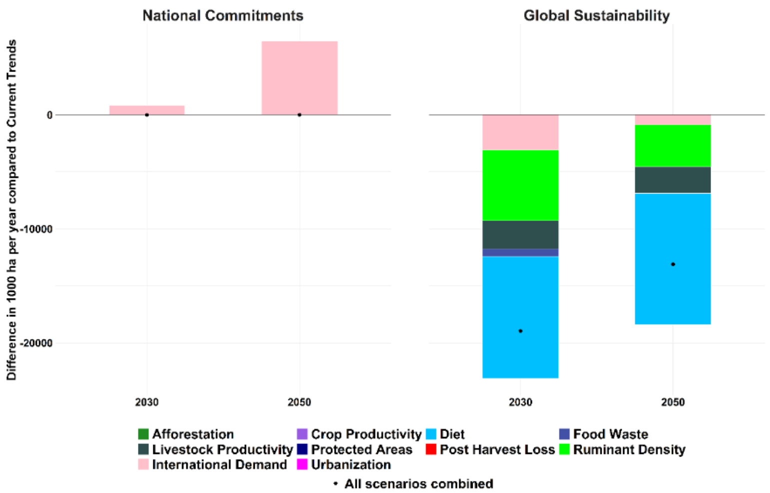


Figure 2-10: *Isolated impacts of single scenarios on irrigation water use using the FABLE-C*

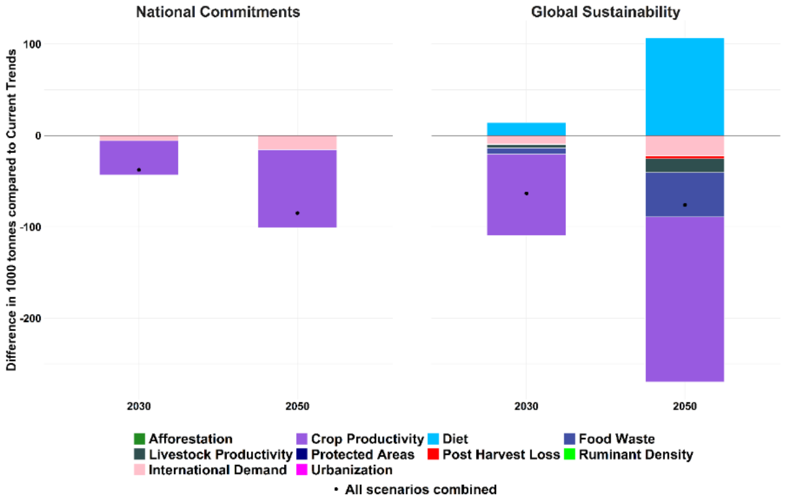


Figure 2-11: *Isolated impacts of single scenarios on nitrogen application using the FABLE-C*

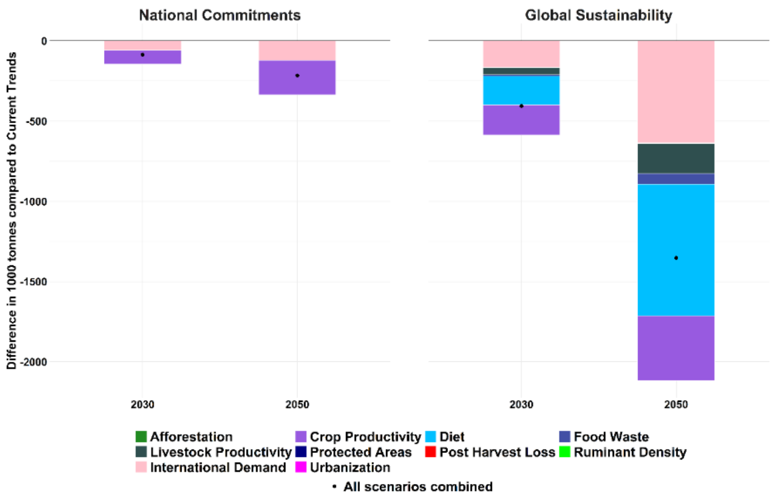
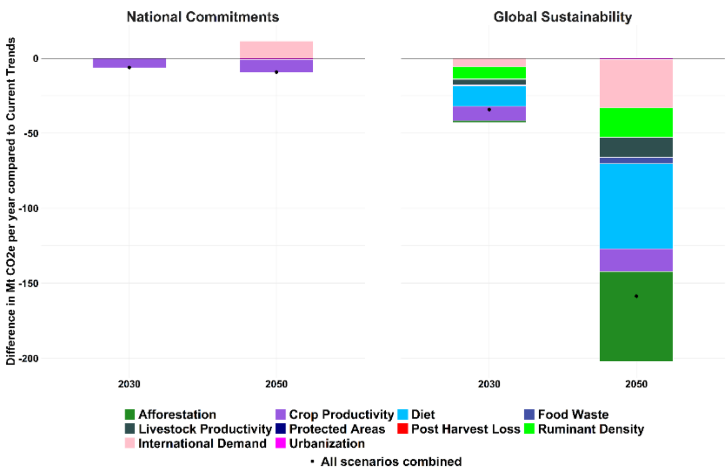


Figure 2-12: *Isolated impacts of single scenarios on net GHG emissions in CO2eq using the FABLE-C*



2.3.5 Impacts of the agrifood system's hidden costs

The results of the hidden costs modeling applied to Australian FABLE pathways shows there is a tendency for hidden costs to decrease over time as dietary change takes place, GHG emissions decrease and improvements in livestock productivity reduce the amount of land needed to meet demand for food (Table 2-5, Figure 2-13).

Health/social costs (due to burden of disease) are projected to decrease from 44.3 billion 2020 PPP dollars to 21.7 billion 2020 PPP dollars under CT or NC and to 15.5 billion 2020 PPP dollars under GS due to the adoption of EAT-Lancet type diets.

Environmental costs observe a decline from ~25 billion 2020 PPP dollars to ~11 billion 2020 PPP dollars in 2050 under CT and NC, but a steeper decrease to -6.9 billion 2020 PPP dollars under GS (Figure 2-13).

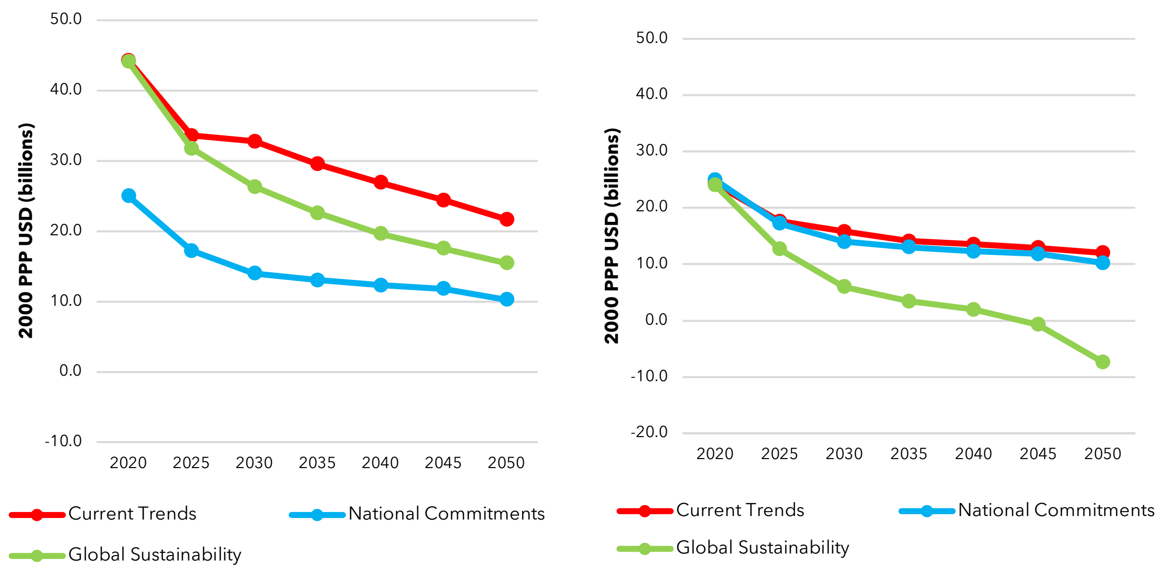
Under GS, environmental hidden costs would reach net zero by 2045. Most of the decrease is due to the return of grazing land that is surplus to requirement to its natural status and the associated increase in carbon sequestration through vegetation regeneration, but please note that the marginal cost of the "other natural habitat return" category was adjusted here based on Australian data and an internal assessment of pasture utilization rate in Australian rangelands. The original marginal cost data (average 11,000 2020 PPP dollars/ha) was deemed too high, so we sought to compare and validate it with Australian data.

Table 2-5: *Hidden costs of agriculture in Australia under the three FABLE pathways (2020–2050) by cost type including health, social and environment totals.*

Scenario	Year	Burden of Disease	CH4	CO2	Forest Habitat Return	N leaching	N run-off	N2O	NH3 to air	NOx to air	Other Natural Habitat Return (adjusted)	Total Health/Social	Total Environment
Current Trends	2020	44.3	3.6	-2.5	0.0	0.6	8.1	3.3	10.6	0.7	0.0	44.3	24.3
Current Trends	2025	33.6	3.3	-3.9	-0.9	0.5	7.4	3.5	9.6	0.6	-2.5	33.6	17.6
Current Trends	2030	32.8	3.4	-4.6	-0.3	0.5	7.2	3.2	8.9	0.5	-3.1	32.8	15.8
Current Trends	2035	29.5	2.9	-4.9	-0.3	0.5	6.8	3.0	8.9	0.5	-3.3	29.5	14.1
Current Trends	2040	26.9	2.9	-4.9	-0.3	0.4	6.6	2.6	8.3	0.5	-2.5	26.9	13.5
Current Trends	2045	24.4	2.7	-5.1	-0.3	0.4	6.4	2.4	8.1	0.5	-2.2	24.4	12.9
Current Trends	2050	21.7	2.7	-4.7	-0.2	0.4	6.0	2.3	7.7	0.4	-2.5	21.7	12.0
National Commitments	2020	44.0	3.9	-3.0	0.0	0.7	8.8	3.4	10.6	0.7	0.0	44.0	25.0
National Commitments	2025	33.7	3.9	-4.3	-0.9	0.6	7.6	3.5	9.3	0.6	-2.8	33.7	17.2
National Commitments	2030	32.6	3.2	-5.1	-0.3	0.5	6.8	3.1	9.0	0.5	-3.8	32.6	14.0
National Commitments	2035	29.7	3.2	-4.9	-0.3	0.5	6.9	2.5	8.3	0.5	-3.6	29.7	13.1
National Commitments	2040	27.0	2.9	-5.2	-0.3	0.4	6.5	2.3	8.1	0.5	-2.9	27.0	12.3
National Commitments	2045	24.4	2.7	-5.4	-0.3	0.4	6.3	2.3	7.6	0.4	-2.3	24.4	11.8
National Commitments	2050	21.7	2.5	-5.2	-0.2	0.4	5.8	2.1	7.1	0.4	-2.6	21.7	10.2
Global Sustainability	2020	44.2	3.6	-3.0	0.0	0.6	8.1	3.6	10.5	0.7	0.0	44.2	24.0
Global Sustainability	2025	31.8	3.7	-5.5	-1.0	0.6	7.9	3.3	9.5	0.6	-6.3	31.8	12.7
Global Sustainability	2030	26.3	3.0	-6.7	-0.3	0.5	6.9	2.8	8.5	0.5	-9.2	26.3	6.0
Global Sustainability	2035	22.6	2.8	-6.7	0.0	0.4	5.9	2.4	6.9	0.4	-8.7	22.6	3.4
Global Sustainability	2040	19.7	2.3	-7.3	-0.2	0.4	5.4	2.1	6.4	0.4	-7.5	19.7	2.0
Global Sustainability	2045	17.5	2.1	-8.1	-2.1	0.3	4.6	1.8	5.9	0.3	-5.6	17.5	-0.7
Global Sustainability	2050	15.5	1.9	-10.1	-6.2	0.3	4.4	1.5	5.3	0.3	-4.8	15.5	-7.4

Note: Adjusted values for other natural habitat return are 12% of the original estimated present value.

Figure 2-13. *Hidden costs of Agriculture in Australia under the three FABLE pathways (2020–2050)*



Note: The left pane shows total health/social costs (due to the burden of disease). The right pane shows total environmental costs excluding other habitat return.

Sangha et al. (2021) published an assessment of the ecosystem service value in Australian tropical savannas (region over 600mm rain/year). Their research suggests that the non-marketable ecosystem service value for grasslands and shrublands under pastoral lease is about USD 445/ha per year, and about USD 896/ha per year in woodland under pastoral lease. Non-marketable ecosystem services include protection of biodiversity, improvement in soil condition, and water resources that further support provision of food, water, cultural and ceremonial activities for indigenous Australians (Sangha et al., 2021).

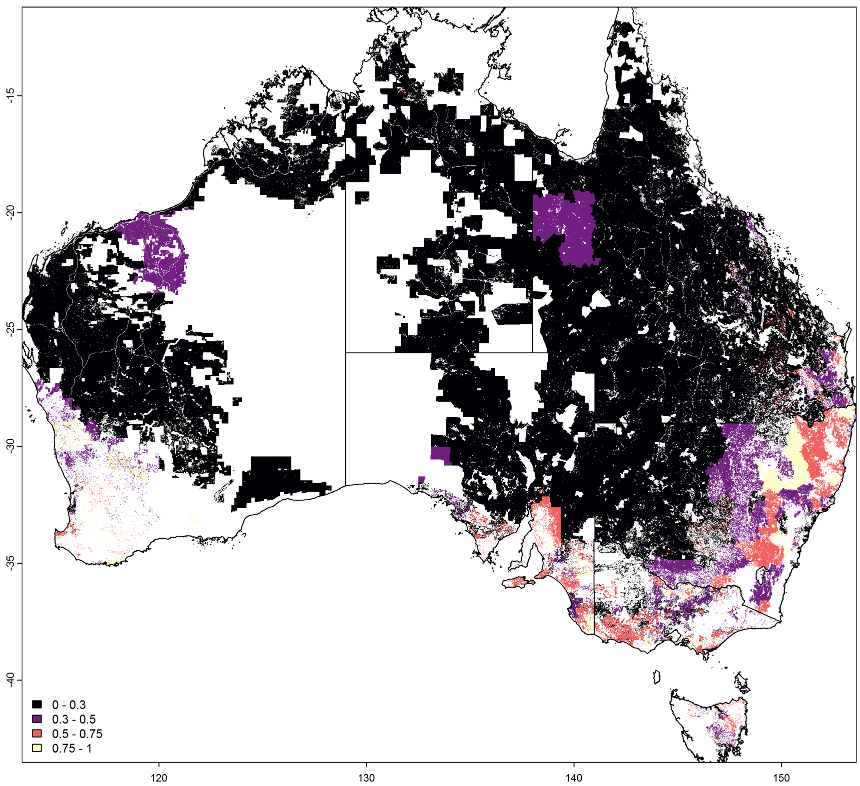
A rough approximation of the present value of ecosystem services would be USD 4,450 and USD 8,960 respectively (Steven Lord, personal communication), but that would be assuming that the entire ecosystem service value disappears because of grazing. In reality, growth of livestock productivity and density, and reductions in red meat demand are most likely to result in reductions of area requirement in the Australian rangelands which are already considered low-intensity production systems occurring in non-modified land. Therefore, the notion that all ecosystem service value is lost due to rangelands being used for grazing does not seem reasonable.

Internal CSIRO modeling based on a method originally developed by Marinoni, Navarro Garcia et al. (2012) indicates that most of Australian rangelands have a pasture utilization rate below 30%. The 30% marker is generally considered a long-term safe pasture utilization rate that prevents landscape degradation and preserves pasture quality. We argue it is therefore reasonable to assume that grazing in the rangelands impacts the ecosystem services value by no more than 30%, and hence we nominate a conservative "recoverable" value that is about USD 130 per hectare in grasslands and shrublands (Table 2-6). The resulting present value is about 12% of the original average marginal cost of USD 11,000 per hectare, or approximately USD 1,335 per hectare (Table 2-6). We argue this present value is conservative and likely overestimates the ecosystem service value in the arid/semi-arid rangelands as the values provided by Sangha et al. (2021) relate to the Australian tropical savannas which feature much higher average rainfall than the arid and semi-arid rangelands.

Table 2-6: *Ecosystem values in Australian Rangelands (Sangha et al. 2021). Note the recoverable portion of ecosystem services value is conservatively estimated at 30%.*

Ecosystem type	State	Area (kha)	ES value (USD M 2020)	ES value USD/ha	ES value recoverable (USD/ha)	ES value recoverable plus marketable	Present value USD	Present value AUD	Present value PPP 2020
Woodland	NT	760	681	896	269	276	2764	4007	2883
Woodland	QLD	3,147	2820	896	269	276	2764	4007	2883
Woodland	WA	844	756	896	269	276	2764	4007	2883
Shrubland	NT	1	1	450	135	143	1427	2069	1488
Shrubland	QLD	9	4	437	131	139	1386	2009	1446
Shrubland	WA	-	-	-	-	-	-	-	-
Grassland	NT	107	48	445	134	141	1411	2045	1471
Grassland	QLD	15	7	445	133	141	1411	2045	1471
Grassland	WA	-	-	-	-	-	-	-	-

Figure 2-14: *Estimated pasture utilization rate based on 2005-2015 livestock population*



Source: map based on method by Marinoni, Navarro Garcia et al. 2012.

Note: Most of the Australian rangelands feature a pasture utilization rate below 30%.

2.4 Entry points for action and foreseen implementation challenges

Australian food and fiber exports are a key driver of regional economic growth within the country and contribute to the food security of millions in the Asia-Pacific region and globally. However, this sector faces growing global and domestic issues (e.g., climate change, trade barriers and other supply chain disruptions, changes in diets, geopolitical uncertainty). The results of the 2023 Scenathon and previous modeling (Brinsmead et al., 2019; Navarro, Marcos-Martinez et al., 2023) suggest that there are pathways to a more sustainable and resilient Australian future with better socioeconomic and environmental outcomes than under the current trends scenario. However, this future requires significant structural changes and coordinated interventions in several components of the domestic system to increase its resilience and environmental and socioeconomic performance. Significant buy-in from key stakeholders about the need for systemic change could help drive coordinated actions to maintain the local and global relevance of the Australian agricultural and food sector.

An optimistic but not infeasible sustainable pathway enables the identification of conditions needed to achieve multiple sustainability targets simultaneously. However, such a scenario will likely require substantial transformative action, as it appears to be at the higher bound of what is technically or socially achievable in terms of productivity increases, environmental performance and behavioral change.

In 2023 the CSIRO conducted an extensive consultative effort across more than 120 stakeholders from industry, government, NGOs and the research sectors to determine the main challenges and priorities facing Australia's food system, and to formulate a roadmap towards a sustainable, productive and resilient future for Australia's food system, its environment and people. The resulting Food Systems Roadmap (CSIRO Futures, 2023) identified five main areas of focus and produced a comprehensive list of entry points (opportunities and research needs) (Table 2-7). Most of these activities (if not all) will require close collaboration between various actors across the food system and the building of shared values and understanding to ensure advances are safe, equitable and fair and thus benefit society at large (CSIRO Futures, 2023). Information on the status quo around each focal area as well as details about each opportunity and R&D priority can be found in the report.

Some recent trends towards more plant-based eating are encouraging, as seen in a 1.5% rise from 2012 to 2016 in the number of vegetarians (from 9.7% to 11.2 %) (Roy Morgan, 2019), as well as the increasing number of people reducing their red meat consumption in favor of more non-animal sources of protein (Waldhuter, 2017). However, the main challenge is that most Australians at present consume high-calorie diets with very high amounts of meat, with the current average consumption for red meat estimated to be 24% higher than the maximum recommended intake in the Australian Dietary Guidelines (ADGs) (NHMRC, 2013). The current starting point for shifting diets in Australia towards the recommended EAT-Lancet diet is the high animal-protein intake diet, with an average of 95kg/cap/yr of meat intake compared to the OECD average of 69kg/cap/yr (OECD, 2020). Introducing stronger sustainability principles in the upcoming iteration of the ADGs, along with strong monetary incentives to push consumption patterns towards more sustainable diets, could accelerate ongoing positive trends.

Table 2-7. *CSIRO's Food Systems Roadmap focal areas, opportunities, and R&D priorities (CSIRO Futures, 2023)*

Focal Areas	Opportunities	R&D priorities
Enabling equitable access to healthy and sustainable diets	Integrate equity and sustainability principles into the Australian Dietary Guidelines.	Integrated data platforms to enable greater engagement and participation for all stakeholders across the value chain.
	Secure access to healthy and safe food for Aboriginal and Torres Strait Islander communities.	Improve population data and nutritional surveillance to inform policy responses towards food-related inequities and chronic illnesses.
	Support localized food systems and innovative business models.	Research into current best practice tools and approaches for fostering consumer behavior change.
	Government and business collaboration to reshape commercial food environments.	Research of systems-based approaches that balance ecological, health, social, cultural and economic goals.
	Leverage institutional procurement to prioritize healthy and sustainable diets.	Expand research into microbes and viral agents that contribute to adverse health outcomes (and food loss).
	Educate and empower consumers to eat healthier.	Innovations to extend shelf-life of perishable foods.
Minimizing waste and improving circularity	Implement sustainable and recyclable packaging with improved labeling.	Investigate methods to estimate the true cost of products and their disposal, and embed product LCA data into costing.
	Educate and empower consumers to reduce food waste.	Map the quantity and quality of both avoidable and unavoidable food loss and waste.
	Transform waste into Australian value-added products.	Develop and scale new production platforms to process by-product waste streams.
		Sustainable packaging to extend the shelf-life of food.
		Life-cycle assessments of plastic use across the value chain and its comparison to alternative bio-based packaging.
		On-farm plastic waste solutions.
Facilitating Australia's transition to net zero emissions	Reducing emissions through nature-based solutions (e.g., reducing synthetic fertilizer application, improving soil quality, nature protection and restoration).	Collaborative research that develops a systems approach to emissions reduction in food systems.
	Expanding the availability of climate-neutral foods.	Research to improve the efficacy of carbon markets in reducing emissions.
	Reducing emissions through innovative technologies (precision agriculture, feed additives to reduce methane in livestock).	Develop negative emission technologies for agriculture and food production.
	Integrate renewable energy sources throughout the food supply chain.	Tools to improve GHG emissions data collection, measurement and modeling.
	Creating diversified lower emission protein products and markets.	Tools and best practices to disseminate the latest data and recommendations to farmers and businesses.
	Reduce emissions from food loss and waste.	Develop accessible technology platforms to help primary producers reduce emissions.
		Research and pilot studies to investigate current best practice for sustainability labeling on foods
		Continued collaborative research into Indigenous land management techniques used by Aboriginal and Torres Strait Islanders.

Aligning resilience with socioeconomic and environmental sustainability	Diversify food supply chains to improve system flexibility.	Research into resilient and climate-tolerant cultivars.
	Strengthen Australia's sovereign manufacturing capabilities and workforce.	Selective breeding for climate-tolerant livestock.
	Bolster transparency and trust of food supply chains.	Process engineering for greater flexibility within production, manufacturing and transportation operations.
	Promote integrated regional planning for industry development.	Improved and efficient water management and infrastructure.
	Advance industry-wide adoption of risk management and sustainability strategies.	Developing and enhancing digital systems that can collect and aggregate data for multi-use purposes that support resilience outcomes.
		Development and deployment of automation, drones and robotics technologies to address labor shortages
		Research and piloting of new market mechanisms and business financing models to improve business resilience
		Research of agroecological and environmentally sustainable farming practices, including Aboriginal and Torres Strait Islander techniques.
		Further research on links between marine and terrestrial food production systems to reduce land use pressures.
Increasing value and productivity	Diversify exports for long-term economic prosperity.	Digital technologies to verify food credentials and enable traceability across domestic and international supply chains.
	Create additional value-add opportunities for Australia in global value chains.	Digital and automated export compliance procedures.
	Regional leadership through the sharing of technology solutions and expertise.	New product development of functional foods, alternative healthy foods, and value-added products.
	Promote healthy landscapes to protect current and future productive capacity.	Develop and scale new production platforms.
	Expand Australia's self-determined Aboriginal and Torres Strait Islander food industry.	Research into best practice tools and frameworks to inform business decisions.
		Tools and data to improve resource management.
		Co-production of robust social and cultural Aboriginal and Torres Strait Islander food metrics.

2.5 References

ABARES (2023). Environmental sustainability and agri-environmental indicators—international comparisons. https://daff.ent.sirsidynix.net.au/client/en_AU/search/asset/1034821/0

ABS (2015), Australian Health Survey: Usual Nutrient Intakes (reference period 2011-12 financial year). https://www.abs.gov.au/statistics/health/health-conditions-and-risks/australian-health-survey-usual-nutrient-intakes/latest-release

ABS (2021), Water Use on Australian Farms, Australian Bureau of Statistics (2020-21) https://www.abs.gov.au/statistics/industry/agriculture/water-use-australian-farms/latest-release#cite-window1

Australian Commission on Safety and Quality in Health Care (2019). Hospital-Acquired Complication 13 - Malnutrition (Selected Best Practices and Suggestions for Improvement for Clinicians and Health System Managers).

Australian Institute of Health and Welfare (2012). Australia's food & nutrition 2012. https://doi.org/10.25816/5ec1da0b2547b

Brinsmead, T., Rendall, A., Baynes, T., Butler, C., Kelly, R., Adams, P., Hayward, J., Reedman, L., Nolan, M., Lennox, J., Hennessy, K., Wynn, K., Ahmad, M., Marcos-Martinez, R., Collins, L., Lu, Y., Che, N., Qiu, J., & Kanudia, A. (2019). Australian National Outlook 2019 - Technical Report. https://doi.org/https://doi.org/10.25919/5d0934b82e649

CSIRO Futures (2023) Reshaping Australian Food Systems – A Roadmap towards a more sustainable, productive and resilient future for Australia's food, its environment and people. CSIRO, Canberra.

Davis, B., Mane, E., Gurbuzer, L.Y., Caivano, G., Piedrahita, N., Schneider, K., Azhar, N. et al. 2023. Estimating global and country-level employment in agrifood systems. FAO Statistics Working Paper Series 23–34. Rome, FAO. https://doi.org/10.4060/cc4337en

DCCEEW(2023). National Inventory Report 2021. Commonwealth of Australia. https://www.dcceew.gov.au/climate-change/publications/national-inventory-report-2021

FABLE (2020). Pathways to Sustainable Land-Use and Food Systems. 2020 Report of the FABLE Consortium. Laxenburg and Paris: International Institute for Applied Systems Analysis (IIASA) and Sustainable Development Solutions Network (SDSN). https://doi.org/10.22022/ESM/12-2020.16

FABLE, 2024. Transforming food and land systems to achieve the SDGs. In Sachs et al. (2024) The Sustainable Development Report 2024. SDSN, New York and Paris.

FAO (2023a). The State of Food and Agriculture 2023 – Revealing the true cost of food to transform agrifood systems. Rome. https://doi.org/10.4060/cc7724en

FAO (2023b). FAOSTAT Climate Change: Agrifood systems emissions, Emissions Totals, http://www.fao.org/faostat/en/#data/GT

FAO (2023c). FAOSTAT SDG Indicators: Prevalence of moderate or severe food insecurity in the population (%). https://www.fao.org/faostat/en/#data/SDGB

FAO (2023d). AQUASTAT. https://www.fao.org/aquastat/en/databases/glossary/

FAO, 2024. The State of Food and Agriculture 2024: Value driven transformation of agrifood systems. Rome.

Foodbank (2023). Hunger Report 2023. https://reports.foodbank.org.au/foodbank-hunger-report-2023/

Healthdirect (2019). Malnutrition. Health Topics. https://www.healthdirect.gov.au/malnutrition

Hochman, Z., Gobbett, D., Horan, H., & Navarro Garcia, J. (2016). Data rich yield gap analysis of wheat in Australia. Field Crops Research, 197, 97-106

Howarth, R., Swaney, D., Boyer, E., Marino, R., Jaworski, N., Goodale, C. (2006). The influence of climate on average nitrogen export from large watersheds in the Northeastern United States, Nitrogen Cycling in the Americas: Natural and Anthropogenic Influences and Controls pp 163-186. https://link.springer.com/chapter/10.1007/978-1-4020-5517-1_8

Kleve, S., Gallegos, D., Ashby, S., Palermo, C., & McKechnie, R. (2018). Preliminary validation and piloting of a comprehensive measure of household food security in Australia. Public Health Nutrition, 21(03), 526–534. https://doi.org/10.1017/S1368980017003007

Lal, A., Peeters, A., Brown, V., Nguyen, P., Tran, H., Nguyen, T., Tonmukayakul, U., Sacks, G., Calache, H., Martin, J., Moodie, M., Ananthapavan, J. (2020) The Modelled Population Obesity-Related Health Benefits of Reducing Consumption of Discretionary Foods in Australia. Nutrients, Feb 28;12(3):649. doi: 10.3390/nu12030649. https://www.mdpi.com/2072-6643/12/3/649

The Lancet (2018). The Global Burden of Disease Study 2017. 392(10159) p1683-2138, e14-e18. https://www.thelancet.com/journals/lancet/issue/vol392no10159/PIIS0140-6736(18)X0048-8

Lord, S. (2023). Hidden costs of agrifood systems and recent trends from 2016 to 2023 – Background paper for The State of Food and Agriculture 2023. FAO Agricultural Development Economics Technical Study, No. 31. Rome, FAO. https://doi.org/10.4060/cc8581en

Marinoni, O., Navarro Garcia, J., Marvanek, S., Prestwidge, D., Clifford, D., Laredo, L. (2012). Development of a system to produce maps of agricultural profit on a continental scale: An example for Australia. Agricultural Systems 105, 1 (2012), pp. 33-45 https://doi.org/10.1016/j.agsy.2011.09.002

McKay, F. H., Haines, B. C., & Dunn, M. (2019). Measuring and Understanding Food Insecurity in Australia: A Systematic Review. International Journal of Environmental Research and Public Health, 16(3), 476. https://doi.org/10.3390/ijerph16030476

Mosnier, A., Penescu, L., Perez-Guzman, K., Steinhauser, J., Thomson, M., Douzal, C., Poncet, J., 2020. FABLE Calculator documentation- 2020 update. IIASA (Laxenburg) and SDSN (Paris).

Mosnier et al. (2023) A decentralized approach to model national and global food and land use systems. Environ. Res. Lett. 18 045001

National First Nations People Agency, 2020. Food prices and accessibility in remote communities: 'simple basket of goods' snapshot, July 2020

Navarro Garcia, J., Marcos-Martinez, R., Mosnier, A. et al. (2023). Multi-target scenario discovery to plan for sustainable food and land systems in Australia. Sustain Sci 18, 371–388 (2023). https://doi.org/10.1007/s11625-022-01202-2

Navarro, J., Hadjikakou, M., Ridoutt, B., Parry, H., and Bryan, B.A. (2021). Pesticide Toxicity Hazard of Agriculture: Regional and Commodity Hotspots in Australia. Environmental Science & Technology 2021 55 (2), 1290-1300, DOI: 10.1021/acs.est.0c05717

NHMRC. (2013). Australian Dietary Guidelines Introduction. In Archives of Pediatrics & Adolescent Medicine (Vol. 20, Issue 1). https://doi.org/10.1001/archpedi.1979.02130080108026

OECD. (2020). Meat consumption (indicator). Retrieved from OECD website: https://data.oecd.org/agroutput/meat-consumption.htm

Sangha, K.K., Evans, J., Edwards, A., Russell-Smith, J., Fisher, R., Yates, C., Costanza, R. (2021). Assessing the value of ecosystem services delivered by prescribed fire management in Australian tropical savannas. Ecosystem Services Vol 51, 2021, 101343, ISSN 2212-0416, https://doi.org/10.1016/j.ecoser.2021.101343

Thorburn, P., Wilkinson, S. (2013). Conceptual frameworks for estimating the water quality benefits of improved agricultural management practices in large catchments. Agriculture, Ecosystems and Environment 180, 192-209. https://www.sciencedirect.com/science/article/pii/S0167880912000059

USDA. (2019). Household Food Security Survey Module. Retrieved from https://www.ers.usda.gov/topics/food-nutrition-assistance/food-security-in-the-us/survey-tools/#household

Van Wart, J., Van Bussel, L.G.J., Wolf, J., Licker, R., Grassini, P., Nelson, A., Boogaard, H.L., Gerber, J., Mueller, N.D., Claessens, L.F.G., Van Ittersum, M.K. & Cassman, K.G. (2013). Use of agro-climatic zones to upscale simulated crop yield potential. Field Crops Research, 143, 44-55.

Waldhuter, L. (2017, April 5). What the changing food habits of Australians tell us - ABC News. Retrieved from https://www.abc.net.au/news/2017-04-05/australians-are-changing-their-eating-habits/8415526

West, P. C., Gerber, J. S., Engstrom, P. M., Mueller, N. D., Brauman, K. A., Carlson, K. M., Cassidy, E. S., Johnston, M., MacDonald, G. K., Ray, D. K., & Siebert, S. (2014). Leverage points for improving global food security and the environment. Science, 345(6194), 325–328. https://doi.org/10.1126/science.1246067

WHO. (2020). Nutrition Landscape Information System (NLIS) Country Profile Australia.

Wiedmann, T., & Lenzen, M. (2018). Environmental and social footprints of international trade. In Nature Geoscience (Vol. 11, Issue 5, pp. 314–321). Nature Publishing Group. https://doi.org/10.1038/s41561-018-0113-9

Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., Garnett, T., Tilman, D., DeClerck, F., Wood, A., Jonell, M., Clark, M., Gordon, L. J., Fanzo, J., Hawkes, C., Zurayk, R., Rivera, J. A., Vries, W. D., Sibanda, L. M., … Murray, C. J. L. (2019). Food in the Anthropocene: The EAT–Lancet Commission on healthy diets from sustainable food systems. The Lancet, 393(10170), 447–492. https://doi.org/10.1016/S0140-6736(18)31788-4

Chapter 3. Brazil

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Highlights

- In this study, we assessed the evolution of hidden costs for Brazil's agrifood system as presented in the SOFA 2023 report and analyzed strategies for reducing them through stakeholder consultation and modeling using the FABLE approach.

- The scenarios were developed using FABLE-Calculator, a tool that computes land use, emissions, and food system projections over 2000–2050. The hidden costs were analyzed by integrating the TCA methodology with the FABLE Calculator outcomes, exploring three alternative pathways to achieve sustainability.

- Results indicate that over half of the hidden costs are linked to dietary choices, followed by nitrogen flows and climate components. However, these results are driven by methodological and data choices that were questioned by the stakeholders consulted. They suggested national datasets should be used instead and methods should be adjusted to reflect national context.

- Strategies from different actors from the public and private sectors are needed to reduce the hidden costs in Brazil. National and local actions to shift towards healthier diets and to reduce GHG emissions can be important to diminish these costs, such as government subsidies and incentives for sustainable agricultural practices and organic food production.

- The findings highlight the importance of enhancing analytical capacity through stronger collaboration between Brazilian institutions and the FAO, as well as the need for additional national datasets that reflect Brazil's diversity and complexity.

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3.1 Introduction

The aim of this chapter is to provide country-specific feedback for the improvement and further development of the estimates of the hidden costs of agrifood systems in Brazil. Brazil-specific scenarios were developed with the FABLE Calculator to provide inputs for the evolution of hidden costs by 2030 and 2050. The feedback presented here was collected and produced via literature review and expert consultation with stakeholders in civil society, government, and academia. The consulted experts have expertise spanning the areas of economics, social sciences, agricultural sciences, food and land use systems, low carbon and climate resilient development, and sustainability transformations.

Brazil is the largest net exporter of food products in the world, the largest producer of soybeans, and the second largest beef producer. It is also the most biodiverse country in the world, home to large swathes of remaining Amazon rainforest, home to native plants, animals and Indigenous communities. The country's high suitability for agricultural production at industrial scales has enabled a thriving agricultural sector with large contributions to GDP and employment. This has come at the expense of natural habitats and ecosystems causing greenhouse gas emissions, soil degradation, biodiversity loss and pollution of air, land and water. While productivity increases have contributed substantially to increasing production, expansion of agricultural land over native vegetation has continued to this day, and chronic inefficiencies remain.

Our results show there is high potential for improving yields, adopting conservation agriculture, increasing inclusivity, incentivizing more healthy diets, and capturing revenues from carbon sequestration in land sinks, and this is in line with a large literature (e.g., see Köberle et al., 2020; de Oliveira et al., 2017; Assad et al., 2018). However, this literature also shows that challenges that need to be overcome to fully grasp the opportunities include increasing access to finance, strengthening enforcement of existing environmental and land regulation, and creating robust carbon and nature markets that properly value climate and biodiversity stocks (see e.g., NatureFinance 2022; Rochedo et al., 2018). While industrial agriculture dominates commodity production for export markets, smallholders and family farmers make a sizable contribution to supplying domestic food markets. Yet, unhealthy diets increasingly contribute to health issues, and the widespread use of biocides undermines both human and environmental health. In both grain and beef sectors, market power by a handful of companies is both a cause of current externalities and an opportunity to transform agricultural value chains through active engagement of a limited number of actors. Technological and process innovation can deliver both environmental and economic benefits and facilitate a transformation that maximizes well-being in a country that still needs to bring a large share of its population out of poverty and low-income traps.

Still, while science points to the high potential for a sustainable transformation of food systems in Brazil which would have many benefits, there would still be an uneven distribution of benefits and trade-offs, which imply the results can elicit strong reactions and can be perceived as politically charged.

Feedback was requested via email from key stakeholders of the agricultural sector, including from academia, government, and civil society. To provide respondents with relevant information, a slide deck was prepared with key messages and figures from the hidden costs analysis. Respondents were then asked to provide their feedback via an online form in which they could provide i) their personal information such as sector, affiliation, and anonymity preferences; ii) responses to prepared questions about specific topics; and iii) their opinions regarding results as well as suggestions for improvements to the analysis or alternative datasets (cf. Annex).

The emails were sent out in mid-February and respondents were given a period of two weeks to respond. While a longer period would have been desirable to elicit the largest possible number of responses, the tight production timeline of the report plus the summer holiday season in Brazil constrained our options in that regard. In a second round, requests were sent to the 32 respondents to participate in a virtual meeting set in early April. Only nine responses were obtained from the online survey, all with expertise in disciplines of economics and agriculture. The virtual meeting in April was attended by nine participants, with five of them being stakeholders who responded to the online survey. Based on the limited number of responses, it is already evident that the results will elicit a broad range of responses from different stakeholders.

When asked "How well do you think the analysis reflects hidden costs in Brazil?", two stakeholders had diametrically opposite responses to the size of the hidden costs' estimates, one suggesting they were overestimated while the other saying they were underestimated. A third responded by saying "Not very well" and said it was "Probably due to the high uncertainty associated to the data used for such analyses."

The personal views of respondents also seem to be influenced by respondents' disciplines, suggesting this exercise may trigger subjective reactions. For example, the respondent who thought the hidden costs were underestimated works in an economic thinktank and is active in the rural development field, while the one who thought they were overestimated is tied to an agronomic research facility. These responses suggest that stakeholders may respond subjectively in the face of uncertainty or perceived lack of clarity about the assessment, raising the possibility that the results may trigger politically charged debates. This is useful in preparing for broader engagement with society through a proper framing of the questions posed and the insights highlighted.

3.2 SOFA 2023 hidden costs analysis

3.2.1 Main cost components and explanations of the results

In 2020, the hidden costs from food production in Brazil totaled around 500 billion 2020 PPP dollars. This is roughly equivalent to 16% of Brazil's GDP on a PPP basis, implying that Brazil's GDP PPP would be roughly 16% lower if the hidden costs were to be accounted for in 2020. The main cost components for Brazil's TCA are the burden of disease, nitrogen flows and climate, accounting for 270 billion (54%), 231 billion (30%) and 2.2 billion (15%) 2020 PPP dollars respectively of the total hidden costs (FAO, 2023).

SOFA 2023 TCA analysis shows the cost of unhealthy diets has been steadily increasing from 2016 to 2023 (Figure 3-1), in line with Brazilian studies showing increasing costs from diets rich in processed meat (Rocha et al., 2023) and increasing overweight and obesity rates (Ferrari et al., 2022). Rocha et al. (2023) used national data to estimate an increasing burden of non-communicable diseases (NCDs) from hospitalizations and outpatient procedures of around USD 9 million in 2019, and age-standardized DALYs estimated at around 35/100,000 for 2019. (Ferrari et al., 2022) estimated direct healthcare costs related to NCDs attributable to high body mass index (BMI) of USD 654 million. Both these studies results are in market exchange rate (MER), not PPP, making direct comparisons to SOFA 2023 TCA more challenging.

The estimated 2023 costs of agrifood work poverty and blue water use are much smaller, at 3.5 billion and 34 million 2020 PPP dollars, respectively (Figure 3-2), and the cost of undernourishment is shown as being zero.

Figure 3-1: *Burden of disease costs for Brazil as estimated in SOFA 2023 TCA*

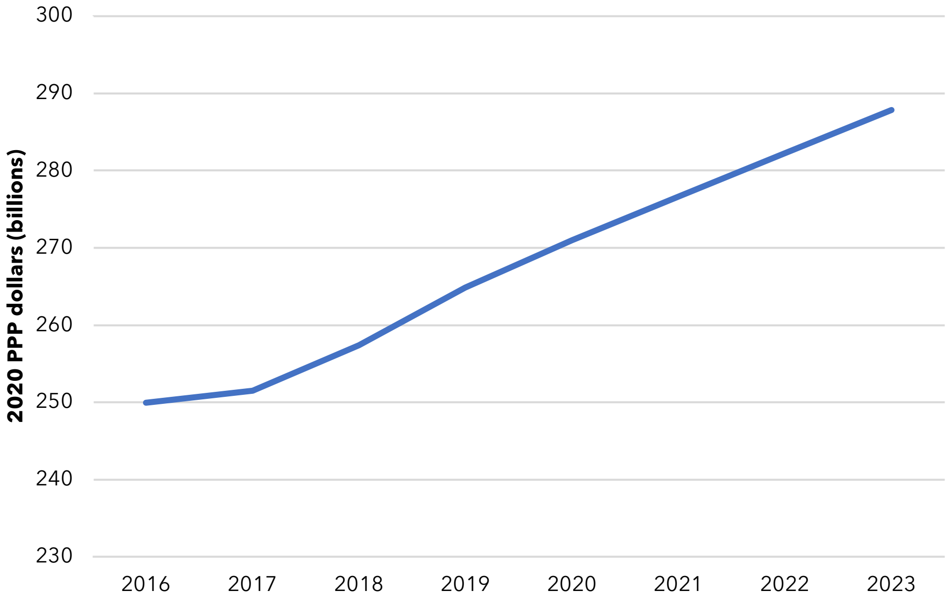
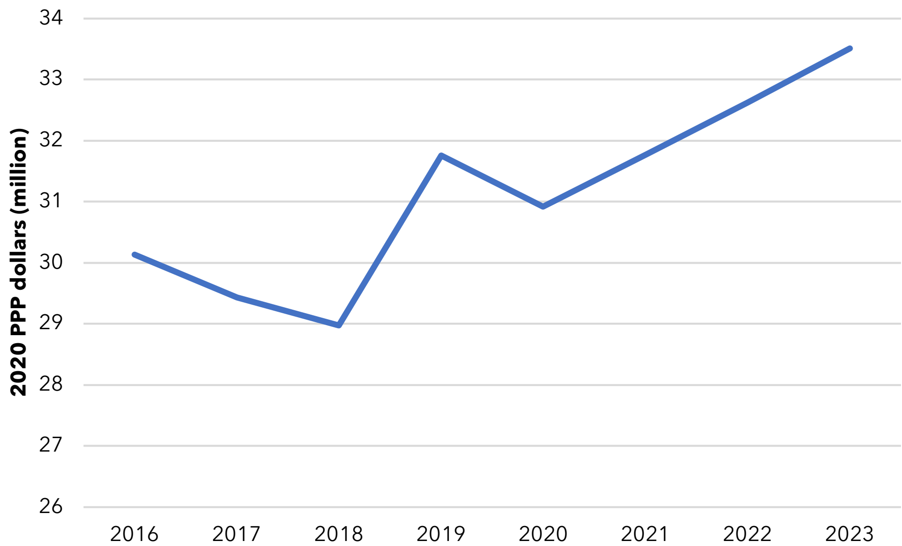


Figure 3-2: *Blue water costs for Brazil as estimated in SOFA 2023 TCA*



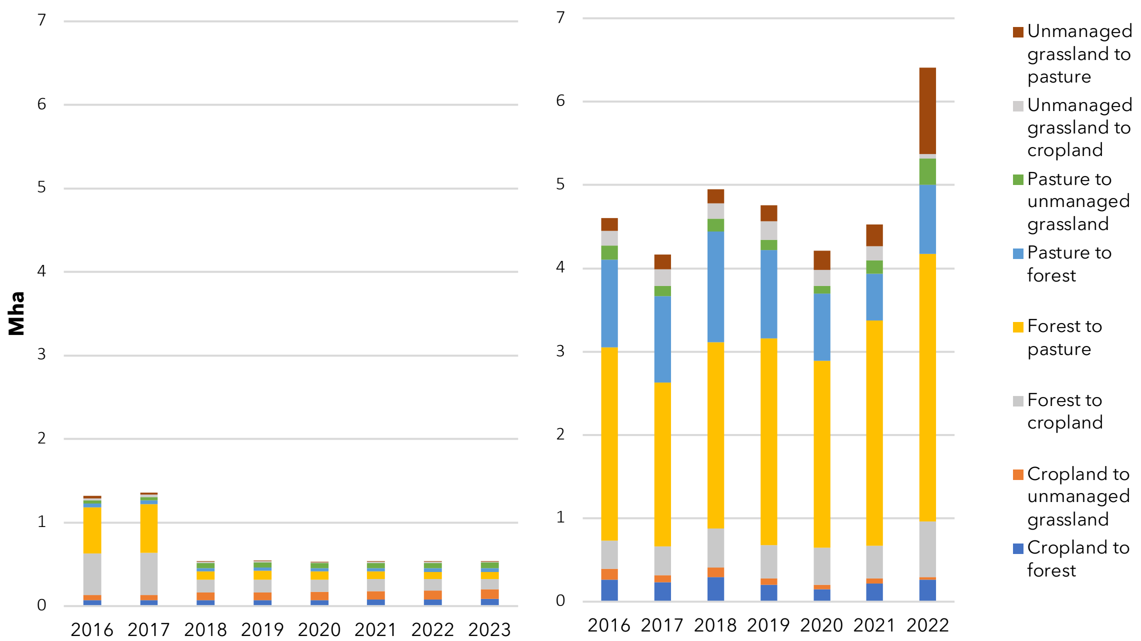
The increasing costs of unhealthy diets are in line with rising obesity and overweight in Brazil. Land use data needs to be checked against Brazilian datasets as it does not match observed trends in the last decade (see Section 3.3.1). As an agricultural powerhouse and one of the main exporters of commodity food items in the world, it is expected that agriculture would play a large role in the costs estimated. Indeed, this does show up through the sizeable contributions of climate and nitrogen run-off costs, which are driven by CO_2 emissions from deforestation (associated with expansion of agricultural areas), CH_4 emissions (mainly from enteric fermentation) and N_2O emissions (mainly from synthetic fertilizer application but also from manure). Nitrogen run-off is associated with increasing use of fertilizer application associated with robust growth in agricultural production in recent decades, and with nitrogen use efficiency not visibly improving, even showing signs of worsening according to a few studies (Pires et al., 2015; Santos et al., 2023). Finally, the increase in the use of irrigation in agriculture signals a rise in the cost associated with blue water withdrawals, although Brazilian agriculture is mainly rainfed (only about 10% of the agricultural area is irrigated).

3.2.2 Comparison of SPIQ data with national datasets

Brazil is one of the largest food exporters globally and as such, has a high share of its anthropic land surface used for agriculture, including crops and livestock. Land use transitions are extracted from the HILDA+ dataset, a yearly worldwide dataset obtained at a resolution of 1 km by satellite data. The trend smooths out after 2020 because data was extrapolated beyond that period. The data indicates a drop in forest conversion to agricultural land between 2017 and 2018, with a reduction of 77% in forest loss in a single year and staying roughly constant until 2023. This is not corroborated by national data such as the MapBiomas land use transition datasets, which shows an increasing trend in the natural vegetation loss in the period 2018–2022 (MapBiomas in Souza et al., 2020), as shown in Figure 3-3.

Additionally, a 3–6 million hectares disparity exists in the total land use transition area when comparing the two datasets over the years. On the one hand, this may imply that the TCA for land use is likely to be underestimated based on land conversion alone. However, TCA only considers a limited set of land use changes, and further analysis is necessary to account for the full range of land use transitions. Importantly, there is much uncertainty in the marginal costs of land use change, so combining the land use flux with this uncertainty leads to a high range of land use related hidden costs.

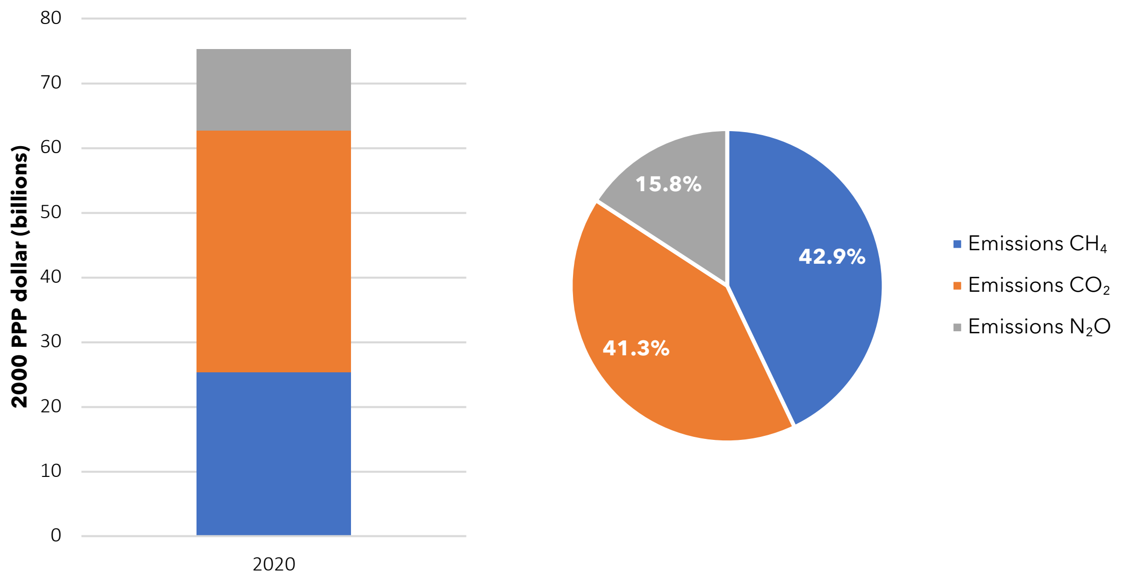
Figure 3-3: *Comparison of HILDA+ land use change dataset for Brazil used in TCA results (a) and land use transitions based on MapBiomas (b) for land use transitions. MapBiomas Collection 8 has information up to 2022.*



Regarding greenhouse gas (GHG) emissions, the TCA considers three types of gas when calculating the hidden costs: CO_2, CH_4 and N_2O. CO_2 corresponds to 50% of the total hidden costs from emissions in the TCA results for the year 2020 (Figure 3-4a). Emissions from CH_4 and from N_2O cause 33% and 17% of the hidden costs, respectively.

This breakdown aligns with the emissions profile for the agriculture, forestry and other land use (AFOLU) sectors in the same year according to national data from SEEG (SEEG, 2023). Agricultural non-CO_2 emissions account for more than half of total AFOLU emissions (Figure 3-4b).

Figure 3-4: *Comparison of hidden costs from GHG emissions decomposed by gas in the SOFA 2023 analysis (left) and the percentages of emissions based on SEEG emissions (right) for the agricultural and LULUCF sectors in 2020.*



3.2.3 Recommendations for tailored country hidden costs analysis

An essential measure for tailoring the analysis quality is to include national datasets that are more precise for the Brazilian context. Respondents suggested improvements using national databases, such as those provided by the Ministry of Agriculture and Embrapa. Suggestions for specific data included food security in rural populations, carbon sequestration in agricultural lands, but also new datasets that fill existing gaps. For example, global datasets could be replaced using land use/cover data from the MapBiomas platform; social and agricultural data from the Brazilian Institute of Geography and Statistics (IBGE); environmental data from the National Emissions Registry System (SIRENE/MCTI), and the Greenhouse Gas Emissions and Removals Estimation System (SEEG); and agricultural productivity data from the Ministry of Agriculture, Livestock, and Supply (MAPA). For the undernourishment analysis, data from The Brazilian Research Network on Food and Nutrition Sovereignty and Security could be used. Additionally, improving the nitrogen and water analysis is crucial, given their importance in the agricultural context, direct implications in food production, and the high share of nitrogen-related costs represented in the Brazilian case. Stakeholders also emphasized the importance of future analyses that consider the different Brazilian regions and biomes. Recognizing the diversity and complexity across different regions and ecosystems is essential for meeting equitably the specific needs of each locality. They also suggested closer collaboration between Brazilian institutions and FAO to strengthen analytical capacity.

Methodologically, suggestions ranged from including poverty costs of unequal land distribution, use of pesticides on health and biodiversity, differentiation between types of agricultural systems, and revising water usage parameters. The full allocation of hidden costs to producing countries was seen as unbalanced and singles out Brazil, a major exporter of agricultural products. Including the hidden costs to consumer countries would reveal an alternative view that would emphasize the role played by importing nations in driving the hidden costs from Brazilian production systems. However, this may reduce the ability for the analysis to reveal entry points for reducing the hidden costs through policy interventions. As a corollary of this, it may be useful to frame this analysis as seeking to reveal the entry points for policy action, which would support a production-based assessment.

3.3 Evolution of hidden costs by 2030 and 2050

3.3.1 FABLE Calculator for Brazil

The FABLE Calculator (Mosnier et al., 2020) for Brazil included several adjustments to adapt to the national context. Historical land cover maps have been updated with information from MapBiomas (Souza et al. 2020) and from the Brazilian Institute of Geography and Statistics (IBGE) (PAM/IBGE, 2023). Data from IBGE replaced the area and production for soybeans, corn, sugarcane, beans, rice, cassava, and wheat. Adjustments were also made to the export calculations for soybeans and corn to align with historical data from the FAO (FAOSTAT, 2023) and forecasts by the Brazilian Ministry of Agriculture, Livestock, and Food Supply.

Furthermore, GHG emissions calculations incorporate Brazil's average carbon content (418.4 tCO_2e/ha) as reported in Brazil's Third Emissions Inventory, used in the official documents of the United Nations Framework Convention on Climate Change in 2016 (MCTI, 2016). The analysis also integrates the data by de Andrade Junior et al. (2019), which describes potential ethanol demand scenarios in Brazil through 2030 and replaces the biofuel feedstock use for sugarcane in the model.

3.3.2 Scenathon 2023 pathways assumptions

We present three alternative pathways for reaching sustainable objectives for Brazil's food and land use systems. The Current Trends (CT) pathway is characterized by medium population growth, no constraints on agricultural expansion, no deforestation control, and a business-as-usual (BAU) scenario regarding diets and biofuel feedstock used for ethanol. This translates into a future that, given current policies and past trends, would also result in a low growth in agricultural productivity and a significant increase in the volume of exports of the major commodities.

A future in which national policies and activities are aligned with Brazil's commitments is represented by the National Commitments (NC) pathway. We assume that this future considers the restoration of 12 million hectares of forest by 2030, the expansion of protected areas, and no deforestation beyond 2030, reflecting Brazil's international commitments. Also, we assume that this future would lead to higher livestock productivity growth and medium crop productivity growth. This future also considers food waste and post-harvest loss reductions, and a renewable fuel-oriented scenario.

The Global Sustainability (GS) pathway represents a future in which national actions/policies are aligned with global sustainability targets. Assumptions on population growth, agricultural productivity, diets and reforestation targets differ from the NC pathway. We assume this future would lead to low population growth, higher crop productivity growth, and an evolution towards a healthier diet (EAT-*Lancet* recommended diet). Additionally, we considered a restoration target of approximately 27 million hectares by 2050 to go beyond Brazil's NDC commitment of restoring 12 million hectares of forests by 2030. This restoration target considers the amount of environmental debt from the Rural Environmental Cadastre (CAR) for all biomes but the Atlantic Forest, where we take into account the Atlantic Forest Pact target of restoring 15 million hectares.

3.3.3 Results across the three pathways

Land use change and afforestation/restoration targets

The main changes in the agricultural land cover led to increased cropland and decreased grassland areas in the three pathways by 2050 (Figure 3-5). The results suggest that cattle ranching intensification is sparing land for cropland expansion, which is in line with other Brazilian studies (Strassburg et al., 2014; de Oliveira et al., 2017, Köberle et al., 2020; NatureFinance 2022, Orbitas 2024). Under the CT pathway, we estimated a decrease of forest from 558 to 534 million hectares between 2020 and 2050 but assumptions on agricultural land expansion, reforestation targets, and the creation of protected areas differ under NC and GS. In these scenarios, Brazil will have no deforestation after 2030, and the restoration goals will align with Brazil's commitments. However, there was a significant increase in land abandonment in the GS pathway compared to CT, mainly driven by improved agricultural productivity and dietary change assumptions.

Food consumption

Two dietary changes were implemented to evaluate their impact on land use change and GHG emissions for the three pathways. These two diets represent specific targets for the calorie consumption of each food group, intended to be achieved by 2050 (Figure 3-6). The diet scenario used in the CT and NC pathways is based on projections of food consumption in 2050 given by the FAO (2018), built upon the narratives of the shared socioeconomic pathways SSP2 and SSP3. The diet contains a high share of cereals, animal-based products, and sugars, with a net calorie intake of 3,480 kcal/cap/day by 2050. Under the GS pathway, the diet is based on the recommendation of the EAT-Lancet Commission, providing a net calorie intake of 2699 kcal/cap/day. This diet is characterized by significantly reducing animal-sources food consumption compared to the diet scenario used in the other pathways. The three pathways indicate a daily consumption higher than MDER (minimum dietary energy requirement) for all years (Figure 3-7).

Figure 3-5: *Evolution of area by land cover type under each pathway*

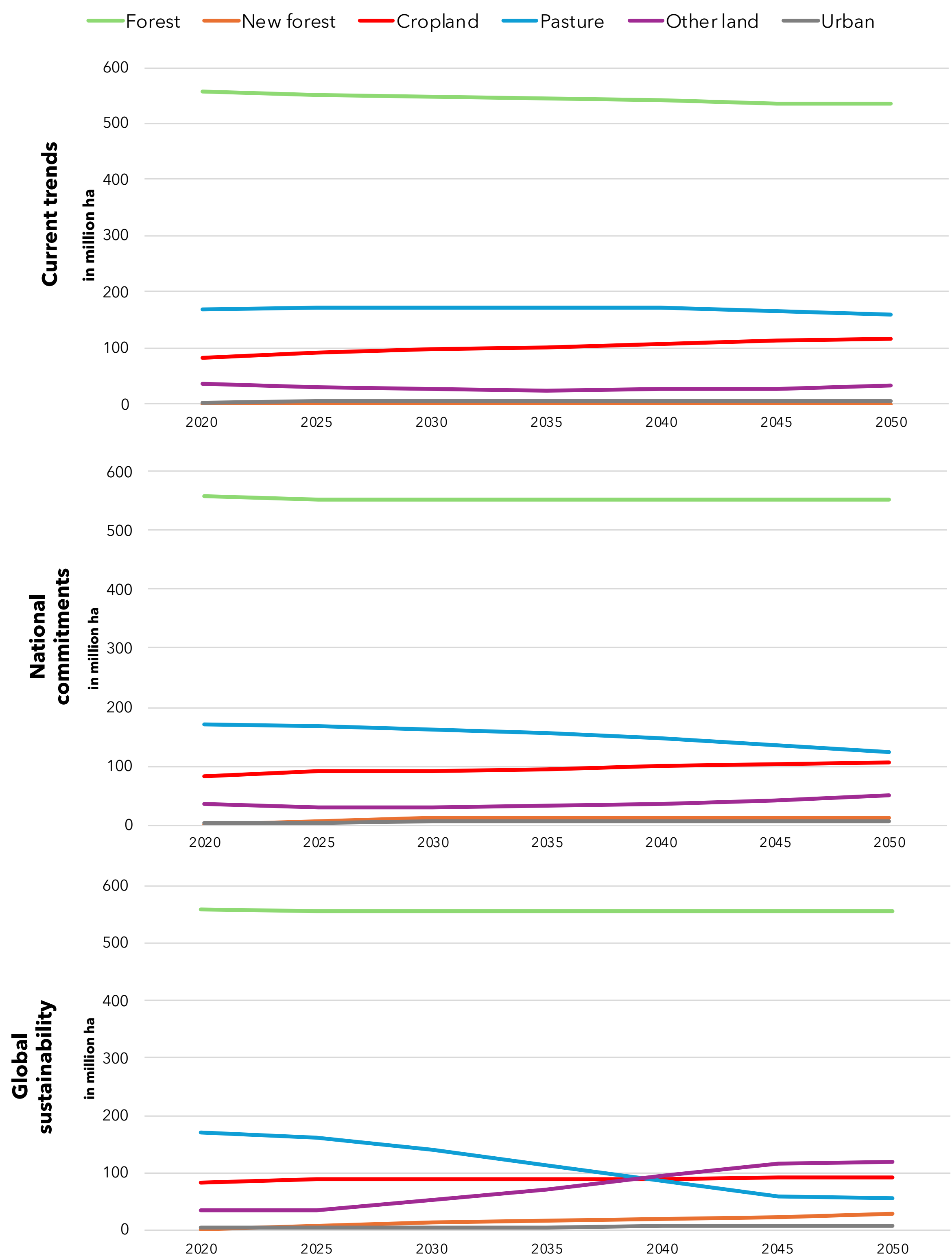


Figure 3-6: *Food consumption (kcal/cap/day) by food group by 2050 for the three pathways for Brazil.*

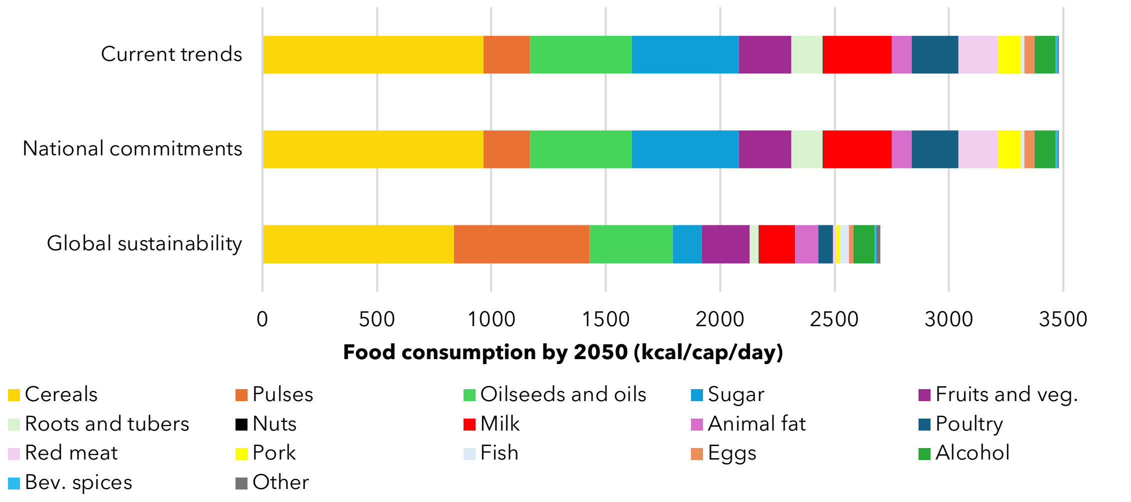
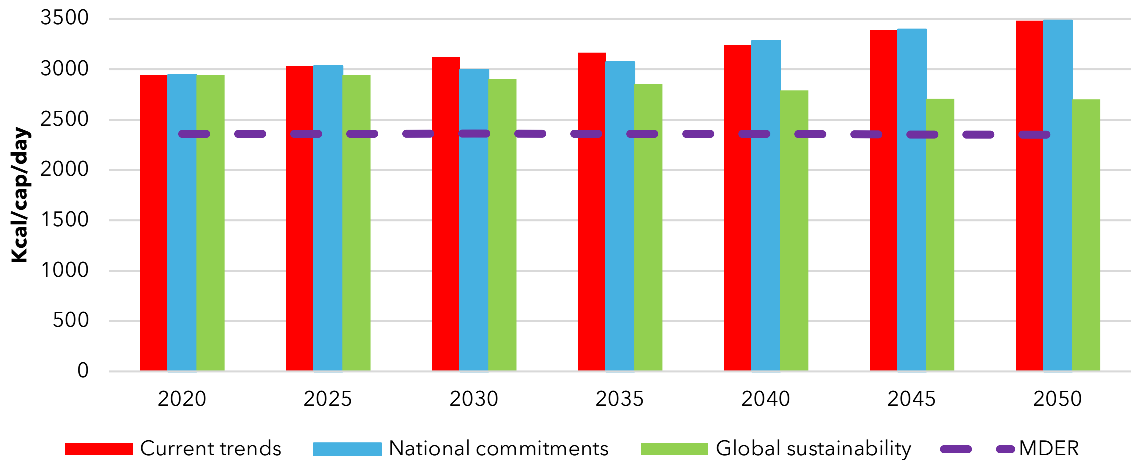


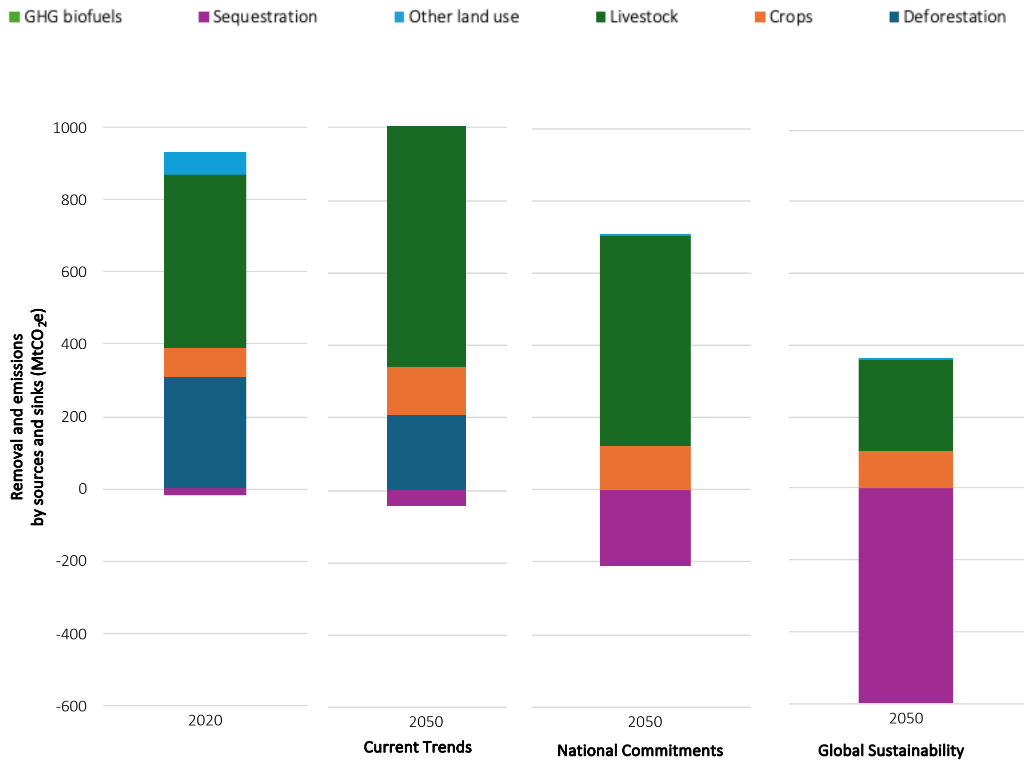
Figure 3-7: *Evolution of the food consumption for the three pathways during 2020–2050. The results indicate a consumption above the MDER (purple dotted lines) for all years.*



GHG emissions

The potential emissions reductions under the NC pathway are dominated by the CO_2 sequestration from the forestry and land use change sector if compared with the CT results (Figure 3-8). The most important drivers of this reduction are the ban on deforestation by 2030, and the carbon uptake from natural vegetation regrowth and afforestation. Under the GS pathway, GHG emissions from CO_2 sequestration from the forestry and land use change sector, enteric fermentation, and manure management are further reduced when compared to the NC pathway due to the ambitious afforestation/reforestation targets and the healthier diet assumption, with low consumption of red meat.

***Figure 3-8**: Removal and emissions decomposed by the primary sources for three pathways by 2020 and 2050.*



Water

The blue water footprint in agriculture is projected to reach 5,337 to 6,890 Mm^3/yr under the CT pathway between 2020 and 2050 (Figure 3-9). In contrast, the results indicated a rise in blue water use in the NC pathway (8,690 Mm^3/yr in 2050). Under the GS pathway, the blue water footprint decreases more when compared with the NC pathway, reaching 6,451 Mm^3/yr in 2050. Both the NC and GS pathways were based on a higher expansion of irrigated areas compared to CT. The reduction observed in the GS pathway was primarily due to the huge decrease in agricultural land driven by dietary changes.

Figure 3-9: *Evolution of blue water footprint in the three pathways (top) and decomposition of the main drivers of the changes of water related hidden costs across scenarios (bottom)*

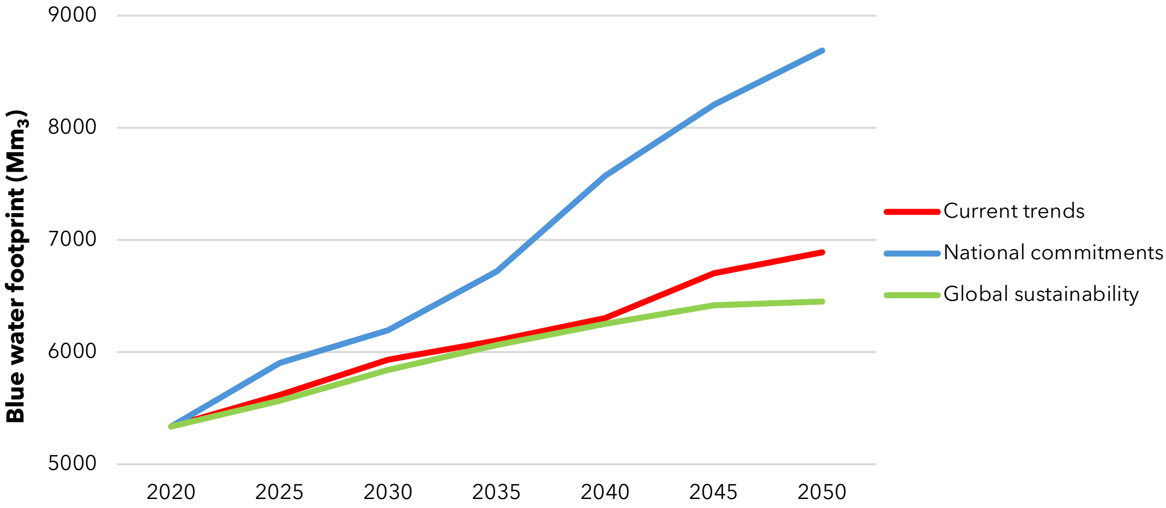
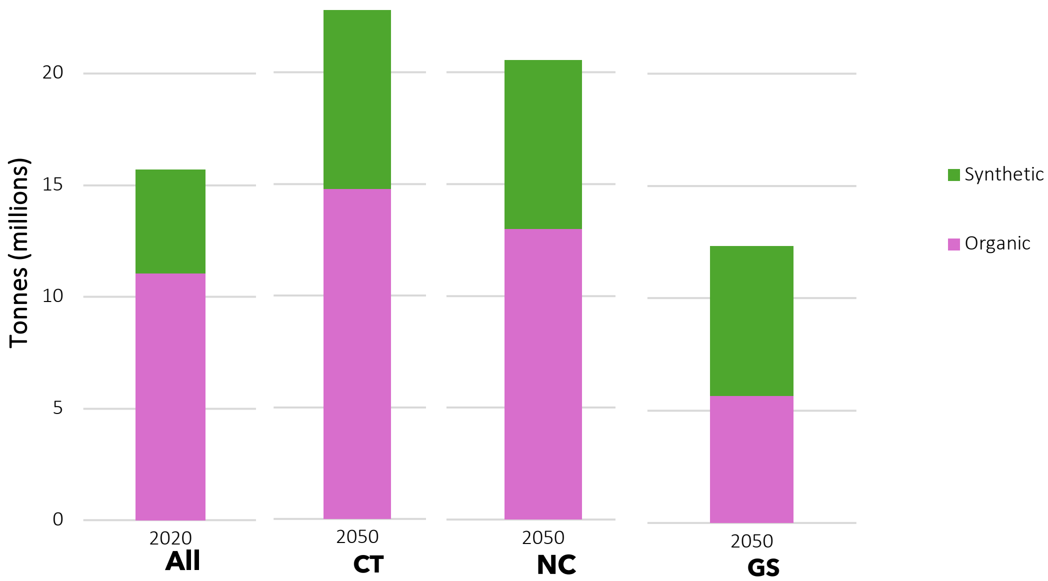


Figure 3-10: *Organic and synthetic nitrogen use in cropland areas in 2020 and 2050.*



Notes: CT = Current Trends pathway, NC = National Commitments pathway, and GS = Global Sustainability pathway.

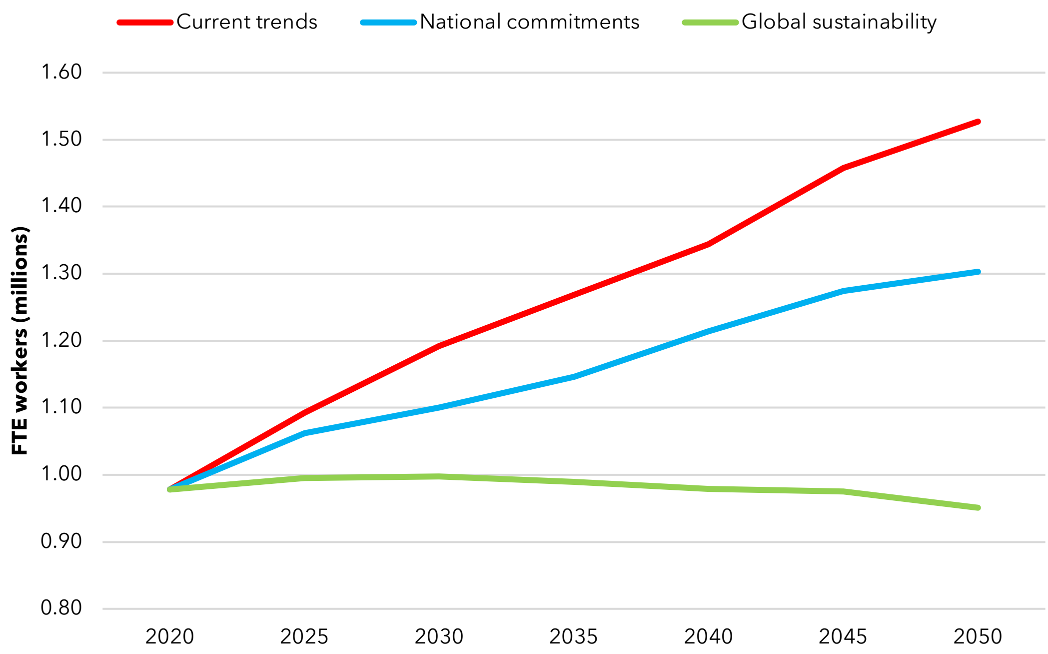
Nitrogen use

Organic and synthetic nitrogen use gradually increased in the three pathways during 2020–2050 (Figure 3-10). The results indicate a reduction of 10% in the National Commitments pathway by 2050 if compared with the current trends projections (12.3 Mt), mainly attributed to the combined effects of crop productivity, population growth and food consumption changes.

Farm labor

The Current Trends pathway shows a steady increase in the full time equivalent (FTE) farm labor workforce from 2020 to 2050. Conversely, the National Commitments pathway also indicates but with a notable reduction of 0.24 million FTE workers compared to the CT scenario by 2050. Notably, the global sustainability pathway stands out as the pathway where the number of workers experiences a significant decline from 2020 to 2050, reducing 38% of the workforce compared to CT (Figure 3-11). This reduction can be primarily attributed to the substantial decrease in livestock due to reduced consumption of animal-source foods imposed by the chosen diet.

Figure 3-11: *Evolution of the farm labor workforce in the three pathways during 2020–2050*



3.3.4 What are the most influential factors to reduce the hidden costs by 2030 and 2050?

Figure 3-12 shows the decomposition of the differences between the two transition pathways (National Commitments and Global Sustainability) and the current trends. The figures represent the contribution of each component to the reduction in hidden costs for the years 2030 and 2050, with the left panel showing NC vs CT, and the right GS vs CT.

It shows that dietary changes provide the largest driver for reducing CH_4 and N_2O emissions. Crop and livestock productivity gains, and food waste reduction also contribute significantly to GHG emissions reduction by 2050. Increases in irrigation contribute the most to the hidden costs associated with water withdrawals, which in fact increase in both transition scenarios relative to CT, while increases in crop productivity and diet changes contribute the most to reduce these costs.

Dietary changes were also projected to be the main contributor in reducing the pasture area and increasing land abandonment in the GS pathway. Other factors, such as ruminant density, livestock productivity and food waste, had a smaller contribution in both land use change projections (Figure 3-13). Crop yield improvements and dietary changes were the main contributors of cropland reduction in GS. The key factors for forest increase in GS pathway were the constraints on agricultural area expansion regarding zero deforestation, crop yield gains and changes in international demand and diets.

***Figure 3-12**: Decomposition analysis for feasible kcal consumption, total nitrogen, CH_4 emissions and blue water used for irrigation*

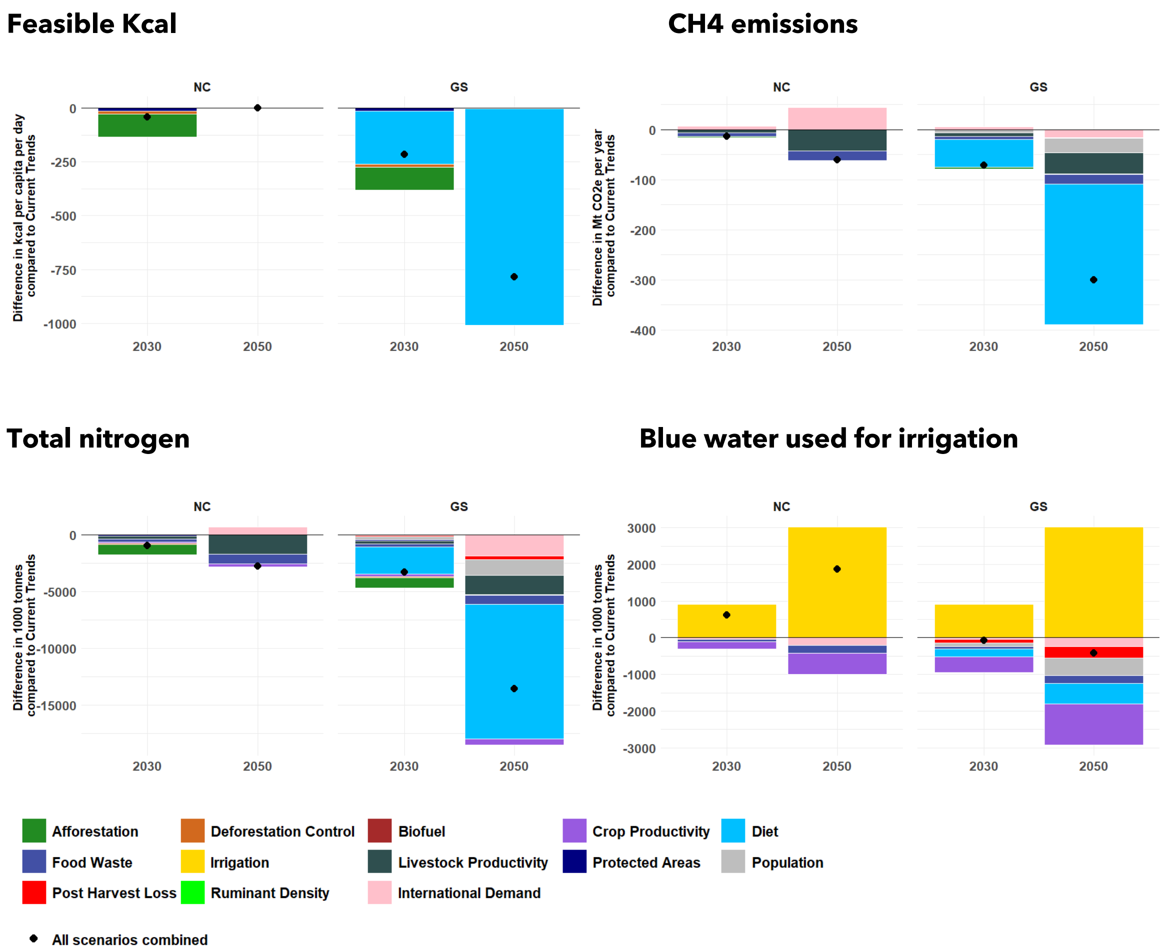
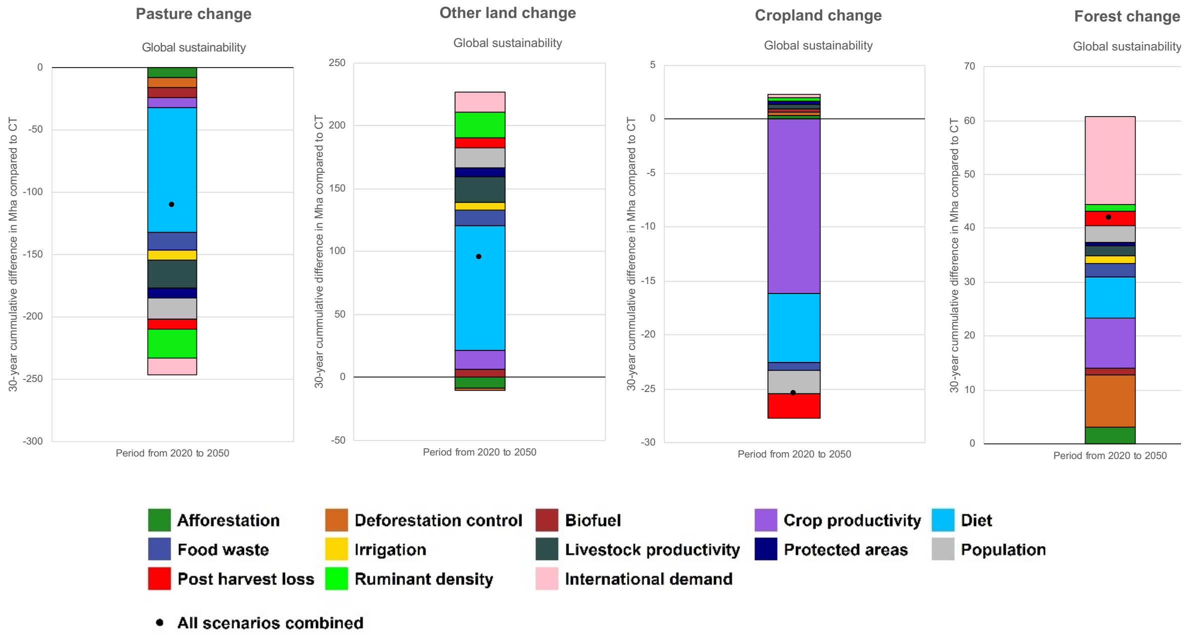


Figure 3-13 *– Cumulated impact over 2021-2050 of each scenario change between the Global Sustainability and Current Trends pathways on land cover*

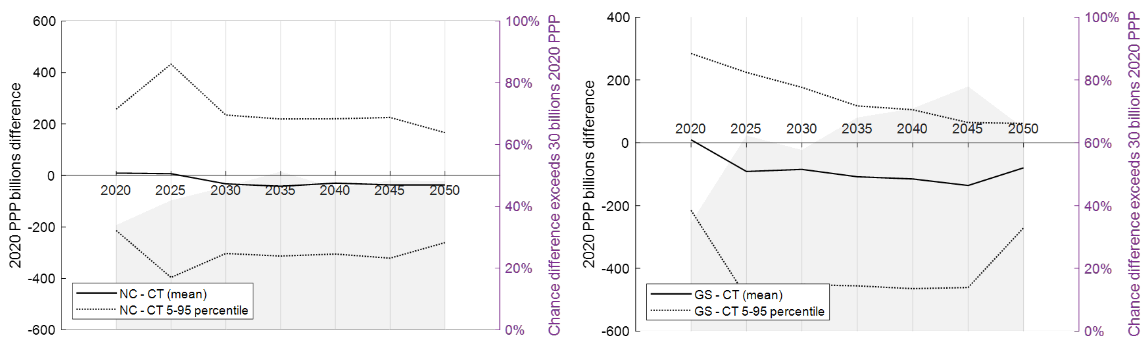


3.3.5 Impacts on the agrifood system's hidden costs

A new study of the hidden costs was produced by Lord (2024) in the FABLE context, with a specific analysis for Brazil. The updated analysis estimated the hidden costs for Brazil as 340 billion 2020 PPP in 2023. GDP would be roughly 11% lower if the hidden costs were to be accounted for in 2020. It is important to note that estimates from other analyses, such as SOFA 2023, reported slightly higher costs of 350 billion 2020 PPP by incorporating obesity and poverty costs, which FABLE does not consider.

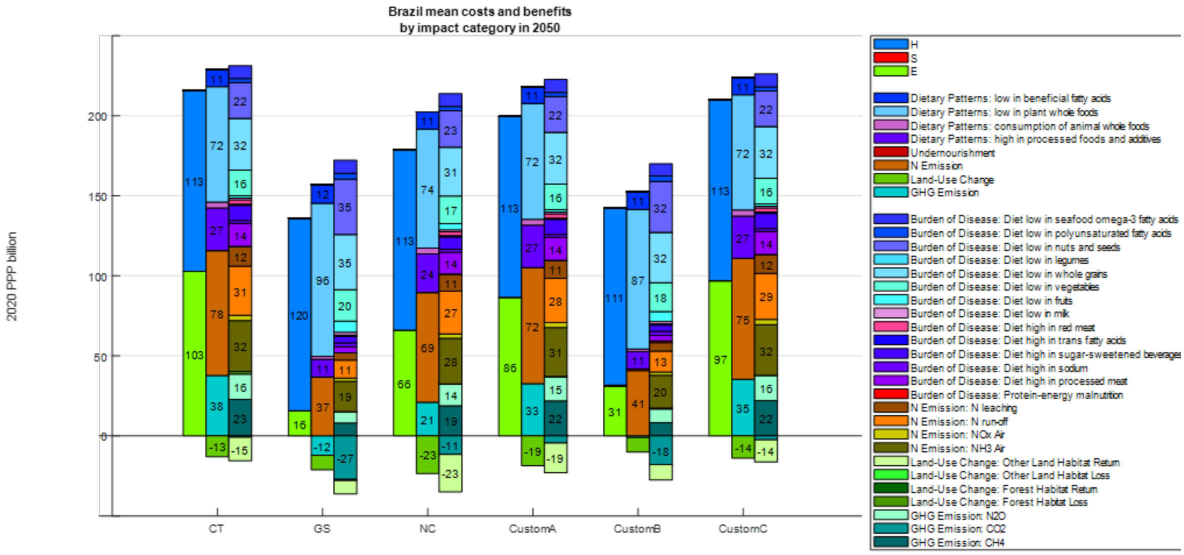
The NC pathway projected a reduction of the accumulated hidden costs by 8% compared to CT, averaging 25 billion 2020 PPP per year. Meanwhile, the GS pathway suggests significant changes in food production and consumption between 2020 and 2050, potentially reducing these hidden costs by 32% compared to CT.

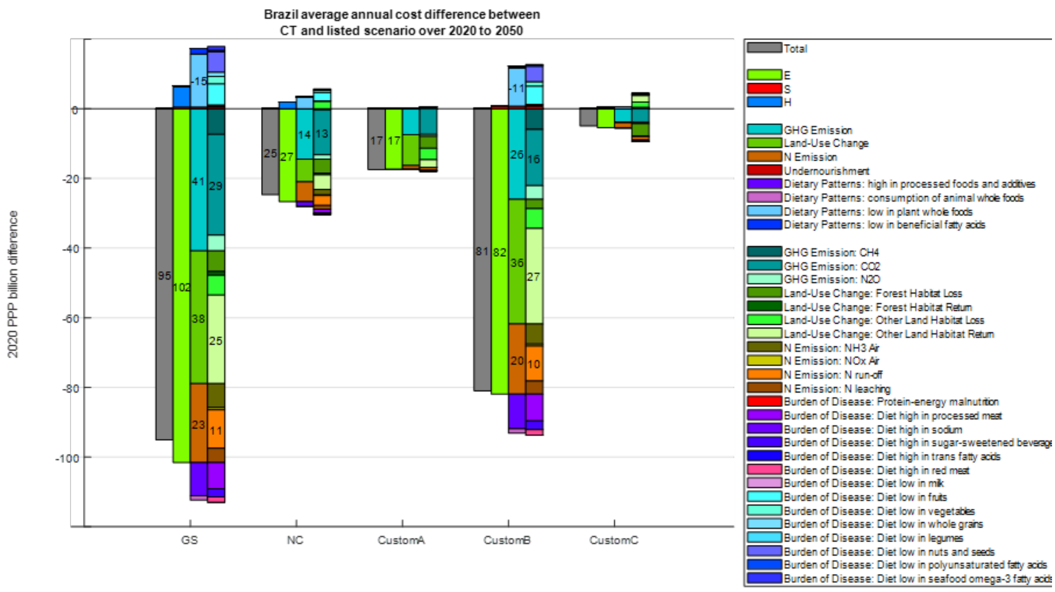
Figure 3-14: *Brazil annual cost trajectory between CT and NC (left), and between CT and GS (right) with uncertainty estimate.*



In addition to the CT, NC, and GS pathways, three new scenarios highlighting the most impactful factors have been created to explore their contributions to the reduction in hidden costs (Figure 3-15 top). For Brazil, the three scenarios are crop productivity (Custom A), dietary change (Custom B) and the constraint of zero deforestation after 2030 (Custom C). As seen in Figure 3-15, the key factor for the most savings is the dietary change component, specifically reducing red meat consumption in favor of plant-based proteins, which would lead to decreased agricultural land use, reduced greenhouse gas emissions, and less nitrogen pollution. According to the new analysis, the GS pathway projects to avoid 38 billion 2020 PPP from preventing land use changes. Additionally, 41 billion 2020 PPP can be avoided from changes in GHG emissions and 23 billion 2020 PPP from reducing nitrogen run-off and human productivity losses from ammonia air pollution (Figure 3-15 bottom).

Figure 3-15: *Breakdown of Brazil hidden costs in 2050 (top) and annual average hidden cost reduction under alternative pathways compared to CT (bottom) in 2020 PPP. The breakdown is illustrated in different levels of detail separating the cost categories.*





Source: Lord (2024)

3.4 Entry points for action and foreseen implementation challenges

The results show that more than half of the hidden costs are related to dietary choices. Shifting dietary behaviors is crucial, yet further investigation is needed to determine effective implementation strategies. Furthermore, national and local actions hinge upon the choices made by policymakers, landowners, and consumers. Measures such as decreases in loss and waste distribution, subsidies for organic food production, and policies that provide the public with essential health information and encourage healthy behaviors can increase the availability and access to nutritious foods. Government procurement policies (e.g., for public school meals) can serve as catalysts to boost demand for products that make up healthy diets, providing opportunities for raising awareness of their benefits. The Dietary Guidelines for the Brazilian Population, published in 2014, contains a full set of recommendations to promote the health and well-being of the whole Brazilian population, now and in future. The guidelines were elaborated in a participatory manner and in consultation with multiple sectors of society, the Ministry of Health and academia but lack a comprehensive implementation plan (FAO, 2024). Nevertheless, many initiatives exist to promote healthy diets, including schools programs (WFP, 2024), and a framework that highlights two main implementation pathways, namely educational materials and public policies (Gabe et al., 2021)

Another entry point is adopting agroecological practices, such as economic incentives for low carbon emission techniques and implementing integrated crops, livestock and forest systems. The recuperation of degraded areas, especially pastures, has high potential to spare land that can be dedicated to other uses such as crop production, bioenergy or afforestation. This is reflected in the Brazilian NDC and several national studies (de Oliveira et al., 2017; Köberle et al., 2020). Healthy pastures provide more nutritious grazing for livestock, which can also reduce emissions of CH_4 from enteric fermentation. National policies and programs towards those practices have the potential to uphold and improve soil quality, conserve water, sequester carbon, enhance animal yield and welfare by providing thermal comfort, mitigate greenhouse gas effects, and aid in the recovery of degraded areas. Realizing this potential requires investments, a challenge to about two thirds of Brazilian farmers who lack technical skills and access to finance, and interventions to address this can improve environmental performance and farm profitability (NatureFinance 2022). Extension services already exist (e.g., through Embrapa and ANATER[6]), but they need to be expanded to effect change at the scale and pace needed.

It is important to note that, as hidden costs are likely underestimated for land use change in Brazil (see Section 2.3.2), efforts to reduce deforestation could have a higher impact than would follow from the current hidden cost estimates. Ending illegal deforestation and incentivizing preservation of natural vegetation to prevent legal deforestation would effectively prevent conversion of natural vegetation and reduce (or ideally, eliminate) losses of ecosystem services.

When asked to suggest specific entry points for different actors or potential challenges, respondents mentioned the following:

- Subsidies for organic food production.
- Land governance aiming at land redistribution in territories with high land concentration.
- Incentives for the implementation of agroforestry systems.
- Support for the establishment of short supply chains for food production and consumption.
- Economic incentives for low carbon emission agricultural techniques.

[6] Embrapa - Empresa Brasileira de Pesquisa Agropecuária (https://www.embrapa.br/); ANATER - Agência Nacional de Assistência Técnica e Extensão Rural (https://www.anater.org/)

In final considerations, one respondent emphasized the need to adopt a TCA approach, but sounded a note of caution in that "one needs to be completely sure about the approach, otherwise is going to considerably impact some countries' economy (such as Brazil) using data with a huge uncertainty".

3.5 References

de Andrade Junior, M. A. U., Valin, H., Soterroni, A. C., Ramos, F. M., & Halog, A., 2019. Exploring future scenarios of ethanol demand in Brazil and their land-use implications. Energy Policy, 134, 110958. https://doi.org/10.1016/j.enpol.2019.110958

de Oliveira Silva, R., Barioni, L. G., Hall, J. A., Folegatti Matsuura, M., Zanett Albertini, T., Fernandes, F. A., & Moran, D. (2016). Increasing beef production could lower greenhouse gas emissions in Brazil if decoupled from deforestation. Nature Climate Change, 6(5), 493-497. https://doi.org/10.1038/nclimate2916

de Oliveira Silva, R., Barioni, L. G., Hall, J. A. J., Moretti, A. C., Veloso, R. F., Alexander, P., Crespolini, M., & Moran, D. (2017). Sustainable intensification of Brazilian livestock production through optimized pasture restoration. Agricultural Systems, 153, 201–211. https://doi.org/10.1016/j.agsy.2017.02.001

FAO, 2024. Food-based dietary guidelines – Brazil. https://www.fao.org/nutrition/education/food-based-dietary-guidelines/regions/countries/brazil/en/

FAO, 2023. The State of Food and Agriculture 2023: Revealing the true cost of food to transform agrifood systems. FAO, Rome. https://doi.org/10.4060/cc7724en

FAO, 2024. The State of Food and Agriculture 2024: Value driven transformation of agrifood systems. Rome.

FAOSTAT, 2023. FAOSTAT database. http://www.fao.org/faostat/en/

Gabe, K. T., Tramontt, C. R., & Jaime, P. C. (2021). Implementation of food-based dietary guidelines: conceptual framework and analysis of the Brazilian case. Public Health Nutrition, 24(18), 6521-6533. doi:10.1017/S1368980021003475

Köberle, A. C., Rochedo, P. R. R., Lucena, A. F. P., Szklo, A., & Schaeffer, R., 2020. Brazil's emission trajectories in a well-below 2 °C world: The role of disruptive technologies versus land-based mitigation in an already low-emission energy system. Climatic Change, 162(4), 1823–1842. https://doi.org/10.1007/s10584-020-02856-6

L.F.M., 2022. The economic burden of overweight and obesity in Brazil: perspectives for the Brazilian Unified Health System. Public Health 207, 82–87. https://doi.org/10.1016/j.puhe.2022.03.015

Lord, S. (2024) Avoided hidden costs in FABLE food system pathways to 2050: Brazil Key Figures. Background Brief Food and Agriculture Organization of the United Nations (FAO) State of Food and Agriculture (SOFA). Environmental Change Institute, University of Oxford.

Martins, S. C., Assad, E. D., Pavão, E., & Lopes-Assad, M. L. R. C. (2018). Inverting the carbon footprint in Brazilian agriculture: an estimate of the effects of the ABC plan.

MCTI, 2016. Third National Communication of Brazil to the United Nations Framework Convention on Climate Change – Executive Summary/ Ministry of Science, Technology and Innovation. Brasília: Ministério da Ciência, Tecnologia e Inovação, 2016. 42 p.: il. ISBN: 978-85-88063-22-8

Mosnier, A., Penescu, L., Perez-Guzman, K., Steinhauser, J., Thomson, M., Douzal, C., Poncet, J., 2020. FABLE Calculator documentation- 2020 update. IIASA (Laxenburg) and SDSN (Paris).

Nature Finance, 2022. Opportunities for the Brazilian agri-food system. Finance, Nature and Food transitions. Report. https://www.naturefinance.net/wp-content/uploads/2022/09/FinanceNatureandFoodTransitions-1.pdf

Orbitas, 2024. Brazil's Cattle Sector Amidst Climate Transitions. Report. https://orbitas-15d5b.kxcdn.com/wp-content/uploads/2024/04/Orbitas-Brazils-Cattle-Sector-Amidst-Climate-Transitions.pdf

PAM/IBGE, 2023. Produção Agrícola Municipal – Instituto Brasileiro de Geografia e Estatística; https://sidra.ibge.gov.br/pesquisa/pam/tabelas.

Pires, M.V., Cunha, D.A. da, Carlos, S. de M., Costa, M.H., 2015. Nitrogen-Use Efficiency, Nitrous Oxide Emissions, and Cereal Production in Brazil: Current Trends and Forecasts. PLOS ONE 10, e0135234. https://doi.org/10.1371/journal.pone.0135234

Rocha, C.E.F., Parajára, M. do C., Machado, Í.E., Vegi, A.S.F., Menezes, M.C. de, Meireles, A.L., 2023. Chronic diseases attributable to a diet rich in processed meat in Brazil: Burden and financial impact on the healthcare system. Frontiers in Nutrition 10.

Santos, E.A., Cunha, D.A., Travassos, G.F., 2023. Nitrogen demand and agro-environmental efficiency in Brazilian cereal production. Braz J Biol 83, e268927. https://doi.org/10.1590/1519-6984.268927

Souza, C.M., Z. Shimbo, J., Rosa, M.R., Parente, L.L., A. Alencar, A., Rudorff, B.F.T., Hasenack, H., Matsumoto, M., G. Ferreira, L., Souza-Filho, P.W.M., de Oliveira, S.W., Rocha, W.F., Fonseca, A.V., Marques, C.B., Diniz, C.G., Costa, D., Monteiro, D., Rosa, E.R., Vélez-Martin, E., Weber, E.J., Lenti, F.E.B., Paternost, F.F., Pareyn, F.G.C., Siqueira, J.V., Viera, J.L., Neto, L.C.F., Saraiva, M.M., Sales, M.H., Salgado, M.P.G., Vasconcelos, R., Galano, S., Mesquita, V.V., Azevedo, T., 2020. Reconstructing Three Decades of Land Use and Land Cover Changes in Brazilian Biomes with Landsat Archive and Earth Engine. Remote Sensing 12, 2735. https://doi.org/10.3390/rs12172735

Strassburg, B. B. N., Latawiec, A. E., Barioni, L. G., Nobre, C. A., Silva, J. F., V. P. Valentim, Vianna, M., & Assad, E. D., 2014. When enough should be enough: Improving the use of current agricultural lands could meet production demands and spare natural habitats in Brazil. Glob Environ Chang, 28, 84–97. https://doi.org/10.1016/j.gloenvcha.2014.06.001

3.6 Annex

Questionnaire of the online survey

Question
1. How well do you think the analysis reflects hidden costs in Brazil?
2. Please provide any suggestions on how the analysis of hidden costs could be improved by using national datasets instead of the global data used for the SOFA 2023 analysis.
3. Please provide any suggestions on how the methodology of the SOFA 2023 analysis could be improved to give a more accurate estimate of hidden costs for Brazil, e.g. by including additional cost categories (where data is available), or through new research to fill data gaps.
4. Please provide any comments or feedback on the FABLE model assumptions and baseline projection to 2050, and the implications for biodiversity, climate, food security and health.
5. Please suggest: • - potential levers for reducing the hidden costs of agrifood systems; • - specific entry points for different actors; • - any potential challenges associated with these levers.
6. If there are any other updates you would like to share that are not covered by the previous questions, please let us know.

Chapter 4. Colombia

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Highlights

- We study alternative pathways for the Colombian agrifood system's hidden economic costs. For this, the FABLE Calculator, a pathway development and analysis tool, is integrated with the True Cost Accounting methodology developed for SOFA 2023.
- The estimated hidden costs for 2050 under the Current Trends pathway are sizeable, representing more than 2% of GDP. These costs decreased by 3.8% and 39% in the National Commitments and Global Sustainability pathways.
- Cost reductions are due to several measures. Mainly, dietary changes that reduce the potential burden of disease of the population, and reductions in CO2 emissions, nitrogen run-off, and NH3 emissions to the air.
- Maintaining the status quo, as implied in the Current Trends pathway, is costly for the economy. To decrease the hidden costs, action is required on several fronts well beyond the set of measures embodied in the National Commitments pathway.
- We recommend prioritizing measures that support the development of healthy dietary decisions, as well as rolling-out strong technical assistance to support producers in the sustainable intensification of agricultural production, ensuring sufficient financing for production projects with a strong component in sustainable practices, and improving and keeping momentum for restoration and afforestation.

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4.1 Introduction

This document reports on the results arising from the experience of integrating the TCA with a particular pathway analysis tool, the FABLE Calculator, applied to Colombia.

We reviewed the country results in SOFA 2023 (FAO, 2023) for appraising their perceived adequacy to Colombia's conditions and for assessing the quality of the data that was used, considering the available national data. Then a round of consultations was held with national and international experts to discuss the SOFA 2023 results, the structure of the TCA approach as used in this report, avenues for bettering national data collection that could be useful for improving and enriching the use of the TCA approach, and plausible scenarios for implementation in the FABLE Calculator. With this background, a set of pathways to 2050 was estimated for Colombia that provided the necessary impact quantities that go as input for the TCA. The TCA was run on these and other required data and the estimation of the Colombian agrifood system hidden costs, for the dimensions that the FABLE calculator comprises, was produced for analysis (Lord, 2023).

The Food, Agriculture, Biodiversity, Land and Energy (FABLE) Consortium unites research teams from developed and developing countries to evaluate national food system pathways within global sustainability contexts. In Colombia, the Pontificia Universidad Javeriana has been a long-standing member of the FABLE Consortium, leading the development and assessment of food system pathways for the country (FABLE, 2020). The study presented here had the kind support of the Centre of Studies on Production and Sectoral Trade of the Colombian Central Bank (under the leadership of Margarita Gáfaro) and the Colombia Office of the FAO, who were instrumental in suggesting and convening participants for the consultation process.

The report is organized as follows. Section 2 presents and discusses the initial assessment of the country results from the SOFA 2023 report, including the input from the consultation process and recommendations for a country-tailored hidden cost analysis. Section 3 reports on the definition of the pathways implemented in the FABLE Calculator, presents and discusses the results for the pathways by using a decomposition analysis, and discusses the results of the TCA. Lastly, section 4 lists and discusses the entry points for action for transforming the Colombian agrifood system and the foreseen implementation challenges.

4.2 SOFA 2023 hidden costs analysis

4.2.1 Main cost components and explanation of the results

Results from the SOFA 2023 for Colombia show that hidden costs from the agrifood system amount to more than 12% of GDP in 2020, above the world average (of almost 10%) and slightly above the average for its country grouping (upper-middle income, of 11%). Environmental and health costs are of a similar magnitude, each contributing more than 48% to total hidden costs, while social costs contribute the remaining 2.9%.

In 2020 the highest contribution to environmental costs was through nitrogen flows estimated at 35 billion 2020 PPP dollars while the most important component within the health dimension was the burden of disease (dietary choices) costs estimated at 45 billion 2020 PPP dollars. Nitrogen flow costs have increased by nearly a quarter (23%) compared to 2016 levels while burden of disease costs increased by 14% over the same period. At the subcategory level and compared to the global average, climate, and nitrogen, contribute more to total hidden costs (29% more than in the global average, a difference mostly due to nitrogen that accounts for more than 25% of the difference). On the other hand, water, land, unhealthy dietary patterns, and poverty, contribute less to total hidden costs: 29% less than the global average, with unhealthy dietary patterns accounting for more than 24% of the difference. Lastly, undernourishment contributes about the same share of hidden costs as it does to the global average.

Most of the stakeholders consulted were surprised by the absolute and relative magnitude of health costs and some of them considered that the environmental costs were probably underestimated. The contribution of deforestation to hidden costs was also deemed by some as too low, given its importance for GHG emissions in the country.

4.2.2 Comparison of SPIQ data with national datasets

Impact quantities

We can rely on the data provided by the national authorities in the Second and Third Biennial Update Reports (BUR), using the years 2014 and 2018 as references, respectively (Colombian Government, 2019, 2022). For the comparison with SPIQ quantities, we focus on the Third Colombian BUR because the SPIQ database covers the years from 2016 to 2023. Having an exact match between the data in the BUR and the data in SPIQ is not possible, in some cases, due to the different levels of aggregation used to report the figures.

Given the above, Table 4-1 reports emission levels by gas and item (or item group) in SPIQ and the Colombian BUR. As seen, emissions in SPIQ are higher than as reported in the BUR, being on average 58% above. In terms of composition, land use change contributes 82.3% to CO2 emissions in the SPIQ database while it does so 94.7% in the BUR; farm gate emissions contribute 80% to CH4 emissions in the SPIQ database and 99.8% in the BUR; and farm gate emissions contribute 94.3% to N2O emissions in the SPIQ database and 99.2% in the BUR; Therefore, despite these differences, the composition of emissions by gas and item is roughly preserved.

Table 4-1: *GHG emissions in 2018 in thousands of tonnes of gas*

Item	SPIQ database			BUR		
	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O
Farm gate	4,595.7	1,771.5	63.4	682.9	1,651.1	36.7
Land use change	82,452.7	21.3	1.9	59,639.4	-	-
Pre and postproduction	13,104.9	423.1	1.8	2,636.3	2.4	0.4
Total	100,153.2	2,215.9	67.2	62,958.5	1,653.6	37.0

Source: SPIQ database and Colombian BUR 2020

As for levels, the numbers in Table 4-1 for CO_2 farm gate emissions correspond to energy use in agriculture in both sources (IPCC item 1A4c in the case of the BUR), so the difference in level is not affected by classification issues, and the item probably is overestimated in the SPIQ database. In the case of land use, in the SPIQ database, the data come from FAO's item net forest conversion, so it includes net changes between forest land and other land uses (not only agricultural uses), while in the BUR it comes from forest land converted to cropland and pastureland, without accounting for cropland and pastureland converted to forest land (there is no explicit accounting in the BUR for unmanaged pastures). Therefore, it is very likely that the figure in the SPIQ database is an overestimate. Lastly, pre and postproduction CO_2 emissions, in the SPIQ database include items from fertilizer manufacturing emissions to industrial wastewater, while the BUR only comprises energy consumption emissions from food, beverages, and tobacco processing activities. Hence, in this case, the data from the BUR is underestimate.

In the case of CH_4 emissions, emissions at the farm gate in the SPIQ database include those from livestock activities and energy use in agriculture, while the BUR data include livestock activities, biomass burning, rice cultivation, and energy use in agriculture. Despite the inclusion of these items, emissions in the BUR are slightly below those in the SPIQ database. Finally, for pre and postproduction emissions, the situation is the same as reported for CO_2 emissions in terms of items reported, but the level of emissions is higher under the BUR, so this set of emissions is likely underestimated in the SPIQ.

Lastly, for N_2O emissions, the SPIQ database and the BUR's data have a similar coverage. However, the value in the SPIQ database is more than 70% higher. For pre and postproduction apply the same comment as in the cases before, with the particularity that the emissions level in the SPIQ is higher, so it is likely to be a better estimate than that under the BUR.

Several stakeholders agreed on the relative weakness of the estimates of nitrogen flows for the case of Colombia. Estimates are built based on data on fertilizer imports and domestic production and the assumption is made that they are fully consumed in the year of importation or production. However, there is no reliable data on the use of fertilizers by different crops and in different regions, which renders the calculation of emissions rather uncertain. Given this situation, they also raised doubts about the figures that are used by SPIQ.

Costs associated with the climate category in SOFA 2023 show an upward trend that arises from changes in impact quantities. While the upward trend seems correct, the level of impact quantities in the model differs considerably from the one observed in national data. The costs arising from nitrogen emissions in SOFA 2023 may be overestimated as the impact quantities associated with the agrifood system in the model database are considerably larger than those corresponding to national historical data, although the latter also show an upward trend.

Water

Data on water use in the SPIQ database shows figures for blue water withdrawals for 2016 and 2020 in the order of 21,000 and 25,035 million cubic meters (Mm^3), respectively. These figures are closer to total water withdrawals. The preferred data source for Colombia is the National Water Study (ENA for its Spanish language acronym), which provides data for 2008, 2012, 2016, and 2020 (IDEAM 2023). According to the ENA, in 2016 and 2020 total water demand was 20,645 and 19,496 Mm^3, respectively; this includes demands from agriculture and post-harvest activities, aquaculture, and livestock and cattle slaughter. According to the ENA, the blue water footprint in 2016 and 2020 was 9,313 and 7,597 Mm^3, correspondingly, so the SPIQ database may be grossly overestimating this item.

There have been methodological changes in the calculation of water demand in Colombia, as the number of hectares with pasture cover for livestock use was adjusted around 2019, leading to a fall in water demand estimates. The adjusted figures for 2008 and 2012 are 23,198 and 19,463 Mm^3, respectively. Therefore, there is a downward trend in water demand between 2008 and 2020, which may look counterintuitive, especially in the light that the ENA 2022 (which provides the data for 2020) projects an increase in water demand between 2020 and 2040 (IDEAM, 2023).

Land use change

Data on land use change in the SPIQ comes from the HILDA+ model, which provides figures for the eight categories included in it. The main data source on land use in Colombia is the estimation that the IDEAM (the Colombian institute in charge of providing emissions and other relevant data) performs based on the Corine Land Cover Methodology, which currently has data for 2000–2002 (the base period) 2005–2009, 2010–2012, and 2018 (*Metodologia CORINE Land cover – IDEAM*, n.d.). However, there are two difficulties associated with this data (at least at the level of information that is publicly provided in the country). One is that it uses a set of categories that makes it difficult to map to the ones used by SPIQ. The other is that it allows tracking changes through time for each category but does not allow tracking changes among categories, i.e., the required land use changes.

For these reasons, a quick way forward for estimating land use changes among the categories needed is to build them from the reported emissions for the categories of land use changes included in the BUR. This requires using conversion factors that allow to go from CO_2e emissions to hectares and that are dependent on the conditions under which they were calculated. Assuming these conditions remain constant, the conversion factors should provide a good proxy for estimating the areas required.

Table 4-2 shows the number of hectares associated with land use changes for 2018. As can be appreciated, all categories show very large differences that result, in the case of the SPIQ database, in a net gain in forest cover of more than 12 thousand hectares. In contrast, the BUR-based data show small figures for transitions from agricultural uses to forests as well as from forests to cropland, while a large one for transitions from forests to pastures, in line with the stylized facts on land use change in the country. These figures yield a net forest cover loss of almost 116 thousand hectares, which is about 60% of the total deforestation reported for that year.

Table 4-2. *Land use changes in 2018 (hectares)*

Item	SPIQ database	BUR-based
Cropland to forest and unmanaged grassland	13,178	462
Pasture to forest and unmanaged grassland	27,310	2,314
Forest and unmanaged grassland to cropland	5,435	1,635
Forest and unmanaged grassland to pasture	22,627	117,019
Net change (forest – agricultural use)	12,426	-115,878

Source: SPIQ database and estimates based on the Colombian BUR 2020

Nitrogen, dietary choices, and undernourishment

As far as our knowledge goes, there are no available national figures on nitrogen emissions to air, leaching to groundwater, or run-off to surface water, so there is no way to improve the data in the SPIQ database. It is convenient to recall the observation made by some stakeholders on fertilizer use and nitrogen volatilization and lixiviation made above, in the sense of the weakness of these data in Colombia. The same is true for dietary choices, as the National Health Observatory from the Ministry of Health and Social Care refers to the Global Burden of Disease, Injuries, and Risk Factors Study 2013, which is the data source for the SPIQ. (Observatorio Nacional de Salud Revistas Indexadas). This is also the case with the burden of disease due to undernourishment since most of the work done in the country refers to child undernourishment; however, the country produces enough information for the Global Hunger Index (GHI) to be calculated. For 2023 the country had a GHI of 7.0 which is considered low (Colombia – Global Hunger Index (GHI) – Peer-Reviewed Annual Publication Designed to Comprehensively Measure and Track Hunger at the Global, Regional, and Country Levels, n.d.).

However, the high contribution of dietary choices to hidden costs and the upward trend of the latter between 2016 and 2023 are in line with the nutritional situation in the country. According to the 2015 National Demographic and Health Survey (the last one that was conducted), overweight and obesity among children under four increased to 6.3% in 2015 concerning 2010 (4.9%), 24.4% of children between five and twelve years of age were overweighted (an increase of 5.8 percentage points concerning 2010), 17.9% of teenagers were also overweighted, and 37.7% of adults (between 18 and 64 years old) were overweighted and 18.7% were obese. In total, 56.4% of the population was overweight (up from 51.2% in 2010). (Encuesta Nacional de Demografía y Salud – ENDS, n.d.)

Concerning undernourishment, some stakeholders observed that the lack of micronutrients may be an important component of the hidden costs and that it may be underrepresented in the SPIQ database that focuses on the energy deficit.

Poverty

The poverty headcount is just an approximation in the SPIQ database and there is no national data available for improving them. However, processing of the Colombian Integrated Household Survey could be used to perform the necessary calculations, as suggested in the stakeholder consultations. (Gran Encuesta Integrada de Hogares – GEIH | Datos Abiertos Colombia, n.d.)

Instead of processing the survey and as a first approximation for having an estimate to compare with the data in the SPIQ database, data was taken from the national employment matrix for 2020 on the number of full-time equivalent jobs associated with both the agricultural and agroindustry sectors (food, beverages, and tobacco), which are the available categories that can be mapped to the agrifood system (DANE – Matrices Complementarias, n.d.). These were converted to the number of workers by using the average number of hours worked in these sectors (differentiating among salaried workers and self-employed, and by gender). Then poverty incidence rates for the rural and urban populations were used to estimate the number of workers in poverty in the two sectors (assuming poverty incidence within the sectors is the same as that for the whole population), and the number of persons per household (differentiating rural and urban) was used to estimate the poverty headcount associated with the agrifood system. Aside from all the assumptions made, this estimate is likely to overestimate the headcount, as it implies that each person employed maps to one and only one household (i.e. there are no households with more than one worker in the sector).

The result from this exercise yields a headcount of more than 4.8 million people versus almost 3.7 million people registered in the SPIQ database.

Review of unit costs to GDP

Unit costs to GDP in the case of Colombia seem in line with costs for comparable countries and are consistent with the national data on GDP and its long-term projections.

4.2.3 Recommendations for tailored country hidden costs analysis

The main and most immediate avenue for tailoring the analysis is using national datasets on impact quantities wherever viable and to the extent possible. Beyond this, there are some areas in which there may be some improvements in the precision of this data either by building on national data already available or by refining their collection process. Among them, it is worth mentioning:

- Estimate GHG emissions from national production of agricultural inputs.
- Estimate GHG emissions from national food production alone (excluding emissions from beverages, and tobacco products production).
- Estimate GHG emissions from households cooking (distinguishing them from other emission sources).
- Estimate emissions from food waste (within the solid waste category).
- Estimate the poverty headcount associated with the Colombian agrifood system.
- Estimate land use changes with explicit reference to transitions between categories.
- Improve data collection and analysis on fertilizer application and nitrogen flows.
- Improve data collection and analysis on dietary choices and undernourishment for the whole population.

From the consultation process emerged a set of additional activities, actors, or externalities to be considered for deepening the national analysis of the hidden costs of the agrifood system. The most relevant are listed below.

- Estimate emissions and other costs associated with the transportation and distribution of food products in different stages of the supply chain (there is some work already done on this front).

- Consider and appraise the role of international demand for national food products.
- Improve estimates on post-harvest losses (before actual final consumption).
- Consider soil degradation and the costs associated with it.
- Improve estimates of biodiversity loss and its associated costs.
- Introduce differentiation between broad types of agricultural production (peasant/small scale vs. commercial/large scale).
- Consider regional differences among several of the dimensions included in the study, as national averages are deemed of scant use for policy design in a country as socioeconomically and environmentally diverse as Colombia.

4.3 Evolution of hidden costs by 2030 and 2050

4.3.1 FABLE Calculator for Colombia

The collaborative effort involved the employment of the FABLE Calculator (Mosnier et al., 2020) to investigate the complexities of land use and food dynamics. This tool has been progressively adapted to reflect the specific conditions of Colombia by the academic team at Pontificia Universidad Javeriana (FABLE Colombia) in collaboration with the UN Sustainable Development Solutions Network (SDSN) (Mosnier et al., 2020). This adaptation process was centered on updating the data originally included in the Calculator, which primarily originated from global databases supplemented with national information from official institutions and sectoral sources. Specifically:

- Land cover data for the years 2000, 2005, and 2010 were revised using information published by IDEAM.
- Yield values for crops and pastures were adjusted based on data from the 2019 Municipal Agricultural Evaluations published by the Agricultural Rural Planning Unit (UPRA) of the Ministry of Agriculture and Rural Development.
- Population data and projections were updated according to reports from the National Administrative Department of Statistics (DANE).
- National diet information was revised using data from the Food Balance Sheet (HBA) provided by the Colombian Institute of Family Welfare (ICBF).
- Food waste rates were adjusted according to the 2016 reports from the National Planning Department (DNP).
- Areas of crops under irrigation were updated for each crop in accordance with UPRA reports.
- Biofuel consumption scenarios were revised based on reports from FEDEBIOCOMBUSTIBLES, among other minor changes.

This adaptation process ensures the model provides accurate insights relevant to Colombia's unique environmental and agricultural context, facilitating informed decision-making in land use planning and food security strategies.

4.3.2 Scenathon 2023 pathway assumptions

Current Trends pathway

In the context of the current trends (CT) pathway, we envision a scenario influenced by a complex interplay of factors. We project moderate population growth, which is expected to increase from 50.9 million people in 2020 to 57.3 million by 2050. Concurrently, free expansion of the agricultural frontier is foreseen. No further afforestation is anticipated, in line with recent decades' trends. This scenario does not include plans for the expansion of existing protected areas but does project modest improvements in agricultural productivity. The proportion of domestic consumption fulfilled by imports is expected to remain stable. On the economic front, we anticipate a 10% increase in exports for specific agricultural commodities, such as coffee, cocoa, palm oil, bananas, sugar, and other fruits.

In this way, while existing policies and historical patterns may contribute to a modest deceleration in population growth, they are unlikely to effectively address ongoing environmental challenges. This scenario portrays a pathway where some progress is achieved, but significant challenges persist.

National Commitments pathway

In this pathway, food waste is reduced by 30% compared to the CT pathway, and imports of products such as corn, rice, and soybean meal remain stable. Additionally, livestock productivity is projected to increase by 50% by 2050 compared to 2020, while the stocking density remains the same as in the CT pathway. Crop yields are expected to close a 10% yield gap, and the area under agroecological practices is diversified and increased to 10% of the total agricultural area. Efforts continue to achieve the goals established by the Bonn Challenge, aiming to restore 1 million hectares of forest.

The NC pathway represents a balanced approach to economic growth, resource management, and environmental conservation, offering a roadmap for a transition toward a more sustainable future but with room for significant improvements.

Global Sustainability pathway

In this pathway, GDP is projected to increase by 5% annually, and the population is expected to reach 58.7 million. Diets play a crucial role in driving change, with a partial implementation of the EAT-Lancet diet at 40% of the minimum quantities for each food group. Food waste is reduced by 15% compared to the CT pathway. Imports of key products such as corn, wheat, rice, and soybean meals are projected to decrease by 50% compared to CT. Livestock productivity is expected to increase by 80% by 2050 compared to 2020 levels. Crop yields are anticipated to close a 40% yield gap, and the area under agroecological practices is diversified and increased to 10% of the cropland area. Additionally, stocking density would increase by 35%, reaching one head of cattle per hectare by 2050. Efforts continue to achieve the goals established by the Bonn Challenge, aiming to restore 1 million hectares of forest.

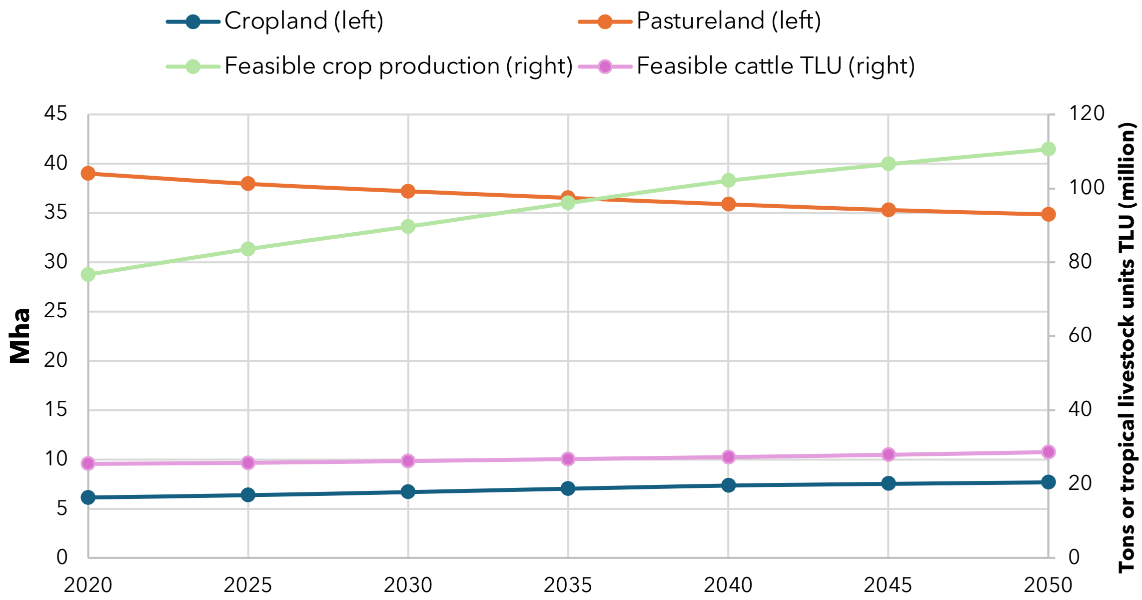
However, it is worth noting that water consumption is expected to increase by 25% from 2020 to 2050 due to intensified productivity processes. This sustainable pathway outlines a promising future where Colombia's commitment to sustainability and strategic policy implementation leads to enhanced economic, environmental, and social outcomes.

4.3.3 Results across the three pathways

To illustrate the results from the simulations, we first select a set of model outcomes and discuss their behavior under the CT pathway and then use a decomposition analysis to show both how they change from the CT to the NC and GS pathways, and to identify what factors generate these changes.

Figure 4-1 shows the path followed by cropland and pastureland areas and by feasible crop production and feasible cattle stocks. As follows from there, cropland will increase from 6.13 million in 2020 to 7.7 million in 2050 in response to the projected increase in demand that arises from population and per capita income growth. Feasible crop production increases too, at a higher pace than cropland, reaching almost 111 million tonnes, as the pathway contemplates a modest increase in physical productivity. Pastureland decreases almost 12% between 2020 and 2050 keeping with the most recent historical trend (associated with rising consumer prices) and because the pathway posits a slight increase in productivity.

Figure 4-1: *Area for cropland and pastureland under the Current Trends pathway*



The dynamics associated with the above trajectories lead to a general increase in emissions. As follows from Figure 4-2 and Figure 4-3, total GHG emissions increase by 14% between 2020 and 2050, representing 86.6 Mt CO_2e at the end of the period. Methane is the largest contributor to the increase in absolute terms, but it is the gas with the lowest relative increase. CO_2, N_2O, and total nitrogen (organic and synthetic) emissions grow faster than those of methane, so there is some change in terms of the gas composition of the emissions.

To this, it must add the associated land use changes and their corresponding emissions. The combined effect of the increase in cropland and the decrease in pastureland discussed above leads to a net decline of 1% in forest land between 2020 and 2050, an increase of new 'other land' (former pastureland) of 132% during the same period, and an increase in urban land of 60%, whose dynamics are independent of land used for productive purposes and is an independent scenario. The behavior of GHG emissions from land use change (LUC) is presented in Figure 4-3. As noticed, there is a major drop in reported emissions from 2020 to 2025 because 2020 is the last year based on historical data and includes emissions from deforestation and other LUC that originate in sources other than agricultural activities (such as illegal mining, illicit crops cultivation, land cleared for land-grabbing, etc.), while the figures from the simulation (from 2025 on) only capture the portion of emissions that is due to LUC from agricultural activity and urbanization. Given this, it is observed an overall increase in emissions from deforestation and other LUC, as well as an increase in sequestration associated with regeneration of abandoned agricultural land.

Figure 4-2: *GHG emissions from agriculture under the Current Trends pathway*

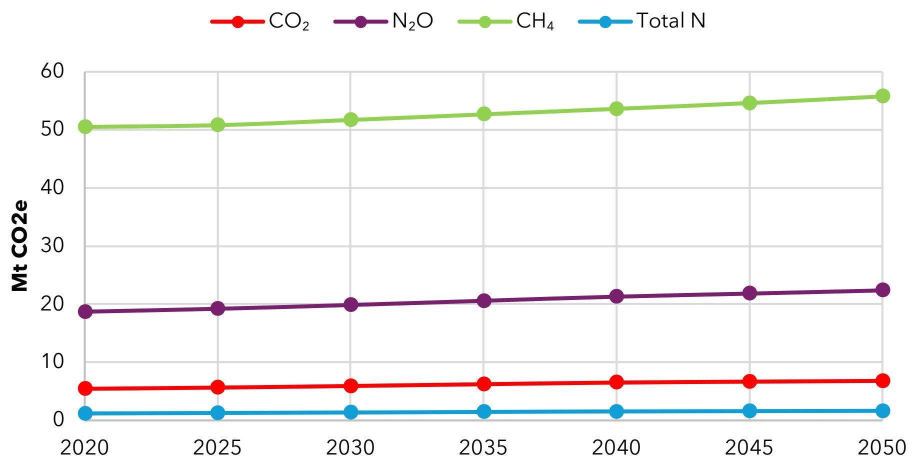
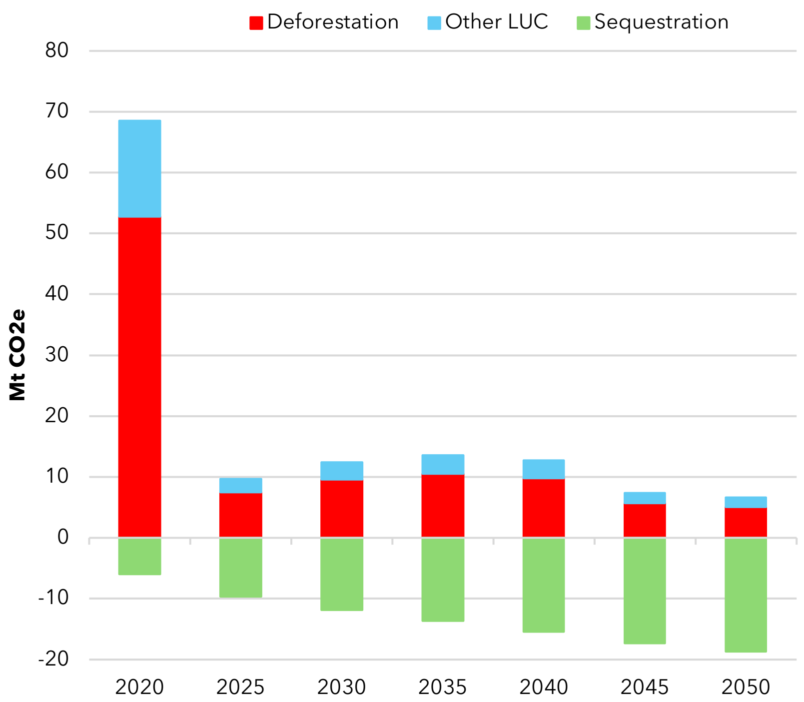


Figure 4-3*: GHG emissions from land use change under the Current Trends pathway*



Lastly, the behavior of farm labor, blue water use, feasible kilocalories, poverty, water use, and nutrition outcomes are important components of the agrifood system's hidden costs. Farm labor, measured in full-time equivalent units (FTE), shows a relatively stable behavior oscillating between a low level of 0.6 million FTE and a high of 6.3 million FTE, with a slight tendency to increase. Bluewater use will increase significantly between 2020 and 2025, as there is an important increase in sugarcane harvested areas (one of the crops with the highest water demands). Feasible kilocalories per capita increase by 11% between 2020 and 2050 in a steady way, because of an increasing availability of food during the period.

4.3.4 What are the most influential factors to reduce the hidden costs by 2030 and 2050?

We now compare the results arising from the NC and GS pathways vis a vis the CT using a decomposition analysis (cf. Section 1.8.4). We compare the results of the decomposition analysis for cropland and pastureland changes under the NC and GS pathways as compared to CT (Figure 4-4).

For the period 2020–2050, cropland decreases 29% under the NC and 56% under the GS pathways, mainly because of the increased crop productivity that is needed for both satisfying an increasing demand but doing so in a sustainable way and decreasing land use change that is to the detriment of carbon sequestration. As can be observed in the left-hand side of the figure, cropland decreases under these two pathways yielding rather similar decreases by the end of the implementation period (2050).

In both cases, the main individual driver of cropland reduction is increased crop productivity which, as described above, rises from the CT to the NC and then again to the GS pathway. On the other hand, the main cause of increases in cropland under both pathways is the trade adjustment effect (i.e., the trade effect arising from the conciliation of trade flows across countries that comes from the Scenathon). As shown, the trade adjustment effect implies a net increase in exports from the country, that must be met with larger production and cropland use. Under the GS pathway, the significant influence of other scenarios is noticeable. This pathway includes as a scenario a change in consumer preferences manifested in a shift to a healthier diet (the average EAT-Lancet diet) that is key to lowering hidden costs associated with health. This scenario also favors a lower consumption of certain foods and an increase of others, that, on balance, require less cropland area. Conversely, the higher increase in irrigated areas that this pathway allows and the increase in ruminant density, which only operates in this case, push cropland use upward as new irrigated land comes into play and demand for feed increases due to higher stocking rates.

For the NC pathway, there is an overall decrease in pastureland of 5% between 2020 and 2050, while for the GS pathway it decreases by 11%. As shown in the figure, under the NC pathway the decrease in pastureland for 2030 is greater than under the CT, but for 2050 the decrease is lower, resulting in a positive value (Figure 4-4).

As protected area expansion is allowed in the NC pathway but not in the CT, the scenario exerts a downward effect on pastureland, that is particularly strong by 2030 but lessens significantly by 2050 as the intensity of the implementation of the scenario decreases as time goes by.

For the GS pathway, there are reductions in pastureland for both 2030 and 2050 when all scenarios are implemented simultaneously (represented by the dot in the graph). The largest contributor to the decline is the increase in ruminant density, which operates in this pathway and not in the others, and directly impinges on the area required for sustaining the animals. The second largest contributor to the decline is the change in diets that decreases the demand for beef (calories originated in red meat must decline by 22% for 2050 according to the implementation of the scenario). The third is the effect of protected areas, which in this pathway (as well as in the NC) are allowed to increase. Lastly, lower post-harvest losses contribute to the decrease in pastureland as a larger portion of the end products can enter the market without changing production levels. As in the NC pathway, in this one livestock productivity, which increases in different degrees in all pathways, generates lower reductions in pastureland and therefore is shown as making a positive contribution.

Figure 4-4: *Decomposition analysis for cropland, pastureland, other land and forest changes*

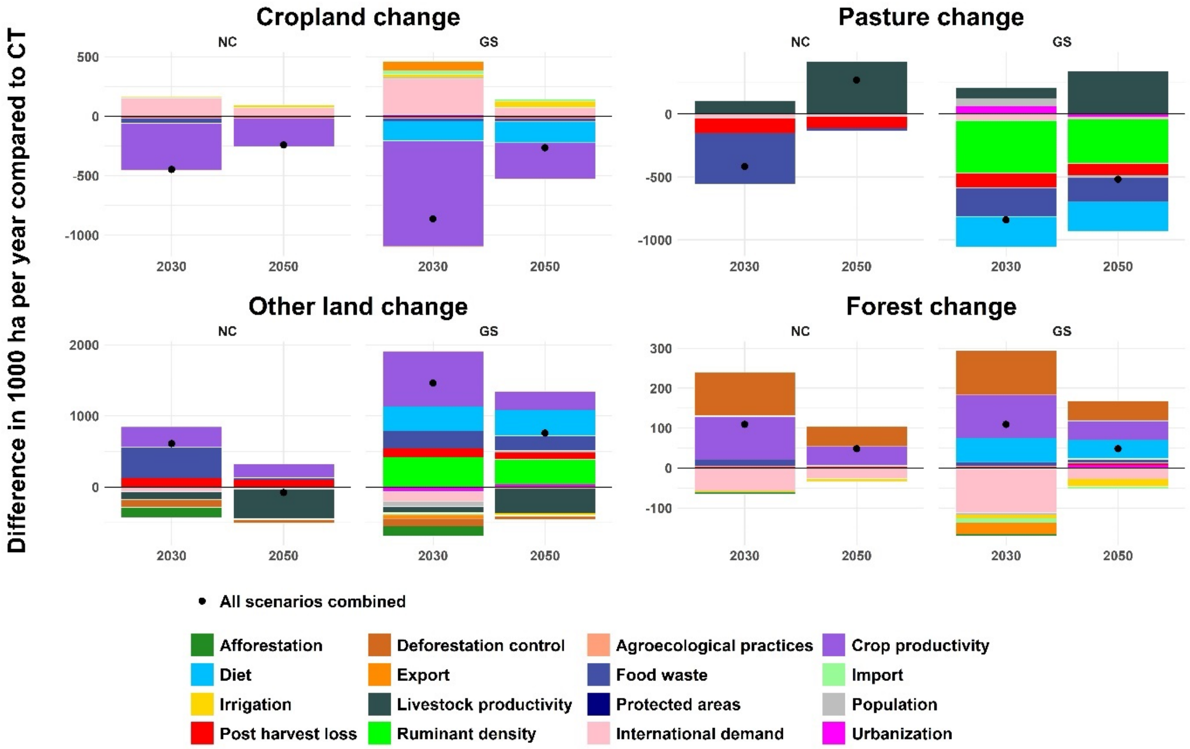
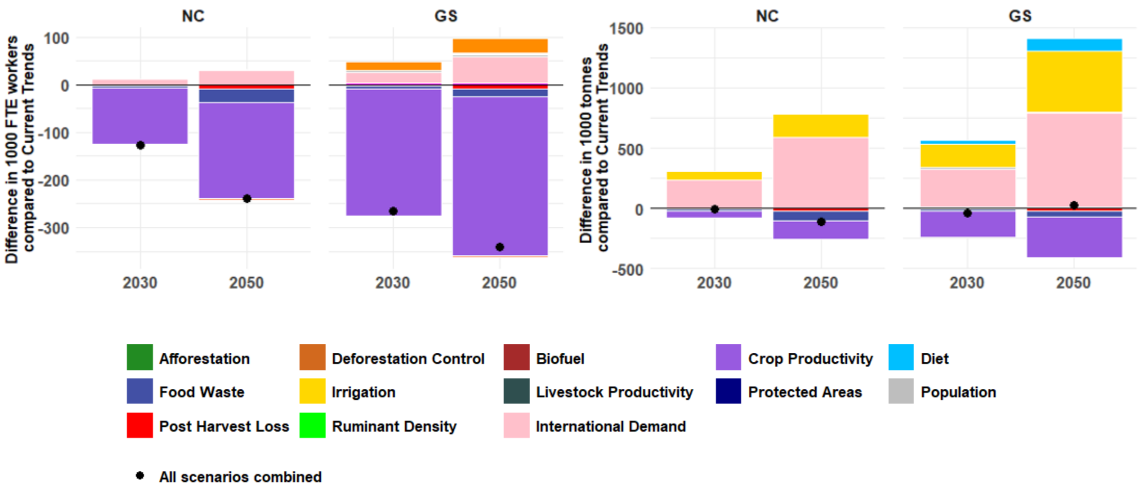


Figure 4-5: *Decomposition analysis for farm labor (left) and blue water use changes (right)*



Consistent with the changes in cropland, farm labor decreases under both the NC and the GS pathways as can be appreciated in Figure 4-5. As could be expected, the main driver of this decline is the increase in crop productivity. In the opposite direction, slowing down the fall in farm labor use, the main driver is the trade adjustment effect that increases net exports. This scenario exerts a stronger effect under the GS pathway, under which the effect of exports in general (aside from the trade adjustment effect) also helps in dampening the decline in farm labor use.

On the other hand, water irrigation requirements remain almost unchanged under the NC pathway and increase by about 27% by 2050 for the GS pathway. As seen in the right side of Figure 4-5, the largest effects on water use arise from the trade adjustment effect that is linked to the dynamics of exports of bananas, sugar products, and other citrus, while the other significant scenario common to both pathways is the increase in irrigated land that is allowed in them but not in the CT. Under the GS pathway, there is also a positive effect arising from dietary changes as cereal consumption is increased and there is a high share of rice cultivation in irrigated lands. Conversely, the increase in crop productivity harms water irrigation requirements.

As mentioned above, the dynamics of LUC reported here refer only to the portion that is directly linked to agricultural activity. As in the NC and GS pathways, it is assumed that Colombia fulfills its commitment to reach net zero deforestation. Forest area decreases in both cases by slightly more than 1% between 2020 and 2050. The main drivers of forest land change are the trade adjustment effect on the negative side and crop productivity, agricultural expansion, and, for the GS pathway, dietary changes on the positive side (Figure 4-4).

For 2030 and 2050, the trade adjustment effect contributes more to the decline of forest land than it does under the CT pathway, with the effect being greater for 2030. The increases in crop productivity contribute more to the decline in deforestation under these scenarios than they do in the CT pathway and the same happens with agricultural expansion (i.e., they increase the amount of land under protection from agricultural expansion) which was not a feature under the CT pathway. Additionally, for the GS pathway, the effect of a partial transition towards a healthier diet also contributes to lowering the decline in forest land.

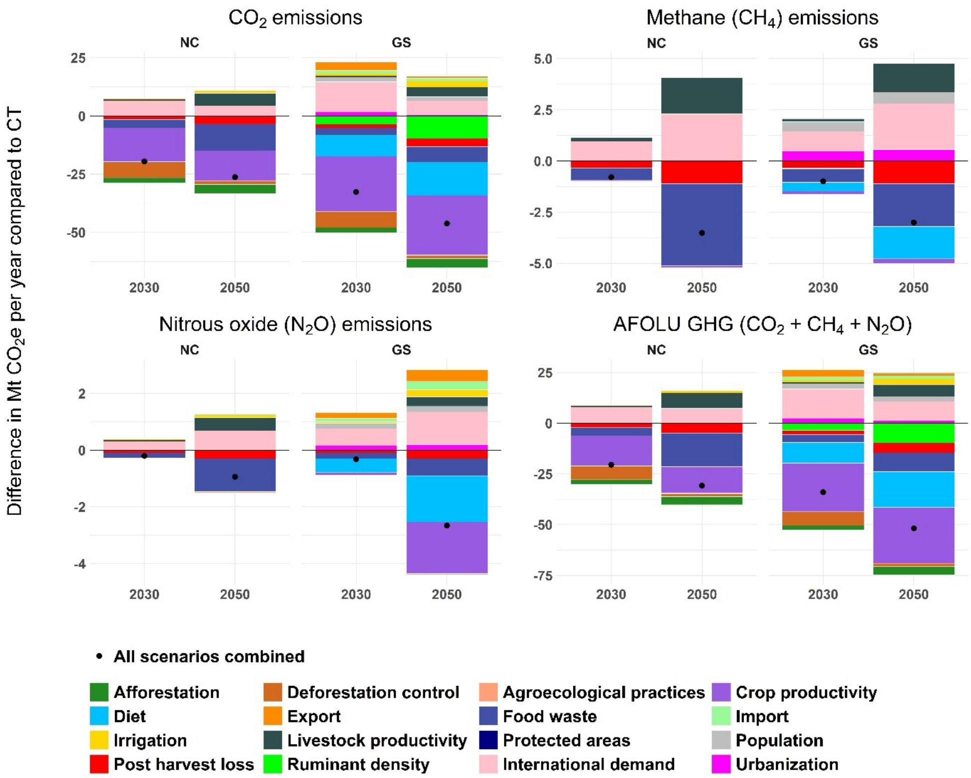
Changes in 'other land' are positive as the category increases more than 33% between 2020 and 2050 in the NC pathway and 92% in the GS.

Several scenarios contribute to the results, the dominant ones being livestock productivity, crop productivity, post-harvest losses, afforestation, and, only for the GS pathway, diet changes (Figure 4-4). While getting into the specifics of these contributions exceeds the needs of this discussion, what is useful to retain is that the dynamics of 'other land' are dependent on the behavior of cropland, pastureland, deforestation, and urban expansion and its increase is largely related to the declines in cropland and pastureland that depend significantly on crop and livestock productivities.

The results of the decomposition analysis for GHG emissions show that, as expected from the scenarios implemented in the NC and GS pathways, emissions decrease across the board for all gases (Figure 4-6). For the NC pathway CO_2 emissions decreased by 168% concerning the CT pathway for 2050, while CH_4 emissions decreased by 5.6%, N_2O emissions by 3.4%, and total nitrogen by 1.6%. In the case of the GS pathway, CO_2 emissions decreased by 313% concerning the CT pathway, while CH_4 emissions decreased by 10.8%, N_2O emissions by 12% and total nitrogen emissions by 25.1%.

Several scenarios have significant effects on CO_2 emissions. For the NC pathway, it is worth mentioning crop productivity, agricultural expansion, afforestation, and decreases in food waste among those that lead to declines in emissions, and the trade adjustment effect among those that tend to increase them. To these scenarios we must add, for the GS pathway the increase in ruminant density on the declining emissions side, and exports and urbanization on the increasing emissions side. Lastly, increases in livestock productivity contribute less to the reduction in emissions in these two pathways than under the CT.

***Figure 4-6**: Decomposition analysis for GHG emissions*



The number of scenarios impacting emissions of the other gases is smaller, especially for the NC pathway. For CH_4 emissions, lower food waste and post-harvest losses are the main drivers for reductions (as expected given the chemical processes involved) and in the GS pathway, there is also a role for the change in diets. The trade adjustment effect and livestock productivity scenarios, however, contribute more to emissions reductions under the CT pathway. In the case of N_2O emissions, there is a situation somewhat similar in that lower food waste and post-harvest losses are important in driving emissions down and that changes in diets add to this effect in the case of the GS pathway, while exports and imports tend to contribute less to emission reduction.

As for total nitrogen (Figure 4-7), lower food waste and the trade adjustment effect are the main drivers in the NC pathway, but under the GS pathway changes in diets, exports and imports, and expanded irrigated land come into play.

The last dimension of the analysis that is important to mention given its very significant role in determining the hidden costs is nutrition. Measured as the availability of kcal per capita per day, the amount is above the minimum requirements for all pathways. Given this, the main factor determining changes in kcal availability is the adjustments in the diet that are introduced in the GS pathway. Kcal availability remains constant between the CT and the NC pathways and decreases by 8% for the GS. As shown in Figure 4-7.

There is an increase in kcal originating in animal products, that is more than compensated by a decline in those that are plant-based for a net decline of about 207 kcal per capita per day (Figure 4-8).

***Figure 4-7**: Decomposition analysis for nitrogen use*

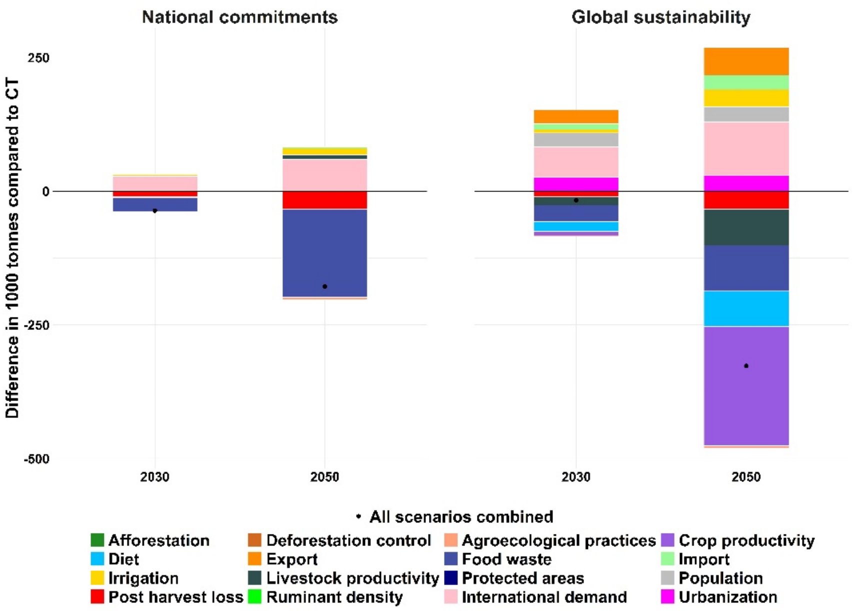
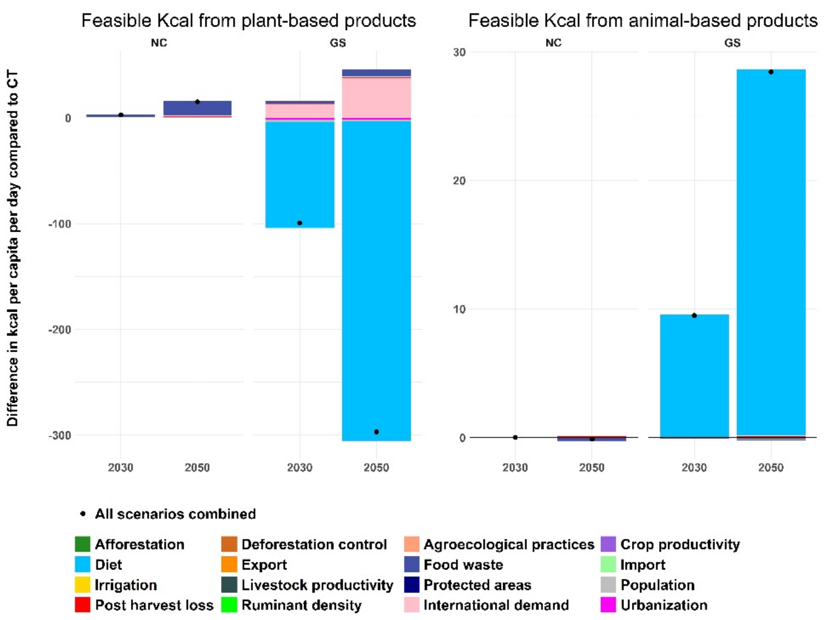


***Figure 4-8:** Decomposition analysis for feasible Kcal from animal and plant origins*



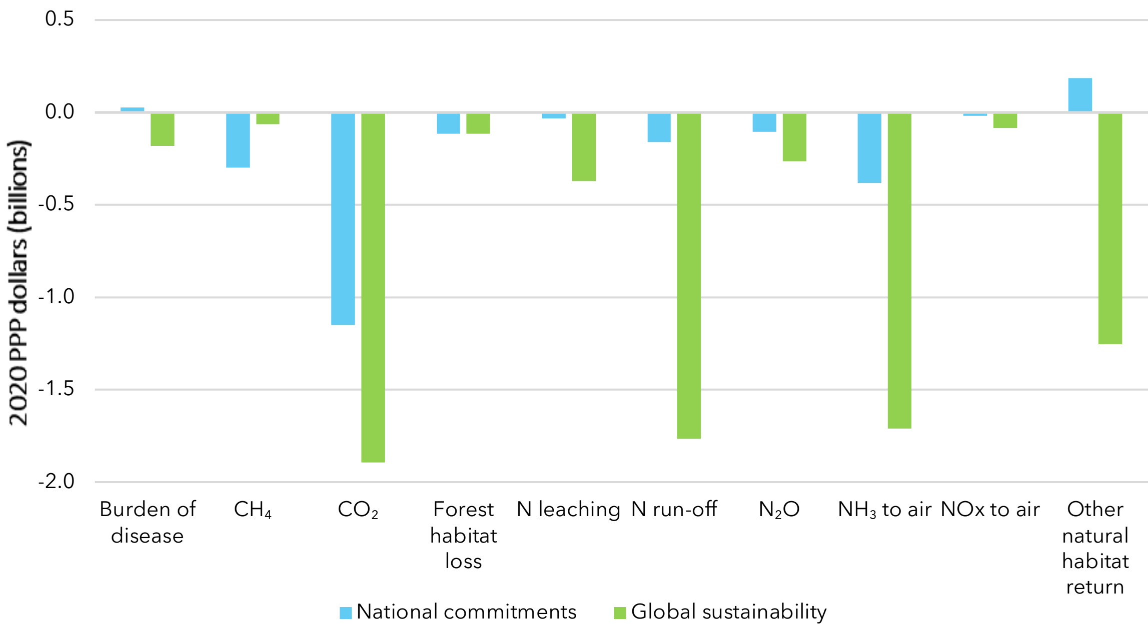
4.3.5 Impacts on the agrifood system's hidden costs

To identify the main factors for reducing the hidden costs of the Colombian agrifood system, the discounted economic costs valued at US dollars of 2020 at PPP were estimated for 2050, using the TCA methodology outlined in the FAO's SOFA 2023 report (FAO, 2023). The estimation was performed for part of the social and environmental dimensions of the hidden costs, comprising burden of disease (undernourishment and dietary patterns), CH_4 emissions, CO_2 emissions, forest habitat loss, forest habitat return, nitrogen leaching, nitrogen run-off, N_2O emissions, NH_3 emissions to air, NOx emissions to air, other natural habitat loss, and other natural habitat return.

This set of costs amounts to 30.4 billion 2020 PPP dollars by 2050 under the CT pathway, representing 2.04% of the estimated Colombian GDP for this year. These costs decrease by 3.8% and 39% in the NC and GS pathways concerning the CT case, amounting to 1.96% and 0.95% of GDP by 2050, so the scenarios implemented in these pathways (especially in the GS pathway) are effective in significantly reducing the hidden costs of the agrifood system.

Figure 4-9 shows the changes in costs between the NC and the GS pathways compared to CT for each of the cost categories. As seen, most changes reflect decreases in costs, being larger in the GS pathway. The exceptions to this are costs associated with the burden of disease (dietary patterns and undernourishment) and 'other natural habitat' return under the NC pathway. The largest decreases (in absolute terms) correspond to dietary patterns, CO2 emissions, nitrogen run-off, NH3 emissions to air, and other natural habitat return (in the case of the GS pathway). In most cases impact quantities decline, but the behavior of marginal costs varies. Marginal costs increase slightly for CO2 emissions, and nitrogen run-off, but decrease for NH3 emissions to air under the NC pathway, while they all decline for the GS pathway. In the case of other natural habitat returns, quantities decrease for the NC pathway and increase for the GS, while the marginal cost decreases under the NC pathway and increases under the GS (leading to an increase in cost in the first case and a relatively large decline in the second, given that this is a negative cost, i.e., a benefit).

Figure 4-9: *Cost changes concerning the Current Trends pathway by cost categories (2050)*



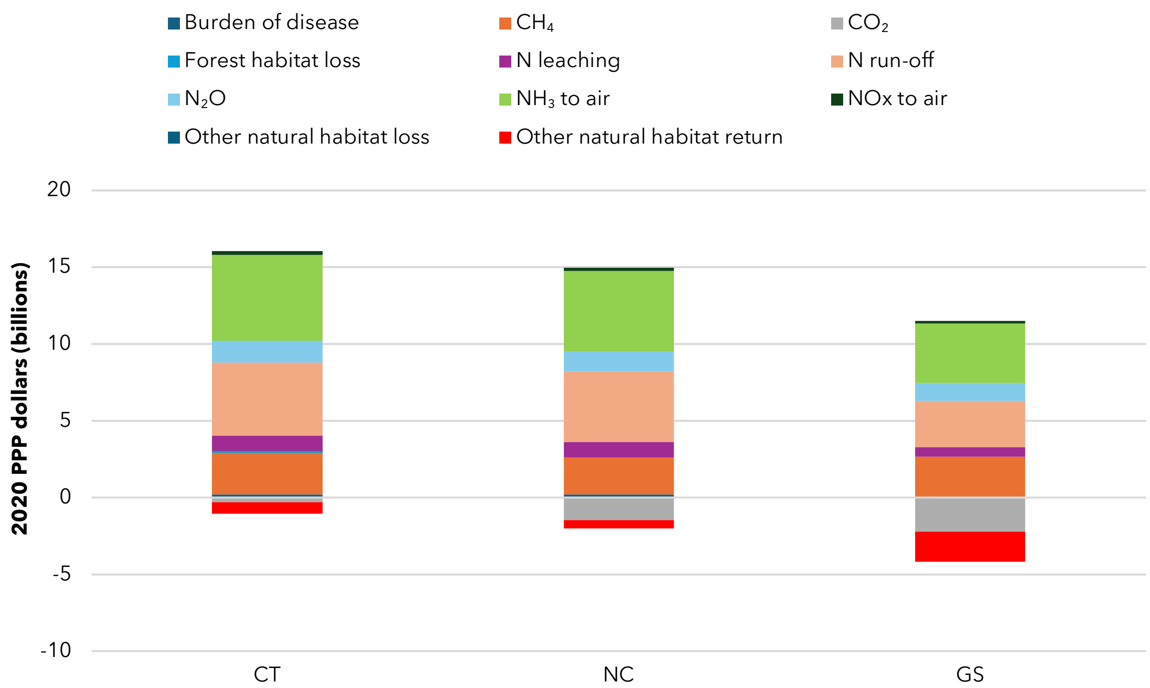
It is important to recognize that the dynamics of LUC reported here refer only to the portion that is directly linked to agricultural activity. This implies that CO_2 emissions in the base year (2020) include those arising from deforestation due to sources other than agriculture, but the simulations do not account for them. As such, there is an overestimation of the reduction in costs due to this source, and benefits arising from negative emissions of CO_2 relate only to avoided deforestation from agriculture.

The costs and benefits by impact category for the three pathways are illustrated in Figure 4-10. Benefits arise from reduced CO_2 emissions from agriculture-related avoided deforestation and from the increase in areas in natural habitat return (restoration) and are found in the three pathways at different levels. Lower costs come from the categories discussed above, which tend to be larger under the GS pathway. Costs from CH_4 emissions decline but the decline is steeper for the NC pathway than for the GS pathway for whom both activity level and marginal cost increase with respect to the NC.

For the GS pathway, the largest contribution to costs in 2050 comes from dietary patterns (49.3%), followed by NH_3 to air (17.2%), nitrogen run-off (13.2%), and CH_4 (11.7%), the rest of the categories (nitrogen leaching, N_2O, and NOx to air), contributing the remaining 5.8% to costs. On the side of benefits, CO_2 abatement from avoided agriculture-related activities and other natural habitat return contribute roughly the same proportions, 52.5% and 47.5%, respectively. More detailed results, particularly regarding the cost effects of the composition of diets and the role of uncertainty are provided in Lord (2024).

Given these results and the decomposition analysis, for the set of impact categories included in the analysis, the main factors for reducing the hidden costs of the Colombian agrifood system are increased crop productivity, forest restoration, and protected areas, lower post-harvest losses, and diet change.

Figure 4-10: *Mean costs and benefits by impact category by 2050*



4.4 Entry points for action and foreseen implementation challenges

The importance of dietary patterns for hidden costs is strongly highlighted by both their share in total hidden costs and their contribution to lowering them in the GS pathway, as instrumented through the simulated change in diets. Consistently with this, the stakeholders consulted considered that the set of actions that have been envisaged by the government in terms of creating an enabling environment for **the development of healthy dietary decisions should be prioritized**. This effort comprises a broad range of measures, going from adequate food labeling and healthy taxes to education campaigns and education programs starting from primary school. The principles of this policy are set out in the National Council for Economic and Social Policy's document 113 of 2008 (Política de Seguridad Alimentaria y Nutricional – PSAN, 2008).

Implementation of the policy needs reviewing and adjusting, including the institutional dimension. An evaluation carried out in 2015 found an imbalance in its main components, that, among other implications, led to prioritizing only vulnerable groups of the population to the detriment of other interventions. It also identified a lack of intersectoral actions and disarticulation between national and territorial plans and the usual operations of the public administration, as well as an inability to secure financial resources for implementation (G-Exponencial, 2015). Furthermore, an evaluation by the World Food Program found that 30% of Colombians experience high levels of food insecurity and that structural and conjunctural factors have worsened food insecurity in the country, implying that tackling the sources of the increasing levels of vulnerability is required (WFP, 2023).

The second entry point is the roll-out of **technical assistance to support producers in the sustainable intensification of agricultural production** that is required to satisfy an increasing demand while also reducing GHG and nitrogen emissions, soil degradation, and water pollution. Sustainable agricultural intensification is key for preventing or reducing agricultural expansion into forest land and other land uses that are significant carbon sinks. Current efforts include the sustainable livestock program included in the Colombian Nationally Determined Contribution, several small-scale projects for enhancing agroecological practices, and the recently proposed (but not yet approved) law for the promotion of agroecological practices (AGROECOLOGÍA | Camara de Representantes, n.d.; Documentos Oficiales Contribuciones Nacionalmente Determinadas, n.d.). The roll-out of the extension service could be supported by its current financing system, but it would certainly require a larger budget allocation.

A third entry point is **ensuring sufficient financing for establishing production projects that have a strong component in sustainable practices**, covering the spectrum of available technologies (agroecology, agroforestry, sustainable cattle ranching, implementation of biodigesters, etc.). This implies not only reviewing credit priorities, conditions, and incentives (e.g., subsidized interest rates, temporary rent tax forgiveness) but also integrating the programs envisioned in the comprehensive climate change management plans at the sectoral and regional levels with the planning of the national agricultural credit program.

An interesting possibility is to **coordinate actions on these three entry points** with the United Nations' initiative for transforming food systems (Home | UN Food Systems Coordination Hub, n.d.). In the case of Colombia, the latter intersects with food production diversification; the improvement of national food markets and promotion of fair trade for producers and consumers; the promotion of family agriculture, including through the valuation of their traditional knowledge; agroecology; food security and nutrition, including policies focused on vulnerable groups such as pregnant women and children; sectoral plans for adaptation to climate change and reduction of carbon emissions in agriculture; strengthening resilience to climate change, pandemics and conflicts; and professionalization and digitization of public services for agriculture and agribusiness. An effort in this direction would be of great help by providing much-needed coordination among plans and programs that otherwise have low interaction and tend to create an undesirable dispersion of efforts.

Lastly, **improving and keeping momentum regarding restoration and afforestation** is key. The National Plan for Ecological Restoration, Rehabilitation, and Recovery of Degraded Areas, the National Policy for the Integral Management of Biodiversity and its Ecosystem Services and Law 2173 of 2021 for promoting ecological restoration are important instruments to enhance and preserve mega biodiversity and ecosystem services in our country. Therefore, it is imperative to sustain the implementation of programs such as Forests of Peace, the Adaptation to Climate Change project in High Mountain Ecosystems (Páramos), the REDD+ program, and others. Moreover, decision-makers must consider the following anticipated challenges, such as:

- Deforestation and ecosystems degradation: Despite significant efforts by the current government, Colombia continues to experience high deforestation rates, particularly in the Amazon and Andean regions. This deforestation is primarily driven by agricultural expansion, illegal crops and mining, and infrastructure development.
- Climate change: The increased frequency of extreme weather events, such as fires and floods, poses additional challenges to restoration efforts.
- Funding: Securing adequate funding and resources for large-scale restoration projects remains critical. This challenge includes financial resources and the necessary technical expertise to implement effective restoration strategies.
- Community engagement: Ensuring the active participation and engagement of local communities, Indigenous groups, and other stakeholders is essential for the long-term success and sustainability of restoration projects. Their involvement is crucial for fostering ownership and ensuring that restoration efforts are aligned with local needs and knowledge.

By addressing these challenges, Colombia would take great steps towards continuing its leadership in ecological restoration, leveraging its rich biodiversity and commitment to sustainable development. Articulation and strengthening of policies, increasing investment in restoration projects, and fostering collaboration between the government, NGOs, academia, and local communities will be crucial for advancing these efforts.

4.5 References

AGROECOLOGÍA | Camara de Representantes. (n.d.). Retrieved June 21, 2024, from https://www.camara.gov.co/agroecologia-0

Colombia - Global Hunger Index (GHI) - peer-reviewed annual publication designed to comprehensively measure and track hunger at the global, regional, and country levels. (n.d.). Retrieved June 20, 2024, from https://www.globalhungerindex.org/colombia.html

Colombian Government. (2019, April 11). Colombia. Biennial update report (BUR). BUR 2. National inventory report. | UNFCCC. https://unfccc.int/documents/194659

Colombian Government. (2022, January 14). Colombia. Biennial update report (BUR). BUR3. | UNFCCC. https://unfccc.int/documents/424157

DANE - Matrices complementarias. (n.d.). Retrieved June 20, 2024, from https://www.dane.gov.co/index.php/estadisticas-por-tema/cuentas-nacionales/cuentas-nacionales-anuales/matrices-complementarias#matriz-de-trabajo

Documentos Oficiales Contribuciones Nacionalmente Determinadas -. (n.d.). Retrieved June 21, 2024, from https://www.minambiente.gov.co/cambio-climatico-y-gestion-del-riesgo/documentos-oficiales-contribuciones-nacionalmente-determinadas/

Encuesta Nacional de Demografía y Salud – ENDS. (n.d.). Retrieved June 20, 2024, from https://profamilia.org.co/investigaciones/ends/

FABLE. (2020). Pathways to Sustainable Land-Use and Food Systems. 2020 Report of the FABLE Consortium (p. 715). International Institute for Applied Systems Analysis (IIASA) and Sustainable Development Solutions Network (SDSN). https://doi.org/10.22022/ESM/12-2020.16896

FAO. (2023). The State of Food and Agriculture 2023 – Revealing the true cost of food to transform agrifood systems. In The State of Food and Agriculture 2023. FAO. https://doi.org/10.4060/cc7724en

FAO. (2024). The State of Food and Agriculture 2024: Value driven transformation of agrifood systems. Rome.

G-Exponencial. (2015). Evaluación institucional y de resultados de la política nacional de seguridad alimentaria y nutricional-PSAN-que permita identificar la capacidad institucional de las entidades a cargo de su formulación e implementación, a nivel nacional y territorial, e identificar el cumplimiento de los objetivos y el avance de las metas, de acuerdo a lo establecido en el documento CONPES 113 DE 2008-DNP 509 DE 2014. www.gexponencial.com

Gran Encuesta Integrada de Hogares - GEIH | Datos Abiertos Colombia. (n.d.). Retrieved June 20, 2024, from https://www.datos.gov.co/Estad-sticas-Nacionales/Gran-Encuesta-Integrada-de-Hogares-GEIH/mcpt-3dws/about_data

Home | UN Food Systems Coordination Hub. (n.d.). Retrieved June 21, 2024, from https://www.unfoodsystemshub.org/en

IDEAM. (2023). Estudio Nacional del Agua 2022.

Lord, S. (2024). Avoided hidden costs in FABLE food system pathways to 2050: Colombia Key Figures. Background Brief Food and Agriculture Organization of the United Nations (FAO) State of Food and Agriculture (SOFA) 2024.

Lord, S. (2023). Hidden costs of agrifood systems and recent trends from 2016 to 2023 – Background paper for The State of Food and Agriculture 2023. https://doi.org/https://doi.org/10.4060/cc8581en

MADS. (n.d.). PNR. Retrieved June 21, 2024, from https://archivo.minambiente.gov.co/index.php/bosques-biodiversidad-y-servicios-ecosistematicos/gestion-en-biodiversidad/restauracion-ecologica

METODOLOGÍA CORINE LAND COVER - IDEAM. (n.d.). Retrieved June 20, 2024, from http://www.ideam.gov.co/web/ecosistemas/metodologia-corine-land-cover

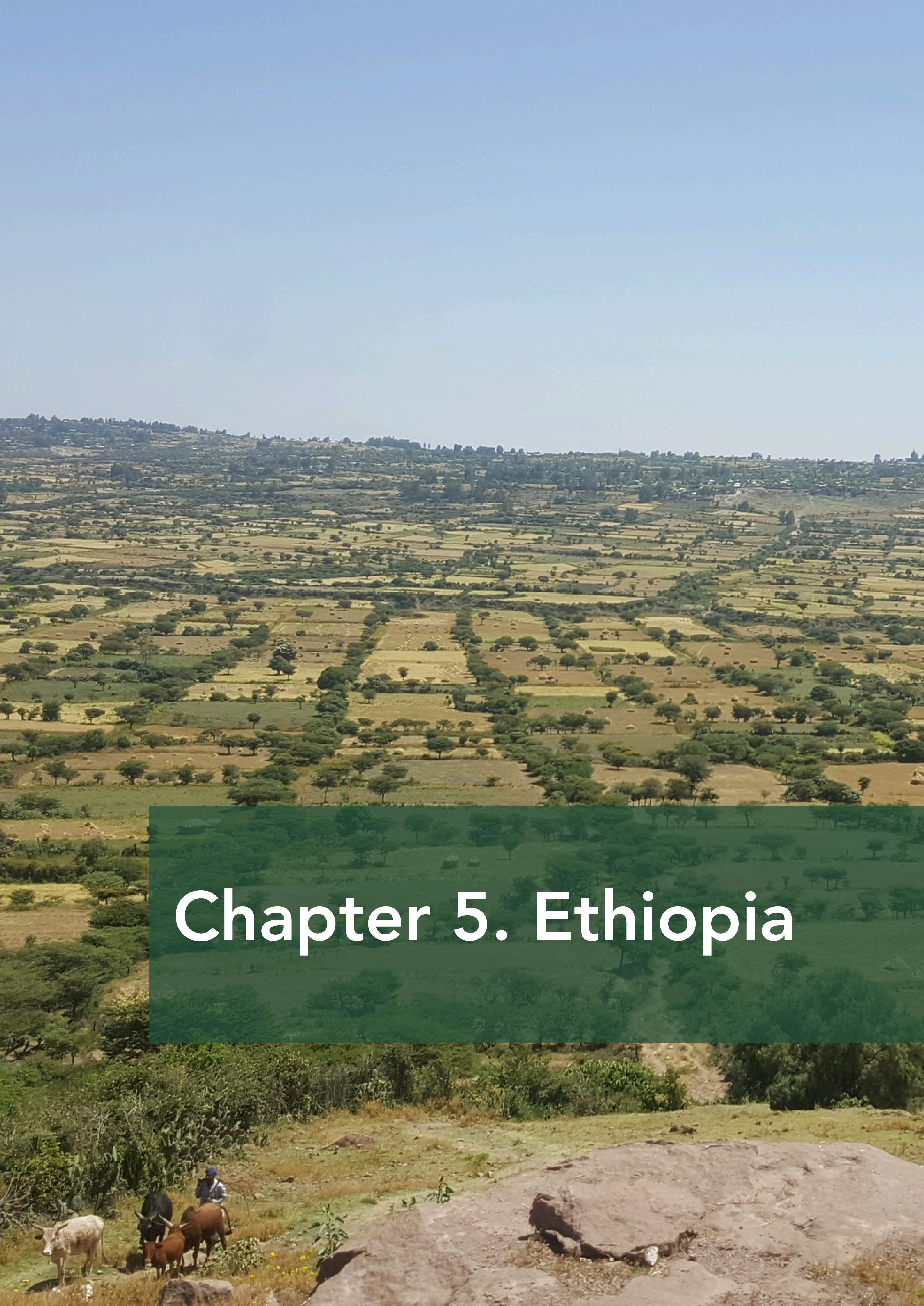
Mosnier, A., Penescu, L., Perez-Guzman, K., Steinhauser, J., Thomson, M., Douzal, C., Poncet, J., 2020. FABLE Calculator documentation- 2020 update. IIASA (Laxenburg) and SDSN (Paris).

Mosnier, A., Schmidt-Traub, G., Obersteiner, M., Jones, S., Javalera-Rincon, V., DeClerck, F., Thomson, M., Sperling, F., Harrison, P., Pérez-Guzmán, K., McCord, G. C., Navarro-Garcia, J., Marcos-Martinez, R., Wu, G. C., Poncet, J., Douzal, C., Steinhauser, J., Monjeau, A., Frank, F., … Wang, X. (2023). How can diverse national food and land-use priorities be reconciled with global sustainability targets? Lessons from the FABLE initiative. Sustainability Science, 18(1), 335–345. https://doi.org/10.1007/s11625-022-01227-7

Observatorio Nacional de Salud Revistas Indexadas. (n.d.). Retrieved February 25, 2024, from https://www.ins.gov.co/Direcciones/ONS/revistas-indexadas

Política de Seguridad Alimentaria y Nutricional-PSAN, 1 (2008).

WFP. (2023). Food Security Assessment Colombian Population. Executive Summary.



Chapter 5. Ethiopia

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Highlights

- Despite the significant role of agriculture in Ethiopia's economy, the economic damage caused by negative externalities within the agri-food system has been largely unknown due to the intangible nature of these impacts.

- This research aimed to evaluate the evolution of hidden costs in Ethiopia's agri-food system by leveraging the 2023 FAO-SOFA flagship report through literature review, stakeholder consultation, and FABLE-based modeling.

- The total hidden costs of Ethiopia's agri-food system were estimated to be 51 billion 2020 PPP dollars per year. The most significant contributor to these hidden costs was the social sector, particularly poverty among agri-food workers, accounting for 24.3 billion 2020 PPP dollars annually. Environmental externalities related to climate change and land-use change were the second-largest contributors, reaching 19 billion 2020 PPP dollars per year.

- The total hidden costs were estimated at 51 billion 2020 PPP dollars annually, with the social sector, especially poverty among agri-food workers (24.3 billion PPP dollars), being the primary contributor. Environmental externalities related to climate change and land-use change followed closely at 19 billion PPP dollars.

- Specific recommendations to reduce hidden costs include a lower population growth path, decreasing livestock numbers, and increasing crop and livestock productivity.

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5.1 Introduction

Ethiopia, a nation of 1.1 million km² in East Africa, supports a population of 110 million. Prior to the global pandemic and ongoing political instability after 2020, Ethiopia stood out as one of Africa's fastest-growing economies, boasting an average annual GDP growth rate approaching 10% between 2009 and 2019 (ESS, 2020). Agriculture is the cornerstone of the Ethiopian economy, with subsistence farming employing over 67% of the workforce and contributing 34% to GDP (Bank, 2018; WB, 2020). The sector forms the core of Ethiopia's agrifood system, which is undergoing transformations in response to recent economic growth (Diao et al., 2023). This report delves into the hidden costs associated with Ethiopia's agrifood system, employing the framework established by the Food and Agriculture Organization's (FAO) 2023 SOFA report (FAO, 2023).

AFS encompasses all interconnected actors involved in producing, consuming, and regulating food and agricultural products and jobs (Fanzo et al., 2020). By analyzing the contribution of each component – primary agriculture, agro-processing, trade and transport, food services, and input supply – we can characterize the structure and economic contribution of all agrifood system stages (Fanzo et al., 2020). Ethiopia's agrifood system reflects a typical low-income country structure, with a high contribution of primary agriculture (48% of GDP) and a low contribution of off-farm components (12.8% of GDP) (Diao et al., 2023).

This heavy reliance on primary agriculture mirrors the vulnerabilities of Ethiopia's agrifood system, posing significant challenges to food security and nutrition. Value added per agricultural worker falls considerably short of other sectors, and major crop productivity remains low on a large portion of farm plots. Additionally, the sector's dependence on rainfed cultivation renders it highly susceptible to climate variability and extreme weather events (Bizikova et al., 2022; Reardon et al., 2019).

Despite these limitations, the primary agriculture sector nourishes the vast Ethiopian population through a subsistence-based production system, minimizing reliance on commercial food imports (FDRE, 2021; Minten et al., 2018). However, this economic mainstay also faces scrutiny for its environmental impact, including deforestation, soil erosion, water pollution, and greenhouse gas emissions. Quantifying the true cost of these negative externalities on the Ethiopian economy presents a significant challenge due to their abstract nature. Hidden cost accounting offers a solution by incorporating these externalities into economic analyses. By estimating the net present value (NPV) of negative externalities like emissions, land use change, pollution, and social damage, hidden cost accounting offers valuable annual snapshots of the agrifood system.

The objective of this chapter is to contextualize the 2023 FAO-SOFA hidden cost estimation for Ethiopia's agrifood system. We analyze the structure of Ethiopia's hidden costs, compare results and input datasets with national databases, and recommend strategies to reduce these costs. This analysis is based on an extensive literature review, stakeholder consultations (both in-person and through phone interviews), and FABLE based modeling results for analysis of evolution of hidden costs under three different scenarios (FABLE, 2024).

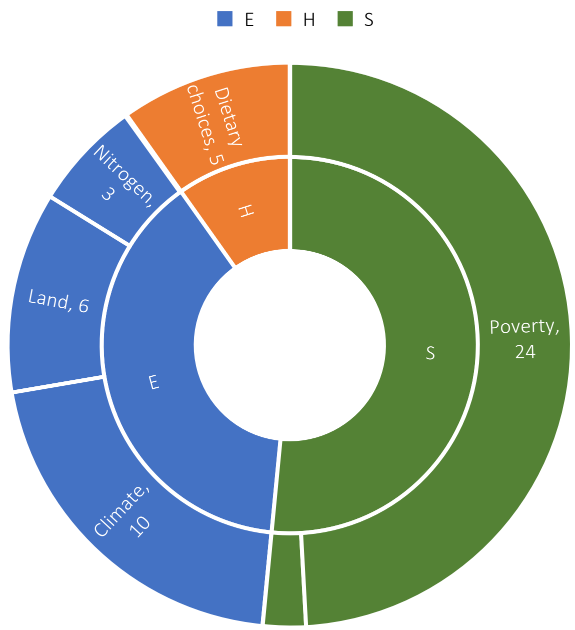
5.2 SOFA 2023 hidden costs analysis

5.2.1 Main cost components and explanation of the results

The breakdown of average annual hidden costs associated with Ethiopia's agrifood system, categorized by major components is presented in Figure 5-1. The combined total from these three sources reaches a staggering 51 billion 2020 PPP dollars, an estimate which sparked debate during the stakeholder consultation. Some stakeholders questioned if it meant half the GDP was lost, or that agriculture produced net losses (considering its 35% GDP contribution). Clarification on the definition led to a consensus: the total cost might not reflect actual economic losses. Instead, stakeholders found unit cost indicators like AEIR, DPIR, and SDIR to be more accurate for assessing the true economic impact.

Notably, the cost structure reveals a dominant burden on the social sector (S), followed by environmental (E) and health (H) components. This pattern aligns with the observed cost structure in many low-income countries, where the social sector often bears the brunt of hidden costs associated with food production

***Figure 5-1**: Hidden costs of Ethiopia's agrifood system by cost type and category based on the FAO-SOFA report*



Source: Authors based on SOFA 2023 results

Within the cost breakdown, poverty among agrifood workers emerges as the most significant contributor, accounting for 49% (approximately 24.3 billion 2020 PPP dollars per year) of total hidden costs. This reflects the high concentration of rural populations living below the poverty line in Ethiopia. World Bank data indicates that an estimated 83% of the country's total poor population are engaged in agriculture (WB, 2020), providing compelling support for the observed predominance of poverty costs within the agrifood system.

Undernourishment, reflecting productivity losses arising from protein-energy malnutrition (PEM)-related disease burden, constitutes the second category of social hidden costs associated with agrifood system in Ethiopia, after poverty. However, its share of the total cost remains the smallest among all categories. Despite this, undernourishment stands as the most prevalent development challenge within the country's agricultural sector. Current estimates for its associated costs fail to adequately capture the complex and multifaceted impact of this problem on a national level.

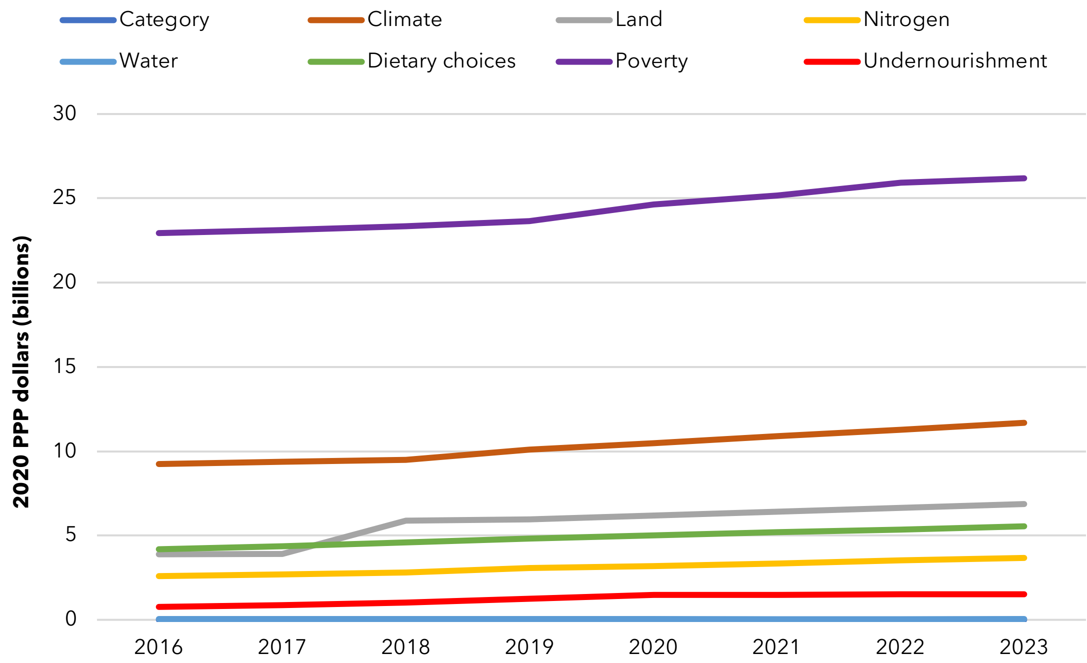
Climate and land-related expenses from the environmental sector follow closely, averaging 10 and 6 billion 2020 PPP dollars annually, respectively, representing 20% and 11% of the total average cost. Dietary choices within the health sector contribute approximately 5 billion 2020 PPP dollars per year. GHG emissions primarily stem from the massive livestock numbers in the country; which is Africa's largest livestock population with 65 million cattle, 40 million sheep, 51 million goats, 8 million camels, and 49 million chickens in 2020 (Mekuriaw and Harris-Coble, 2021). This translates to significant emissions, with the sector estimated to be the largest agricultural emitter, responsible for 146 million tonnes of carbon dioxide equivalent (Mt CO_2e) annually. Further contributing to the environmental cost, ongoing agricultural land expansion in Ethiopia is estimated to contribute 125 Mt CO_2e yearly through land use change. Additionally, rising synthetic fertilizer use fuels nitrogen emissions, which follows land use change in terms of cost contribution among the environmental cost components.

Stakeholders recognized the agrifood system's social cost structure as a realistic reflection of Ethiopia's poverty challenge. Millions of smallholder farmers are trapped in a cycle of poverty due to low returns on their products. This can be attributed to factors like low market value for crops, inefficient and fragmented market chains, unequal access to land and resources, a gender pay gap, and limited safety nets like agricultural insurance and social programs.

However, health costs present a complex picture. While Ethiopia's traditional cereal-based diet and active rural lifestyles likely contribute to lower dietary-related costs compared to other countries, concerns exist about the accuracy of health data. Relying solely on hospital records might underestimate the true burden of such illnesses, as many people may not seek medical care.

Similarly, environmental costs raise data discrepancy concerns. Differences in CO_2 emission data between national and international databases highlight the need for improved data collection and policy considerations to inform effective climate mitigation strategies.

Figure 5-2: *The temporal evolution of hidden costs of the agrifood system*



Trends in the agrifood system hidden costs reveal a persistently upward temporal trend from 2016 to 2023. No major change was observed in the proportional distribution of different types of costs. Poverty ranks as the highest cost driver in all the periods, followed by climate and land-related costs. Poverty-related costs have risen from 22.9 billion 2020 PPP dollars in 2016 to 26.1 billion 2020 PPP dollars by 2023. Compared to the other categories, the rate of change was relatively stable (average annual growth of 1.92%). Costs from greenhouse gas emissions (GHG) increased from 9.2 billion to 11.6 billion 2020 PPP dollars between 2016 and 2023; with average annual growth rate of 3.42%. The cost from land use change rose from 3.8 billion to 6.8 billion 2020 PPP dollars between 2016 and 2023, which is with the second-highest growth rate (9.5% annually) recorded. Nitrogen emissions, while ranking third in terms of overall cost, experienced the fastest growth rate (5.1%), with costs increasing from 2.5 billion to 3.6 billion 2020 PPP dollars over the study period. Undernourishment, despite having the lowest overall cost, demonstrated the highest growth rate (10.6% annually), increasing from 765 million 2020 PPP dollars in 2016 to 1.5 billion 2020 PPP dollars by 2023. The cost from agricultural blue water use remains the lowest with little sign of change throughout the study period (Figure 5-2).

The temporal evolution of most of the cost categories aligns with scientific records and national level databases. Agricultural expansion is a continued process in the country, which aligns with the highest growth rate of land use change induced hidden costs. The increasing trend in nitrogen usage, GHG emissions, and dietary-related costs are all explainable with ongoing environmental changes in the country related to agricultural production process. An exceptional contradiction is the trend of undernourishment, which was found to be the highest growing hidden costs across time, contradicting ongoing reports of reduced undernourishment and food insecurity levels in the country. The other exception is the cost from agricultural blue water consumption. Despite seemingly constant blue water consumption costs reported in the FAO-SOFA report, it appears to contradict contemporary observations of rising irrigation water withdrawals within the country.

Stakeholders acknowledged the seemingly realistic trends in hidden costs over the past five years align with Ethiopia's recent political and climatic challenges. The rapid rise in undernourishment costs suggests a potential reversal of food security gains made before 2020, raising concerns about renewed deterioration after 2020.

5.2.2 Comparison of SPIQ data with national datasets

Poverty

The FAO SOFA report calculated poverty-related externalities using poverty headcount data from the World Bank. However, this data shows a discrepancy with Ethiopia's national poverty database. According to the World Bank, roughly 50 million individuals, or 11.6 million households (77% of agricultural households), lived below the national poverty line in 2016. This figure appears inflated when compared to a 25.6 % estimate of the national poverty report (FDRE, 2012). Their 2019 report indicates that 25.6% of total households (roughly 15 million individuals, from the total 75 million individuals who rely on farming activities for their livelihood) fall below this absolute poverty line. This translates to approximately 3.7 million households (18.7 million individuals) within the agricultural sector living in poverty. Several factors contribute to these discrepancies, including:

- **Different poverty lines:** While the World Bank poverty estimates include a range of thresholds, the FAO SOFA report appears to have adopted the higher USD 3.65 per day threshold, compared to the national poverty line of USD 1.90 per day. This has resulted in a higher number of poverty figures than the national poverty line of USD 1.90 per day.
- **Headcount unit disparities:** The national data relies on household headcounts, potentially capturing agricultural households more accurately than the FAO-SOFA estimate based on average individual income.
- **Self-employment and land ownership**: Ethiopia's prevalence of self-employed agricultural workers, often owning their land, may not align well with FAO-SOFA's accounting system, which might require information on working-age individuals within each household, often unavailable in Ethiopian data.

Therefore, considering the distinct methodologies and data sources, the household-based poverty headcount from the national data may provide a more realistic picture of rural poverty in Ethiopia.

Undernourishment

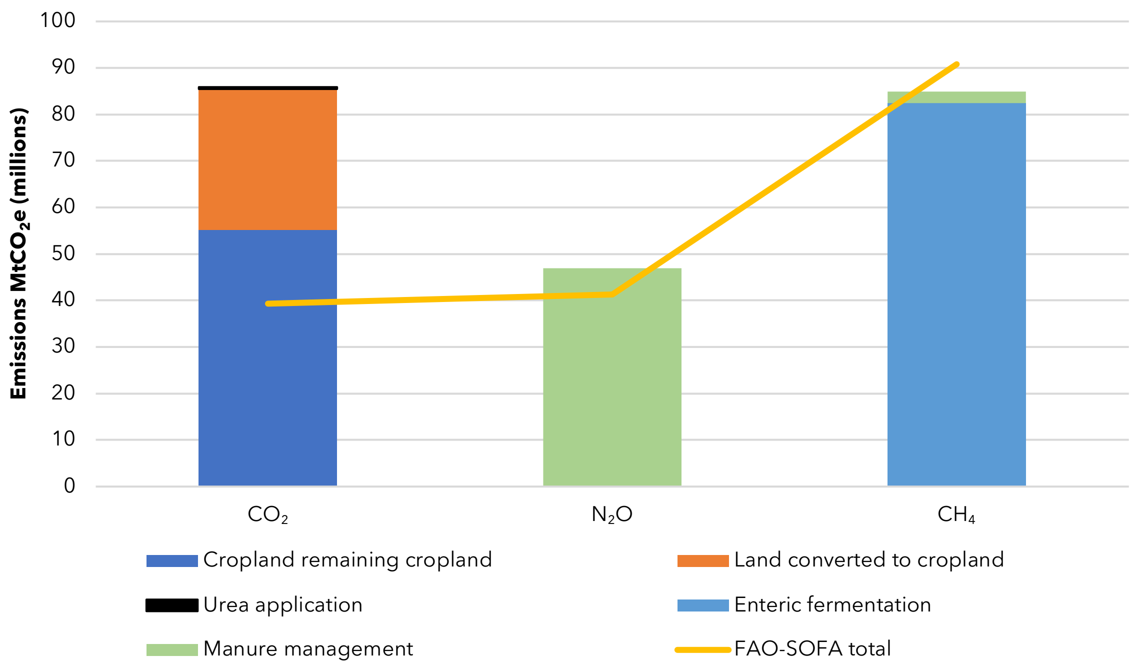
Similar to poverty; estimates of undernourishment prevalence in Ethiopia also show discrepancies between the national database and the FAOSTAT data source used by the FAO SOFA report. The national poverty report (FDRE, 2012) conceptualize undernourishment as "food poverty," defining it as the income shortfall required to meet a predetermined minimum caloric intake (2200 kilocalories per adult equivalent per day). Based on this definition, an estimated 24.8% of households fall below the minimum calorie requirement, translating to approximately 22 million individuals considered undernourished in 2016. This figure is significantly higher than FAO SOFA undernourishment estimates for Ethiopia in the same year, where the undernourished population is estimated to be approximately 14 million. This discrepancy persists even by accounting for the national data's higher caloric threshold for defining undernourishment.

GHG emissions

A comparison of the national GHG assessment report (FDRE, 2022) with the FAOSTAT data used by the FAO SOFA report for estimating GHG externalities reveals a high degree of convergence in emissions estimates for most greenhouse gases. However, a notable exception exists for carbon dioxide (CO_2) emissions. Notably, the national-level assessment estimates CO_2 emissions at 86 Mt CO_2e annually, exceeding the FAOSTAT reports by 54%. This variance primarily stems from the FAOSTAT's exclusion of CO_2 emissions from cropland that remains cropland representing approximately 64% of the national total. This includes emissions and removals of GHG from biomass and soil carbon stock changes of the cropland during the estimation year (Guendehou, 2006). While total N_2O emissions appear broadly comparable in both reports, a closer look reveals inconsistencies. Emissions from manure management in the national database (47 million CO_2e) approximately align with the FAO-SOFA agrifood system report (41 million CO_2e). However, another significant category, "aggregate sources and non-CO_2 emissions on land," encompasses land use change-induced emissions totalling 26 Mt CO_2e. Unfortunately, this category lacks the disaggregation needed to isolate emissions specifically within the agrifood system boundaries, necessitating their exclusion from the comparison with the TCA-FAO report.

Total methane emissions are roughly equivalent in both reports. However, the national database excludes land use change methane emissions, solely accounting for enteric fermentation (82 Mt CO_2e) and manure management (3 Mt CO_2e) emissions.

***Figure 5-3**: Comparison of national GHG emissions and TCA-FAO marginal quantities*



Review of unit costs to GDP

The SPIQ-FS model operates on a unit-by-unit basis, calculating the damage inflicted by one unit of an impact (e.g., one tonne of GHG emissions) on GDP. This damage is then expressed in standardized 2020 PPP dollars for global comparability.

GHG costs: GHG costs were estimated using impact data from simulations conducted by the Interagency Working Group on the Social Cost of Greenhouse Gases (IWG-SCGHG). Unlike the usual approach of a general "CO_2 equivalent" value, the IWG-SCGHG provides distinct economic cost estimates for each greenhouse gas (CO_2, CH_4, and N_2O) emitted per tonne. Notably, the marginal cost values are globally applicable, with Ethiopia experiencing similar rates to other nations. Nitrogen exhibits the highest unit cost at 19,279.1 2020 PPP dollars per tonne, followed by methane at 1,491.3 2020 PPP dollars per tonne and carbon dioxide at 51 2020 PPP dollars per tonne. While these estimates appear reasonable, using separate units instead of converting to CO_2

equivalents may present challenges in directly comparing them with existing scientific literature.

Water withdrawal costs: The water withdrawal cost for Ethiopia exhibits the highest value at 4,818 2020 PPP dollars per million cubic meters compared to 440 and 746 2020 PPP dollars per million cubic meters utilized for Colombia and Brazil, respectively. However, the FAO-SOFA report lacks an explanation for these disparities in marginal cost values, hindering further interpretation and comparison across the nations.

Land use change: Ethiopia's marginal costs for forest and other habitat loss amounted to 27,814 and 13,647 2020 PPP dollars per hectare, respectively. Conversely, habitat gain through regeneration yielded marginal profit of 4,264 and 2,314 2020 PPP dollars per hectare for forest and other land transitions.

Nitrogen emission: Marginal costs for nitrogen emissions varied across countries, with Ethiopia exhibiting values of approximately 0.8, 3, and 0.14 2020 PPP dollars per kilogram (kg) for NH_3 emission to the air, NH_3 deposition to the air, and NO_3 leaching to groundwater, respectively. While these values are lower compared to established marginal costs for similar N_2O emissions in other countries, the FAO-SOFA report lacks detailed explanations for the underlying factors contributing to these variations.

Undernourishment and dietary risk: Ethiopia exhibits unique undernourishment unit costs: 4,877.17 2020 PPP dollars per DALY lost due to dietary choices and 51.2 2020 PPP dollars per DALY lost due to undernourishment. Notably, the dietary choice cost stands significantly higher compared to other countries (e.g., 37, 198, and 36,410 2020 PPP dollars for Colombia and Brazil), while the undernourishment cost remains one of the lowest globally, contrasting with values like 111 2020 PPP dollars for both Colombia and Brazil.

The cost of poverty: Ethiopia's cost of poverty ranges (in 2020 PPP dollars) from 456 (2016) to 450 (2023) per poverty headcount, aligning with estimates for other countries like Brazil (558) and Colombia (490).

5.2.3 Recommendations for tailored country hidden costs analysis

The objectives, scope and methodological approach of the FAO-SOFA report best aligned with external costs associated with Ethiopia's agrifood system, focusing on the crucial nexus between social, environmental, and health dimensions.

The FAO-SOFA system, while valuable, overlooks crucial variations in Ethiopia. The use of unit costs and externalities generated based on the context of resource-intensive, large-scale farming system in high-income countries might bias cost assessments for Ethiopia's small-scale farmers, who dominate the landscape with average holdings of two hectares and annual production of 3 tonne per household. Tailored systems considering land use, resource intensity, and socioeconomic factors are needed for accurate cost assessments.

The FAO-SOFA system further overlooks Ethiopia's substantial pastoralist and agro-pastoralist population (over 15%). Their distinct livelihoods require separate cost assessments due to differing marginal units and unit costs compared to crop-based systems.

Beyond generic limitations, the FAO-SOFA system misses crucial Ethiopian costs like soil degradation and biodiversity loss. Ethiopia's severe soil loss (42 t ha–1 y–1) threatens future productivity, while agricultural expansion harms ecosystems and displaces species. Ignoring these critical dimensions underestimates the true cost of Ethiopian crop production and jeopardizes long-term sustainability. Furthermore, FAO-SOFA overlooks significant post-harvest losses (estimated at 30% of production volume). This hidden cost has a significant impact on the food system and overall economy and needs inclusion in future assessments.

The FAO-SOFA system also misses the benefits of Ethiopia's diverse practices: agroforestry, intercropping, organic fertilizers, and conservation tillage. These practices improve soil health, suppress pests, reduce pollution, and control erosion. Additionally, the system ignores the positive externality of *enset*, a staple crop with high carbon sequestration potential (144.30 t CO2-eq/ha). Accounting for these positive externalities is crucial for a more accurate assessment.

Reflections from the stakeholders also show that while the hidden cost accounting system's concept and its ability to reveal unseen aspects of the agrifood system were commended, concerns arose regarding the scope of its analysis. Specifically, concerns were raised regarding missing components related to soil loss and biodiversity degradation.

Stakeholders also worried about capturing unforeseen events and temporal changes in the model. Ethiopia's ongoing political instability, they noted, can rapidly alter production, poverty, health, and undernourishment. They suggested mechanisms to handle these uncertainties. Climate extremes, like crop failures due to droughts, were also flagged as potential drivers of higher hidden costs, particularly undernourishment.

Incorporating national data sources can significantly strengthen the comparability and relevance of hidden cost estimates to national policies and strategies. Utilizing population data from the official national database can facilitate direct comparisons between hidden cost estimates and population-based targets outlined in national plans. Similarly, leveraging data from the national GHG inventory could provide a robust foundation for evaluating the hidden environmental costs. Moreover, integrating headcount data on poverty and undernourishment from national sources would enhance the policy relevance of the hidden cost estimates by explicitly linking them to key social vulnerabilities within the country.

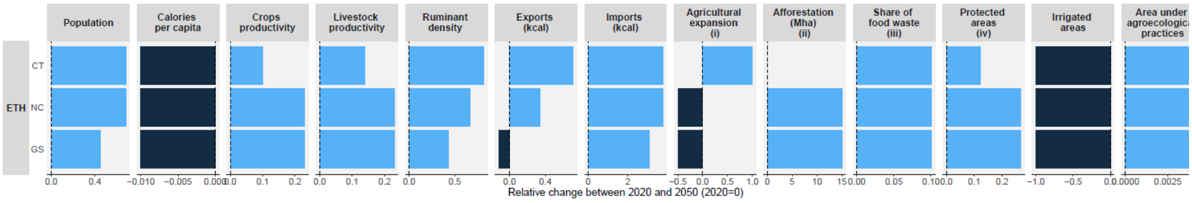
5.3 Evolution of hidden costs by 2030 and 2050

5.3.1 FABLE Calculator for Ethiopia

The FABLE Calculator (Mosnier et al., 2020) was used to analyze the temporal dynamics of the food-land-biodiversity nexus in Ethiopia. The FABLE team adapted the calculator to the Ethiopian context by incorporating country-specific data on items and commodities missing from the original database. This included adding teff, a staple crop in Ethiopia, to the FABLE Calculator's commodity list using data from the CSA. Teff was previously categorized as "other crops" in FAOSTAT data and was absent from the original FABLE Calculator commodity lists. Additionally, scenario parameters were refined based on stakeholder consultations and document reviews, including the development of a country-specific dietary scenario aligned with Ethiopian Public Health Institute (EPHI) dietary guidelines. Afforestation and reforestation scenarios were further adjusted to reflect national decadal and mid-century targets. Model outputs were evaluated against development targets outlined in national government policies and strategies. Additionally, stakeholder consultation workshops were conducted to validate both the modeling process and its outputs.

5.3.2 Scenathon 2023 pathways assumptions

Figure 5-4: *Overview of the assumptions under three different pathways by 2050*



Ethiopia's 2023 FABLE Scenathon pathways (FABLE, 2024) were developed through a comprehensive analysis of scientific literature, government policies, and international agreements aligned with global sustainability goals.

Current Trends pathway

The assumption for Current Trends (CT) was drawn based on the business-as-usual trajectory, which assumed the continuation of current development trends without significant changes. This scenario was informed by a review of scientific literature and data documenting temporal trends in key development goals. Historical data on major indicators for the past decade, primarily from secondary sources and scientific reports, were used to establish a baseline and projected future trajectory. This approach assumes that past trends will continue, resulting in similar magnitudes, directions, and dimensions of change in key development indicators compared to those observed between 2010 and 2020.

Projection of major development indicators under CT indicates population increase to 200 million by 2050. Dietary shifts are expected, with a slight decrease in cereal consumption and an increase in fruits, vegetables, pulses, oilseeds, milk, and poultry. Crop and livestock productivity are expected to increase by less than 10% and 50%, respectively. Food trade is anticipated to increase, with a higher import especially for wheat, milk, and corn. Regarding land, the CT scenario assumes free expansion of agricultural, with no establishment of new forest areas (no afforestation) beyond existing land. The no afforestation assumption is that the high deforestation rates will continue, and any natural and manmade forest gains will remain lower than forest loss.

National Commitments pathway

This pathway (NC) aligns with established government policies and strategies focusing on key development goals across food security, environmental sustainability, and economic growth. These policies aim to achieve sustainable development by the end of the decade and by the mid-century. Therefore, this scenario expects successful implementation of these development policies, leading to significant deviations from business-as-usual trends.

Global Sustainability pathway

This pathway (GS) adopts a green growth paradigm, assuming concerted efforts towards achieving the Sustainable Development Goals (SDGs). It postulates a trajectory in which economic growth becomes decoupled from environmental degradation, leading to sustainable development.

GS population is projected to be 14% lower than CT and NC by 2050. These projections align with the Ethiopian National Statistical Office's estimates, which forecast a reduced population growth rate due to increased contraceptive use (from 29% to 65% by 2050), delayed marriages, and higher school enrolment (CSA, 2013). These demographic shifts are consistent with national policies aimed at reducing fertility rates, including the National Reproductive Health Strategy (FMoH, 2016), National Adolescents and Youth Health Strategy (FMoH, 2021), and the National Guideline on Family Planning (FMoH, 2011).

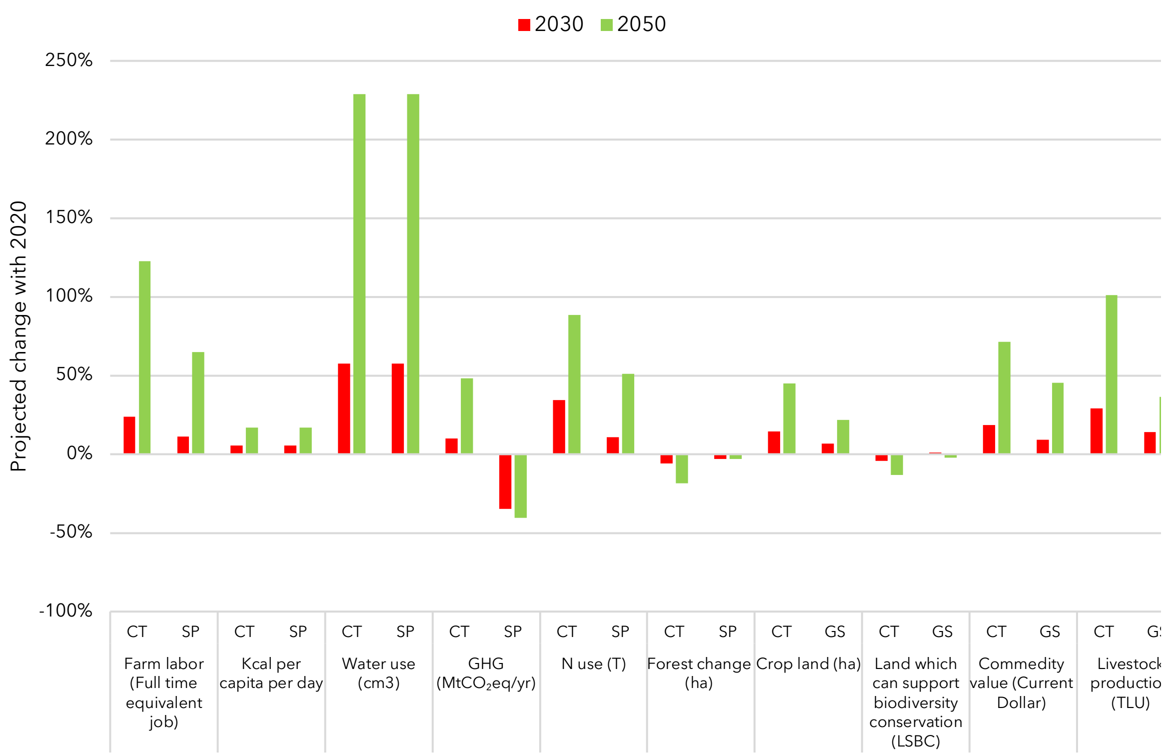
Crop and livestock productivity are expected to increase by over 20% and 100%, respectively, by 2050. Similar to CT, both NC and GS pathways project a slight rise in food import share, reaching 37% by 2050 from its historical level of 20%. However, the GS scenario diverges on exports, aiming to double coffee and sesame exports compared to the current trend.

Regarding agricultural expansion and afforestation, NC and GS scenarios envision policy interventions to forbid agricultural expansion in forested land. Agricultural land expansion would be primarily directed towards lowland areas with planned investments in mechanized irrigation systems. Furthermore, both pathways aim for significantly higher afforestation targets, aiming for 15 million hectares of new forest cover by 2050, aligning with the Bonn Challenge national plan and contributing to broader sustainability goals. While NG and GS scenarios envision a significant increase in protected areas exceeding 30% by 2050, the CT scenario maintains current levels. All scenarios assume irrigation area expansion, with GS and NC anticipating the most significant growth in lowlands due to planned government investments.

In summary, while NC and GS scenarios offer a more sustainable development path compared to the current trend, they both emphasize population control, agricultural advancements, strategic food trade, and responsible land management for long-term food security and environmental health. On the other hand, all three pathways share a similar dietary scenario due to the current cereal-dominated diet with limited intake of diverse food groups. Consumption trends suggest an increase in animal-source foods and fruits/vegetables, aligning with national guidelines and SDG 2: Zero Hunger (balanced diets). We posit ongoing food system shifts will converge with national and global targets, justifying the uniform dietary scenario.

5.3.3 Results across the three pathways

Figure 5-5 *- Projected changes in the major indicators based on the FABLE results*



Analysis of FABLE results based on the CT assumption indicates a projected increase in the production value of all commodities. By 2030 and 2050, total commodity value is expected to reach 66 billion 2020 PPP dollars and 91 billion 2020 PPP dollars, respectively. Corn, wheat, sorghum, teff, and barley will likely remain the most important food crops, with an average production volume increase of 18% and 45% by 2030 and 2050 compared to the baseline year (2020). Livestock production is also projected to rise substantially. Cattle herds are expected to reach 45.7 million TLU (tropical livestock unit) by 2020, with sheep and goats reaching 12.4 million TLU by 2030. These represent a 24.7% and 22.4% increase compared to the 2020 baseline.

Based on the assumption of free agricultural land expansion without afforestation, cropland is projected to expand from 20 million hectares in 2020 to 24 million hectares in 2030 and 31 million hectares in 2050. This expansion, along with the absence of afforestation efforts, is expected to lead to a projected decrease in forest area which is projected to decline from 14 million hectares in 2020 to 13 million and 11 million hectares by 2030 and 2050, respectively. Pastureland is expected to remain relatively stable throughout the projection period.

Consistent with the projected increase in livestock numbers and decrease in forest cover, a rise in greenhouse gas (GHG) emissions is anticipated. Net emissions of CO_2 equivalent (CO_2e) are projected to increase by 64% and 200% by 2030 and 2050, respectively, compared to the 2020 baseline of Mt 171 CO_2e emission.

Compared to the CT pathway, the NC scenario shows similar increasing trends for total commodity production value (reaching 66 billion 2020 PPP dollars and 91 2020 PPP dollars by 2030 and 2050, respectively). However, the GS pathway forecasts lower values (61 billion 2020 PPP dollars and 78 billion 2020 PPP dollars) due to its lower population assumption (169 million by 2050) compared to CT and NC (197 million). This difference in population growth also translates to lower projected increases in major cereal crops (corn, wheat, sorghum, teff, barley) for GS, with an average increase of 20% by 2050 compared to 41% for CT and NC. Livestock production shows a similar trend. NC forecasts a 20% increase in cattle and sheep/goat tropical livestock units (TLU by 2030, rising to 67% by 2050. GS exhibits lower growth (10% for both by 2030, rising to 45% for cattle by 2050) due to the assumption of increase in productivity, enabling similar production goals with fewer animals.

5.3.4 What are the most influential factors to reduce the hidden costs by 2030 and 2050?

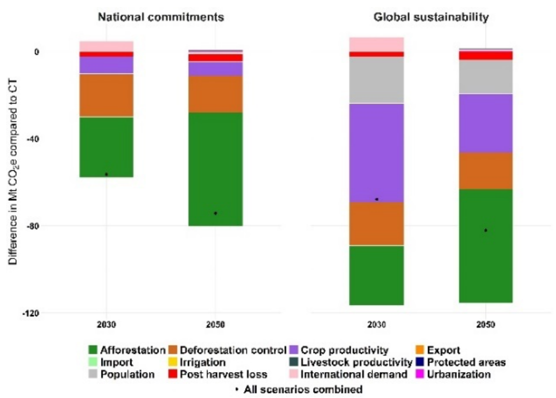
Compared to the CT scenario, both NC and GS pathways exhibit relatively lower rates of cropland expansion. By 2030 and 2050, the cropland area in the NC scenario is projected to reach 23 million and 29 million hectares, respectively, while the GS scenario projects 22.2 million and 26 million hectares, respectively. Decomposition analysis suggests that the primary driver for the lower expansion rates in both NC and GS pathways, compared to CT, is a combined effect of increased crop productivity and reduced post-harvest losses (Figure 5-6). These improvements enable the achievement of production targets without resorting to significant land use change, thus mitigating the need for cropland expansion. While both scenarios share the assumption of improved productivity and reduced losses, the GS pathway projects a lower cropland area requirement due to its lower population growth assumption compared to NC.

In contrast to the CT scenario, both NC and GS pathways project a decline in pastureland. By 2030 and 2050, pastureland is projected to decrease from 20 million hectares in 2020 to 18 million and 17 million hectares, respectively. This trend coincides with a relatively higher net forest cover compared to the CT pathway, reaching 13 million hectares by 2030 (compared to 11 million hectares in CT). Decomposition analysis suggests that afforestation is the primary driver of this land use shift, with projections indicating a conversion of approximately 500,000 hectares of pastureland to forest every five years in both NC and GS scenarios. Furthermore, decomposition analysis reveals that the combined assumption of non-deforestation agricultural expansion and increased crop productivity is a key factor contributing to the rise in the forest area in NC and GS pathways compared to CT. Additionally, the lower population assumption in the GS pathway contributes to a higher projected forest area compared to the NC pathway.

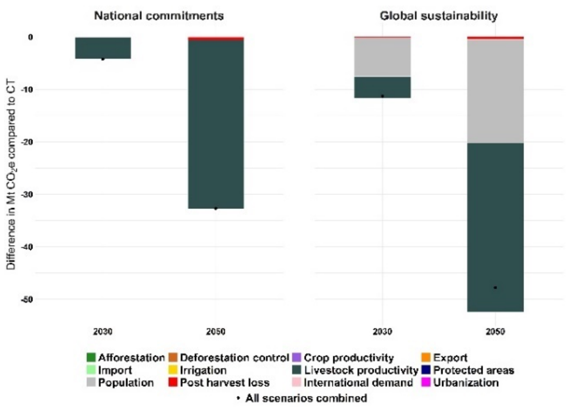
The most prominent distinction between the scenarios lies in greenhouse gas (GHG) emissions. NC projects a 21% decline by 2050, while the GS achieves a significantly steeper reduction (39%). Both pathways share common factors contributing to lower emissions compared to the CT scenario, including increased afforestation, enhanced crop productivity, reduced agricultural expansion (mitigating CO_2-equivalent emissions), and improved livestock productivity (leading to reduced methane emissions). Notably, the GS pathway is projected to achieve a higher rate of CO_2e and methane reduction than NC due to its lower population growth assumption.

***Figure 5-6**: Isolation of the impact of single scenarios on major model's outputs*

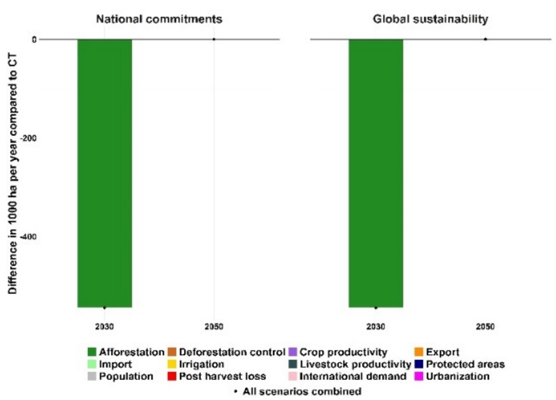
CO_2 emissions



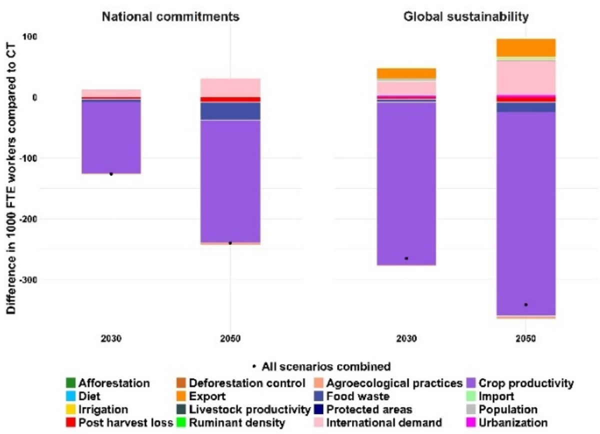
CH_4 emissions



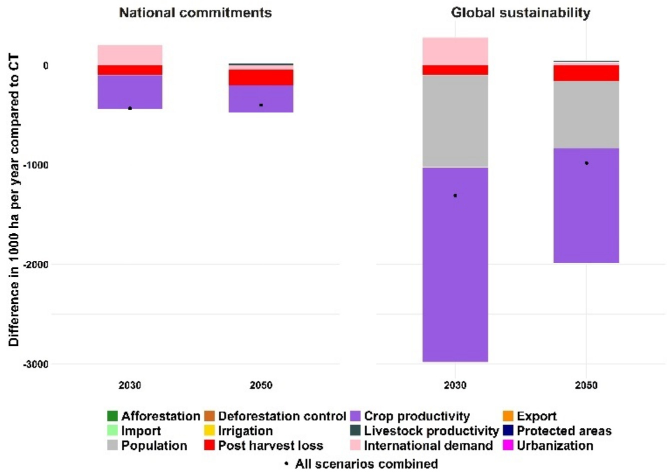
Pasture change



Farm labor FTE



Cropland change

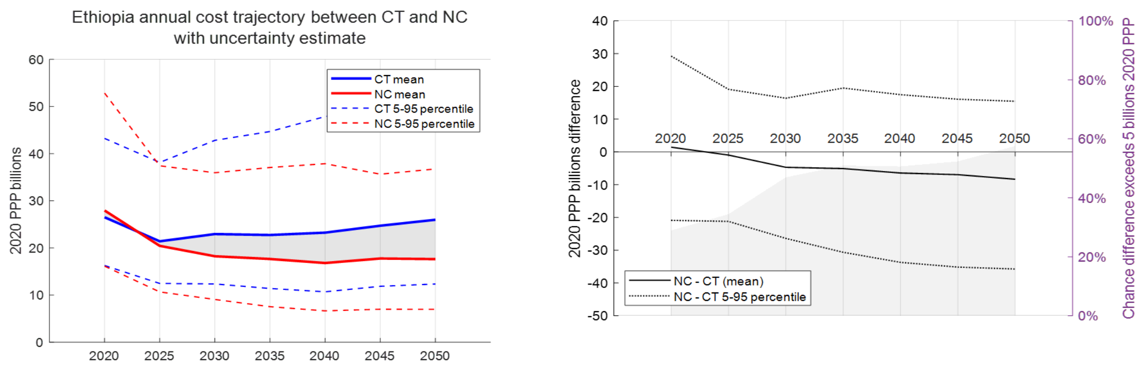


5.3.5 Impacts on the agrifood system's hidden costs

Projections show agrifood system hidden costs steadily rising under the CT scenario until 2050. This highlights the contradiction of economic growth alongside continued land use changes and high GHG emissions. Excluding poverty externalities (estimated at 24 billion 2020 PPP dollars by 2020), total hidden costs are projected to reach 25 billion 2020 PPP dollars by 2050, adjusted for social discounting based on anticipated economic growth (Figure 5-7).

Environmental externalities, primarily driven by high emissions and land use expansion, are expected to remain the most significant contributor to hidden costs, reaching 24 billion 2020 PPP dollars by 2024. However, under the NC and GS scenario, hidden costs are projected to decrease by 25% compared to the CT scenario. This translates to total hidden costs of 16 billion 2020 PPP dollars by 2050, representing an average annual avoidance of 6 billion 2020 PPP dollars. These reductions stem from the assumption of lower population growth rates, decreased livestock numbers, and increased crop and livestock productivity, all of which can significantly reduce emissions, pollution, and land use change impacts, thereby lowering hidden costs.

Figure 5-7: *Trajectory of Ethiopia total annual hidden costs and cost reduction for CT and NC with uncertainty estimate*



Note: The top graph in each panel shows the expected hidden costs under CT (blue) and alternative pathway (red). The shaded area between the trajectories indicates the mean value of the total reduction under the alternative pathway over the period 2020–2050 in 2020 PPP dollars.

5.4 Entry points for action by type of actor of the agrifood system and foreseen implementation challenges

Ethiopia's widespread poverty in agriculture is a major issue that leads to hidden costs. Stakeholders focus on reducing poverty and ensuring everyone has enough to eat as starting points. The stakeholders suggested that the upcoming FAO-SOFA report can inform policy decisions to address rural poverty and increase access to safe, nutritious food. This can be achieved by:

Limited population growth: Decomposition analysis and projections of hidden costs reveal that a lower population growth rate in the GS (14% less than NC and CT assumptions) significantly reduces hidden costs of the agrifood system. By curbing population growth, GHG emissions and farmland expansion decrease, leading to lower environmental and social externalities. Consequently, controlling population growth emerges as a primary strategy for mitigating the hidden costs associated with agrifood systems.

Increasing crop production and productivity: The high poverty rates among agrifood workers highlight the issue of income inequality and the need to break the cycle of poverty. A key strategy to achieve this is by increasing crop land productivity from its current very low average levels. This will empower farmers to raise their income and improve their livelihoods, while also reducing the negative externalities associated with low production. Boosting crop productivity aligns perfectly with the strategic development goals outlined by the government and relevant stakeholders.

Diversifying livelihood options: The high poverty rates among agrifood workers are partly due to their continued reliance on low-productivity farming system. To address this, a key solution is to encourage a significant shift in the labor force, enabling workers to transition from agriculture to higher-paying sectors like industry and services. This shift can offer a crucial pathway out of poverty.

Dietary diversification and enhanced nutrition interventions: High malnutrition costs highlight Ethiopia's economic burden so shifting the focus beyond solely quantity to nutrition is crucial. This means promoting nutrient-rich crops, food fortification, and dietary education. Ethiopia has begun improvements to promote nutritious food production with the development of national food fortification standards. Examples include mandatory iodine fortification (2011) and voluntary fortification of edible oil with vitamin A and wheat flour with iron, zinc, and B vitamins (2018) (Rudolph and Aydos, 2021). These efforts, along with existing strategies to increase production of nutritious foods like potatoes and sweet potatoes (MoE, 2024), demonstrate a commitment to improving national food security and reducing malnutrition. Furthermore, encouraging farmers to cultivate a wider variety of crops aligns with the National Nutrition Sensitive Agriculture Strategy (MoANR and MoLF, 2017), as well as promoting food diversity, access, and consumption for better family nutrition and reduced reliance on purchased staples.

Indigenous dietary practices: Ethiopia's low rates of diet-related health externalities compared to the world suggest its traditional dietary practices, rich in cereals and plant-based foods, may offer valuable insights. Building upon this existing wisdom, rather than imposing complete dietary changes, could be a more effective approach to improving national food habits. This aligns with the country's national food policy, which prioritizes promoting indigenous food and dietary practices (FDRE, 1986).

Improved market access and value optimization: High social costs reflect underlying income inequality in Ethiopia. Promoting direct sales to consumers through improved infrastructure, farmer cooperatives, and market data access can empower farmers and reduce costs by streamlining marketing processes. This aligns with the Ethiopia Rural Connectivity to Support Food Security Project (RCSFSP) (MoA and ATI, 2024), which aims to create physical and digital access for rural communities, enhancing market linkages.

Enhancing food security through low-emission agriculture: Decomposition analysis shows possible ways of reducing environmental externalities in agrifood systems through enhancing crop and livestock productivity without compromising yields. This strategy fosters lower greenhouse gas emissions by minimizing the need for farmland expansion and reducing livestock populations. Aligning with this principle, the Ethiopian Environmental Protection Agency's Climate-Resilient Green Economy strategy (FDRE, 2011) prioritizes low-emission crop and livestock production systems, coupled with afforestation efforts.

5.5 References

Bank, W., 2018. Ethiopia Economic Update: The Inescapable Manufacturing-Services Nexus. World Bank.

Bizikova, L., De Brauw, A., Rose, M.E., et al., 2022. IISD.org ii Achieving Sustainable Food Systems in a Global Crisis: Ethiopia International Institute for Sustainable Development Achieving Sustainable Food Systems in a Global Crisis: Ethiopia Ceres2030 Deep Dives into the Nexus of Food Systems, Climate Ch.

CSA, 2013. Population projections for Ethiopia 2007–2037. Fed. Democr. Repub. Ethiop. Popul. Census Comm. Addis.

Diao, X., Pauw, K., Thurlow, J., Ellis, M., 2023. Ethiopia's agrifood system structure and drivers of transformation.

Fanzo, J., Haddad, L., McLaren, R., et al., 2020. The Food Systems Dashboard is a new tool to inform better food policy. Nat. Food 1, 243–246. https://doi.org/10.1038/s43016-020-0077-y

FABLE (2024) Transforming food and land systems to achieve the SDGs. In Sachs et al. (2024) The Sustainable Development Report 2024. SDSN, New York and Paris

FAO, 2024. The State of Food and Agriculture 2024: Value driven transformation of agrifood systems. Rome.

FAO, 2023. The State of Food and Agriculture 2023: Revealing the true cost of food to transform agrifood systems. Rome.

FDRE, 2022. Ethiopia's Third National Communication to the United Nations Framework Convention on Climate Change (UNFCCC) 1–349.

FDRE, 2021. Vision 2030: Transforming Ethiopian Food Systems.

FDRE, 2017. Federal Democratic Republic of Ethiopia Ethiopia ' s Progress Towards Eradicating Poverty :

FDRE, 1986. Food and Nutrition Policy. Food Nutr. Bull. 8, 1–6. https://doi.org/10.1177/156482658600800310

FDRE, F.D.R. of E., 2011. Ethiopia's Climate Resilient Green Economy (CRGE) Strategy. Fed. Democr. Repub. Ethiop. 200.

FMoH, 2021. National Adolescents and Youth Health Strategy.

FMoH, 2016. National Reproductive Health Strategy. FMoH 1–49.

FMoH, 2011. National Guideline for Family Planning Services In Ethiopia.

Guendehou, G.H.S., 2006. IPCC NGGIP Technical Support Unit Inventory Internship Land-Use Changes and Greenhouse Gas Fluxes : Scientific Understanding and Contribution to Improving Methodologies for Greenhouse Gas Inventory in BENIN. Strategies 2005–2006.

Mekuriaw, Z., Harris-Coble, L., 2021. Ethiopia's livestock systems: Overview and areas of inquiry.

Minten, B., Dereje, M., Bachewe, F., Tamru, S., 2018. Evolving food systems in Ethiopia : Past , present and future.

MoA, ATI, 2024. Rural Connectivity to Support Food Security Project (P176303) Appraisal Federal Democratic Republic of Ethiopia Ministry of Agriculture (MoA) and Agricultural Transformation Institute (ATI) 1–11.

MoANR and MoLF, 2017. Federal Democratic Republic of Ethiopia National Nutrition Sensitive Agriculture Strategy 1–35.

MoE, 2024. The National Potato and Sweetpotato Development Strategy (NSPSDS) 2024-2030.

Mosnier, A., Penescu, L., Perez-Guzman, K., Steinhauser, J., Thomson, M., Douzal, C., Poncet, J., 2020. FABLE Calculator documentation- 2020 update. IIASA (Laxenburg) and SDSN (Paris).

Reardon, T., Echeverria, R., Berdegué, J., et al., 2019. Rapid transformation of food systems in developing regions: Highlighting the role of agricultural research & innovations. Agric. Syst. 172, 47–59. https://doi.org/10.1016/j.agsy.2018.01.022

Rudolph, S., Aydos, E., 2021. Lessons learned from the implementation of ETS. Carbon Mark. Around Globe 1–7. https://doi.org/10.4337/9781839109096.00013

WB, 2020. Ethiopia poverty assessment: Harnessing continued growth for accelerated poverty reduction.

Chapter 6. India

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Highlights

- We review the hidden costs of food systems in India as developed in the FAO SOFA 2023 report and evaluate the results in the context of India. Additionally, we assess the factors of change to reduce the hidden costs of food systems in India through a multi-model approach.
- We use a suite of interconnected models to implement scenarios and assess their impact on reducing the hidden costs. We create two scenarios of transformation and evaluate them across 14 indicators of food system changes encompassing the four dimensions of health, environment, inclusion, and economic costs. We also conduct stakeholder consultations to discuss the analysis and gather stakeholder opinions.
- We find that large average hidden cost reductions until 2050 come mainly from shift towards healthy diets, improved crop and livestock production, avoided cropland expansion and mitigated NO3 run-off.
- Timely shifts in dietary patterns, curbing nitrogen emissions from cropland surface runoff, and managing land use change emerge as pivotal factors for reduction of hidden costs in India.
- Our analysis points towards the importance of assessment of hidden costs of food systems in India using existing data and evidence. At the same time, the results from our analysis highlight the importance of reviewing analysis of hidden costs, methodological validation, and forward-looking projections within agrifood systems.

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6.1 Introduction

India's agricultural and food systems in the last five decades have been driven by the Green Revolution and policies surrounding the goal of increasing agricultural productivity to meet food security of the growing population. This was powered by a multitude of subsidy programs – the largest of which have been fertilizer, power, seed and machinery subsidies. It was complemented by price support policies that ensured minimum prices for key cereal crops such as rice and wheat and provided the much-needed boost to India's productivity growth over the years (Chand and Singh, 2023). However, this growth necessitated extensive use of inputs including fertilizer, water and land resources. The interconnected nature of the agricultural sector, environment and natural resources were overlooked in the policy framework. As a result, food systems in the country at present face critical challenges in sustainable agricultural development, farmer livelihoods, consumer welfare, and environmental impacts, where isolated interventions often overlook the interconnectedness of these issues (Pingali et al., 2019). On the other hand, focusing solely on climate-resilient and sustainable agriculture practices may disrupt the supply of agricultural products and create an imbalance without a matching shift in consumer demand (Scherer and Verburg, 2017). Furthermore, discussions on transforming India's food systems have largely treated agricultural advancement, food and nutrition security, and biodiversity conservation as separate entities. The policy landscape has not adequately addressed the Sustainable Development Goals' principles of equitable economic development, social justice, and inclusive growth (Bajpai and Biberman, 2020). This siloed approach hinders the holistic development and sustainable transformation of India's food systems.

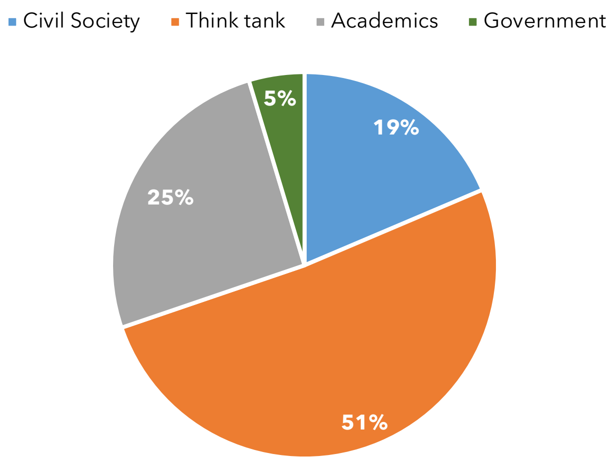
The costs of implementation of these policies to ensure food security are only analyzed through program implementation and subsidy budgets. They often overlook the future costs of land and environmental degradation as well as human health impacts due to undernourishment and burden of disease. Indicators such as gross product count the value added of current activities in purchasing power terms but do not account for the future deficits. This is why the "true" costs are hidden from national accounts and not factored into current markets. Unlike shocks such as the global financial crises or the COVID-19 global, the food system incurs costs year on year. The hidden deficit accumulates in real terms and poses risk to future growth and development.

In this chapter, we delve into the assessment of a True Cost Accounting framework for India based on the State of Food and Agriculture 2023 report (FAO, 2023). We present results from stakeholder engagements that were conducted to critically analyze the assumptions and datasets used in the analysis and any gaps that may have existed (more on stakeholder consultations is discussed below). We also present validation of SOFA 2023 results concerning hidden costs in agrifood systems, encompassing an overview of the SOFA 2023 method and an examination of primary hidden cost sources in India from 2016–2023. The exploration extends to the driving factors behind current hidden cost estimates, specifically disentangling contributions from impact quantities and marginal costs. A comparative analysis with national datasets is presented, covering dimensions such as poverty, land use, greenhouse gas (GHG) emissions, water, and health outcomes. Furthermore, this chapter identifies gaps in the SOFA 2023 analysis and offers insightful suggestions for improvements. The subsequent section explores the evolution of hidden costs by 2030 and 2050, employing the SPIQ-FS model (Lord, 2023a) and the Model of Agricultural Production and its Impact on the Environment (MAgPIE) (Dietrich et al., 2019a). This involves detailing scenarios for enhancing sustainability in contrast to current trends. This comprehensive approach ensures a thorough investigation into hidden costs, methodological validation, and forward-looking projections within agrifood systems.

Stakeholder consultations in India were conducted in two rounds in the months of December 2023 and January 2024. These consultations were conducted across north and south India (Delhi and Bangalore) to attract and represent experts from all domains and regions. Across these events, more than 50 participants from all sectors – policy, academia, practitioners, think tanks, and civil society – were represented (Figure 6-1). Critical assessment of the SOFA 2023 report including datasets, assumptions and methodology was undertaken and feedback summarized.

The stakeholders provided valuable insights that merit consideration for refining our approach. It was highlighted that policymakers may initially overlook the presented hidden cost figures, especially given the evidence from parallel studies indicating substantial value of agrifood systems in India, estimated at approximately 16% of GDP. Therefore, a cautious presentation of current results was suggested. The transition costs to alternative agrifood systems need careful consideration, acknowledging the potential variability. Recognizing India's diverse landscapes and food systems, there was a recommendation to present the analysis at the sub-national level to enhance relevance for policymaking. They underscored the method-specific nature of the calculated costs, urging for an acknowledgment of alternative calculation methods that account for demanded goods, both tradeable and non-tradeable. A need was felt to integrate broader perspectives by including net benefits from India's agricultural sector, considering it is a net sink of greenhouse gas emissions. Stakeholders also suggested that a more comprehensive evaluation of quality-of-life statistics be conducted, moving beyond the simple years of life lost metric and mooted the inclusion of awareness costs associated with shifting diets into the analysis. In short, incorporating these recommendations will enhance the relevance, accuracy, and applicability of our hidden cost analysis within the intricate landscape of India's agricultural and food systems.

Figure 6-1: *Professional background of the stakeholders consulted for SOFA 2024 across two workshops and regions in India (North and South)*



6.2 SOFA 2023 hidden costs analysis

6.2.1 Overview of the SOFA 2023 method

The SOFA 2023 report highlights the magnitude of hidden costs of agrifood systems in India to the tune of 1.17 trillion 2020 PPP dollars (Lord, 2023). India reports the third largest hidden costs of agrifood systems after China and the USA. In Indian currency, this is equivalent to approximately 220 trillion Indian rupees. The total budget on India's largest public scheme – the Public Distribution System (PDS) for food grains, for the fiscal year 2020–2021 was around 2.42 trillion Indian rupees.

These costs include the costs of annual Indian GHG emissions, nitrogen pollution, and habitat losses and returns from land use change from food production, poverty, and productivity losses from consumption of unhealthy diets. In essence, these hidden costs capture the externalities and market failures of India's agrifood systems over the period of 2016–2023, compared to their marginal damage to GDP PPP.

The figures presented in this report should not be interpreted as an indication that alternate policy options can fully eliminate the hidden costs of agrifood systems in India. Furthermore, these numbers do not imply that India's GDP could experience a 16% increase if these costs are avoided. A comprehensive comparative assessment of costs and benefits, utilizing consistent methods and assumptions, would be required to substantiate such claims.

Table 6-1: *Description of costs included in the SOFA 2023 analysis*

Environmental	**GHG emissions**	Fertilizer manufacture for agricultural use, manure management, enteric fermentation, and land use change
	Land use change	Habitat loss associated with non-food agricultural commodities such as tobacco, cotton and biofuels, land use conversion from forests to cropland, pastures and other association losses of ecosystem services
	Blue water	Agricultural losses and productivity losses due to the burden of disease from protein-energy malnutrition, due to water deprived from economic use, and scarcity in water availability for economic use in the future
	NH_3 emissions in air	Labor productivity losses due to burden of disease from air pollution
	NOx emissions	Negative impacts on agricultural and ecosystem services resulting from imbalances in nutrients and the acidification of terrestrial biomes caused by deposition
Health	**Disability-adjusted life years (DALYs)**	Productivity losses due to burden of disease due to protein-energy malnutrition and obesity (high BMI and NCDs)
Social	**Poverty**	Income shortfall below the moderate poverty line of agrifood workers

6.2.2 Main cost components and explanation of the results

Environment

The environmental costs of food systems are calculated by accounting for external costs of GHG emissions from the farm gate and land use change, land use transition to and from cropland and pasture, and blue water use for agricultural production. For the SOFA 2023 results, India reports hidden environmental costs to the tune of 0.287 trillion 2020 PPP dollars. These costs are divided by the Gross Value Added (GVA) of agriculture, forestry, and fishing sector to create the agricultural externalities impact ratio (AEIR) – it is the cost of agricultural externalities due to production, per unit of value added to GDP. As compared to the global AEIR of 0.31, India's is 0.13, thereby suggesting that the environmental costs of food systems in India are lower than the global average but indicating that every 2020 PPP dollar of agricultural production results in 0.13 2020 PPP dollars of external environmental costs, specifically nitrogen. India estimated 144 billion 2020 PPP dollars in 2023 due to nitrogen emissions, third largest after China and Brazil.

Health

From the SOFA 2023 report, India reports hidden costs to the extent of 0.73 trillion 2020 PPP dollars due to health outcomes of agrifood systems in India. As per the Global Burden of Disease 2019 study, malnutrition and air pollution are two major determinants of DALYs and contribute to the maximum hidden costs of health. This is driven by the double burden of malnutrition and obesity that currently affects India's population. Like the AEIR, a comparable measure of costs due to consumption patterns is the dietary patterns impact ratio (DPIR). This indicator is developed by dividing productivity losses from dietary patterns by national GDP PPP. This value for India is 0.07, compared to the global value of 0.072, equivalent to about 7% of India's GDP PPP. Since this value is relative to total GDP, it is considered of high concern. According to an estimate by the World Bank, the health cost of air pollution alone in India in 2019 was USD 36.8 billion.

Social

Hidden costs from agrifood systems in India report the least costs: 0.15 trillion 2020 PPP dollars. Like the environmental and health outcomes, the social distribution impact ratio (SDIR) is developed by specifically accounting for income shortfall of agrifood systems workers in moderate poverty and productivity losses from undernourishment, divided by the total income of the moderately poor. This assumes that most loss of productivity from undernourishment is experienced by the moderately poor. The value of this ratio for India is 0.24.

6.2.3 Driving factors of the current hidden cost estimates

As per the SOFA 2023 report, from 2016 to 2023, there was a 3% increase in farm gate CH_4 emissions in India, amounting to approximately 20 million tonnes of CH_4 emissions in 2023 as well as an increase of pre-and post-production activities emissions by about 5% (0.5 million tonnes in 2023). At the same time, a steep reduction of approximately 69% is observed in CH_4 emissions from land use change processes. Marginal costs across the emissions categories remain the same for India and do not change over time. The environmental challenges manifest through high marginal costs associated with nitrous oxide (NO_3) run-off and human sewerage to surface water, as well as NO_2 emissions into the air due to nitrogen deposition and ammonia (NH_3) emissions to air from particulate matter. No change in blue water withdrawals are noted in the analysis for India, which is a major gap in the analysis and is discussed later in the chapter.

We observe a significant increase from croplands to forests for India between 2016 and 2023 (1019%) (Table 6-2) which is attributable to extensive efforts towards the protection and expansion of forest cover and is accounted under the category of forest habitat return. A small degree of conversion between forest to cropland and pastures is also observed in this assessment, as is a reduction in the conversion of unmanaged grasslands to pastures.

Table 6-2: *Rate of change in land use across categories for India between 2016 and 2023*

Category of land use change	Rate of change between 2016 and 2023 (%)
Cropland to forest	1019
Cropland to unmanaged grassland	20
Forest to cropland	55
Forest to pasture	34
Pasture to forest	119
Pasture to unmanaged grassland	23
Unmanaged grassland to cropland	-19
Unmanaged grassland to pasture	-99

Source: Authors' calculations from the SOFA 2023 report. Values indicate percentage change in land use conversion rates in 2023 compared to the conversion rate in 2016.

Over the same period, there is a notable 9% decline in the marginal costs of agrifood worker productivity. This decline is attributed to rising overall incomes, subsequently reducing the mean income shortfall among agrifood workers. The burden of disease related to dietary choices, measured in DALYs, is also observed to increase by 24% from 2016 to 2023. This rise is linked to an uptick in non-communicable diseases (NCDs) and changes in BMI resulting from shifts in food consumption patterns, following the western style diets trajectory. Notably, NCDs accounted for approximately 63.7% of total annual deaths in India, with substantial associated costs reflected in out-of-pocket healthcare expenditures and income loss in 2017 (Bukhman et al, 2020). Excessive nitrogen use in the production of cereal crops remains a key driver of these health and economic challenges, posing complex implications for policy considerations. These trends are exacerbated by the continued application of high nitrogen in agriculture, fueled by adverse subsidy programs, farmer awareness, and behavioral change. Additionally, escalating air pollution, attributed to both household air pollution (HAP) and ambient air pollution (AAP), significantly contributes to the national burden of disease, with implications for mortality rates.

6.2.4 Comparison with national datasets

Poverty

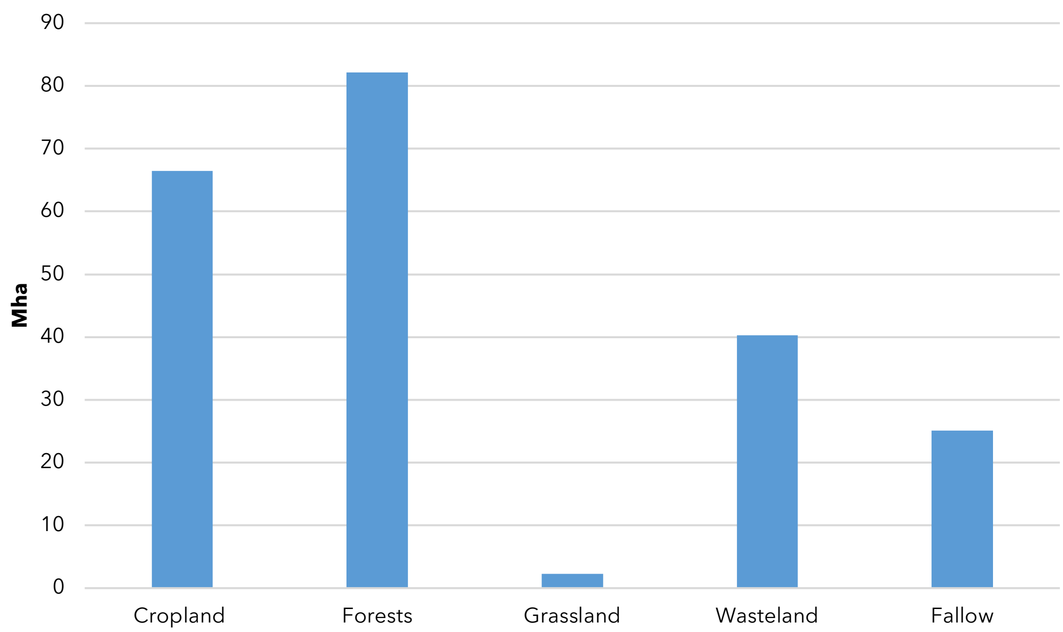
Approximately 22.2% of the Indian population remained at the USD 3.65 per day poverty threshold in 2017 (World Bank, 2024). This is equivalent to 655 million people living below the poverty line. However, in the True Cost Accounting (TCA) estimates, this number is 331 million agrifood workers under poverty and does not compare to other available statistics. As per the latest estimates from the Participation in Labor Force Survey (PLFS) (NSSO, 2023), the TCA figures are close to the USD 1.9-a-day poverty threshold instead of the USD 3.65 per day. The evaluation of poverty indicators in India relies on the Multidimensional Poverty Index (MPI) (Niti Aayog, 2023), recognizing the limitations of income as the sole metric, which may overlook crucial information about household deprivations in health, education, and living standards. India's national MPI consists of three equally weighted dimensions – health, education, and standard of living – represented by 12 indicators. Notably, the health component addresses nutrition gaps for adolescents and maternal health, suggesting a potential enhancement in the health cost metrics within the SOFA 2023 report. Furthermore, the MPI sub-indices not only account for the incidence of poverty by considering numbers but also measure the intensity of poverty by weighing the deprivation scores of all poor individuals, summing them up, and dividing by the total number of poor people. Over two rounds of this index, the report indicates that between 2015–16 and 2019–21, approximately 135 million people were uplifted from multidimensional poverty. While this does not directly attribute to poverty among agrifood system workers, the reduction in poverty within rural areas, from 32.59% to 19.28% between 2015–16 and 2019–20, serves as a proxy. This reduction mirrors a 15% decrease in agrifood worker poverty, as reported by SOFA 2023.

Land use

To compare statistics on land use change with SOFA 2023, we rely on available sources within India. One dataset is the India Water Resource Information System (WRIS) that reports the various categories of land use and land cover every year. However, the latest data is only until 2017.

Figure 6-2 presents the classification of total land across various land types, as obtained from WRIS for 2017. A trend analysis from this source is unavailable to draw relative comparisons between SOFA datasets which only report change in land use categories.

Figure 6-2: *Classification of various land use types in national dataset*



Source: Authors' calculations using data from the Water Resource Information System (WRIS), Government of India, for 2017 (indiawris.gov.in)

Latest statistics from land cover maps of NRSC in India suggest that cropland occupies about 46% of total land areas in India, followed by forests at 38%, fallow at 8% and pastures at 3%. We also gather data from the NASA LP DAAC at the USGS EROS Center and curate yearly MCD12Q1.061 MODIS Land Cover Type to determine the following conversion rates between land types between 2016 and 2022 (Table 6-3).

While a direct comparison cannot be made between the two sources due to difference in methodologies, estimates from the alternative dataset show large changes from grasslands to croplands and grasslands to forests over the years, and only small conversions from cropland to forests or grasslands.

Table 6-3: *Change in land cover type between 2016 and 2022*

Land use change type	Change from 2016 to 2023 in million hectares
Forest to croplands	0.73
Cropland to forest	0.83
Cropland to grassland	1.37
Forest to grassland	2.64
Grassland to cropland	3.43
Grassland to forest	2.80

Source: Author's calculations using yearly land cover data from The Terra and Aqua combined Moderate Resolution Imaging Spectroradiometer (MODIS) Land Cover Type (MCD12Q1) Version 6.1.

GHG missions

Greenhouse gas emissions comparisons for India use data from the GHG Platform for India (Solanki et al., 2022) which reports GHG emissions from all sectors including AFOLU from 2005 until 2018. Statistics from this platform were used by India in their third Biennial Update Report (BUR III) to the United Nations Framework Convention on Climate Change (UNFCC) (MoEFCC, 2021). 2018 is the latest year for which comparisons can be made with the SOFA 2023 report as presented in Table 6-4 below. Challenges in comparing data sources arise from variations in source classification and differing accounting methods, as illustrated below. For example, CH_4 emissions from SOFA 2023 classified as "farm-gate" are approximately 19.73 million tonnes. To compare with data from the national dataset, we combine CH_4 emissions from all these sources: biomass burning in cropland, biomass burning in forest land, rice cultivation, enteric fermentation, and manure management. This value is 14.02 million tonnes, much less than the SOFA estimate. Total CO_2 emissions from the SOFA 2023 report are 261.22 million tonnes. This is much higher than the emissions from AFOLU sector reported in India (170 million tonnes of CO_2) in 2018.

Table 6-1 shows the difference in contribution of each emission type between data sources (India's report to UNFCC and the SOFA 2023) for the year 2016. The comparison reveals that the SOFA 2023 dataset underestimates methane (CH_4) emissions from agricultural production in India while overestimating carbon dioxide (CO_2) emissions. Notably, SOFA 2023 fails to report any CO_2 emissions attributed to land use change in India, an omission significant in scale, as these emissions approximate 180 million tonnes of CO_2 equivalent. Such a substantial omission compromises the conclusiveness of the comparison.

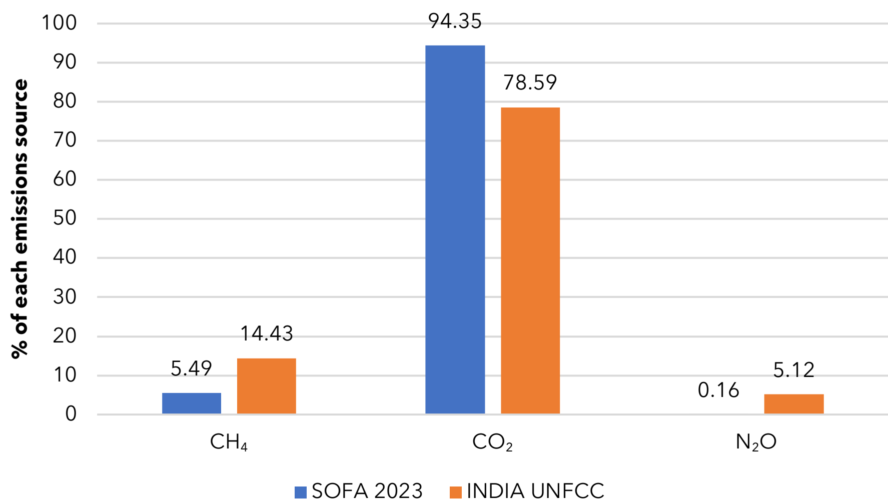
Table 6-4: *Comparison of GHG emissions from GHG platform India and SOFA 2023*

GHG platform	Type	2016	2017	2018
Agriculture soils	CO_2e (t) GWP-AR6	44.79	44.81	46.29
Biomass burning in cropland	CO_2e (t) GWP-AR6	7.82	8.45	8.79
Biomass burning in forest land	CO_2e (t) GWP-AR6	1.98	1.90	1.91
Rice cultivation	CO_2e (t) GWP-AR6	88.88	89.29	89.94
Enteric fermentation	CO_2e (t) GWP-AR6	267.50	267.65	267.81

Manure management	CO_2e (t) GWP-AR6	27.37	27.41	27.45
Land use change	CO_2e (t) GWP-AR6	-104.98	-104.98	-180.97
Agriculture soils	N_2O (Mt)	0.16	0.16	0.17
Biomass burning in cropland	N_2O (Mt)	0.01	0.01	0.01
Biomass burning in forest land	N_2O (Mt)	0.00	0.00	0.00
Manure management	N_2O (Mt)	0.00	0.00	0.00
Biomass burning in cropland	CH_4 (Mt)	0.22	0.24	0.25
Biomass burning in forest land	CH_4 (Mt)	0.06	0.06	0.06
Rice cultivation	CH_4 (Mt)	3.19	3.20	3.22
Enteric fermentation	CH_4 (Mt)	9.59	9.59	9.60
Manure management	CH_4 (Mt)	0.96	0.96	0.96
SOFA 2023				
Farm gate	CH_4 (Mt)	19.73	19.88	20.03
Land use change	CH_4 (Mt)	0.03	0.02	0.01
Pre- and post- production	CH_4 (Mt)	5.60	5.65	5.69
Farm gate	CO_2 (Mt)	18.51	16.34	14.92
Land use change	CO_2 (Mt)			
Pre- and post- production	CO_2 (Mt)	417.15	439.57	442.79
Farm gate	N_2O (Mt)	0.72	0.73	0.75
Land use change	N_2O (Mt)	0.00	0.00	0.00
Pre- and post- production	N_2O (Mt)	0.03	0.03	0.03
Total		**461.77**	**482.23**	**484.22**

Source: Authors' calculations from data obtained from the GHG platform. All values are in million metric tonnes.

Figure 6-3: *Greenhouse gas emissions across data sources*



Source: Author's estimations using data from SOFA 2023 and UNFCC report of India. Values reflect percentage difference in CO2 equivalents

Water

The representation of blue water withdrawals for India matches the statistics from FAO AQUASTAT with withdrawals at 688 billion cubic meters per year for the year 2023. However, there is scope for improvement in the analysis by incorporating irrigation water use efficiency in the analysis. Additionally, assessment of true costs of water would also benefit from accounting of water use for various other agricultural activities such as fertilizer production.

Health/dietary patterns

In India, the high prevalence of poor dietary patterns and the corresponding burden of disease are supported by India's State of Health Report (ICMR et al. 2017). This report shows the change in burden of disease between 1990 and 2016 and reports that for India, 33% of the total DALYs resulted from communicable, maternal, neonatal, and nutritional diseases (CMNNDs) and, 55% from non-communicable diseases (NCDs), and 12% from injuries in 2016. In 1990, this was 61%, 30%, and 9% of DALYs, respectively, thereby suggesting a reduction in the extent of CMNNDs and an increase of NCDs. The SOFA 2023 report has integrated the burden of disease from NCDs and high BMI and reports an increase in the total burden of disease between 2016 and 2023 by 0.24% which is much lower than the assessment of the ICMR report. In further support of the TCA data, several studies have shown that the consumption patterns of most Indians are not diverse. Specifically, a study by Sharma et.al. (2020) used the nationally representative Consumption Expenditure Survey (CES) Data from 2011–12 in India to demonstrate that the average daily calorie consumption in India was below the recommended 2503 kcal/capita/day across all groups compared, except for the richest 5% of the population. They found that processed food accounts for nearly 10% of the average total caloric intake in both rural and urban India, with urban households consuming as much as 30%. Most recent highlights from the latest CES survey reveal an alarming trend in the consumption of processed foods across both rural and urban areas where processed foods contribute to approximately 20% share in total food expenditure in rural areas, and 27% in urban areas (MoSPI 2024). Another study on physical activity assessments had also found that about 34% of Indians were physically inactive, thereby suggesting that productivity losses from inactivity/burden of disease could also be high (Gautam et al., 2023). Healthier diets are also associated with the costs of consumption and studies have shown that healthy diets are not affordable by more than two thirds of the population in India (Raghunathan et al., 2021; Sharma et al., 2020).

6.2.5 Recommendations for tailored country hidden costs analysis

Notable gaps in the SOFA 2023 report necessitate attention for comprehensive improvement:

- Agricultural production accounting: The absence of a distinction between agricultural production for domestic consumption and import stands as a major gap. While this differentiation may not directly impact cost estimations, its inclusion would significantly enhance the analysis, prompting countries to consider hidden costs associated with their trading patterns.
- Incomplete consideration of blue water withdrawals: The current analysis overlooks the critical aspect of whether all blue water withdrawals for agriculture are utilized in crop production. Poor water use efficiency contributes to high withdrawals with relatively low rates of crop production. Furthermore, the substantial freshwater usage by fertilizer industries, estimated at 182 million cubic meters in India in 2019, underscores the need for a more comprehensive evaluation, as reported by the Centre for Science and Environment.
- Unaccounted pesticide use: The report fails to account for pesticide use, despite its significant implications for both

human and environmental health. To provide a holistic assessment of hidden costs, it is crucial to incorporate the cost of pesticide production and the industrial use of water and power in the overall analysis.

- Alternative data sources: In assessing disease burden and health-related indicators, demographic data, including age-specific death rates and population age distribution, can be sourced from the Registrar General of India. This dataset provides updated information that can be used to analyze the disease burden. The Periodic Labor Force Survey 2022 provides recent labor force statistics, particularly those related to individuals employed in agrifood systems. Furthermore, data from the National Sample Surveys and the National Family Health Survey (5th round) play crucial roles in determining food consumption patterns and evaluating protein-energy malnutrition, essential for understanding and improving productivity losses due to undernourishment in India. Some studies have utilized the 75th round of the National Sample Survey Organization, specifically the "Key indicators of social consumption in India: Health" for 2018, to assess quality-adjusted life years (QALYs) as an alternative to DALYs for representing health outcomes.

Several observations were made by stakeholders in the two consultation events organized by IIMA in India in December 2023 and January 2024. Key points that emerged are as below:

1. The calculation of environmental costs should include the role of agricultural machinery during production and transport to provide a comprehensive analysis.
2. Include energy costs associated with the production of pesticides and fertilizers to ensure a more accurate assessment of hidden costs.
3. Account for health issues arising from the application of pesticides in production, acknowledging the potential impacts on both human health and the environment.
4. Incorporate the climate impact and associated costs in the analysis to address the broader environmental consequences of agricultural practices.
5. Evaluate hidden costs related to bringing about the transformation of food and land use systems, recognizing the intricate implications for sustainability.
6. Consider future trends and evolving consumer tastes to provide insights into the shifting dynamics of the agrifood sector.
7. Recognize the significant awareness costs associated with transitioning diets and incorporate them into the analysis.
8. Revisit marginal cost calculations to ensure accuracy and relevance in capturing the dynamic nature of economic factors, especially exchange rates and fiscal policies in countries.
9. Include bifurcation of trade in the analysis, especially for countries like India where a substantial portion of food production is exported. Distinguish between the costs of food production for internal consumption versus exports.
10. Explore alternative methods that account for the production of goods for demand, both tradeable and non-tradeable, and elucidate how cost calculations from these methods might differ in the Indian context.

6.3 Evolution of hidden costs by 2030 and 2050

6.3.1 The Model of Agricultural Production and its Impact on the Environment (MAgPIE)

To simulate scenarios for transforming India's food systems, the India country case study employs the Model for Agricultural Production and its Impact on the Environment (MAgPIE). MAgPIE, a partial equilibrium optimization global land-use model, integrates economic, environmental, and biophysical data (Dietrich et al., 2019a) to the minimization of the global agricultural production costs and the fulfilment of agricultural demand. It projects the potential impacts of various agricultural policies and practices on land use, crop yields, and resource utilization and is therefore instrumental in understanding how different policy choices can influence India's agricultural landscape, food security, and environmental sustainability. This model has previously been used to determine sustainable transformation pathways for India, as well as specifically to identify appropriate water governance policy measures in India (Jha et al., 2022; Singh et al., 2023). The scenarios used here are part of a larger suite of scenarios developed for the Food Systems Economics Commission (FSEC) early in 2023. Details of the multi-model system developed for this analysis are presented in Bodirsky et al. (2023) with India specific analysis in Singh et al. (2024).

To identify the main intervention areas for agrifood system transformation and the most influential factors of reducing the hidden costs, we create multiple individual food system measures (FSMs) and external transition pathways that comprise points of action outside the food systems (presented in Table 6-5). Several FSMs are combined into packages and evaluated as individual scenarios to evaluate their contribution towards the desired transformational change represented by the full systems transformation pathway. We call it the "food systems transformation sustainable development pathway" (FSDP). The effects of all scenarios are systematically evaluated across 14 indicators of food system changes encompassing the four dimensions of health, environment, inclusion, and economic costs: underweight, obesity, premature mortality, crop area diversity, biodiversity intactness index, nitrogen surplus, GHG emissions, environmental flow violations, poverty, expenditure on agricultural products, employment, agricultural wages, bioeconomy supply, and production costs.

6.3.2 Scenarios

The baseline scenario, Business-as-usual (BAU) or Current Trends (CT) is the first scenario. This scenario is parametrized according to the "middle-of-the-road" narrative of the shared socioeconomic pathways (SSP2) (O'Neill et al., 2017; Popp et al., 2017; Riahi et al., 2017) where the plausible future state of the food system continues with the current trends. Indicators like human development, lifestyles, economic growth, and technological development align with the currently observed trends. The population in India under this scenario is expected to reach 1.65 billion by 2050 from 1.39 billion in 2020. Urbanization trends are expected to grow moderately as the urban population is expected to increase to 0.87 billion by 2050 from 0.49 billion in 2020. The expected climate change impact on crop yields is based on RCP 6.0 projections (Representative Concentration Pathway). This scenario assumes moderate mitigation efforts to reduce emissions, resulting in a stabilization of radiative forcing at 6.0 W/m² by the year 2100 (van Vuuren et al., 2011). Dietary changes reflect the historical food consumption patterns with moderate consumption growth and increasing share of animal sourced foods (ASFs) along with rising income. Future simulations for crop yields are obtained from the LPJmL global hydrology and vegetation model (Von Bloh et al., 2018). Crop yields are further projected in MAgPIE through spatial allocations and an endogenous investment in yield-increasing R&D and technology which improves future yields at optimal costs. Afforestation targets that are in line with India's commitments on the Nationally Determined Contributions (NDCs) to the Paris Agreement, whereby India has pledged to create an additional carbon sink of 2.5 to 3 billion tonnes of CO_2 equivalent through afforestation and reforestation by 2030. Trade patterns in the model for India adhere to historical trends, prioritizing self-sufficiency goals. The objective is to fulfil agricultural demand through a combination of domestic production and export-oriented strategies at minimum production costs. The model considers trade costs, tariffs and trade margins, to fully account for the dynamic nature of trade. Area-based land conservation approach is implemented in this scenario. Land reserved for area-based conservation is derived from World Database on Protected Areas (WDPA) and is based on observed land conservation trends. The WDPA database includes all areas under legal protection meeting the IUCN and CBD protected area definitions (including IUCN categories Ia, Ib, III, IV, V, VI and "not assigned" but legally designated areas). Natural vegetation and grasslands or pastures within protected areas are not allowed to be converted to other land types.

In comparison, we create an alternative sustainable transformation pathway (FSDP) or Food System's Transformation (FST) which integrates 23 individual food system measures (FSMs). Sustainable food system transformations, especially in the context of developing economies, are intertwined within broader socioeconomic and structural changes outside of the food system (Béné et al., 2022; Nguyen, 2018). Identifying the significance of sustainable external transitions, the FSDP pathway therefore includes an additional five transformation domains from outside the food system.

The total of 28 transformation domains (comprising both within and outside food system changes) are represented by five distinct packages or policy measure bundles: 1) healthy diets and sustainable consumption patterns (Diets); 2) nature-positive agricultural transition (Agriculture); 3) biodiversity protection (Biodiversity); 4) equitable livelihoods (Livelihood); and a broader socioeconomic development external to the food system (CrossSector). However, for the purposes of assessment of hidden costs in the transformations of agrifood systems in India, we use a selection of single transformation pathways, addressing the findings from the SOFA 2023 report, along with three policy measure bundles and the final package FSDP that integrates each of these measures.

The FSDP scenario represents a range of interventions such as healthy dietary changes, sustainable consumption patterns, and targeted reductions in prevalence of malnutrition like increased intake of fruits and nuts, leguminous crops, reduced food waste and loss, sustainable agriculture and biodiversity protection measures including nitrogen efficiency, water conservation through environmental flow protection, land conservation and nitrogen use efficiency in agriculture. Under this scenario, the population would reach 1.60 billion by 2050 from 1.39 billion in 2020 based on the underlying SSP1 parameterization assumption. The urban population is expected to increase to 1.01 billion by 2050 from 0.52 billion in 2020. The climate change scenario is based on RCP 1.9 which limits global warming to below 1.5ºC, aligning with the Paris Agreement. Crop yields increase 0.3% between 2020 and 2050 in this scenario to meet future demand given the transition to SSP1 trajectory of population and GDP. Afforestation targets remain the same as BAU, whereby India's commitments to NDC targets are implemented. A liberalized trade regime that encourages trading patterns through comparative advantage is implemented in the model. This encourages reduction in exports of land- and water-intensive cereal crops in India and increases India's imports of these crops. An expansion of protected areas through the conservation of biodiversity hotspots and intact forest landscapes, in addition to WDPA restrictions, are implemented in this scenario.

These two scenarios – BAU and FSDP – differ in several other indicators. Details of the scenarios selected for this analysis are presented in Table 6-5.

Table 6-5: *FSEC scenario description*

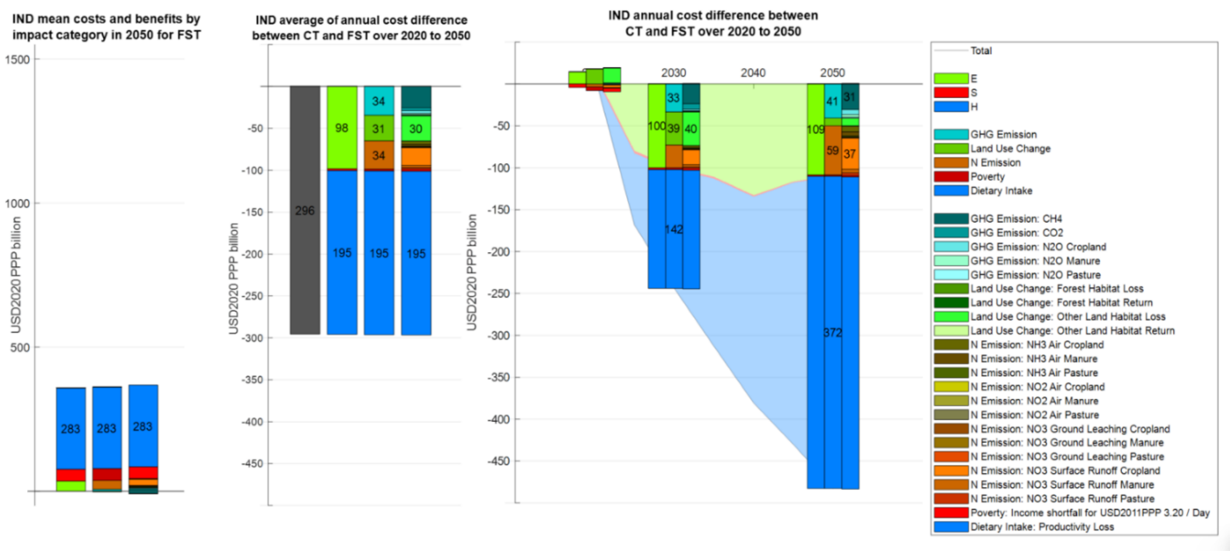
Scenario parameter(s)	BAU/CT	FSDP/FST
Population	SSP2 (1.65 million people by 2050)	SSP1 (1.6 million people by 2050).
Food demand	SSP2 trends	Transition to healthy diets recommended by the EAT-Lancet Commission.
Obesity reduction	No target	Calorie intake is reduced to achieve a reduction of overweight and obesity by 50% relative to BAU. Calorie reduction is BMI-class, country, age-group and sex specific. The intake of half of the people overweight or obese (BMI>25 for adults, BMI +/-1STD for children) is reduced to intake recommended for a healthy BMI (20-25, BMI <+1STD). Relative dietary composition is not affected. The intake of people in other BMI classes is not affected.
Malnutrition reduction	No target	Calorie intake is increased in line with a complete eradication of underweight until 2050 for all age cohorts and sex classes
Trade	Self-sufficiency imposed	Relative cost-competitiveness, in terms of production and trade margins and tariffs are implemented. Liberalized trade is implemented, increased share for crops from 20 to 30% for crops, and from 10 to 20% for livestock and secondary products.
Agricultural wages	No change	A global minimum wage increases wages in the lower income countries. The minimum wage scenario increases wages to at least 3 USD 2005 Market Exchange Rate per hour by 2050.
Agricultural labor	No change – 96 million people employed in agriculture by 2050	Labor supply is increased to reach labor: capital ratio of 80:20 – results in 89 million people employed in agricultural labor by 2050.
Afforestation	Afforestation targets follow NDC/NPI policies to ensure 33 Mha afforestation by 2030 and no change thereafter	Afforestation targets follow NDC/NPI policies to ensure 33 Mha afforestation by 2030 and no change thereafter.
Biodiversity conservation	The protected area based on World Database on Protected Areas (WDPA) is included	The Biodiversity Intactness Index (BII) in each biome of each world region cannot decrease after 2020.
Livestock productivity	No change	Improved future livestock productivity developments and related changes in feed baskets towards more concentrate feeds, using SSP1 instead of SSP2 parametrization (Weindl et al., 2017).
Crop productivity	Endogenous changes in crop yield to meet food demand	Endogenous changes in crop yield to meet food demand.
CH_4 emissions from agricultural production	44 CO_2e by 2050	28 CO_2e by 2050 (reduction by ~50%).
Water withdrawal for agricultural production	40% reduction in water withdrawals by 2050 due to improved irrigation efficiency	Change in crop production and water efficiency results in 35% reduction in water withdrawals by 2050, as compared to 2020.

Use of bioplastics	No change	Of the projected total plastic demand (675 Mt by 2050 (OECD, 2022)), 30% is replaced by bioplastics. Bioplastics require bio-materials as substrates.
Share of food expenditure out of total expenditure	Reduces from 0.06 in 2020 to 0.03 by 2050 (reduction of 50%)	Same.
Timber cities	No target	Wood is used as construction material for cities. We assume that 50% of new urban dwellers (after 2020) are housed in buildings made of engineered wood (Mishra et al., 2022) to replace carbon-intensive steel and concrete housing construction. This increases future timber demand by 2212 million m^3 (compared to 2020) and thereby increases the need for increased harvesting from forests.
Landscape habitats	No target	Conserving at least 20% permanent semi-natural habitats at the landscape level (e.g., for pollination, pest control, soil protection). Semi-natural habitats include forest, non-forest and grassland habitats that can maintain and restore native species diversity.
Nitrogen surplus	Increased nitrogen surplus from land and manure management from 22 Mt Nr/yr in 2020 to 31 Mt Nr/yr by 2050	Reduction in nitrogen surplus from land and manure management by ~45% by 2050 (17 Mt Nr/yr). This occurs through technical measures such as improved land manure application, spreader maintenance, improved agronomic practices, sub-optimal fertilizer applications, nitrification inhibitors and fertilizer free zones.

6.3.3 What are the most influential factors to reduce the hidden costs by 2030 and 2050?

The breakdown of India's annual hidden cost reduction under FSDP in 2020 PPP dollars in 2020, 2030 and 2050 is shown in Figure 6-4. Large average hidden cost reductions under FSDP over 2020–2050 come from a reduction in burden of disease from dietary change, CH_4 emission reductions from livestock and rice production, avoided cropland expansion, and mitigating NO_3^- run-off from cropland (middle panel). These values also include uncertainty in production costs emerging from GHG and reactive nitrogen emissions as well as the loss of habitat from land use changes. Details of the uncertainty estimates are presented in (Lord 2023b). Reduction in nitrogen pollution contributes more during the later period (right panel). Environmental hidden cost reduction and productivity losses from the burden of disease arising out of food consumption have an approximately equal contribution to hidden cost reduction over the period 2020–2050 (middle panel). The reduction in environmental hidden costs stabilizes while the avoided productivity losses from burden of disease increase over the period (right panel). Residual hidden costs by 2050 under the FSDP trajectory are predominately productivity losses from food consumption, income shortfall from the USD 3.20/day (2011 PPP) poverty line, and nitrogen pollution (left panel). There is little difference between BAU and FSDP in income shortfall from the USD 3.20/day (2011 PPP) poverty line and this is because poverty reduction is driven by economic growth of all sectors in SSP2 and not in the implementation of FSDP measure.

Figure 6-4: *Change in hidden costs across cost heads and scenarios BAU and FSDP between 2020 and 2050*



Note: Breakdown of India annual hidden cost reduction under FST in 2020 USD PPP in 2020, 2030 and 2050, developed and presented in (Lord 2023b).

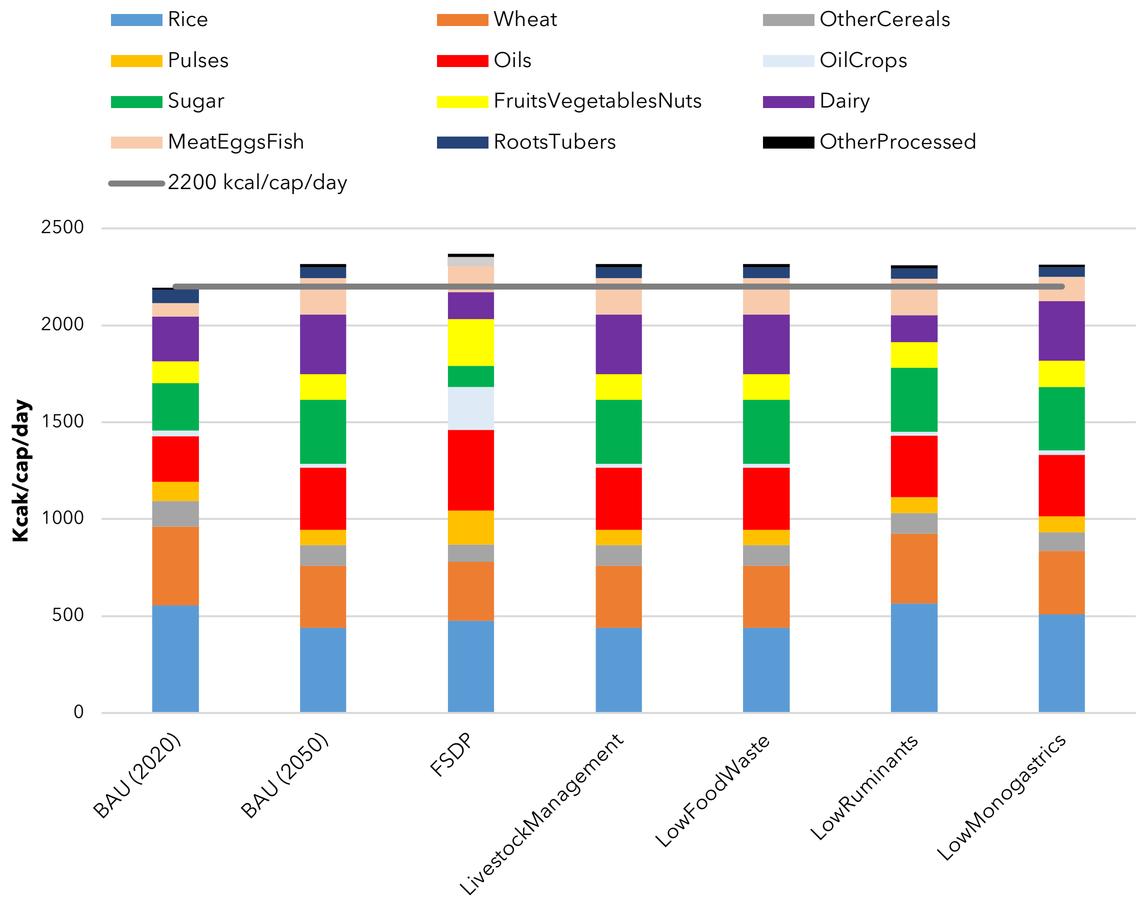
To further elaborate on the drivers of change for the key indicators, we undertook a decomposition analysis with eight single scenarios (scenarios in which only one parameter is changed in comparison to the BAU). We compared each of these between the BAU and FSDP and present detailed results on the ways in which these reductions can be obtained.

Food demand

Since dietary patterns are major drivers of hidden costs in India, we find that changing food demand through the transition to EAT-Lancet diets in the FSDP scenario increases the overall calorie intake to 2,369 kcal per capita per day by 2050. Although the difference in calorie intake between BAU and FSDP is not high, major differences reflect in the change in consumption of key food groups such as rice and wheat, sugars and dairy and meat products. There is no difference in overall calorie intake across single scenarios as food demand is the main driver of the model. In our modeling scenario, it is the change of consumption of various food groups that causes a difference in hidden costs (Figure 6-5).

Transitioning to healthy diets recommended by the EAT-*Lancet* Commission in the FSDP scenario results in overall higher calorie intake than the BAU and the changes in consumption of cereals, legumes and dairy, resulting in the lowering of hidden costs. The EAT-*Lancet* is typically a low meat scenario, but largely applicable for regions with historically high levels of meat consumption. For regions such as India, where meat consumption is historically lower, there is a need to maintain normal levels of consumption. Recent statistics from India's food consumption surveys reveal a remarkable increase in protein sources such as dairy, eggs, and meat over the past two decades. The recommendations for India in our analysis points towards a reduction in cereal crops, milk and sugars and increase in consumption of fruits and vegetables. Other dietary scenarios that target consumption of specific food groups, such as ruminants and monogastrics, also reduce the intake of those food groups, with the calorie gap compensated by cereals. As a result, the consumption of cereals is higher than the FSDP and BAU scenario in 2050 in these scenarios. This is also a contributing factor in the lower hidden costs in the FSDP scenario as compared to BAU.

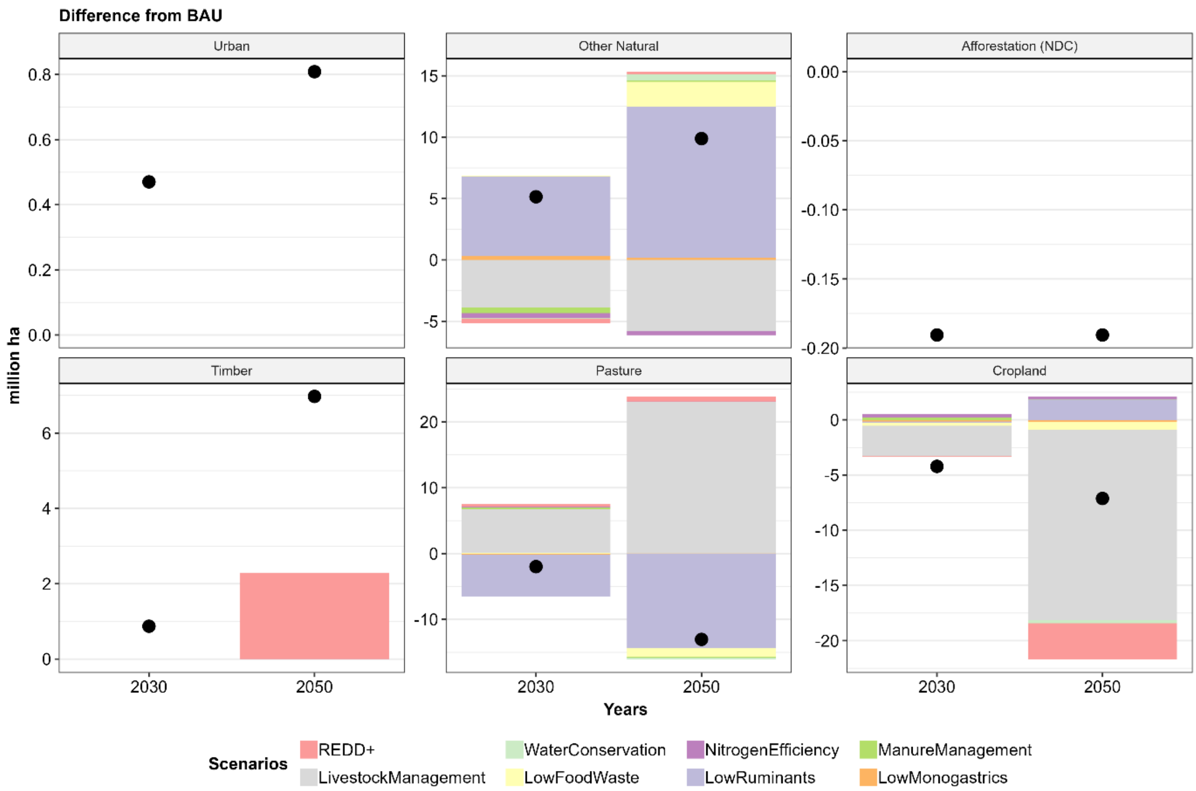
Figure 6-5: *Consumption of various food groups across dietary scenarios between 2020 and 2050*



Land use change

We present the change across land use types across scenarios by 2030 and 2050, in comparison to BAU in Figure 6-6. The livestock management scenario results in greater changes in cropland and pasturelands by 2050 due to improvement in feed efficiency that results in lower requirement of pasture lands and lower requirements of croplands (for production of fodder crops). A large reduction is observed in pasturelands between the two scenarios, with a reduction of approximately 57% between the BAU and FSDP scenarios by 2050. On the other hand, slight increases in timber and urban lands are observed in the FSDP as compared to BAU scenario. We observe no change in afforestation across scenarios from BAU due to the assumption of India's NDC targets even in the BAU scenario.

Figure 6-6: *Changes in land use types across scenarios by 2050, in comparison to BAU*

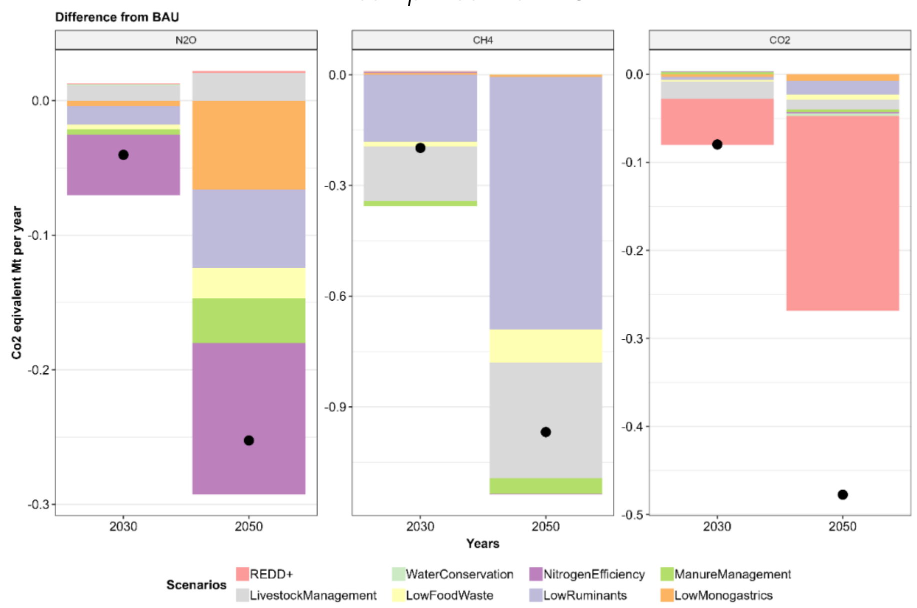


Note: Black dot refers to the FSDP scenario

GHG emissions

We present the trajectory of three types of GHG emissions (N_2O, CH_4 and CO_2) from agricultural activities and land use change in Figure 6-7. We find that the highest reductions in N_2O emissions are brought by the nitrogen efficiency scenario that targets the nitrogen application to soils through advanced practices such as improved manure management. Additionally, mitigation pricing is implemented in this scenario through improved soil nutrient uptake efficiency, resulting in an overall reduction of N_2O emissions by 31% in 2050, as compared to BAU. Similarly, methane emissions are lowest in the low ruminants scenario (reduction by 56%) by 2050 because of the reduced demand for ruminant meat consumption in this scenario, as compared to the BAU. We observe the largest reductions in CO_2 emissions in the REDD+ scenario (200%). This comes from the implementation of carbon prices, which disincentivize deforestation and promote the regeneration of natural vegetation.

Figure 6-7: *Difference in emissions of GHG gases (CH_4, N_2O and CO_2) across scenarios in 2050, in comparison to BAU*

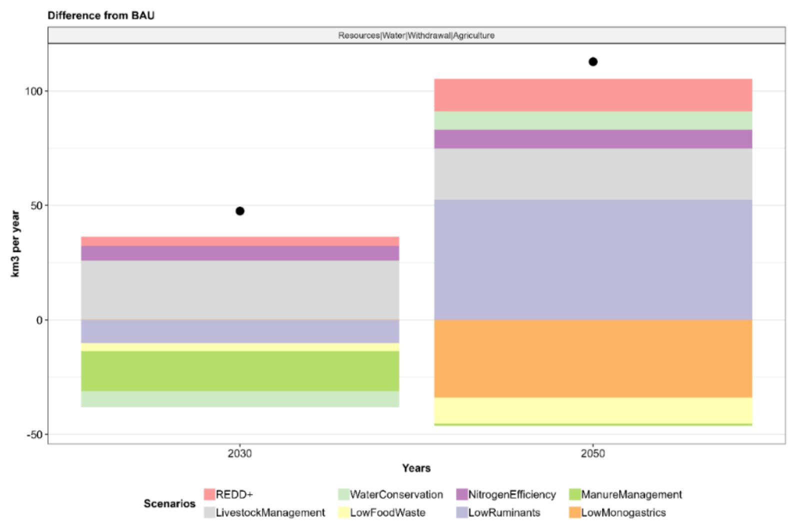


Note: Emission values are converted in CO_2 equivalent for all gases. Black dot represents the FSDP scenario. Emission values represent a result of agricultural activities and land use change.

Water withdrawals

We observe significant trade-offs in blue water use for agricultural withdrawals across the scenarios (Figure 6-8). While benefits of the FSDP measures are observed across all indicators, we find higher withdrawals of blue water in the FSDP scenario (423 billion cubic meters by 2050) and a 36% increase than BAU by 2050. Single scenarios that contribute most to this higher rate of water withdrawals are low ruminants and livestock management, which are 17% and 7% higher than BAU in 2050, respectively.

Figure 6-8: *Change in agricultural water withdrawals across scenarios by 2050, in comparison to BAU*

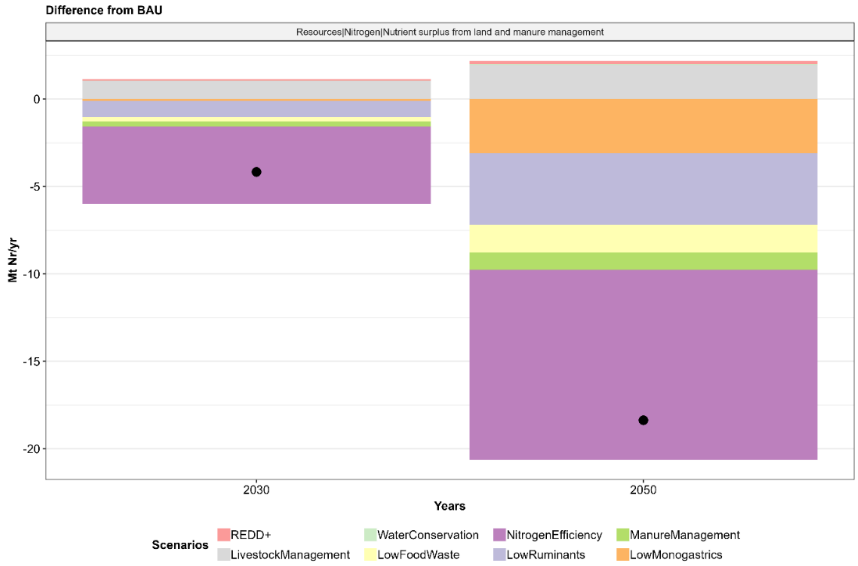


Note: Black dot represents the FSDP scenario.

Nitrogen surplus from land and manure management

We find significant effects of policy measures that target nitrogen usage (nitrogen efficiency scenario) and manure management (manure management scenario) on nitrogen surplus from land and manure (Figure 6-9). Combined in the FSDP, these scenarios result in a reduction of nitrogen surplus on land and manure by 61% in the FSDP scenario by 2050, as compared to the BAU. This occurs due to an increase in nitrogen efficiency uptake rates through technical measures such as improved land manure application, spreaders, but also to meet mitigation rates under nitrogen budgets.

Figure 6-9: *Changes in nitrogen surplus from agriculture and land use change, across scenarios by 2050, in comparison to BAU*



6.3.4 Entry points for action and foreseen implementation challenges

We highlight key entry points for action towards reduction of hidden costs in India as below:

Food security and health

- Strengthen the National Food Security and Nutrition Mission 2021 to promote diverse food group consumption, emphasizing legumes, fruits, vegetables, and nuts, to improve health outcomes.
- Encourage policies to reduce rice consumption and shift towards alternative grains to lower CH4 emissions, considering regional diet preferences.
- Address high disease burden by reducing consumption of sugars and oils (processed foods) in both urban and rural areas to improve labor productivity and mitigate hidden food system costs.

Agriculture

- Reform agricultural incentives by reducing subsidies on nitrogenous fertilizers to curb adverse soil deposition and nitrate run-off impacts.
- Government investments in assessment of soil and water health in croplands. This will help determine the degrading conditions and provide evidence to farmers to nudge towards reducing the excessive nitrogen application.
- Reform energy subsidies aimed at efficient water use to discourage over-extraction of groundwater, thus reducing hidden costs associated with water usage in India.

Land use

- Implement policies to restrict land use changes from forests to cropland and pastures to preserve forest cover.
- Focus on no-deforestation policies and promote afforestation initiatives to minimize forest loss and maintain ecological balance.
- The AFOLU sector in India is a net carbon sink and therefore adequate efforts need to be made to reduce the CH4 and N2O emissions from land use and land use change.

These recommendations highlight specific actions needed in the areas of nutrition, agriculture, and land use to address hidden costs and improve the sustainability of India's food system and environment. Each recommendation targets key factors contributing to hidden costs and offers practical strategies for policy action. Notably, shifts in dietary patterns, curbing nitrogen emissions from cropland surface run-off, and managing land use change emerge as pivotal factors for cost reduction in India. Over the 2020–2050 period, substantial reductions in hidden costs are evident, attributed to factors such as decreased burden of disease from food consumption, methane emission cuts from livestock and rice, avoided cropland expansion, and effective mitigation of nitrate run-off from cropland. The study highlights the balanced contribution of factors like production cost uncertainty, greenhouse gas emission reduction, habitat reservation, and nitrogen pollution reduction to the overall reduction in hidden costs.

6.4 References

Béné, C., Fanzo, J., Achicanoy, H.A., Lundy, M., 2022. Can economic development be a driver of food system sustainability? Empirical evidence from a global sustainability index and a multi-country analysis. PLOS Sustainability and Transformation 1, e0000013. https://doi.org/10.1371/journal.pstr.0000013

Bodirsky, B., Beier, F., Humpenoder, F., Singh, V., 2023. A food system transformation can enhance global health, environmental conditions and social inclusion. preprint. https://doi.org/10.21203/rs.3.rs-2928708/v1

Bukhman, G., Mocumbi, A.O., Atun, R., et al., 2020. The Lancet NCDI Poverty Commission: bridging a gap in universal health coverage for the poorest billion. The Lancet 396, 991–1044. https://doi.org/10.1016/S0140-6736(20)31907-3

Dietrich, J.P., Bodirsky, B.L., et al., 2019. MAgPIE 4–a modular open-source framework for modeling global land systems. Geoscientific Model Development 12, 1299–1317.

FAO, 2023. The State of Food and Agriculture 2023: Revealing the true cost of food to transform agrifood systems. FAO, Rome. https://doi.org/10.4060/cc7724en

FAO, 2024. The State of Food and Agriculture 2024: Value driven transformation of agrifood systems. Rome.

ICMR, PHFI, IHME, 2017. India: Health of the Nation's States. Indian Council for Medical Research. Jha, C.K., Singh, V., Stevanović, M., Dietrich, J.P., Mosnier, A., Weindl, I., Popp, A., Traub, G.S.,

Gautam, S., BN, K., Akashanand, Roy, A., Banandur P.S., Anniappan, A., 2023. Assessment of resources for physical activity and understanding people's perception and practices regarding physical activity in an Indian city. BCM Public Health 23, 1969

Ghosh, R.K., Lotze-Campen, H., 2022. The role of food and land use systems in achieving India's sustainability targets. Environ. Res. Lett. 17, 074022. https://doi.org/10.1088/1748-9326/ac788a

Lord, S., 2023a. Hidden costs of agrifood systems and recent trends from 2016 to 2023 – Background paper for The State of Food and Agriculture 2023 (FAO Agricultural Development Economics Technical Study No. 13). Food and Agricultural Organization, Rome.

Lord, S., 2023b. Regional analysis of hidden costs of the Food System Economic Commission current trends and food system transformation pathways to 2050: India Key Figures.

MoEFCC, 2021. India. Third Biennial update report to the United Nations Framework Convention on Climate Change. Government of India.

MoSPI, G. of I., 2024. Household Consumption Expenditure Survey:2022-23 Factsheet. Nguyen, H., 2018. Sustainable food systems: Concept and framework. FAO, Rome, Italy.

Niti Aayog, 2023. MULTIDIMENSIONAL POVERTY IN INDIA SINCE 2005-06 (No. A Discussion Paper). UNDP, New Delhi, India.

NSSO, 2023. Key Employment Unemployment Indicators (Jan 2023-Dec 2023). Ministry of Statistics and Program Implementation, Government of India, New Delhi, India.

O'Neill, B.C., Kriegler, E., Ebi, et al., 2017. The roads ahead: Narratives for shared socioeconomic pathways describing world futures in the 21st century. 166 Global Environmental Change 42, 169–180. https://doi.org/10.1016/j.gloenvcha.2015.01.004

Popp, A., Calvin, K., Fujimori, S., Havlik, P., Humpenoder, F., Stehfest, E., Bodirsky, B.L., 2017. Landuse features in the shared socio-economic pathways. Global Environmental Change 42, 331–345.

Raghunathan, K., Headey, D., Herforth, A., 2021. Affordability of nutritious diets in rural India. Food Policy 99, 101982. https://doi.org/10.1016/j.foodpol.2020.101982

Riahi, K., Van Vuuren, D.P., Kriegler, E., et al., 2017. The shared socioeconomic pathways and their energy, land use, and greenhouse gas emissions implications: an overview. Global environmental change 42, 153–168.

Sharma, M., Kishore, A., Roy, D., Joshi, K., 2020. A comparison of the Indian Diet with the EAT-Lancet Reference Diet. BMC Public Health. https://doi.org/10.21203/rs.2.19833/v2

Singh, V., Das, P., Stevanovic, M., et al., 2024. An Inclusive agri-food systems transformation pathway for India. https://doi.org/10.21203/rs.3.rs-4767324/v1

Singh, V., Stevanovic, M., Jha, C.K., Beier, F., Ghosh, R.K., Lotze-Campen, H., Popp, A., 2023. Assessing policy options for sustainable water use in India's cereal production system - IOPscience. Environmental Research Letters. https://doi.org/10.1088/1748-9326/acf9b6

Solanki, S., Chakraborty, M., Gupta, S., K.P., R., Dutt, R., Mehta, 2022. GHG Platform India 200-5-2018 National Esimates - 2005-18 Series.
van Vuuren, D.P., Edmonds, J., Kainuma, M., et al., 2011. The representative concentration pathways: an overview. Climatic Change 109, 5–31. https://doi.org/10.1007/s10584-011-0148-z
Von Bloh, W., Schaphoff, S., et al., 2018. Implementing the nitrogen cycle into the dynamic global vegetation, hydrology, and crop growth model LPJmL (version 5.0). Geoscientific Model Development 11, 2789–2812.
World Bank, 2024. Poverty and Inequality Platform.

Chapter 7. UK

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Highlights

- Working with stakeholders from government, business, civil society and academia, we examined the hidden costs of the UK's agrifood system. We identified detailed opportunities for using UK-specific data and methods to improve the accuracy and relevance of the global SOFA 2023 analysis of hidden costs, especially by using UK land use data.

- Using UK data from the FABLE calculator together with a model that emulates the global burden of disease study, we estimate the hidden costs of the UK's agrifood system as 180 billion 2020 PPP dollars in 2023, mainly from unhealthy diets. This is lower than the 2023 SOFA estimate of 255 billion 2020 PPP dollars, partly because obesity cannot yet be modeled using FABLE.

- The hidden costs are over 5% of the UK's 2020 GDP – similar to the total value added from the whole agrifood sector. This hidden deficit accumulates over time, posing economic risk to the UK, especially through the health impacts that weaken human capital.

- The model estimates that a more sustainable pathway could reduce total hidden costs by around 16% (23 billion 2020 PPP dollars per year) – worth around 686 billion 2020 PPP dollars over the next 30 years.
- The main factor for delivering these benefits is shifting to a healthier and more plant-based diet, with lower consumption of ultra-processed food. Coupled with reduced food waste and increased agricultural productivity, this frees up land for restoration to forest and other ecosystems. Together with the use of agroecological farming methods, this delivers benefits for carbon sequestration and biodiversity while also reducing nitrogen pollution. However, this could result in trade-offs with employment in the agriculture sector which need to be carefully addressed.

- More research is needed on how to encourage consumers to shift to healthier diets. Education is not enough, when consumers live in an environment full of unhealthy food choices, so strong government leadership and a holistic set of policies is needed. Some suggestions are provided in the final section of this chapter.

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7.1 Introduction

The 2023 SOFA report highlighted the hidden environmental, social and health costs of the global agrifood system, including the UK (FAO, 2023). For the UK case study in this chapter, we engaged with stakeholders to examine the hidden costs for the UK in more detail, comparing the SOFA 2023 analysis with national data and identifying opportunities to tailor the methodology and data to suit the UK context. We also worked with stakeholders to identify potential factors for change and entry points for actions to reduce the hidden costs, using the FABLE model (Mosnier et al., 2020).

The UK is approximately 70% farmland: 20% cropland, 5% temporary grass, 25% permanent grass and 20% rough grazing (including mountain and moorland areas). There has been little change in these proportions over the last 40 years apart from some loss of rough grazing and increase in permanent grassland (Defra, 2023).

There are large regional differences: Scotland and Wales have a much higher proportion of rough upland sheep grazing, while Northern Ireland focuses on dairy farming. Cropland covers 32% of England, but just 4% of Wales (based on UKCEH, 2020). Some of the most fertile cropland is on drained fenland in the east of England, where the fine peat soils produce very high GHG emissions as well as being vulnerable to wind erosion. Much of this area is also at risk of flooding due to sea-level rise.

Farming employs 1.5% of the UK workforce, but this ranges from 1.2% in England to over 6% in Northern Ireland (Defra, 2019). Many small farms are struggling financially: 20% of farms make a loss from farming activities, and many rely heavily on subsidies and diversified income sources such as tourism. The average age of farmers is 55, and many suffer from poor mental health. Most food is sold via a few large supermarket chains, who set low prices for farm produce and often change or cancel orders at short notice, leading to high levels of food waste.

The UK imports 50% of all food, up from 30% a few decades ago. Yields are relatively high but have stagnated. Consumption of agrochemicals has decreased in recent years with precision farming, but only 3% of UK production is organic. Following Brexit, England is shifting towards a new agri-environment scheme (ELMS), with basic payments being phased out. As a result, support for some basic agroecological methods such as cover crops is gradually improving. There are similar moves in Wales and Scotland.

Health is a major issue in the UK, with very high levels of obesity as well as growing food poverty, though malnutrition is very rare. The national Eatwell dietary recommendations imply that consumption of animal products should decrease to achieve a healthy diet, and the Net Zero plans also depend on dietary change, but over the last decade this goal has not received government support (the position of the new government in June 2024 is not yet clear).

Stakeholder input and feedback was used to inform the analysis in this chapter. Stakeholders already involved with the FABLE model and pathway development (specifically, those who attended the last online UK FABLE workshop in September 2023), additional food system experts identified in consultation with the Food Systems team at ECI, and economists identified by FAO, were invited to provide feedback. We held two one-hour online workshops as some people could not attend the first one, and one additional session with a single expert. Most of the feedback was obtained directly in the workshops, but we also provided an online survey for people to provide further feedback after the workshops. Only a small number of people responded, but these included a range of highly relevant stakeholders and experts across business (4), research (2), civil society (1), and public administrations (5).

7.2 SOFA 2023 hidden costs analysis

7.2.1 Main cost components and explanations of the results

For the UK, the total hidden costs of the agrifood system are estimated at 255 billion 2020 PPP dollars. Of this, the most important hidden cost is identified as the burden of disease from unhealthy diets (Figure 7-1), which steadily increased from 2016 to reach an estimated 201 billion 2020 PPP dollars in 2020 (Figure 7-2). For comparison, the World Obesity Atlas also reports very high prevalence of obesity in the UK (33% for adults, increasing by 2% per year) but estimated costs are lower at USD 61 billion (World Obesity Atlas 2024).

Figure 7-1: *Hidden economic costs of the UK agrifood system in 2020, from SOFA 2023 (billion 2020 PPP dollars)*

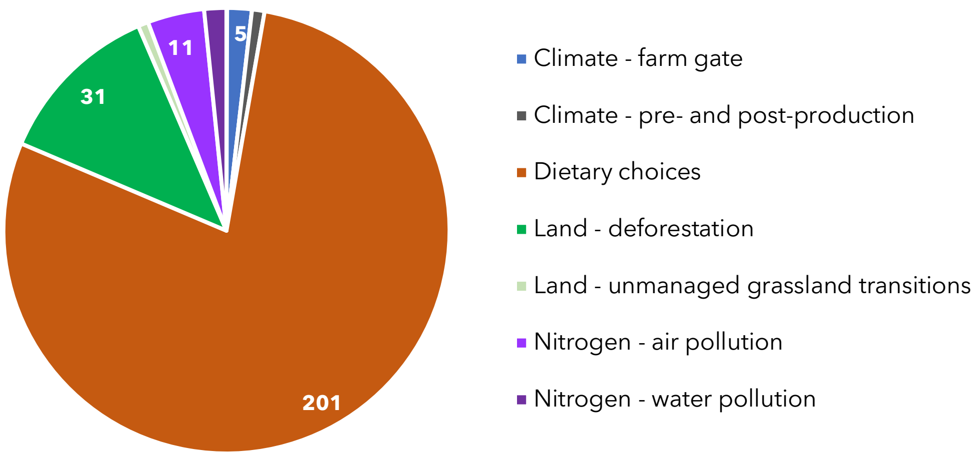
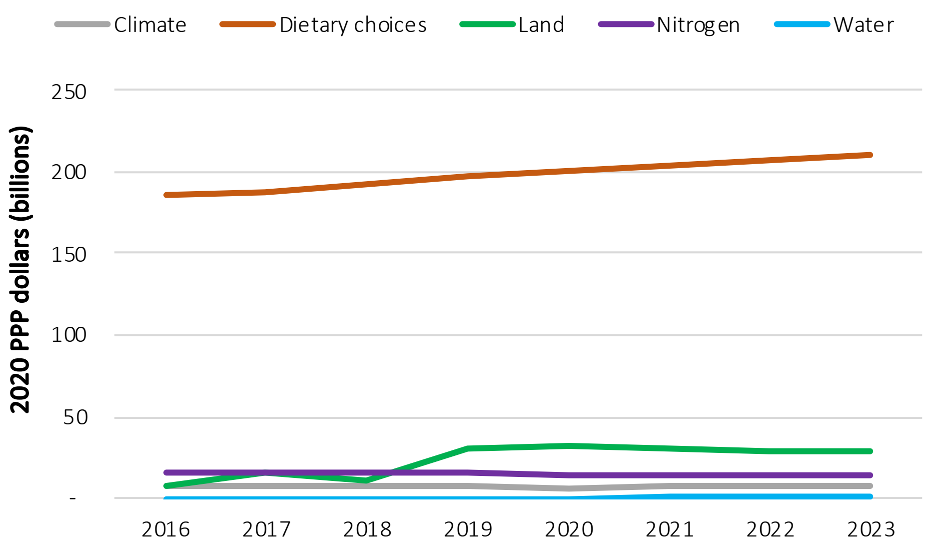
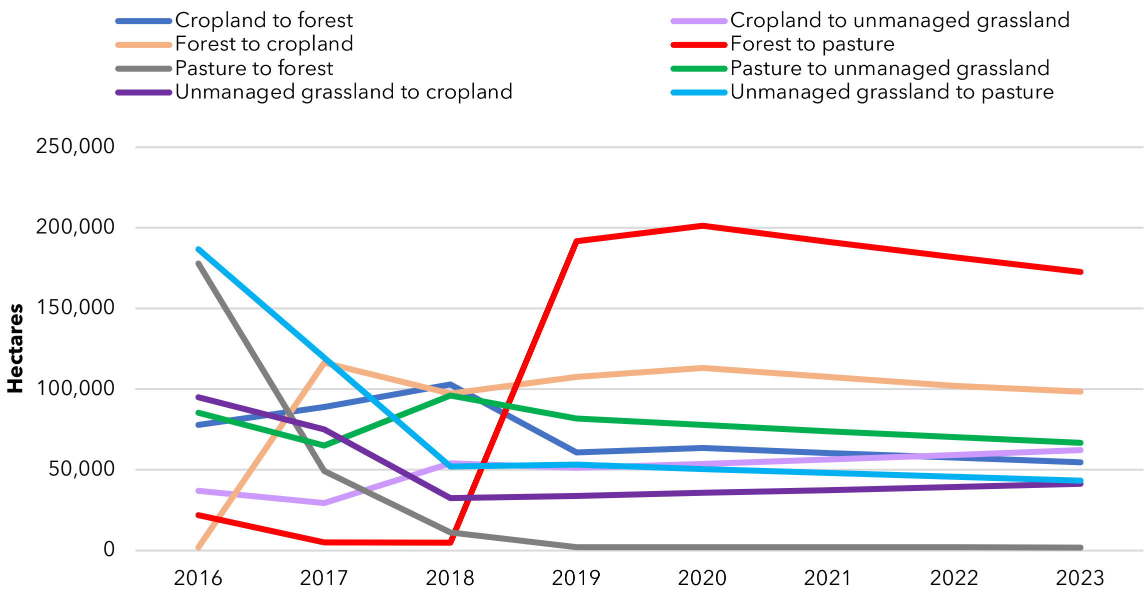


Figure 7-2*: Trends in main hidden economic cost estimates for the UK from SOFA 2023 (billions 2020 PPP dollars)*



The next highest cost was land use change, estimated as 32 billion 2020 PPP dollars. The data appears to fluctuate considerably between 2016 and 2019 and does not match known patterns in the UK (Figure 7-3). The smoothing of the trend after 2020 is because these figures were extrapolated.

Figure 7-3: *Apparent large fluctuations in HILDA+ land use data for the UK from 2016 to 2020*



The third highest cost is 15 billion 2020 PPP dollars from nitrogen emissions, of which 11 billion is from air pollution and the rest from water pollution. This has been gradually declining since 2016, in line with the decreased use of nitrogen fertilizers in the UK due to the uptake of precision farming techniques. This is followed by 7 billion 2020 PPP dollars from greenhouse gas emissions, of which 5 billion is from farm emissions and the rest from pre- and post-production. This relatively low cost may reflect the limited scope of the climate impacts included (agricultural productivity losses and human health impacts from heat stress). Also, the SOFA 2023 methodology paper states that new modeling has increased the social cost of GHGs by 60% since the 2023 analysis. For comparison, a UK study using higher unit costs estimated total costs of GHG emissions from food production as £9.7 bn (16 billion 2020 PPP dollars), more than double the SOFA estimate (Fitzgerald et al., 2019).

The estimated cost of water use is much smaller, at 77 million 2020 PPP dollars, reflecting the relatively low use of irrigation in the UK. Poverty impacts are also low, at 32 million 2020 PPP dollars, reflecting UK laws on the minimum wage – though there are still cases of illegal work where these laws are flouted. The cost of undernourishment is shown as being zero, in line with FAOSTAT figures, although food insecurity is growing in the UK (see below).

7.2.2 Comparison of SPIQ data with national datasets

Impact quantities

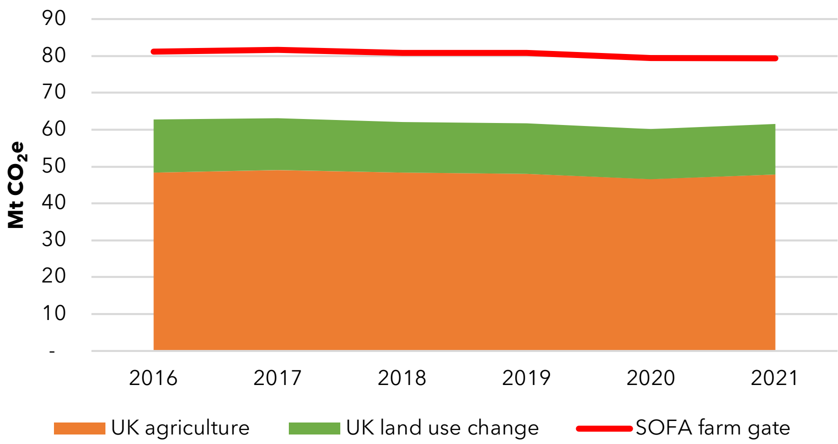
Land use transitions are taken from the HILDA+ dataset – a satellite-derived annual global dataset at 1km resolution. This indicates surprising results for the UK, with an apparent large conversion of unmanaged grassland to pasture at the same time as conversion of pasture to forest in 2016 and

2017. This then gives way to the opposite trend, with apparent large-scale conversion of forest to pasture from 2019 onwards, and forest to cropland from 2017 onwards (Figure 7-3). None of these trends are supported by UK-level datasets such as the UK Greenhouse Gas Inventory (Brown et al, 2022), which shows much smaller transitions (Table 7-1). Also, not all land use transitions are included in the FAO analysis. Those excluded include cropland to pasture, pasture to cropland, forest to unmanaged grassland, unmanaged grassland to forest, and any transitions involving settlements. This could be because some of these are not thought to create significant externalities, and some are not related to the food and farming sector.

As noted by the SOFA 2023 methodology paper, the HILDA+ dataset is prone to misclassification. For the UK, we suspect that commercial forestry plantations that have been felled ready for replanting are classed incorrectly as transitions from forest to cropland or pasture, leading to a high apparent deforestation rate that does not match reality. Also, land use in the UK is highly fragmented and this is very likely to lead to inaccuracies at the HILDA+ resolution of 1km grid cells.

GHG emissions do not match the UK Greenhouse Gas Inventory (GHGI). Farm gate emissions should correspond to UK GHGI agriculture emissions plus land use change involving cropland and grassland but are significantly higher (Figure 7-4). While methane emissions in SOFA 2023 are very similar to those in the UK GHG Inventory, CO_2 and N_2O emissions are higher (Table 7-2). GHG emissions from UK land use change are zero in FAOSTAT, which only considers biomass burning (almost zero in the UK) and net forest conversion (positive in the UK), not transitions from cropland to pasture, or from unmanaged grassland to improved pasture or cropland. However, exclusion of these UK GHGI emissions would be expected to reduce the SOFA estimates, not increase them. The UK added a large new source of emissions from drained organic soils (i.e., peat) to their inventory in 2022, but this also does not explain the difference because it has already been incorporated into FAOSTAT and the SOFA analysis (under farm gate emissions, not land use change). The differences must be due primarily to the use of the Tier 1 methodology for FAOSTAT compared to the more detailed Tier 2 methodology for the UK GHGI. It was not possible to provide a UK-specific estimate for GHG emissions from pre- and post-processing because these figures are not shown in the UK GHGI.

Figure 7-4: *Comparison between SOFA 2023 farm gate GHGs for the UK and the UK GHG Inventory*



Note: All figures have been converted to Mt CO_2e using AR5 conversion factors (28 for CH_4 and 285 for N_2O).

***Table 7-1**: Comparison of HILDA+ land use change for the UK and UK Greenhouse Gas Inventory (hectares), for categories and years that are comparable (UK GHGI does not include a category for unmanaged grassland and currently only goes up to 2020)*

Year	HILDA+ cropland to forest	UK GHGI cropland to forest	HILDA+ forest to cropland	UK GHGI forest to cropland	HILDA+ forest to pasture	UK GHGI forest to grassland	HILDA+ pasture to forest	UK GHGI grassland to forest	HILDA+ cropland to unmanaged grassland	HILDA+ pasture to unmanaged grassland	HILDA+ unmanaged grassland to cropland	HILDA+ unmanaged grassland to pasture
2016	77,964	700	1,999	0	21,841	1,500	177,910	5400	36,871	85,622	95,036	186,762
2017	89,100	600	116,389	0	5,073	1,400	49,437	7600	29,467	65,094	75,130	119,529
2018	102,966	1,900	97,445	0	5,090	1,200	11,184	10200	53,900	96,114	32,522	52,135
2019	60,680	1,100	107,746	0	191,743	1,100	2,268	11900	51,241	81,956	34,002	53,212
2020	63,714	700	113,133	0	201,330	1,400	2,155	11800	53,803	77,858	35,702	50,551
2021	60,528		107,477		191,264		2,047		56,494	73,965	37,487	48,024
2022	57,502		102,103		181,700		1,945		59,318	70,267	39,362	45,622
2023	54,719		98,571		172,615		1,847		62,284	66,754	41,330	43,341

Table 7-2*: Comparison of GHG emissions in FAO SOFA and the UK Greenhouse Gas Inventory (all figures converted into $MtCO_2e$)*

		2016	2017	2018	2019	2020	2021
UK GHGI							
Agriculture	CO_2	6	6	6	6	6	6
Agriculture	CH_4	28	29	28	28	28	28
Agriculture	N_2O	14	14	14	14	13	14
	All GHGs	**48**	**49**	**48**	**48**	**47**	**48**
Land use change	CO_2	11	10	10	10	10	10
Land use change	CH_4	3	3	3	3	3	3
Land use change	N_2O	0	0	0	0	0	0
	All GHGs	**14**	**14**	**14**	**14**	**14**	**14**
Ag + LUC	CO_2	17	17	16	16	16	16
Ag + LUC	CH_4	32	32	31	31	31	31
Ag + LUC	N_2O	14	15	14	15	14	14
	All GHGs	**63**	**63**	**62**	**62**	**60**	**62**
SOFA							
Farm gate	CO_2	28	29	28	29	29	29
Farm gate	CH_4	31	31	31	31	30	30
Farm gate	N_2O	21	22	21	22	21	21
	All GHGs	**81**	**82**	**81**	**81**	**79**	**79**

Nitrogen emissions to air in the form of ammonia (NH_3) in SOFA were taken from the EDGAR database. These estimates appear to be larger than the estimates of NH_3 emissions to air from agriculture in the National Atmospheric Emissions Inventory (NAEI) but smaller than those in the UK Environmental Accounts (the "Blue Book", Office for National Statistics, 2021). Note that the UK data in the Blue Book is presented in SO_2 equivalents (i.e., acidification potential compared to SO_2). To convert it to tonnes, we divided by the acidification potential of NH_3 (1.88) and NOx (0.7) (Table 7-3). We are still investigating the reasons for these differences.

For hidden costs of nitrate pollution in water, we have not yet found a suitable source of UK data for comparison.

Table 7-3*: Comparison of results of SOFA 2023 and UK Blue Book for ammonia (NH_3) and nitrogen oxides (NOx) emissions into air from agriculture*

NH_3	SOFA	Blue Book Air emissions Ammonia (NH_3)- Agriculture, forestry and fishing		Ratio blue book to SOFA	NAEI	Ratio NAEI to SOFA
	kt NH_3	kt SO_2 equivalent	kt NH_3		kt NH_3	
2016	**449**	459	**244**	54%	**239**	53%
2017	**456**	463	**246**	54%	**241**	53%
2018	**452**	457	**243**	54%	**238**	53%
2019	**452**	455	**242**	54%	**237**	52%
2020	**427**	435	**231**	54%	**227**	53%
2021	**406**	443	**236**	58%	**231**	57%

NOx	SOFA	Blue Book Air emissions Ammonia (NOx)-Agriculture, forestry and fishing		Ratio blue book to SOFA	NAEI	Ratio NAEI to SOFA
	kg NOx	kt SO_2 equivalent	kt NOx		kt NOx as NO_2	
2016	**46**	51	**73**	157%	**28**	60%
2017	**47**	51	**73**	155%	**29**	61%
2018	**47**	49	**70**	150%	**29**	61%
2019	**47**	44	**63**	135%	**29**	61%
2020	**44**	41	**59**	133%	**27**	61%
2021	**42**	42	**60**	143%	**27**	66%

Dietary choice impacts are estimated as DALYs, from analysis of the Global Burden of Disease study. We have not found any additional UK datasets to compare against the SOFA analysis. However, there have been several other studies of diet-related health costs. These include a study that compiled estimates from various literature sources to estimate diet-related healthcare costs of GBP 45 billion in 2015, although this includes GBP 17 billion for treating malnutrition (mainly for elderly people) which may be related to other illness or ageing, not the agrifood system (Fitzgerald et al., 2019). This is the healthcare cost only, but it can be used to derive an estimate of lost productivity using the observation that productivity losses are about twice as high as direct healthcare costs in Europe (Candari et al., 2017). Converting to 2020 PPP would give an estimate of around 93 billion PPP dollars in lost productivity if malnutrition costs are excluded, or 150 billion if they are included, both lower than the SOFA estimate of 201 billion 2020 PPP dollars. The study also estimated further healthcare costs from food production (nitrates in drinking water, antibiotic resistance, food poisoning and pesticides) as a further GBP 10.5 billion, equating to 35 billion 2020 PPP dollars in productivity losses. A 2023 study estimated the cost of lost productivity as GBP 150 billion (188 billion 2020 PPP dollars) per year, equivalent to 7% of GDP, with another GBP 70 billion (88 billion 2020 PPP) from lost tax income, benefits payments and costs to the NHS (Oxera, 2023). This is the total cost for all health problems, only a portion of which will be diet-related, so again this is lower than the SOFA estimate. An older study estimated costs of GBP 11 billion in 2007 ($13.7 billion 2020 PPP dollars) for poor diet and obesity combined (Scarborough et al., 2011); this figure was incorporated into the Fitzgerald et al. study along with other health impact categories.

For **undernourishment** the costs are shown as being zero, in line with official figures, but food insecurity is a growing problem in the UK. Surveys estimate that 6% of households were food insecure in 2021/22 (UK Government, 2023) and 15% in January 2024 (Food Foundation, 2023). A rough estimate in 2015 put the cost of treating malnutrition in the UK at GBP 17 billion per year, mainly amongst the elderly, although it is not clear how much of this could be attributed to the agri food system (Fitzgerald et al. 2019).

National data for the other impact quantities (nitrate pollution in water, water consumption for agriculture, and poverty among agricultural workers) have not been found.

Review of unit costs to GDP

For **GHG emissions**, the GHG costs only include limited impacts: agricultural productivity losses and productivity losses associated with heat stress in workers. We would expect the true costs of GHG emissions to be higher if other climate impacts could be taken into account, such as impacts on infrastructure and loss of life from storm damage and flooding, as well as climate feedback and tipping points. Also, climate change costs using standard economic methods assume "optimal abatement", where governments always make the right decisions about how much to mitigate climate emissions. In 2019, a UK study noted that estimates of the social cost of carbon varied from USD 21 to USD 900 per tonne: using an estimate of USD 220 per tonne they estimated total costs of GHG emissions from food production as GBP 9.7 billion, or 16 billion 2020 PPP dollars, more than double the SOFA estimate of 7 billion 2020 PPP dollars (Fitzgerald et al. 2019). The SOFA costs are also seven times lower than the carbon value used by the UK government, which uses a mitigation cost approach (i.e., the cost of reaching the UK's climate targets), with a value of GBP 241 (USD 369) in 2020. If these costs were applied, the hidden cost of GHGs would increase from 7 billion 2020 PPP dollars to around 48 billion 2020 PPP dollars. Use of mitigation costs is not in line with the overall SPIQ approach used for SOFA 2023, but UK stakeholders thought it would be more appropriate for a UK national analysis.

For **land use transitions**, ecosystem service costs were taken from the ESVD database. This contains over 4,800 individual estimates of value per hectare per year of ecosystem services across 92 countries, 15 biomes, and 23 ecosystem services. "Outliers" with particularly high values were removed. Remaining values were aggregated into HDI tiers (low development, medium development, high development, and very high development) and into groups of provisioning, regulating, and cultural services, with the total value for ecosystem services in an HDI tier being the sum of the provisioning, regulating, and cultural ecosystem services. Efforts were made to exclude carbon sequestration to avoid double counting with the GHG emissions category. Nevertheless, the aggregation leads to very high uncertainty: typically, the interquartile range of ecosystem service costs is greater than an order of magnitude. As noted by the SOFA 2023 methodology report, accuracy could be improved by using a mechanistic model such as Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) for country-specific analysis in future. For comparison, a 2019 UK study estimated the costs of biodiversity and ecosystem services losses and soil degradation from food production as GBP 11.4 billion, or 19 billion 2020 PPP dollars, less than the SOFA estimate of 30 billion 2020 PPP dollars (Fitzgerald et al. 2019), but the SOFA estimate is affected by the incorrect estimate of deforestation rates.

The results for the **Agricultural externalities impact ratio** (AEIR) are very high for the UK – over USD 2 of external costs are generated for every USD 1 of agricultural value added. This is attributed to intensive use of agricultural inputs, particularly nitrogen emissions, for sectors that provide a low percentage of total GDP. Although nitrogen fertilizer use is on a declining trend in the UK due to the adoption of precision agriculture, and is not believed to be excessive, there is a high marginal health cost because there are high population densities with very high labor productivity. Also, the agricultural sector provides a low percentage of total GDP, so costs per unit output are high. The AEIR is also affected by the discrepancies in the HILDA+ land use dataset (see above), which could be improved by using UK-specific data.

For the other cost factors, we have not found relevant UK-specific values for comparison.

7.2.3 Recommendations for tailored country hidden costs analysis

Replacing global database with national datasets

Land cover: The UKCEH Land Cover Map offers a more accurate land cover dataset for the UK. However, there are currently inconsistencies in the methodology between different years in the historic data, so some interpolation would be required to smooth these differences. Future annual updates are expected to use a consistent methodology.

Greenhouse gases: UK-specific figures from the Greenhouse Gas Inventory could be used, following further investigation of the differences listed above. However, there are also opportunities to improve the UK GHGI methodology. Stakeholders recommended that UK carbon prices should be used instead of the SPIQ global average social costs.

Nitrogen: UK-specific figures from the Agricultural Ammonia Inventory and nitrogen emission accounts could be used, following further investigation of the differences listed above. Also, the Environment Agency are about to publish a National Groundwater Nitrogen Inventory and Heat Maps for England, aiming to quantify the nitrogen loading onto land or at risk of being lost (via leaching) to groundwater in 2020 from all sectors with data available.

Environmental data: Other data could be checked against the UK Natural Capital Accounts.

Undernourishment: While undernourishment is officially reported as zero, survey data compiled by the Food Foundation can be used to indicate the prevalence of food insecurity, and difficulty of accessing healthy food, which disproportionately affects disadvantaged households. This cannot substitute directly for the undernourishment indicator, as the unit costs would be different, but it could be used for a parallel indicator more appropriate for the UK.

Worker poverty: There are relatively few people employed in primary production in the UK – far more are employed post-farm gate, where low wage jobs are a major problem (dark kitchens, etc.). There are over 4 million jobs in catering and delivery (not clear if delivery is in scope), and more in processing. Data on earnings is here; farm incomes in England here and see also the Farm Business Survey.

Health: The UK has its own DALY costs which could be used instead of the SOFA ones.

Other data sources: The Economist Impact Unit (EIU) produces a Food sustainability index for every few years – a basket of many indicators including food security, waste and environmental impacts. The Global Farm Metric was mentioned by stakeholders, though this is developed to collect data at farm level.

Need for additional research or in-depth analysis

In addition to using more UK-specific data as listed above, more research could improve some aspects of the analysis.

Ecosystem service impacts of land use change: Use of aggregated data from the ESVD has high uncertainty. It would be better to perform a tailored analysis for the UK using national data on the cost of ecosystem service loss from agri-food activities, including cultural ecosystem services.

Nitrate pollution: In countries with strict regulations on drinking water quality, the cost of water pollution is largely realized as additional water treatment costs rather than health costs. It is not clear whether this is a hidden cost.

Undernourishment: Investigate alternative assessment methods that are more relevant for the UK, based on food insecurity and lack of micronutrients.

Food security / insecurity: Current government statistics for food imports are based on the cost of imported food, not calories or nutrition. Can food security be quantified in terms of nutrition? The FABLE model already does this to some extent.

Worker poverty: For the UK and other developed countries it would be more relevant to consider the difference between incomes and the "living wage" (not the government minimum wage), though this would make it harder to compare across countries. Worker poverty should include consideration of disempowerment, inequality, and mental health and well-being impacts, and the resulting costs. Farmer incomes are often below the living wage, but it is difficult to analyze because farm incomes are closely tied in with the provision of a house, vehicles, etc., which are all part of the business.

Offshoring of impacts: Stakeholders emphasized the need to consider the impacts of imported food that occur in food exporting countries. The FABLE model includes imports and exports, and this could potentially be used to allocate impacts to food-importing countries, although specific export-import country links are not identified.

Trade-offs: The University of Oxford produced a trade-off visualizer (www.susfans.eu) illustrating trade-offs across health, environmental, social and economic outcomes.

The use of PPP to determine the value of health impacts enables the costs to be expressed as a percentage of national GDP. However, it is important to clarify that this does not imply that lives and health are worth less in lower income countries.

Hidden benefits / positive externalities

Examples of hidden benefits could include:

- attractive landscapes for recreation and tourism
- local food culture
- thriving rural communities
- food security
- jobs (are these hidden benefits or market benefits?)

There are several overlapping difficulties in assessing these benefits.

1. Some, such as food culture and landscapes, are highly subjective. There is a difference between intensive agriculture and less intensive landscapes with more hedgerows, trees, and wildlife. Some people might also prefer non-agricultural landscapes such as woodlands and wilderness areas.
2. Some are dependent on context. For example, aesthetic benefits are only delivered where land is accessible and attractive. Similarly, nitrogen fertilizer has a positive impact on under-nourishment (by increasing yields), but over-supply of nitrogen causes hidden costs to the environment and health.
3. Some depend on the counterfactual. When compared with a pre-agricultural landscape, the outcomes for biodiversity and some ecosystem services (e.g., carbon sequestration, flood protection, erosion protection, pollination, clean air and water) would be expected to be consistently negative whilst the outcome for food production and employment would always be positive. However, if comparing a more sustainable food production system to conventional unsustainable production, many environmental outcomes would be positive, while food production could be either positive, negative or neutral depending on the context (e.g., there could be a loss of yield from shifting to less intensive production, but there could also be an increase in long-term yield if climate resilience and overall sustainability is enhanced).
4. Some are delivered only by a subset of the agrifood system. For example, there can be high benefits for well-being, mental health, self-esteem, training and employment from community food production on city farms or community orchards, especially from therapy schemes for disadvantaged people, but this only applies to a tiny subset of the agrifood system.

Boundaries of the study

Stakeholders identified additional aspects of the agrifood system that are not included in the SOFA 2023 analysis. While it may not be possible to monetize these, it could be possible to quantify them in non-monetary terms, or report on them qualitatively. For example, numbers of deaths can be estimated and presented alongside the monetary results for productivity loss so that decision-makers can take into account the loss of life and associated impacts on well-being and society.

Land use: biodiversity impacts, alongside ecosystem service impacts.

Land degradation: e.g., soil erosion, compaction, desertification, salinization. Fitzgerald et al. (2019) assessed soil loss. Farmers are being encouraged to do more soil testing, which will help to build the evidence base.

Water scarcity: loss of water for drinking and sanitation, and the environmental cost of water over-abstraction for biodiversity, such as streams and wetlands drying out, or salinization of groundwater due to over-abstraction in coastal areas.

Phosphate pollution: however, this arises largely from sewage rather than agricultural run-off.

Pesticide use: this is included in terms of GHG impacts, but it also has human health and environmental impacts, including adverse impacts on pollination and biological pest control. Fitzgerald et al. (2019) assessed health impacts.

Anti-microbial resistance: the methodology of Fitzgerald et al. (2019) could be a starting point.

Fishing and environmental impacts on oceans.

Impacts of overexploitation (e.g. over-fishing or over-grazing).

Competition from biofuels.

Animal welfare and plant health: animal welfare has an economic cost, e.g., productivity losses from animals with mastitis.

The Food Ethics Council (FEC) has produced metrics that could be useful.

Cost of death, medical treatment and informal care: for some impacts such as air pollution, only productivity impacts are currently included, not deaths. Treatment costs are deemed to be visible economic exchanges within the economy and, therefore, not considered a hidden cost, or else estimates of the inefficiency in GDP terms associated with these direct costs are not available. However, these treatment costs are not explicitly allocated to the agrifood system in decision-making and therefore they should be included in the analysis, to avoid underestimating total costs.

Modern slavery is a big issue in the agrifood sector but by its very nature is hard to quantify, as it is illegal and therefore hidden and not reported.

Food culture: place-specific food is lost in industrialized food systems.

Environmental costs of packaging and plastic: pollution, litter, and microplastics (including from degrading polytunnels).

7.3 Evolution of hidden costs by 2030 and 2050

7.3.1 FABLE Calculator for the UK

The UK FABLE model includes several adaptations to reflect the country context.

1. The UK model distinguishes intensively farmed ("improved") pasture from rough grassland which is extensively (lightly) grazed at a lower stocking density. This is important in the UK, where there are large areas of rough grassland in some regions, because improved grassland (which is typically fertilized and sown with 2–3 high productivity grasses) is more productive but also has lower biodiversity value and higher environmental impacts.
2. We distinguish between semi-natural woodland (mainly broadleaf in the UK) and commercial plantations (mainly non-native conifers with little biodiversity value).
3. The UK model includes hedgerows and agroforestry (silvopasture and silvoarable).
4. The UK model includes greenhouse gas emissions from inter-farmland transitions (cropland to pasture, pasture to extensive grassland, etc.).
5. We also model emissions from degraded peatland, and how these emissions can be reduced by restoring the peat (e.g., by re-wetting drained peat bogs).

7.3.2 Scenathon 2023 pathways assumptions

All pathways assume medium levels of economic growth and population growth, in line with the global SSP2 scenario, which matches recent trends. In the absence of better information, they also assume no change in imports and exports, although this could change as the long-term impacts of Brexit emerge.

Current Trends pathway

The Current Trends (CT) pathway aims to continue policies that are already in place. We assume no dietary change and no change in biofuel demand. We also do not model any change in irrigation, which is not widely used in the UK, although this could change in future. There is no change in crop productivity from current levels (which might be optimistic, as yield losses are expected due to climate change). We assume an 18% increase in milk productivity by 2050 – this is half of current trends, because we assume that the scope for continued increases in yield at the same relatively high rate could be limited by biological constraints and concerns over animal welfare. We assume that the percentage of the herd on extensive grassland decreases by 7%, from 26% to 24%, reflecting the current trend towards intensification.

Tree planting continues at current rates, around 13,000 hectares per year, falling short of government targets. We assume a continuation of the current split of 50:50 broadleaf woodland to conifer plantations.

There is no constraint on agricultural expansion, as there are no laws preventing this in the UK, although in practice the agricultural area is not currently expanding. Protected areas are assumed to stay at the current level of 27%. Note that in the UK, it is estimated that only 3% to 6% of UK land cover is effectively protected and managed for nature – the rest of the 27% consists of National Parks and similar designations which focus on landscape appearance and recreation rather than biodiversity, and designated sites that are in poor condition.

Urban expansion causes pressure on land use. In CT we assume a continuation of current trends, leading to a 50% increase in urban areas by 2050 (from 8% to 12% of UK land cover).

Sustainable pathways

The National Commitments (NC) pathway is based mainly on the Balanced Net Zero (BNZ) pathway developed by the Climate Change Committee (CCC), the government's advisors, to inform the Sixth Carbon Budget (6CB). This is considered by the CCC to be the most widely acceptable pathway for meeting the UK's Net Zero target for 2050 as mandated by the UK Climate Change Act. We have included additional measures that aim to deliver on the government's biodiversity commitment (30% of land protected for nature by 2030), although policies are not yet in place to do this.

The Global Sustainability (GS) pathway is largely based on a set of more ambitious (high level) options presented by the CCC in their Sixth Carbon Budget report as a means of delivering net zero faster. This pathway also includes stronger actions towards the 30x30 nature recovery target. In addition to assuming no constraint on agricultural expansion, the GS pathway assumes no deforestation, to ensure that biodiversity targets are met. We assume that urban expansion is reduced by half due to policies to promote more compact development patterns, limiting the increase in urban area to 25%.

In line with the CCC pathways, we assume that tree planting increases to 36,700 hectares per year for NC and 50,000 hectares per year for GS. In the GS pathway we assume 80% of the woodland created is semi-natural, in line with the need to deliver biodiversity goals. Protected areas are assumed to increase from 27% to 30% in NC and GS, to meet the 30x30 biodiversity target.

The CCC pathways include highly ambitious agricultural productivity assumptions, with a 34% increase in crop productivity. In GS, milk productivity increases by 27%, compared to 18% in CT and NC. For meat production from sheep and cattle grazing, we assume an increase of 10% in NC and GS due to increased stocking density, with a similar increase for chicken production.

In CT, we assume that the percentage of the herd on extensive grassland decreases by 7%, from 26% to 24%, reflecting the current trend towards intensification. In NC we assume the % of herd on extensive grassland decreases by 38%, from 26% to 16%, as the herd shifts to more intensive grazing in line with the CCC BNZ pathway. However, in GS we assume a 14% increase to 30% of the herd on extensive grassland due to the focus on biodiversity targets. We also model the uptake of agroecological options in the NC and GS pathways: increased use of cover crops and uptake of agroforestry and hedgerows. Again, we use more ambitious assumptions for GS than for NC, in view of the need to meet biodiversity targets.

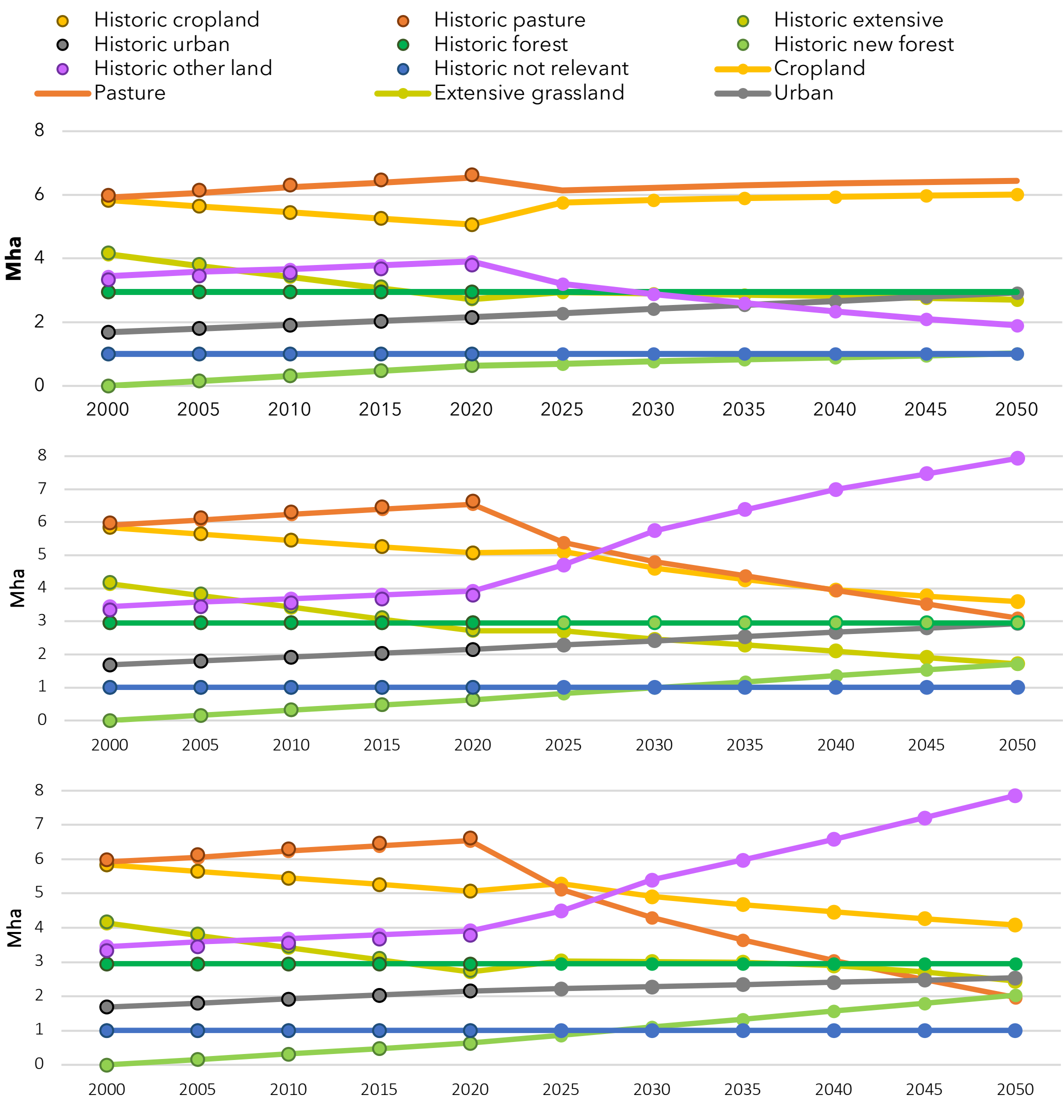
Dietary change is a key component of the CCC pathways. We assume no change for CT, but for NC we assume a 20% cut in meat and dairy by 2030, rising to 35% by 2050 for meat only, to be replaced with plant-based foods (from the BNZ pathway). For GS we use the CCC high ambition assumption of a 50% cut in meat and dairy consumption by 2050. This could entail increased use of lab-grown meat and other novel meat substitutes.

Although the CCC has very ambitious targets for the uptake of woody biofuels such as short-rotation coppice, currently the FABLE model only represents crop-based biofuels such as bioethanol from sugar cane. In the absence of good data, we also do not model any change in irrigation, which is not widely used in the UK, although this could change in future.

7.3.3 Results across the three pathways

For the CT pathway, total agricultural area slowly increases to meet the needs of a growing population, and modest amounts of new forest continue to be planted. Together with continued urban expansion, this results in a steady decrease in non-forest natural land. By 2050, afforestation has increased forest area by 11% compared to 2020, but this is outweighed by a 51% decrease in non-forest natural land, leading to a net loss of 14% in total natural land (extensive grassland, all forest, other natural land, and 'not relevant' land which includes coastal habitats, water and rock). This leads to an increase in GHG emissions, as the emissions from loss of non-forest natural land outweigh the sequestration from afforestation. As there is no dietary change, average consumption of calories continues to be 40% above the MDER, with consumption of fat approximately double the maximum recommended value. This is expected to lead to continuing high rates of obesity and other diet-related non-communicable diseases.

Figure 7-5: *Land use under Current Trends (top), National Commitments (middle) and Global Sustainability (bottom)*



Under NC, the combined effects of dietary change, improved productivity and reduced food waste reduce the area of land needed to meet demand for food. Half of all land in the UK is used for grazing livestock or production of livestock feed, so dietary shifts free up a significant amount of land. This allows non-forest natural land ('other land') to double, from 16% to 32% of the UK, while the more ambitious tree planting targets allow forest to increase by 30%. However, extensive grassland declines by 37% due to significant intensification in this pathway. Overall, natural land increases by 37% and land with potential to support biodiversity increases by 28%, from 39% to 54% of the UK (including extensive grassland, semi-natural forest, other natural land, water, coastal habitats and rock). Sequestration from regeneration of natural land and tree growth, as well as reduced livestock emissions due to smaller herd sizes, lead to a 32% decline in GHGs, although the AFOLU sector does not become a net carbon sink. The dietary change scenario does not involve reduced calorie consumption, so calories are still 40% above MDER.

For GS, dietary change is stronger and there is lower urban expansion due to compact development patterns, but this is offset by the shift towards more extensive grazing. Overall, this allows non-forest natural land to double, similar to the NC pathway. Tree planting is higher, leading to a 39% increase in forest area, and extensive grassland declines by 10% as the shift to more extensive grazing is offset by the declining demand for meat. Overall, natural land increases by 45% and land with potential to support biodiversity increases by 38%. This enables greater GHG reductions than for NC, with a decline of 42% by 2050, when the AFOLU sector becomes a net carbon sink absorbing 9 Mt CO_2e per year. As for the other scenarios, overconsumption of calories continues.

7.3.4 What are the most influential factors to reduce the hidden costs by 2030 and 2050?

The key factors for reducing greenhouse gas emissions were dietary change, food waste reduction and crop productivity, with a smaller contribution from agroecological practices. These factors were also projected to play a key role in freeing up land for nature recovery (Figure 7-6) and enabling tree planting. They are also the main factors for reducing nitrogen emissions into air and water, where agroecological practices play a major role (Figure 7-7).

Both the NC and GS pathways reduce the total area of agricultural land required to produce food, and this is predicted to have a negative impact on employment in the agricultural sector (Figure 7-8). This highlights the importance of working with agricultural communities to develop suitable supporting policies, such as enabling them to diversify employment opportunities and increase profit margins.

***Figure 7-6**: Decomposition analysis for the UK FABLE model showing the impact of each scenario parameter on the area of non-forest (other) natural land*

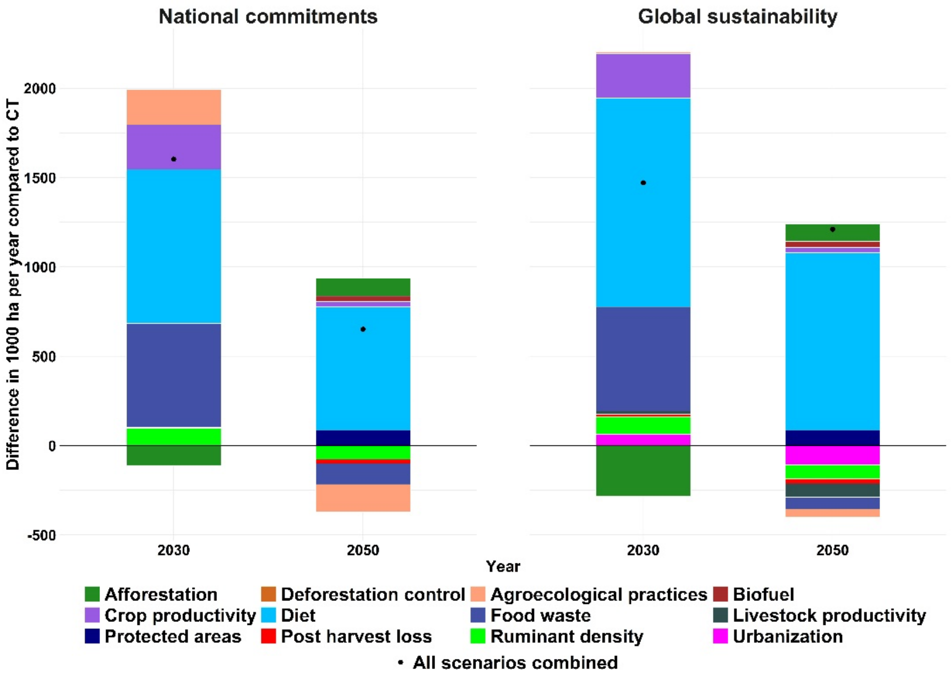


***Figure 7-7**: Decomposition analysis for the UK FABLE model showing the impact of each scenario parameter on nitrogen emissions*

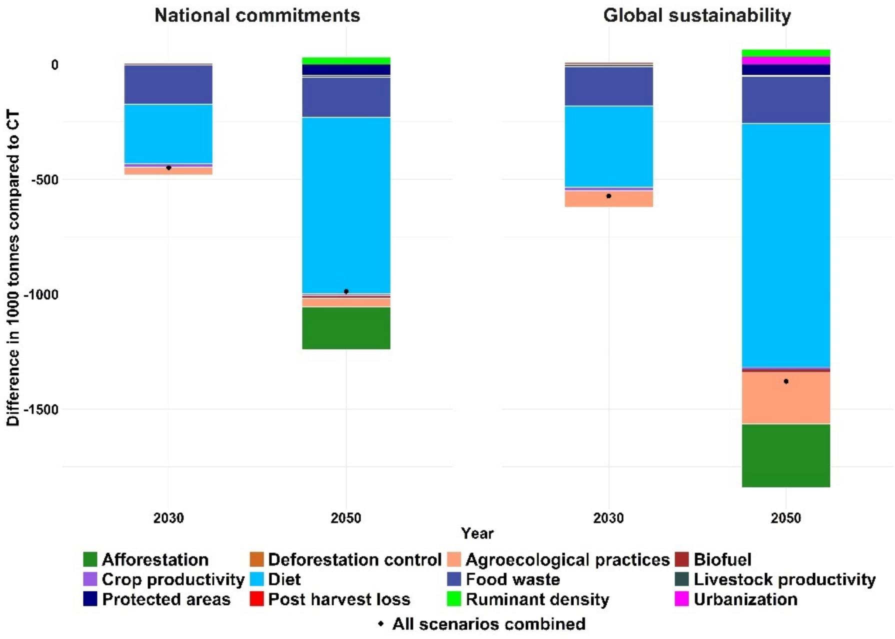
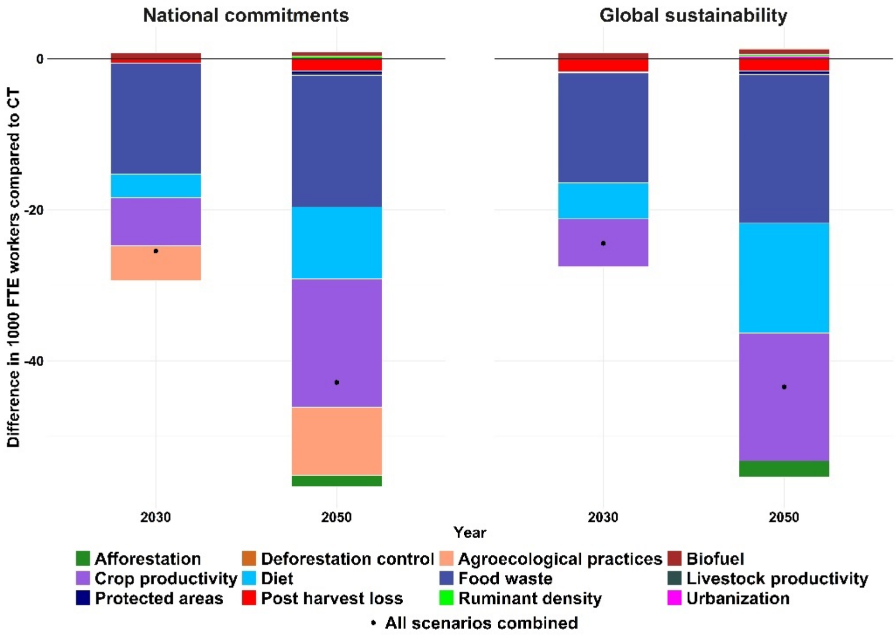


***Figure 7-8:** Decomposition analysis for the UK FABLE model showing the impact of each scenario parameter on farm labor*



7.3.5 Impacts on the agrifood system's hidden costs

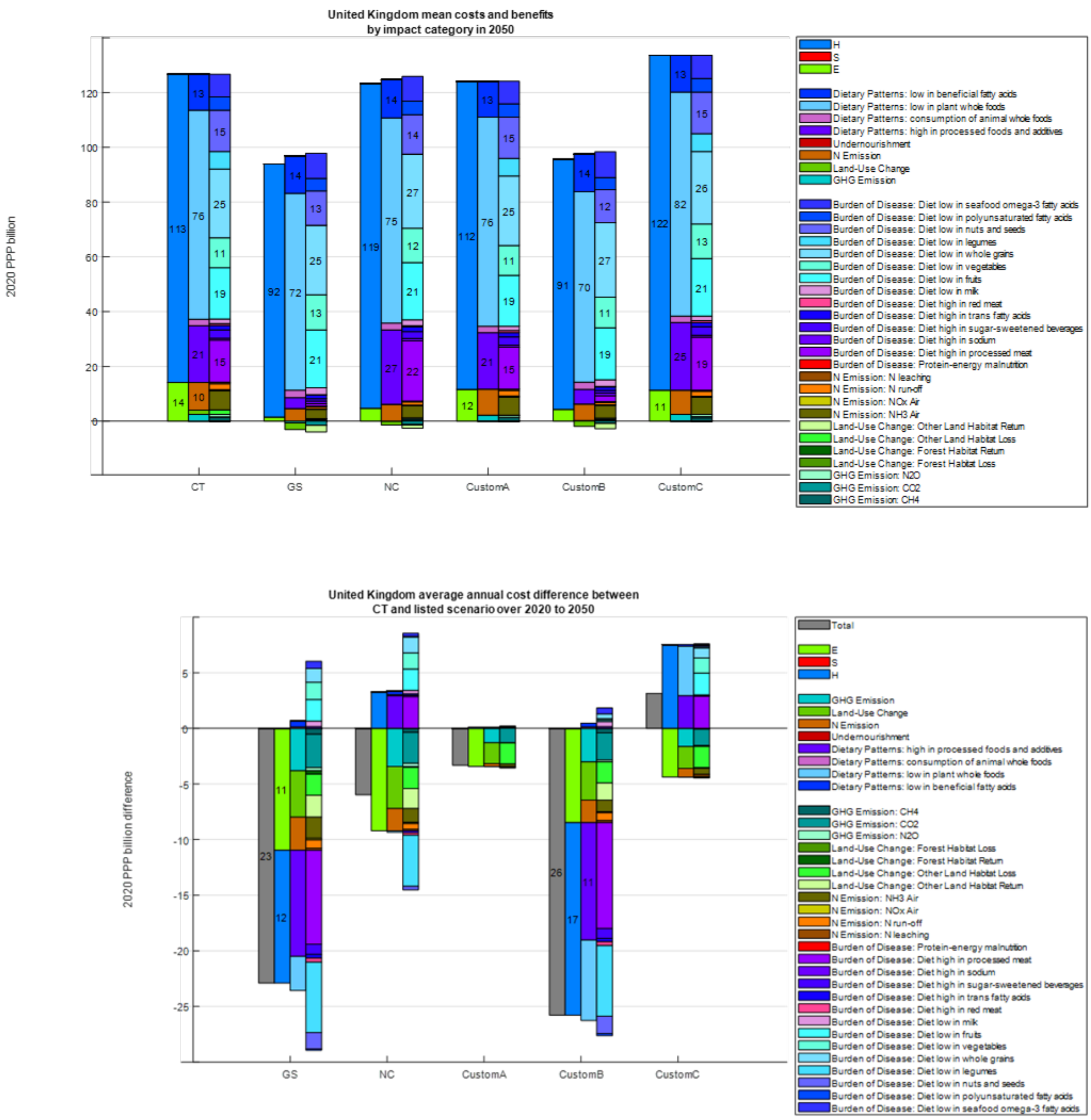
New analysis of hidden costs was carried out based on these FABLE pathways (Lord, 2024). The change in disease burden is estimated in disability-adjusted life years (DALYs) using an emulator of the University of Washington 2017 global burden of disease (GBD). A machine learning approach was used to translate the FABLE diet scenarios into a form suitable for input to the GBD model (see box 7 in FAO 2024). This translation step involved some loss of fidelity compared to the diets, as specified in FABLE. Also, health costs of obesity could not be included in this model.

For the new hidden cost analysis, we made an extra assumption on the future consumption of ultra-processed foods (UPFs) applied to the GS pathway. The UK has one of the highest rates of UPF consumption in the world (Marino et al., 2021), with UPFs forming over 40% of food by weight and over 60% by calories. However, the UK government has not yet set a target to reduce UPF consumption, despite calls by the British Medical Council, although they do agree on action to reduce fat, salt and sugar content of food (UK Parliament, 2023). We assumed an ambitious target for the GS pathway only, of a 50% reduction in UPF consumption by 2050, which would bring UK consumption halfway between current consumption in France and Italy.

The updated analysis estimates current (2023) hidden costs for the UK as 180 billion 2020 PPP dollars, lower than the 2023 SOFA estimate of 255 billion 2020 PPP dollars reported in section 1.2.1 due to the omission of obesity costs. Despite the omission of obesity costs, this is around 5.5% of the UK's 2020 GDP – greater than gross value added from agriculture, forestry, and fishing (~0.6% in 2020) and similar to the total value added from the whole agrifood sector, including manufacturing and retail (~5.5% in 2020) (Defra, 2023). This hidden deficit accumulates over time, posing economic risk to the UK, especially through the health impacts that weaken the human capital which underpins economic activity (Lord, 2024).

The model estimates that the NC pathway could reduce total hidden costs by a relatively modest 4%, around 6 billion 2020 PPP dollars per year. A far greater reduction of around 16% (23 billion 2020 PPP dollars per year) is estimated under the GS pathway (Figure 7-9), worth around 686 billion 2020 PPP dollars over the next 30 years (Lord, 2024). In future work, this potential benefit should be compared to the costs of transition towards a more sustainable agrifood system.

***Figure 7-9**: Breakdown of United Kingdom hidden costs in 2050 (top) and annual average hidden cost reduction under alternative pathways compared to CT (bottom) in 2020 PPP dollars.*



Note: The keys show different levels of detail in the split between cost categories, with the first bars in each group showing the split between health (H), social (S) and environmental (E) costs, the next bars showing a more detailed breakdown, and the third bars the full breakdown.

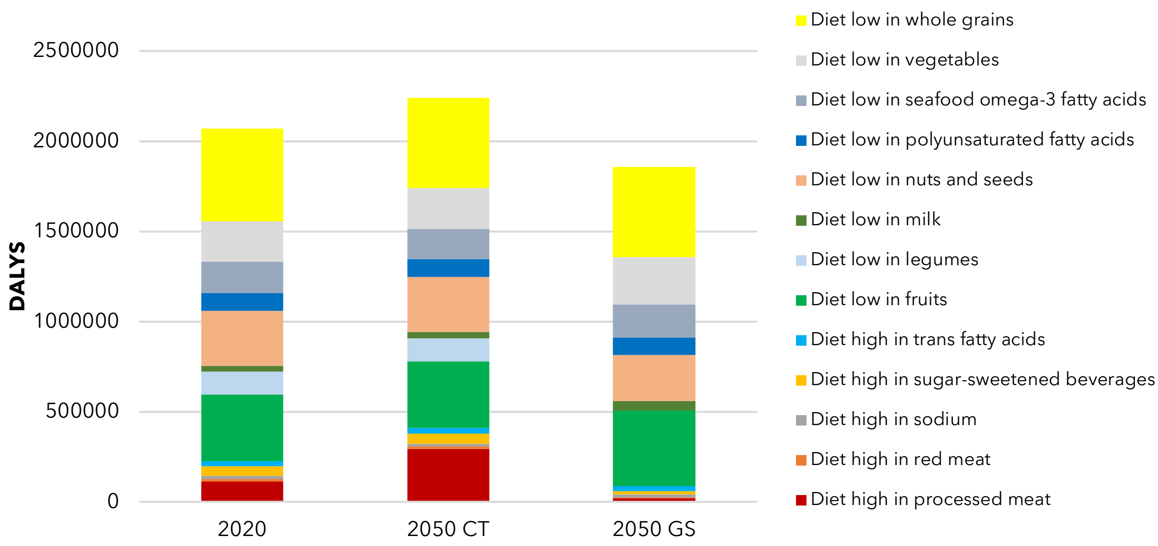
Three key factors have been modeled individually, to illustrate their contributions to the overall reductions in hidden costs: crop productivity (Custom A on Figure 7-9), dietary change (Custom B) and food waste reduction (Custom C). The large reduction in hidden costs for Custom B shows that the main factor for the additional cost reduction in the GS pathway is dietary change, specifically the replacement of meat (especially processed meat) with increased consumption of plant protein (nuts and legumes), together with the large reduction in UPF consumption. The main impact is on human health, as the UK currently has a low intake per capita of legumes and pulses, and the associated hidden costs are eliminated by the large dietary shift towards plant proteins in the GS pathway. This dietary shift results in ~20 billion 2020 PPP dollars of avoided productivity losses from cardiovascular disease and other non-communicable disease outcomes.

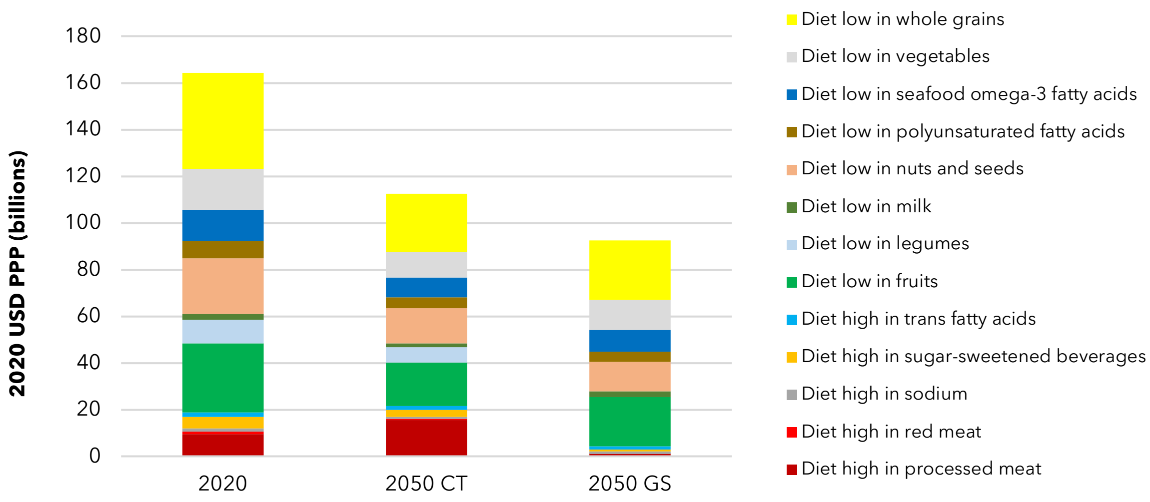
However, the potential benefits of dietary change were limited in our pathways because we did not explicitly specify an increase in fruit and vegetable intake. Indeed, the method used to calculate dietary change for the FABLE Calculator inadvertently resulted in a small decrease in fruit and vegetable consumption for both the NC and GS pathways, which had a surprisingly large impact on the results – due partly to the machine learning approach which associates decreased fruit and vegetable consumption with decreased consumption of all wholefoods. In the GS pathway and the dietary change-only scenario (Custom B), this was outweighed by the assumptions on reduced UPF consumption and increased legume consumption, leading to net health benefits.

However, in the NC pathway the reduced fruit and vegetable consumption outweighed the benefits of increased legume consumption, leading to a net increase in avoided hidden health costs. Despite the improvements under the GS pathway, there is still a large residual economic burden from underconsumption of plant/whole foods in 2050 of ~70–80 billion 2020 PPP dollars (Figure 7-10). This could be reduced through greater emphasis on shifting to a healthy diet rather than just a low-carbon diet.

Unexpected effects also led to an apparent increase in estimated hidden costs under the food-waste-only scenario (Custom C); this could be because the reduction in food waste canceled out the constraints on food production due to lack of land availability that forced a slight decrease in consumption under CT, leading to greater consumption of the UK's current unhealthy diet.

Figure 7-10: *Estimated reductions in DALYs via the GS pathway (top) and associated savings in hidden costs (bottom)*





Dietary shifts also lead to environmental benefits. This is due to the potential for habitat restoration and CO_2 sequestration on former agricultural land that is no longer required for livestock or feed production, each avoiding around 4 billion 2020 PPP dollars of hidden costs, as well as reduced CH_4 and N_2O emissions from livestock, and reductions in nitrogen pollution from manure and feed crop production (avoiding ~3 billion 2020 PPP dollars). Ambitious crop productivity improvements, small increases in protected areas, and large reductions in food waste all resulted in smaller changes.

While these estimates are associated with a large uncertainty, the conclusion that the GS pathway reduces hidden costs by 2050 is robust, although the smaller benefits of the NC pathway are within the uncertainty range. The analysis indicates that UK national commitments, based largely on the CCC Balanced Net Zero pathway, are not sufficient to mitigate the large future debt and economic risk posed by agrifood system hidden costs, but adopting the more ambitious GS pathway could avoid a larger proportion of hidden costs, principally through a shift away from ultra-processed food and towards more plant-based diets. However, both the NC and GS pathways could be substantially improved by incorporating healthier diets with a higher consumption of fruits, vegetables and wholegrains, rather than only focusing on reduction of meat consumption. This will be explored in future FABLE modeling.

7.4 Entry points for action and foreseen implementation challenges

Consultation with stakeholders established a list of potential entry points to reduce hidden costs.

Make hidden costs more visible. This work by the FAO should help to make hidden costs more visible, and this could be effective if there is greater transparency in the agrifood system, e.g., mandatory disclosure of company impacts, and corporate accountability. It is important to make this analysis of hidden costs relevant to people on the street, not just policymakers. For example, rather than presenting it only as the cost to the UK economy it could be presented as the average cost to households per year or week.

Dietary change. In the UK, as the main source of hidden costs is unhealthy diets, dietary change is an important factor. However, reducing the consumption of animal produce will not necessarily lead to a healthier diet unless the whole diet is changed to consume less fat, sugar and total calories. To illustrate this, the FABLE model took the dietary change modeled as part of the Climate Change Committee's scenarios: a 20% reduction in meat and dairy consumption for the NC pathway and a 50% reduction for the GS pathway. However, neither of these diets reduce fat or total calories to the recommended levels for a healthy diet. For comparison, previous FABLE modeling took the Eatwell healthy diet recommended by the UK government (Smith, Harrison et al 2021), which achieves a healthy balanced diet with lower total calories and fat, as well as increasing the ratio of plant-based to animal products. Similarly, the new hidden cost analysis delivered greater health benefits by assuming a large reduction in consumption of ultra-processed food for the GS pathway. This shows the importance of taking a holistic view that aims to maximize multiple benefits, rather than focusing only on climate change.

Stakeholders agreed that as unhealthy diets are the biggest cost, dietary change is important, but we need more research on how to achieve this. Potential factors include a carbon tax on food; a sugar tax; education about healthy food; warning labels on ultra-processed and high sugar food; emphasizing the benefits of a healthy diet; a reduction in the working week so people have more time to cook healthy food; free school meals; and a less unequal society (as disadvantaged groups have less access to healthy food in the UK). Education alone is not enough, as consumers live in an environment full of unhealthy food choices, so it needs to be backed by strong policy in other areas. The Welsh government is working on a dietary-shift systems map which will identify relevant policy instruments and entry points.

Key levers to reduce the hidden costs of the agricultural food system in the UK:

- **Public procurement** of healthy food with lower environmental impacts (e.g., in schools and hospitals).
- **Agri-environment schemes** including ELMS in England and similar schemes emerging in the other UK nations, provided that uptake is significant.
- **Agroecology,** though this can be contentious amongst farmers. Also, there can be a reduction in production for the first few years. Farmers need extra support during that period.
- **Habitat protection.** This not just about creating more protected areas, but also about providing the resources needed to improve the condition of existing protected areas and manage them properly.
- **Innovation** to reduce the impact of agricultural impacts, e.g., precision farming or less toxic agrochemicals.
- **Pollution regulations** are highly relevant, including around storage and application of manure and slurry.
- **Soil conservation** is very poor in the UK – there is a big policy gap.
- **Food waste reduction, diet change and productivity** increases may not produce the expected reduction in agricultural area, as farmers may export more food instead. Hence changes need to be global. Productivity increases may also lead to a rebound effect by making food production more profitable and/or cheaper, leading to more production and consumption.
- **Energy use** is an easier policy lever, but there is not much energy use on farms, and it is hard to decarbonize.
- **New production methods** including new proteins, vertical farming, etc., will emerge over time. However, some of these methods are currently very energy intensive.
- **Access to information.** It is hard for small- to medium-sized organizations (SMOs) to have a sustainability team, and risky for them to change. Risk sharing mechanisms are needed, e.g., ecosystem service payments.
- **Worker poverty.** In Scotland, farms must pay the living wage to farm workers to get government support. However, this is causing problems, especially for fruit and vegetable producers who are scaling back production. Therefore, this type of measure would need to be implemented together with controls on import of cheaper food, which is politically challenging.

- **Food crime**. More work is needed to expose food crime. Imports of unsafe low-cost food is a big threat, as border checks have declined. The Food Safety Agency fights food crime but focuses on authenticity rather than safety.
- **Pay the true cost for food and support low-income consumers through other measures,** such as income support, universal income, etc. This is a sensitive issue politically though the SOFA work will help to quantify the costs.
- **Joined-up policymaking** is needed to exploit synergies and balance trade-offs, e.g., government departments of health, education, business, agriculture, environment, climate, energy, welfare and social security need a coordinated approach to reduce hidden costs in the agrifood system.
- **Further levers**. Further work should explore the Defra Net Zero pathway levers in the Carbon Budget Delivery Plan. The research underlying those comes from the Clean Growth through Sustainable Intensification report.

7.5 References

Brown et al., (2022) United Kingdom. 2022 National Inventory Report (NIR), UNFCCC

Candari CJ, Cylus J, Nolte E. (2017) Assessing the economic costs of unhealthy diets and low physical activity: An evidence review and proposed framework. Copenhagen (Denmark): European Observatory on Health Systems and Policies; 2017. (Health Policy Series, No. 47.) Available from: https://www.ncbi.nlm.nih.gov/books/NBK447219/

Defra (2019) Compendium of Agriculture Statistics.

Defra (2023) Agriculture in the UK, July 2023

FAO (2023). The State of Food and Agriculture 2023 – Revealing the true cost of food to transform agrifood systems. Rome. https://doi.org/10.4060/cc7724en

FAO (2024). The State of Food and Agriculture 2024: Value driven transformation of agrifood systems. Rome.

Fitzpatrick et al. (2019) The hidden cost of UK Food. Report for the Sustainable Food Trust.

Food Foundation, 2023. Food Insecurity Tracking - Round 12

Lord, S. (2024) Avoided hidden costs in FABLE food system pathways to 2050: United Kingdom Key Figures. Background Brief Food and Agriculture Organization of the United Nations (FAO) State of Food and Agriculture (SOFA). Environmental Change Institute, University of Oxford.

Marino M, Puppo F, Del Bo' C, Vinelli V, Riso P, Porrini M, Martini D. (2021) A Systematic Review of Worldwide Consumption of Ultra-Processed Foods: Findings and Criticisms. Nutrients 13(8):2778. doi: 10.3390/nu13082778.

Mosnier, A., Penescu, L., Perez-Guzman, K., Steinhauser, J., Thomson, M., Douzal, C., Poncet, J., 2020. FABLE Calculator documentation- 2020 update. IIASA (Laxenburg) and SDSN (Paris).

Office for National Statistics (2021). UK National Accounts – The Blue Book, 2021 https://www.gov.uk/government/statistics/uk-national-accounts-the-blue-book-2021

Percival, R. (2021) Ultra-processing is the new frontier in public health policy—reflections on the National Food Strategy. The bmj Opinion, July 2021. British Medical Journal. https://blogs.bmj.com/bmj/2021/07/15/ultra-processing-is-the-new-frontier-in-public-health-policy-reflections-on-the-national-food-strategy/

Scarborough, P. et al. (2011) The economic burden of ill health due to diet, physical inactivity, smoking, alcohol and obesity in the UK: an update to 2006–07 NHS costs, Journal of Public Health, Volume 33, Issue 4, December 2011, Pages 527–535, https://doi.org/10.1093/pubmed/fdr033

Smith, A. C., Harrison, P. A., et al. (2022). Sustainable pathways towards climate and biodiversity goals in the UK: The importance of managing land-use synergies and trade-offs. Sustainability Science. https://doi.org/10.1007/s11625-022-01242-8

UK Government, 2023. Family Resources Survey 2021-2022

UK Parliament (2023) Ultra-processed Food. Hansard Volume 831: debated by the House of Lords on Tuesday 18 July 2023. https://hansard.parliament.uk/Lords/2023-07-18/debates/112306A4-3326-4716-8791-8E055BA7E708/Ultra-ProcessedFood

UKCEH (2020). Based on GIS analysis using UKCEH Land Cover Map 2020.

World Obesity Atlas (2024) https://data.worldobesity.org/publications/WOF-Obesity-Atlas-V5.pdf