Chapter 2. Australia

State of Food and Agriculture (SOFA) 2024
Background report

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CONSORTIUM

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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.

Contents

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.

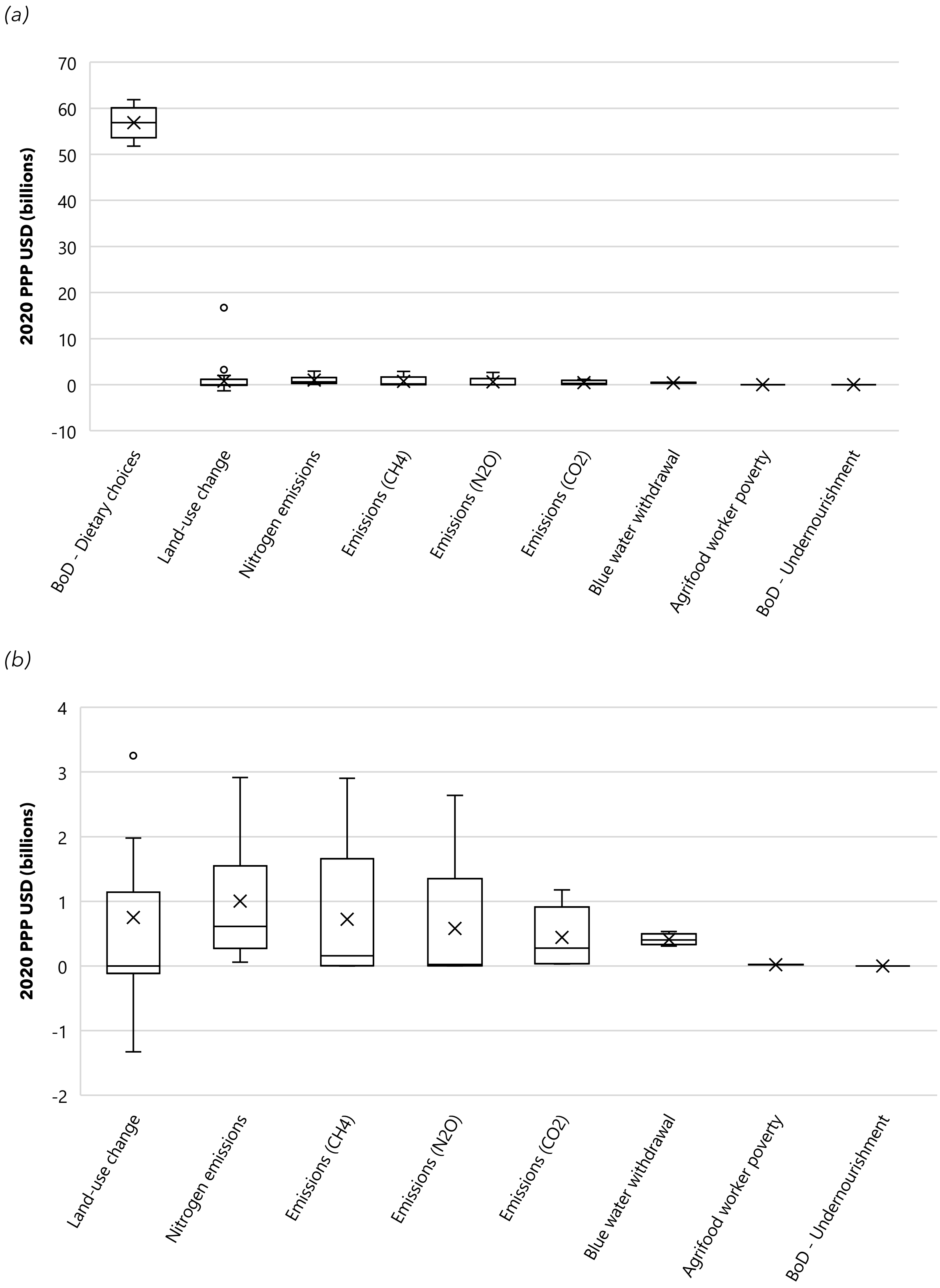
The hidden cost estimates for the SOFA report are derived from the product of the impact units and associated marginal cost function. The impact units cover categories across the environmental, health and social dimensions of the agrifood systems. It is important to recognize that hidden costs for each 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*



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)*

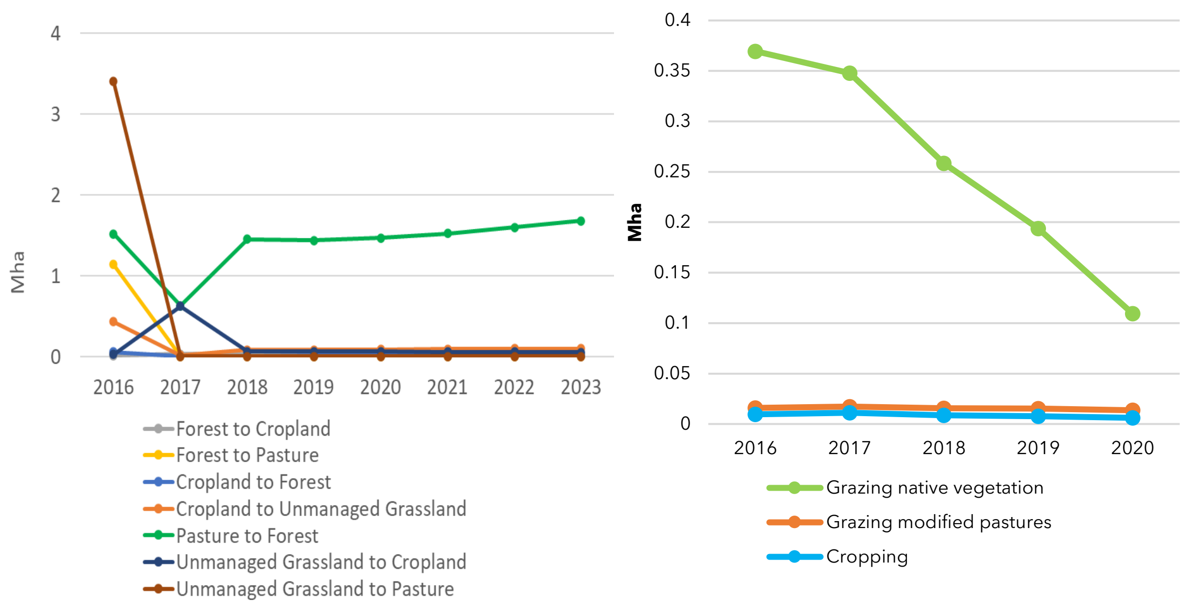
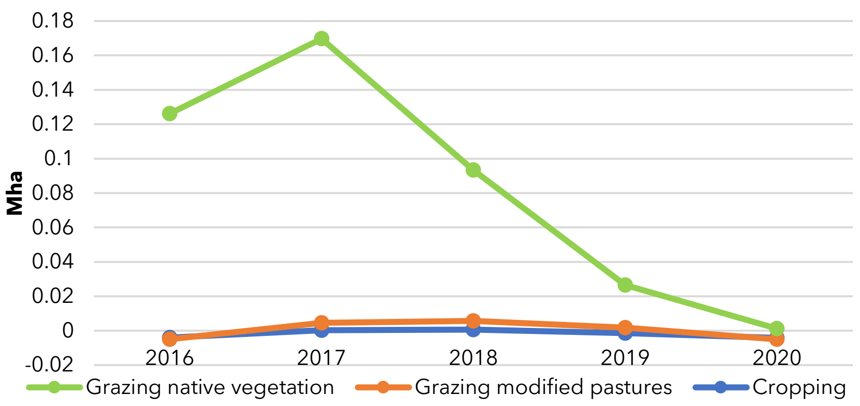


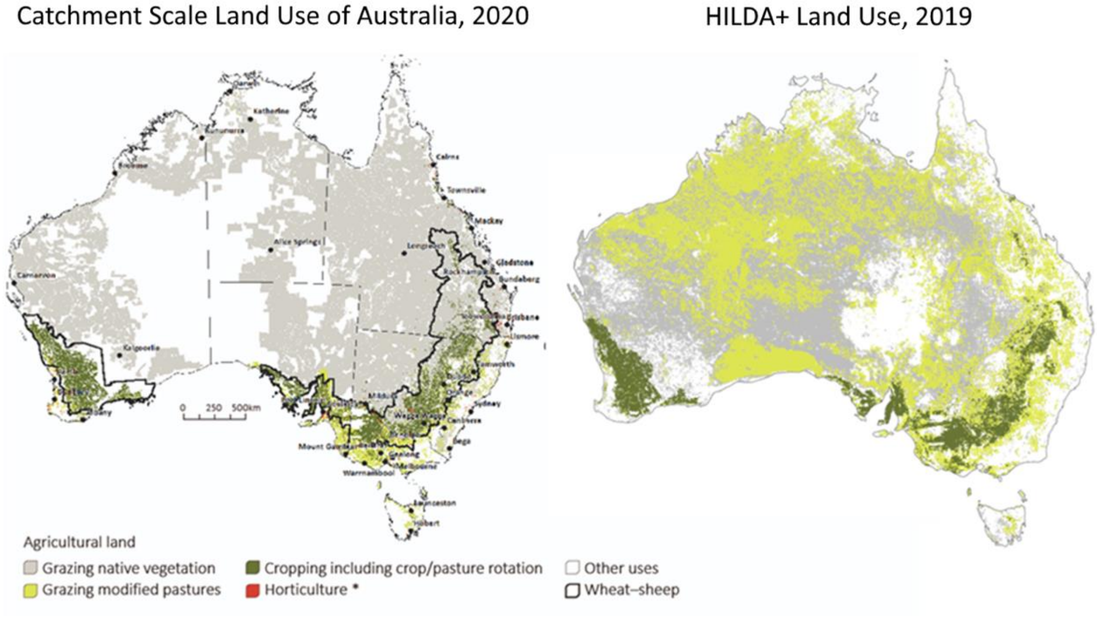
Figure 2-3: *Net vegetation gain reported in the Australian National Greenhouse Gas Inventory 2020*



Source: DCEEW, 2023

Note: Focusing specifically on the year 2020, some of the categories included for the hidden cost estimates are not in alignmen 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 fore 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*



Catchment Scale Land Use of Australia, 2020

HILDA+ Land Use, 2019

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):

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[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.

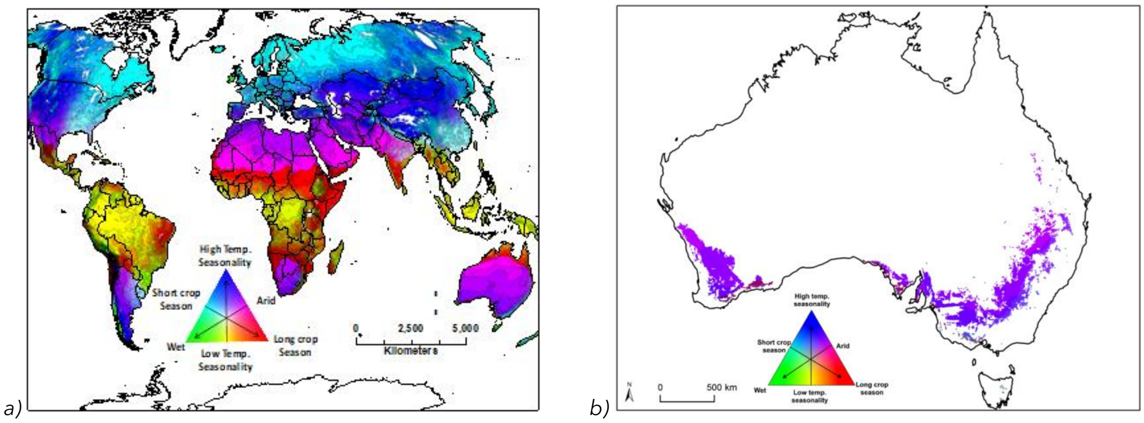
We also suggest a more comprehensive approach to assessing food insecurity and nutritional challenges, particularly among disadvantaged groups like First Nations People and those in remote areas. Furthermore, we recommend refining poverty measures to better reflect the affordability disparities across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

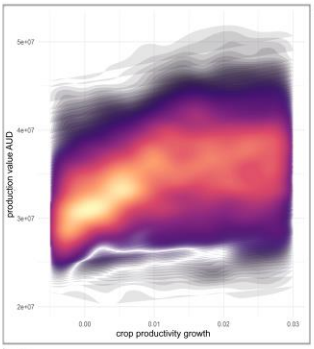
Figure 2-6 shows the correlation between FABLE Calculator input and output variables in the stochastic analysis by Navarro, Marcos-Martinez et al. (2023). There is a high correlation between input "X.Livestock_productivity_growth_scenario" and outputs

"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*



Input parameters																												
X.Total_water_use_change_scenario																												
X.Population_growth_scenario																												-0.8
X.Livestock_productivity_growth_scenario																											0	0
X.Livestock_density_growth_scenario																										0	0	0
X.Imports_scenario																									0	0	0	0
X.GDP_growth_scenario																								0	0	0	0.9	-0.8
X.Food_waste_scenario																							-0.8	0	0	0	-0.8	0.7
X.Post.harvest_loss_scenario																						0.7	-0.8	0	0	0	-0.8	0.7
X.Exports_scenario																					0	0	0	0	0	0	0	0
X.National_diet_scenario																				0	-0.7	-0.7	0.8	0	0	0	0.8	-0.8
X.Crop_productivity_growth_scenario																			0	0	0	0	0	0	0	0	0	0
X.Climate_change_impact_on_productivity_scenario																		0	-0.8	0	0.8	0.8	-0.9	0	0	0	-0.9	0.8
X.Biofuel_production_scenario																	0	0	0	0	0	0	0	0	0	0	0	0
X.Afforestation_scenario																0	-0.9	0	0.8	0	-0.8	-0.8	0.9	0	0	0	0.9	-0.8
X.Population_activity_scenario															-0.6	0	0.6	0	-0.5	0	0.5	0.5	-0.6	0	0	0	-0.6	0.5
Output variables																												
Trade_Balance_USD														0	0	0	0	0	0.1	0.9	0	-0.1	0	-0.3	0.1	0.1	0	0
Total_GHG_emissions_kg_CO2e													0.2	0.4	-0.6	0	0.5	-0.1	-0.6	0.3	0.5	0.5	-0.5	0	0	-0.5	-0.5	0.5
Production_value_target_AUD												0.5	0.7	0.1	-0.1	0	0.1	0	-0.3	0.9	0.1	0.1	-0.1	-0.1	0	-0.1	-0.1	0.1
Production_value_AUD											0.8	0.4	0.8	0.1	-0.1	0	0.1	0.1	-0.3	0.7	0.1	0.1	-0.1	-0.1	0.2	0.2	-0.1	0.1
Area_of_Pastures_Mha										0.3	0.5	0.8	0.2	0.2	-0.2	0	0.2	0	-0.2	0.4	0.1	0.1	-0.2	0	-0.4	-0.6	-0.1	0.1
Area_of_Other_Land_Mha									-1	-0.3	-0.5	-0.8	-0.2	-0.2	0.2	0	-0.1	0	0.2	-0.4	-0.1	-0.1	0.1	0	0.4	0.6	0.1	-0.1
Import_value_USD								0	0	0.1	0.1	0.1	-0.3	0.1	-0.1	0	0.1	0	-0.3	0	0.1	0.2	-0.1	0.9	0	0	-0.1	0.1
Export_target_USD							0	-0.4	0.4	0.7	0.9	0.3	0.9	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Export_value_USD						0.9	0	-0.2	0.2	0.8	0.8	0.2	0.9	0	0	0	0	0	0	0.9	0	0	0	0	0.1	0.2	0	0
Land_that_supports_biodiversity_pct					-0.2	-0.4	0	1	-1	-0.3	-0.5	-0.8	-0.2	-0.2	0.2	0	-0.2	0	0.2	-0.4	-0.1	-0.1	0.2	0	0.4	0.6	0.1	-0.1
Blue_water_target_km3				-0.1	0	0	0.1	-0.1	0.1	0.1	0.1	0.5	0	0.5	-0.8	0	0.8	0	-0.8	0	0.7	0.7	-0.8	0	0	0	-0.8	1
Blue_water_footprint_km3			0.8	-0.3	0.6	0.5	0.2	-0.2	0.2	0.7	0.6	0.6	0.5	0.4	-0.6	0	0.7	0.1	-0.7	0.5	0.6	0.6	-0.7	-0.1	0.1	0.1	-0.6	0.8
Dietary_energy_target_kcal		0.4	0.5	-0.2	0	0	0.1	-0.2	0.2	0.1	0.1	0.4	0	1	-0.6	0	0.6	0	-0.5	0	0.5	0.5	-0.6	0	0	0	-0.6	0.5
Dietary_energy_kcal	0.4	0.6	0.6	-0.2	0	-0.1	0.3	-0.2	0.2	0.4	0.3	0.6	-0.1	0.5	-0.6	0	0.6	0.1	-0.9	-0.1	0.5	0.5	-0.6	0	0.1	0.1	-0.6	0.6

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*

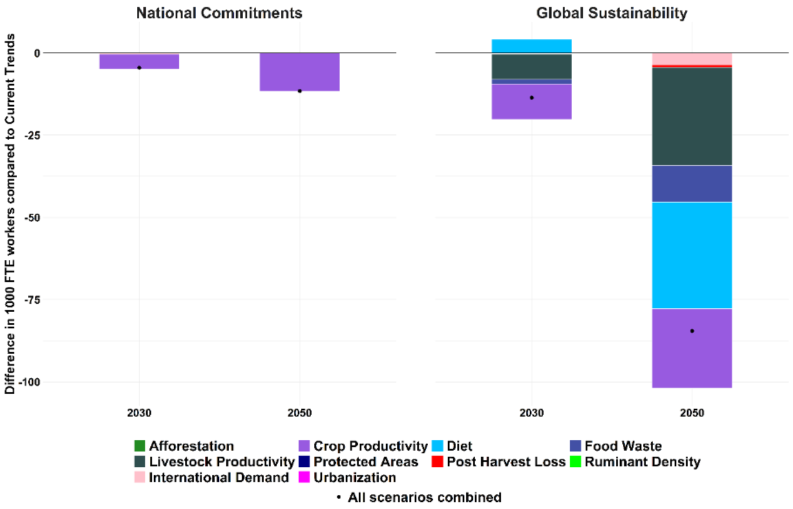


Figure 2-8: *Isolated impacts of single scenarios on cropland area using the FABLE-C*

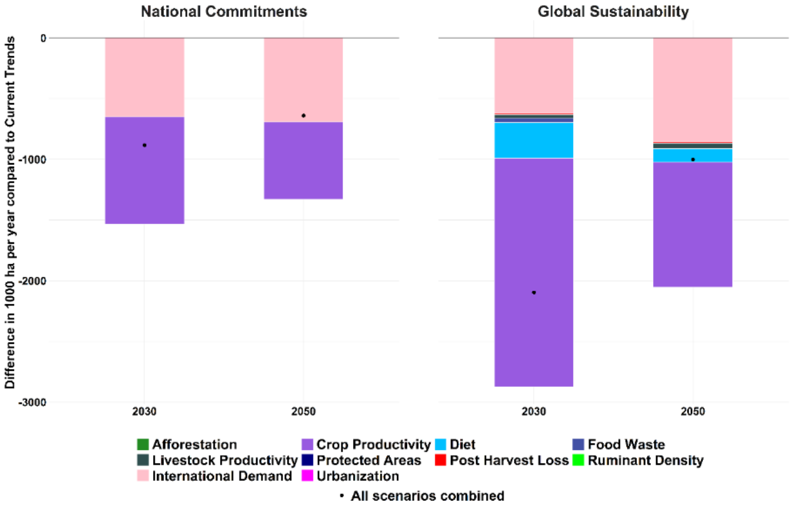


Figure 2-9: *Isolated impacts of single scenarios on pasture area using the FABLE-C*

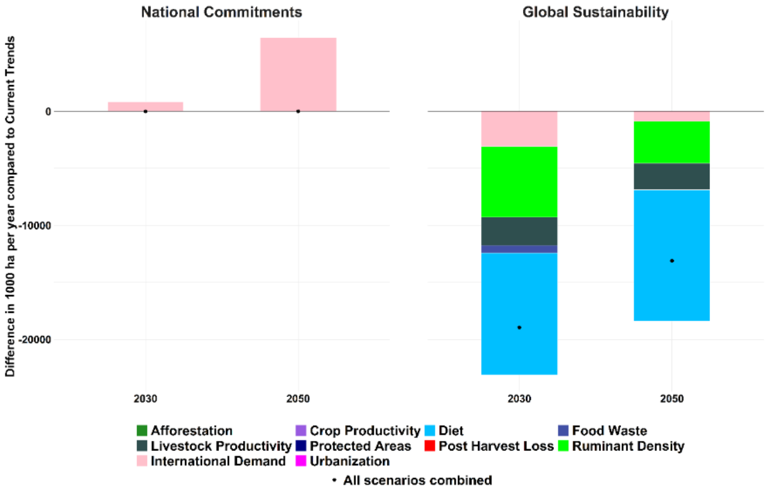


Figure 2-10: *Isolated impacts of single scenarios on irrigation water use using the FABLE-C*

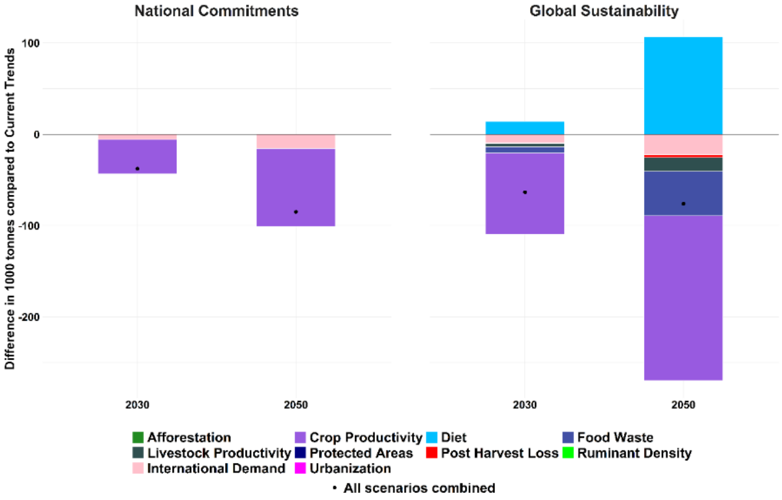


Figure 2-11: *Isolated impacts of single scenarios on nitrogen application using the FABLE-C*

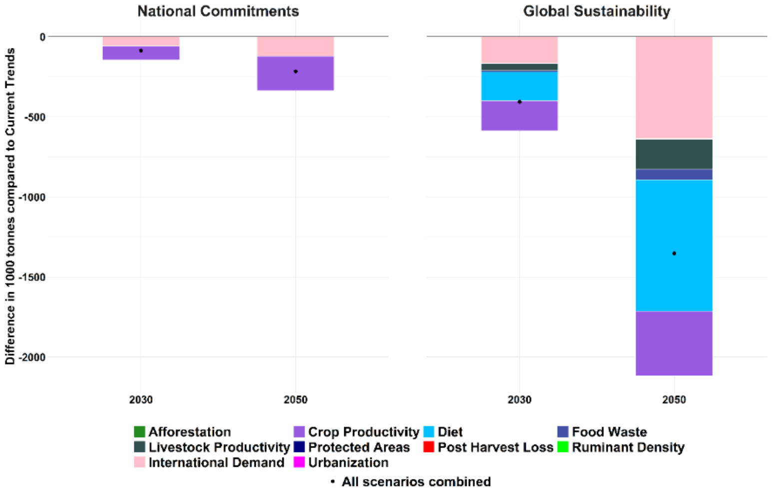
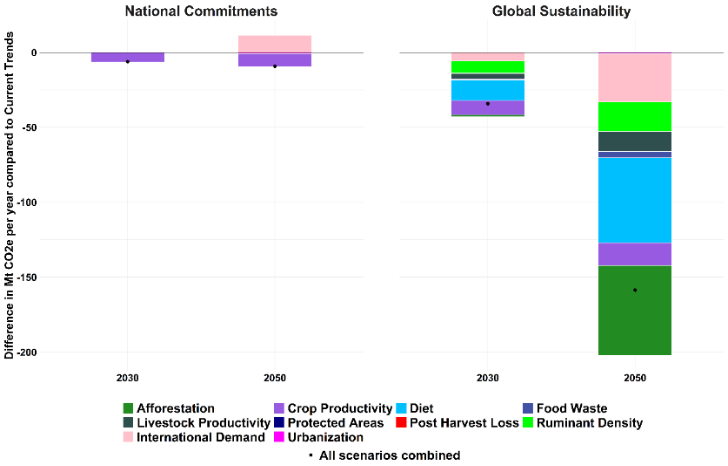


Figure 2-12: *Isolated impacts of single scenarios on net GHG emissions in CO2eq using the FABLE-C*



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).

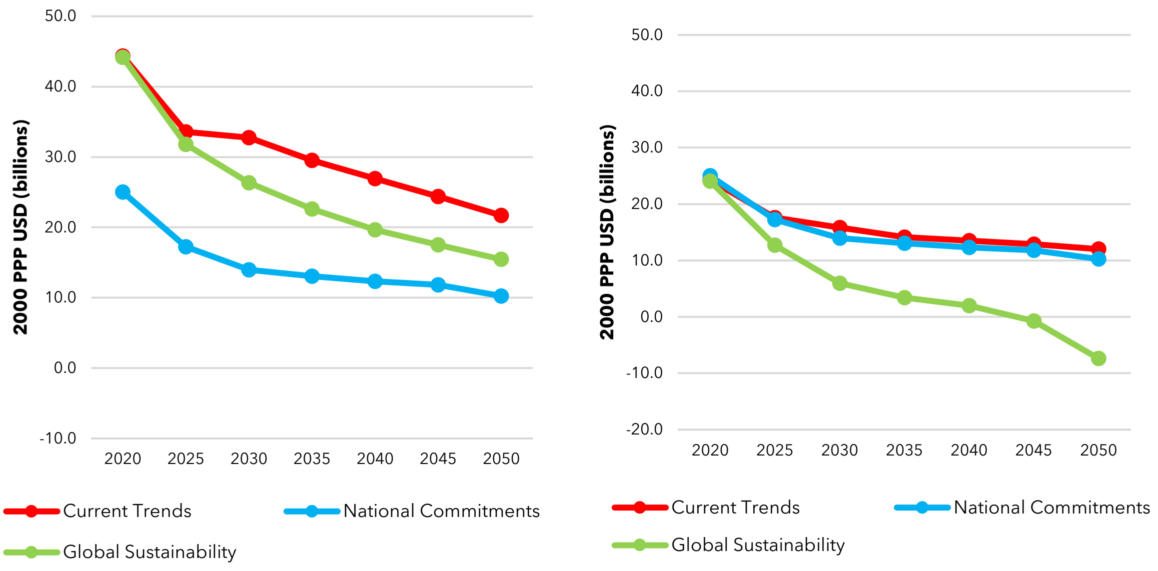
Under GS, environmental hidden costs would reach net zero by 2045. Most of the decrease is due to the return of grazing land that is surplus to requirement to its natural status and the associated increase in carbon sequestration through vegetation regeneration, but please note that the marginal cost 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).

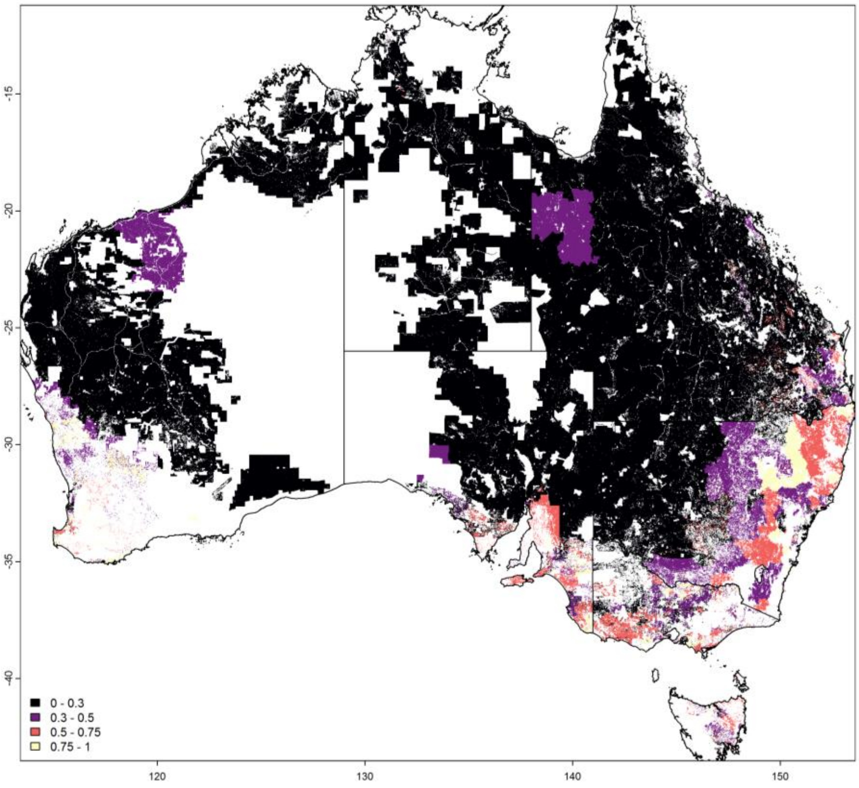
A rough approximation of the present value of ecosystem services would be USD 4,450 and USD 8,960 respectively (Steven Lord, personal communication), but that would be assuming that the entire ecosystem service value disappears because of grazing. In reality, growth of livestock productivity and density, 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.

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