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The Food and Land Use Coalition

2019 Report of the FABLE Consortium

Pathways to Sustainable Land-Use and Food Systems

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2019 Report of the FABLE Consortium

Pathways to Sustainable Land-Use and Food Systems in Australia by 2050

Australia

Javier Navarro-Garcia[1*]; Raymundo Marcos-Martinez[1], Daniel Mason-D'Croz[1], Mike Grundy[1], Michalis Hadjikakou[2], Brett Bryan[2], Eli Court[3]

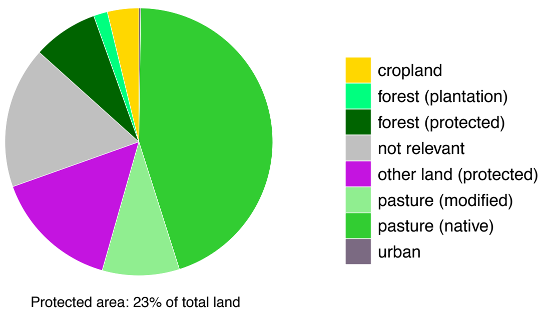
[1]Commonwealth Scientific and Industrial Research Organisation, Brisbane, Australia. [2]Deakin University, Melbourne, Australia. [3]ClimateWorks Australia, Melbourne, Australia. [*]Corresponding author: Javi.Navarro@csiro.au

Land and food systems at a glance

A description of all units can be found at the end of this chapter

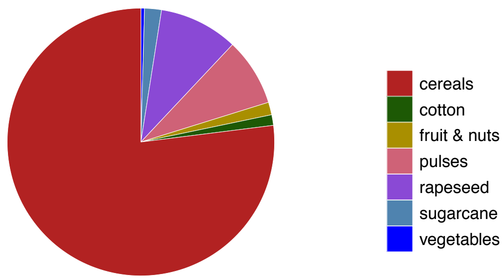
Land & Biodiversity

Fig. 1 | Area by land cover class in 2010



Source: ABARES (2016)

Fig. 2 | Share of harvested area by crop in 2015



Source: ABS (2017)

Annual primary deforestation 2010-2014:200 kha = 0.15% of total forest area (Clearing of regrowth 2010-2014 = 800 kha)

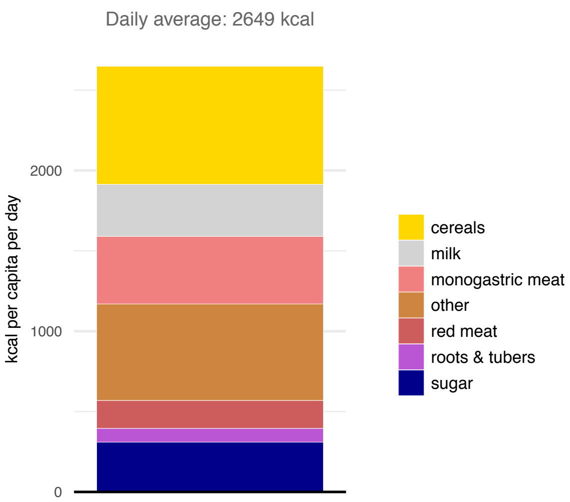
(Metcalfe and Bui, 2017; Montreal Process Implementation Group for Australia and Committee, 2018)

163 endangered species: fishes (17), frogs (14), reptiles (20), birds (54), mammals (37), and other animals (21)

(Department of the Environment and Energy, 2019)

Food & Nutrition

Fig. 3 | Daily average intake per capita at the national level in 2015



Source: FAOSTAT

Prevalence of food insecurity

(McKay et al., 2019)

Nationally (general population)
Single-item measure[1]: 1.6-8%[2]
USDA HFSSM measure[3]: 29%
HFNSS measure[4]: 57%
Disadvantaged groups
Indigenous Australians[5]: 25% (urban), 76% (remote)
Low socio-economic areas: 16% (single-item), 22%

(USDA, 2019)

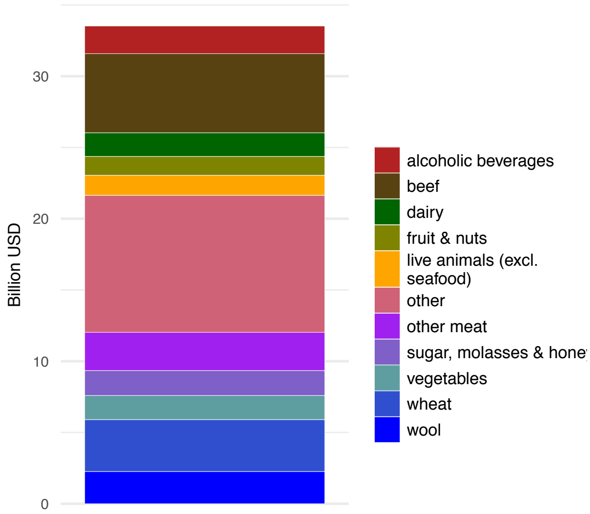
Share of obese and overweight in 2017
31% obese (very similar share male vs. female) and 36% overweight in 2017

Children age 5-17 years: 17% overweight and 8% obese

(ABS, 2018a)

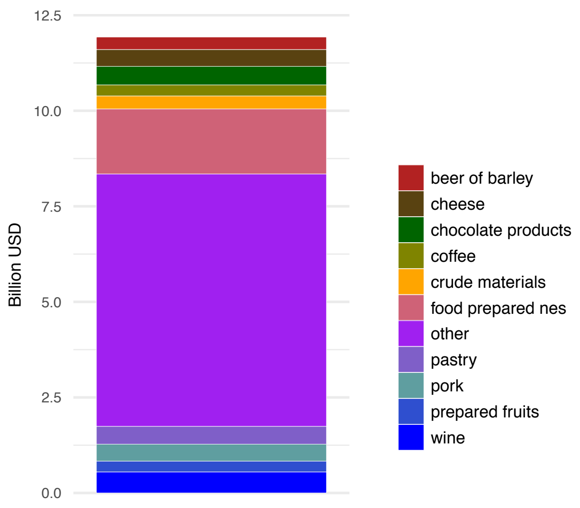
Trade

Fig. 4 | Main agricultural exports by value in 2016



Source: DFAT (2017)

Fig. 5 | Main agricultural imports by value in 2016



Source: FAOSTAT

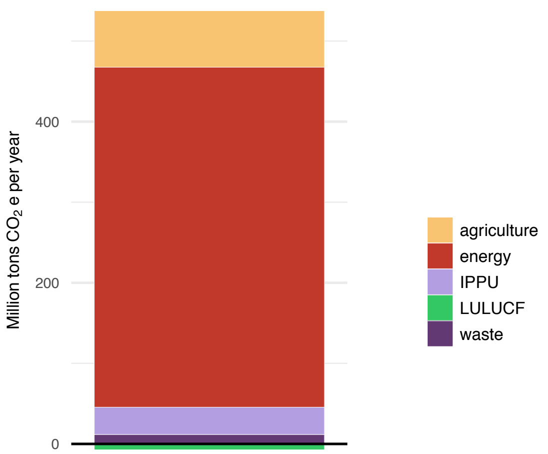
Surplus in agricultural trade balance in 2015: USD 18,550 million

(FAOSTAT, 2019)

World exporter ranking:
#4 for wheat in 2017 (approx. 10% total exports) (FAOSTAT, 2019)
#3 for beef in 2018 (approx. 15% total exports) (USDA, 2019)
#2 for sheep in 2017 (approx. 38% total exports) (UN, 2019)

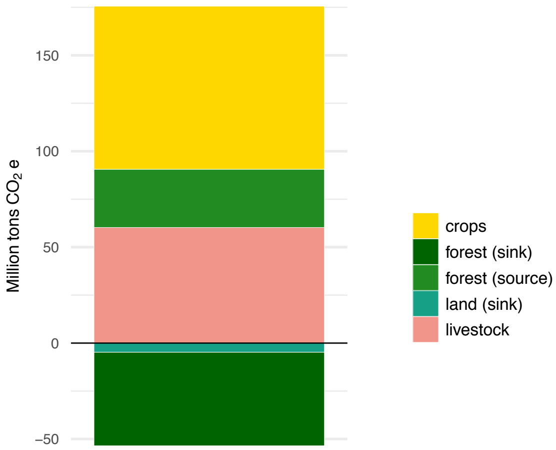
GHG Emissions

Fig. 6 | GHG emissions by sector in 2015



Source: Dept. of the Environment & Energy (2019b)

Fig. 7 | GHG emissions from agriculture and land use change in 2015



Source: Dept. of the Environment & Energy (2019b)

[1] Single-item question is *"In the last 12 months was there any time you have run out of food and not been able to purchase more?"*.
[2] Several studies show that the single-item measure leads to an underestimation of food insecurity prevalence of at least 5%. Appendix B presents an extended description of how to measure food insecurity in Australia.
[3] United States Department of Agriculture Household Food Security Survey Module.
[4] Household Food and Nutrition Security Survey (Kleve et al., 2018).
[5] Both assessed using single-item measure.

Main assumptions underlying the pathway towards sustainable land-use and food systems

For a detailed explanation of the underlying methodology of the FABLE Calculator, trade adjustment, and envelope analysis, please refer to sections 3.2: Data and tools for pathways towards sustainable land-use and food systems, and 3.3: Developing national pathways consistent with global objectives.

GDP GROWTH & POPULATION

	GDP per capita	Population
Scenario definition	GDP per capita is expected to increase from USD 55,043 in 2017 to USD 91,468 in 2050 (annualized growth rate of 1.5% is assumed).	The population is expected to increase by 58% between 2015 and 2050 from 24 mln to 38 mln.
Scenario justification	Based on CSIRO's Australian National Outlook 2019 estimates (Brinsmead et al., 2019) and historical OECD data (2018). Australian GDP increased at an average annual rate of 3.28% from 1984 to 2017. Several global and domestic trends (e.g. technology, climate change) lower future GDP growth expectations. Estimates to 2050 were generated through integrated assessment models that account for global and domestic uncertainties (Brinsmead et al., 2019).	Net overseas migration is the main driver of Australian population growth, such parameter accounted for around two thirds of the population increase in 2016-17 (ABS, 2019). Population projections are based on Australian-specific assumptions of fertility, mortality, international, and domestic migration informed by historical trends (ABS, 2013).

TRADE

	Imports	Exports
Scenario definition	The quantity of fruit and vegetables imports doubles from 2015 to 2050. Import value for other commodities remains at 2015 levels.	The export quantity of peas, oats, barley, beans, rapeseed, sorghum, wheat, cotton, oilseeds (other), onions, oranges, pulses, cotton lint, cotton oil, rapeseed oil, raw sugar, and rye doubles by 2050. Meat and milk exports increase by 2.4 the export value observed in 2015. Export value stays constant for other products.
Scenario justification	The share of total consumption which is imported increases in response to domestic population growth. Historical trends in Australian trade data from 1986 to 2016 (FAOSTAT, 2019) and endogenous changes driven by trade assumptions in the Calculator.	Statistical projections based on FAOSTAT (2019) 1986-2016 data suggest that under historical trends the value of Australian exports by 2050 could be around 1.6 times the 2015 value. Changes in total factor productivity due to technological development allow Australian exports to remain globally competitive. Increases in food demand from the Asian region also contribute to the increase in Australian exports beyond current trends.

Scenario signs no change small change large change

LAND

	Land conversion	Afforestation
Scenario definition	We assume no expansion of agricultural land beyond 2010 agricultural area levels.	High level of afforestation reaching 17 Mha of new forest by 2050 (an average of 0.74 Mha/year until 2045). Net forest growth is observed from 2010 onwards.
Scenario justification	Based on spatially explicit analysis of continental level forest cover change that documents a forest transition around 2008 (Marcos-Martinez et al., 2018).	Based on high levels of forest plantings after 2040, which assume critical preconditions that would enable carbon/environmental forestry becoming a more profitable land use option than cropping or livestock rearing on marginal lands. Such preconditions include: higher than trend productivity increases in remaining agricultural land, available infrastructure to implement large scale forest plantations, social license to convert large areas of agricultural land to forestry, high carbon offset prices. Failure to achieve any of these necessary conditions would significantly affect Australia's capacity to arrive at the level of afforestation assumed here, which reduces the likelihood that this level of afforestation could be achieved. Official reports indicate a net increase in forest cover of 0.78 Mha/year between 2011 and 2016 (Montreal Process Implementation Group for Australia and National Forest Inventory Steering Committee, 2018).

BIODIVERSITY

	Protected areas
Scenario definition	We assume that the extent of protected areas remains constant. The area of land with low anthropogenic impact which can support biodiversity conservation increases from 52% of the Australian land mass in 2015 to 60% in 2050 (a change from 400 Mha in 2015 to 461 Mha in 2050).
Scenario justification	Trends consistent with FAOSTAT data for forest and land with minimal use. National scale land use data for the period 2010-11 indicates that around 40% of the landmass was in conservation status or under minimal use (ABARES, 2016).

Scenario signs no change small change large change

FOOD

	Diet (large change)	Food waste (no change)
Scenario definition	Gradual adoption of healthy diets. Between 2010 and 2050, the average daily calorie consumption per capita decreases from 2450 kcal to 2375 kcal. Relative per capita consumption: - decreases 91% for red meat - decreases 67% for monogastric meat - decreases 15% for oil and fat - decreases 63% for sugar - increases 28% for cereals - increases 30% for fish - increases 20% for fruits and vegetables - is multiplied by 15 for pulses.	Between 2015 and 2050, the share of final household consumption which is wasted remains stable at 16%.
Scenario justification	A gradual transition towards healthy diets is modelled based on recommendations from the EAT-Lancet Commission on healthy diets from sustainable food systems (Willett et al., 2019). Changes in food intake composition are based on default values of the FABLE Calculator.	Waste is halved relative to 2010 levels. According to Bajzelj et al. (2014) and Gustavsson et al. (2011), compounded waste from current consumption is 29.7%.

PRODUCTIVITY

	Crop productivity (large change)	Livestock productivity (large change)	Pasture stocking rate (small change)
Scenario definition	Assumption is 1.5%/year productivity growth, slightly greater than historical productivity growth. Between 2010 and 2050, crop productivity increases: - from 1.95 t/ ha to 3.1 t/ha for wheat, - from 10 t/ ha to 23.5 t/ha for grapes.	Assumption is 1.5%/year productivity growth, slightly greater than historical productivity growth. Between 2015 and 2050, the productivity per head increases: - from 98 kg/TLU to 168 kg/ head for beef meat, - from 6.4 t/TLU to 11 t/TLU for cow milk, - from 88 kg/head to 155 kg/ head for sheep meat.	The average livestock stocking density increases from 0.09 head/ha to 0.1 head/ha pasture between 2000 and 2050. The growth in livestock density is BAU from 2000 to 2015 and half the BAU rate onwards.
Scenario justification	Spatially explicit analysis of growth from 1980-2010 combined with CSIRO's productivity change projections (Brinsmead et al., 2019) that account for ambitious policy environment and significant technological improvements. See Appendix A: spatially explicit modelling of crop productivity.	Productivity change projections consistent with historical trends (ABARES, 2017).	Based on business as usual stocking rate growth between 1980 and 2010, calculated with data from Meat and Livestock Australia (2019).

Scenario signs no change small change large change

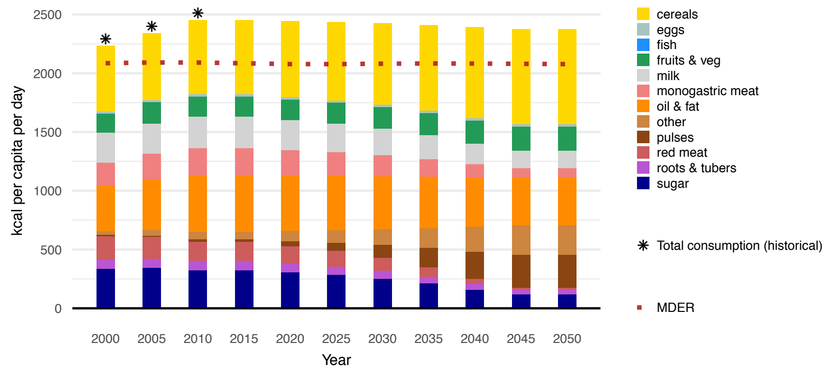
Results against the FABLE targets

The results for FABLE targets as well as "other results" are based on calculations before global trade harmonization.

Food security

Fig. 8 | Computed daily average intake per capita over 2000-2050

Note: The Minimum Daily Energy Requirement (MDER) is computed based on the projected age and sex structure of the population and the minimum energy requirements by age and sex for a moderate activity level. Animal fat, offal, honey, and alcohol are not taken into account in the computed intake.



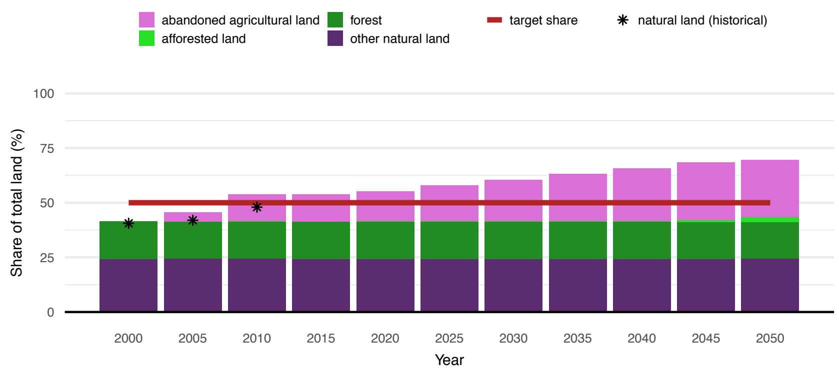
Historical data source: FAOSTAT

Average daily energy intake per capita decreases slightly to nearly 2,375 kcal/capita/day from a peak of 2,450 kcal/capita/day in 2010. The computed energy intake is 5% lower than the FAO due to some products not being included in the calculations. In 2010, 26% of the energy intake came from cereals, 20% from oils and fats, and 14% from sugar, with fruit and vegetables, milk and monogastric meat accounting for close to 10% each (7%, 11%, and 9.5% respectively).

Calorie intake reaches 2,424 kcal over the period 2031-2035 and 2,375 kcal over the period 2046-2050, which is about 15% higher than Australia's MDER in 2050. In terms of dietary breakdown, the scenario outcomes show growth in consumption of calories from cereals, fruit and vegetables, nuts (in the "other" group) and pulses. There is a decline in consumption of sugar, oils and fats, meat and milk.

Biodiversity

Fig. 9 | Computed share of the total land which could support biodiversity over 2000-2050



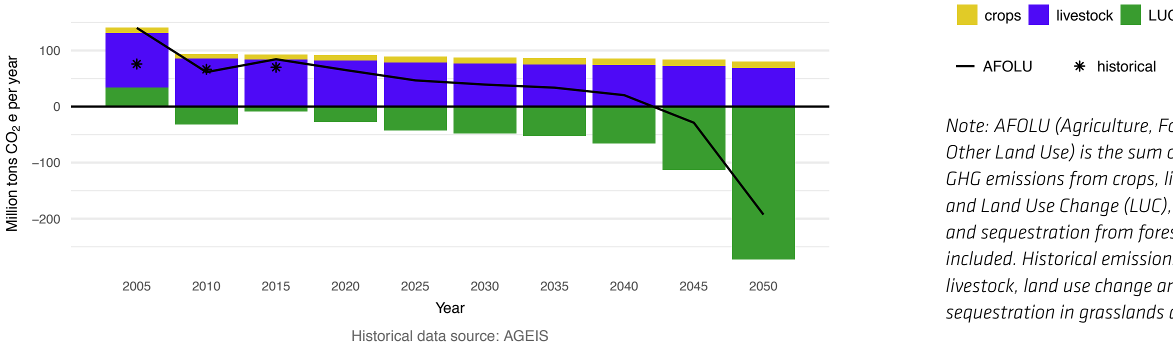
Historical data source: ABARES (2016)

The Share of the Land which could support Biodiversity conservation (SLB) increased between 2000-2015 from 41% to 52%. This number is similar to estimates based on FAO land cover statistics. Australian national land use for the period 2010-11 indicates that around 40% of the landmass is protected or under minimal use. Differences in land use definitions partially explain the difference between FAO and domestic data. The lowest SLB is computed for the period 2000 at 41% of total land. Vegetation regrowth in marginal agricultural land (mostly in pastureland) increases the SLB to 60% by 2050.

Compared to the global target of having at least 50% SLB by 2050, Australian SLB exceeds this target from 2010 onwards.

GHG emissions

Fig. 10 | Computed GHG emissions from land and agriculture over 2000-2050



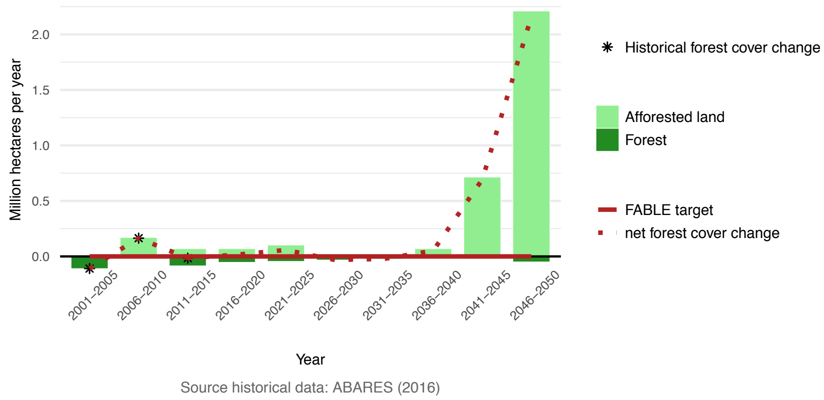
Note: AFOLU (Agriculture, Forestry and Other Land Use) is the sum of computed GHG emissions from crops, livestock and Land Use Change (LUC), emissions and sequestration from forestry are not included. Historical emissions include crops, livestock, land use change and carbon sequestration in grasslands and forests.

Annual net GHG emissions drop from 118 to 84 Mt CO_2e over 2000-2015. In 2005 and 2015 there are some GFG emission increases due to localized deforestation, mostly in the State of Queensland (Simmons et al., 2018). Projected agricultural GHG emissions effects are relatively close to FAO estimates for the agricultural sector particularly from 2000 to 2015. Peak Agriculture, Forestry, and Other Land (AFOLU) GHG emissions are computed for the year 2005 at 140 Mt CO_2e/year. This is mostly driven by GHG emissions from livestock (64%) and by deforestation (30%), mostly due to vegetation clearing in Queensland (Marcos-Martinez et al., 2018), with about 6% contribution from crops. AFOLU GHG emissions reach -193 Mt CO_2e over the period 2046-2050: 80 Mt from agriculture and −274 Mt from LULUCF. Negative net emissions from LULUCF by 2050 are mainly (87%) explained by afforestation, with regrowth playing a smaller role (13%).

Compared to the global target of reducing emissions from agriculture and reaching zero or negative GHG emissions from LULUCF by 2050, the scenario outcomes (driven by assumptions and the FABLE calculator representation of the AFOLU system) exceed that target. Net zero emissions are achieved at some point between 2040 and 2045 due to increased rate of afforestation for carbon plantings, but net emissions are significantly reduced from 2030 compared to the peak. Overall AFOLU emissions by 2050 are very close to the level needed to achieve net zero carbon emissions for the whole economy (Deep Decarbonization Pathways Project, 2015).

Forests

Fig. 11 | Computed forest cover change over 2000-2050



Projected annual forest growth between -0.02 and 2.16 Mha from 2000 to 2050 (average of 0.3 Mha/year). This is lower than the 0.78 Mha of forest growth per year observed between 2011 and 2016, but afforestation was assumed to occur mostly after 2040. Due to such assumption, afforestation peak during the period 2045-50 with 2.16 Mha per year.

The projected afforestation levels were assumed as a potential maximum that would require a significant set of conditions to occur, e.g. productivity increases higher than trends and other socioeconomic factors that turn forest plantings more profitable that alternative land uses. See the discussion section for a description of the conditions assumed to achieve such a large afforestation area. This maximum level is unlikely to be achieved because failure to fulfil any of the necessary pre-conditions would significantly impact Australia's capacity to reach it.

Compared to the global target of having zero or positive net forest change after 2030, the scenario effects indicate forest loss from 2030 to 2035 and large levels of afforestation afterwards.

Other relevant results for national objectives

Table 1 | Other Results

Variable	Unit	2000	2005	2010	2015	2020	2030	2040	2050
Cropland (historical	Mha	47.6	76.5	68.9	46.1				
Cropland (calculated)	Mha	47.6	51.3	45.1	47.8	49.3	51.2	51.3	50.0
Pasture (historical)	Mha	407.9	395.4	355.6	319.5				
Pasture (calculated)	Mha	400.9	366.3	330.6	317.2	309.8	284.6	276.3	251.5
Forest (historical)	Mha	131.8	129.8	129.5	133.1				
Forest (calculated)	Mha	131.8	131.3	131.2	130.8	130.6	130.2	130.0	129.6
Afforested land (calculated)	Mha	0.0	0.0	0.9	1.2	1.5	2.0	2.4	17.0
Other land (historical)	Mha	180.9	193.3	240.1	277.6				
Other land (calculated)	Mha	187.1	218.4	259.2	269.8	275.4	297.8	304.8	315.2
Urban (calculated)	Mha	0.8	1.0	1.2	1.4	1.7	2.4	3.4	4.9

Source of historical data: FAOSTAT

Between 2000 and 2015 FAOSTAT data show a decline in total pasture lands, from a high of 400Mha in 2000 to 320 Mha in 2015 (FAOSTAT, 2019). Such trend is closely approximated by the FABLE Calculator. Several factors contribute to the observed decline:

> Decrease of private pastoral lease land in Northern Australia (from 76% to 57% of the total area between 1976-2006) in favor of aboriginal pastoral leases (0.6% to 6.5%), aboriginal freehold (0 to 21%), and conservation land (0.6% to 8.1%). Most lease changes have occurred in marginal land which has significant limitations for profitable pastoral activities, while a much smaller number occurred on core pastoral lands (Holmes, 2009).

> In Western Australia's arid lands there is a decline of roughly 7 Mha in non-indigenous pastoral lease land mainly towards conservation reserves, but also to aboriginal pastoral leases (van Etten, 2013).

> Improvements in efficiencies over the last 15 years and droughts have likely generated abandonment of the most marginal grazing lands in favor of better production areas. This also explains why most conversions from pastoral leases to aboriginal freeholds have occurred in marginal land.

> Since 2000 philanthropic conservation groups have purchased roughly 10 Mha of pastoral lands in Australia. Most of those purchases were marginal pastures land but there are exceptions where productive pastoral country has been purchased to protect specific vulnerable habitat or threatened species (Andrew Ash pers. Comm.).

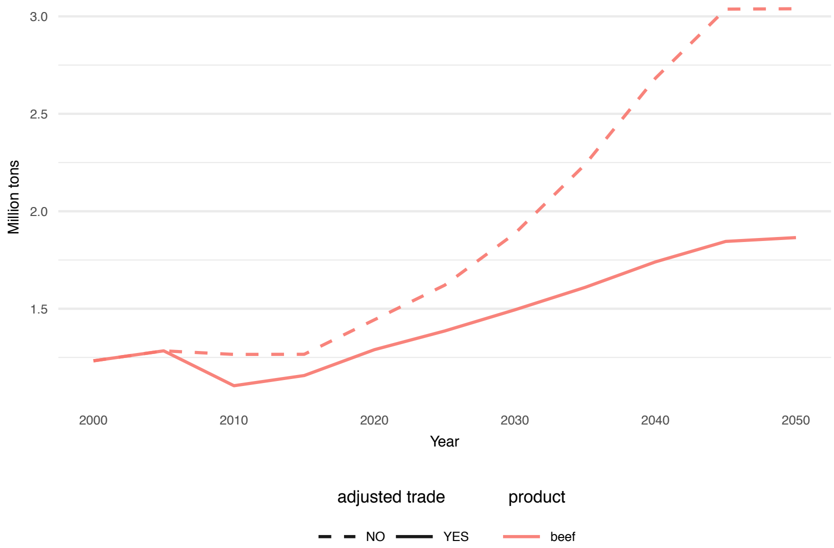
FAOSTAT's yearly reported values of permanent pastures show that there are temporary increases in total grazing land, but a declining long-term trend remains. For the year 2016 ABS reports a slightly larger amount of total grazing land than FAOSTAT (340 Mha vs. 325 Mha) (ABS, 2018b). The yearly values of land under permanent meadows and pastures (FAOSTAT, 2019) reflect a sharp decline between 2014 and 2015. This is due to a change in how Australia reports total grazing land to only report land which is owned by an agricultural business producing over a certain economic value[6].

Our projection indicates that the decline in total grazing land could continue albeit at a slower pace in the coming decades (from 320 Mha in 2015 to 251 Mha in 2050). Improved productivity for livestock (1.5%/year in aggregate), livestock density continuing to grow post-2015 but at half the rate observed between 1980 and 2010, and increased livestock products exports are the main contributing factors to the projection. As grazing land gives way to regrowth (becoming part of the "Other Land" land use category), carbon sequestration from regeneration contributes significantly to total sequestration by 2050.

[6] FAOSTAT Country Notes (FAOSTAT, 2019) Australia indicate that "Agricultural land" refers to the total area of all agricultural establishments (farms); "Land under temporary crops" refers to all crops both temporary and permanent. However, domestic changes in the collection and integration of agricultural data may complicate their intertemporal comparability. For instance, starting in 2015, the Australian Bureau of Statistics (ABS) changed the data collection scope for Agricultural Census and Land Management Practices. The ABS increased the minimum threshold of the estimated value of agricultural operations (EVAO) used to scope agricultural businesses. In addition, in 2018 Australia stopped reporting data on ''Land under permanent meadows and pastures".

Impacts of trade adjustment to ensure global trade balance

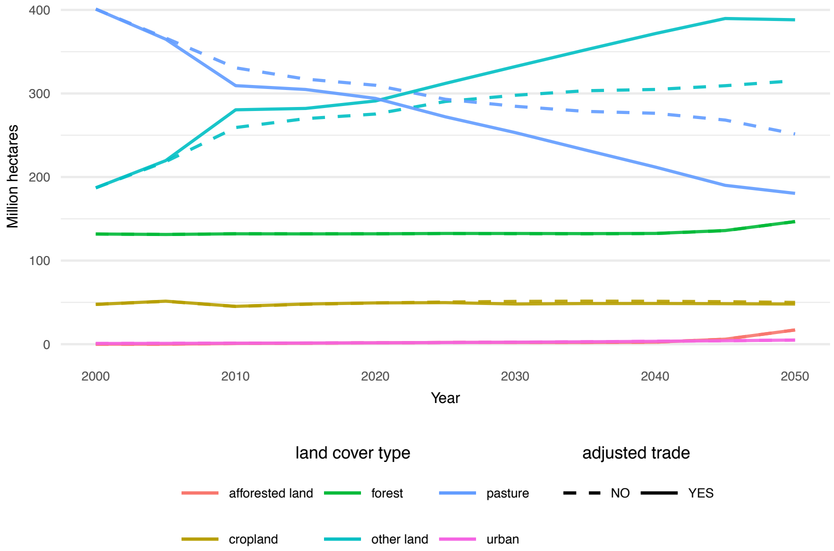
Fig. 12 | Impact of global trade harmonization on main exported/imported commodities over 2000-2050



Trade adjustment causes a decrease in exports for some of Australia's top export commodities: by 2050, beef and wheat exports under the trade adjustment scenario are 40%, and 20% less than the projected export levels before trade is exogenously adjusted.

Fig. 13 | Impact of global trade harmonization on land use over 2000-2050

Note: Dashed lines show the area by land cover without trade adjustment. They are displayed here to better highlight the difference in effects with and without trade adjustment.



By 2050, the decline in beef exports causes total grazing land to drop to 180 Mha, which is about 70 Mha (32%) less than our projection.

Trade adjustment causes deviations from historical trends in pastures and other land (about 15 Mha less than reported by FAOSTAT in 2015). This drop is of the same magnitude than the difference in reported grazing land between FAOSTAT (2019) and ABS (2018b) on the year 2016.

After 2015 the decline is sharper than what the model projects when international agricultural and food supply and demand is not considered. The effects of the chosen scenario without trade adjustment project that grazing area could drop to 300 Mha by 2025, but after trade adjustment this threshold would be passed at some point before 2020.

Impacts of trade adjustment on GHG emissions and Biodiversity indicator are presented in the Appendix C.

Discussion and next steps

The modelled scenario represents an ambitious aspiration for the Australian food and land use sector. It has been informed by analyses of land use options in Australia led by the CSIRO as part of the Australian National Outlook 2019 (Brinsmead et al., 2019), official and peer-reviewed data, and experts' opinions. While the modelled scenario contributes to the generation of a preliminary assessment of the technical potential for Australia to improve its food and land use system, the scenario outcomes are indicative only since they rely significantly on critical assumptions. Therefore, the scenario outcomes should not be interpreted as a pathway for Australia that has been fully endorsed by relevant stakeholders. In particular, we draw attention to the impact that redressing trade imbalances at the FABLE global level has on the evolution of Australian agriculture. Since trade imbalances stem from the modelling choices of other country teams, the impacts of trade balancing on Australian agriculture should be seen as a single 'what if' scenario that demonstrates the possible impacts of potential shifts in international trade, rather than a projection. We note that the Land Use Futures project[7], led by ClimateWorks Australia, Deakin University and the CSIRO, is embarking upon a sustainable food and land use pathway development process that will bring together sophisticated geospatially explicit modelling, tailored to the Australian context, with highly participatory involvement of key Australian stakeholders. The information presented in this chapter may or may not reflect the ultimate results of that broader pathway development process.

The modelled scenario achieves net zero agricultural GHG emissions by 2050 based on a significant level of afforestation and low or marginal net deforestation after 2020. Under the assumed scenario conditions, the AFOLU emission reductions could reach the levels required for the whole of Australia to become carbon neutral by 2050. The modelled scenario pathway assumes global climate change mitigation action to limit warming to no more than 2°C by 2100. A key assumption is that higher demand for emission offsets increases carbon prices to levels that more closely reflect the social costs of carbon emissions (Nordhaus, 2017). Such prices increase the number and scale of emission reduction projects including afforestation projects. It is assumed that carbon forestry achieves higher prices than offsets from other sectors due to the co-benefits that they provide (e.g. biodiversity conservation, local employment). For some landowners, carbon forestry becomes a profitable land use option, particularly for their less productive land. The scenario of afforestation assumed here is likely to be at the highest end of feasible achievement and is dependent on several crucial assumptions. First, carbon offsets reach long term-prices that make carbon forestry a more profitable option than other potential uses. Second, higher than trend agricultural productivity in the remaining agricultural areas allows production increases to continue fulfilling most of the domestic food and other agricultural products demand and to maintain the trend in export shares for related products. Third, that the infrastructure needed to implement large scale afforestation is available (e.g. nurseries, roads, seedlings resistant to more challenging climatic conditions) at a cost that does not compromise the financial viability of plantation forests. Fourth, there is a social license for non-food and fibre production on marginal land (i.e. changes in land use and their corresponding impacts in livelihoods are supported). Failure to achieve any of these necessary pre-conditions would significantly impact Australia's capacity to arrive at the level of afforestation assumed in this analysis.

Globally, the Australian AFOLU sector remains competitive, export-oriented, and able to capitalize on business opportunities. In Australia, the population increases almost two-fold (mostly in existing urban areas), and GDP by 2050 is around 2.6 times 2015 levels. The economic growth and

[7] Such project is part of the global Food and Land Use Coalition and FABLE initiative.

resilience of the domestic FABLE system are significantly driven by increases in total factor productivity of around 1.5% per year. Such rate represents productivity gains across multiple production factors (e.g. crop and land types, farming technologies, know-how, labour skills, financing). In the FABLE Calculator, agricultural productivity gains are modelled as changes in agricultural outputs from yield improvements and animal/crop density changes. The assumed rates of productivity change may be plausible under significant levels of research and development and successful uptake of new and emerging technologies (e.g. digital agriculture, genomics). Some technologies that could have a significant impact in the sector are for example precision agriculture and genetic improvements, automation, seaweed supplementation to reduce enteric emissions, the use of renewable energy to de-couple on-farm operations from fossil fuel use (e.g. CSIRO-developed technology to transport hydrogen power as ammonia), as well as decoupling production of fertilizers and pesticides from fossil fuels, and new Australian technology to extend the life of fresh milk without pasteurization. This could generate cost efficiencies, improve risk management, and reduce waste in related value chains.

Long-term effective regulatory and incentive policy across Australian State and Federal agencies is needed to achieve long-term changes towards a sustainable FABLE system. Long-term effective vegetation management policy across these agencies is needed to maintain the net forest gain trend observed since the late 2000s in the country. The expected uptake of carbon forestry would also require improved regulatory and incentive frameworks to reduce potential trade-offs and balance policy targets (e.g. food and water security, biodiversity protection, large-scale carbon plantings). Improved monitoring of the real impacts of interventions could help reduce trade-offs of interventions or increase their benefits.

Trade-offs and benefits of interventions in the FABLE system at local levels need to be assessed (e.g. water security, externalities due to increased use of fertilizers). The aspatial modelling approach of the FABLE Calculator prevents the analysis of regional and local impacts of assumed socioeconomic, productive, and climatic changes. Spatially explicit modelling of the structure of the domestic FABLE system could provide better insights into potential responses to global and domestic parameters (e.g. climate change, food demand, changes in diets). We have sought to reinforce this analysis by using the best spatially explicit data and modelling available to feed their synthesized results into the appropriate sections of the Calculator. Through this approach, we expect that national values are on aggregate consistent with projections from spatially explicit models. However, for Australian decision-makers to be able to use outputs such as the ones provided here, they need to be able to understand what the local-level impacts of broad land use changes would have. For example, this analysis indicates that there could be declines in pasture lands in the coming decades, but where are these most likely to occur and what are the potential effects on the local communities? These are key considerations that the Australian public (and therefore decision-makers) are increasingly asking science to investigate. In addition, the analysis does not consider the uncertainty around assumptions and the impact of such uncertainty on potential outcomes. For example, uncertainty around the magnitude of productivity increases for livestock industries (currently set at 1.5%/year which is over the historical trend) could have a significant impact on the projections of pasture and other land uses. Future iterations of the FABLE Scenathon, could incorporate stochastic functionality to allow for the exploration of parameter uncertainties and their impact on the modelled outcomes. The analysis also does not consider carbon sequestration from existing forests; this carbon sink would be relatively small, but we are unable to quantify it using the current parameters of the Calculator.

Improvements to the approach applied to balance international trade (e.g. through international prices that guide country-level supply and demand) could also improve the robustness of the analysis and facilitate the investigation of teleconnections of the global FABLE system (i.e. linkages across socioeconomic and environmental systems that transcend country boundaries and temporal scales). Similarly, an improvement in future trade modelling would need to account for variations in the demand of each commodity by country of origin, based on aspects like quality, environmental performance, and inter-country trade relationships.

With regards to the FABLE food security target, measuring adequate energy intake using kcal is a simplification of a complex issue (see Appendix B). We need more broad measures of nutrition or to cover several nutrients (e.g. iron, zinc, vitamin A). We also need to move beyond average measures of consumption and consider the variability of food consumption across the population. There is also a temporal dimension to food security that is very important, as individuals may experience short periods of food insecurity that can be lost when analyzing at an annual or multi-year timestep. This would allow us to estimate the proportion of the population potentially consuming an inadequate amount of specific nutrients based on the Estimated Average Requirement cut-point method. Similarly, the use of commodities as the building blocks of diets is also an over-simplification. People generally do not consume raw commodities, as these undergo a variety of processes to become foodstuffs sold in markets. Raw commodities can be consumed as "core foods" (e.g. wholegrain foods, raw milk, yoghurt, cheese, raw fruit, fruit juice) or as "discretionary foods" (e.g. cakes, pastries, ice-cream, jam/marmalade) (Hadjikakou, 2017). Therefore, what we define here as a healthy diet is just a conceptual approximation.

While significant implications could be derived from the FABLE modelling work, robust identification of pathways towards a sustainable and resilient Australian FABLE system require a significant level of interaction with multiple stakeholders, decision makers, and scientists. Such an exercise is undergoing as part of the Land Use Futures project and expected to result in participatory-based scenarios that will be assessed through more robust modelling approaches that balance ambition and realism regarding the possible implementation of identified pathways.

Units

% – percentage
bln – billion

cap – per capita

CO_2 – carbon dioxide

CO_2e – greenhouse gas expressed in carbon dioxide equivalent in terms of their global warming potentials

GHG – greenhouse gas

Gt – gigatons

ha – hectare

kcal – kilocalories

kg – kilogram

kha – thousand hectares

km^2 – square kilometer

kt – thousand tons

Mha – million hectares

mln – million

Mt – million tons

t – ton

TLU –Tropical Livestock Unit is a standard unit of measurement equivalent to 250 kg, the weight of a standard cow

t/ha – ton per hectare, measured as the production divided by the planted area by crop by year

t/TLU, kg/TLU, t/head, kg/head- ton per TLU, kilogram per TLU, ton per head, kilogram per head, measured as the production per year divided by the total herd number per animal type per year, including both productive and non-productive animals

tln – trillion

USD – United States Dollar

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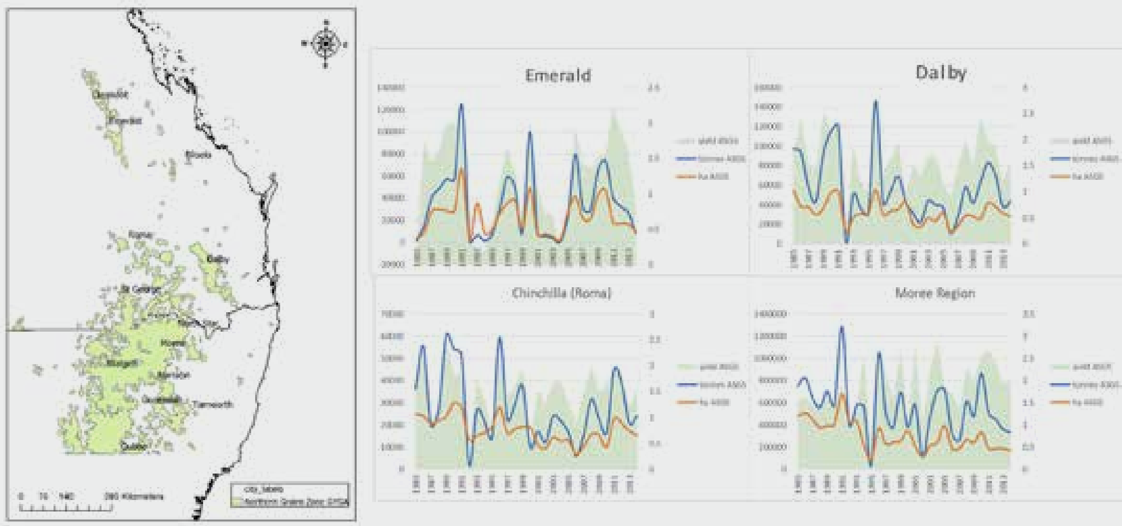
Appendix A. Spatially explicit modelling of crop productivity

Annual data from 1983 to 2010 (ABS, 2017) was used to investigate historical changes in average yields for each commodity. Yield comparisons were done at the statistical local area level (SLA, the smallest spatial unit during non-census years) as opposed to national yields, only for SLAs within main production areas (area sown > 500 ha). The growth in production performance of each SLA was calculated by calculating the difference in yield between the periods 1983-1987 and 2008-2012 (Figure A1). This enabled the investigation of region-specific production performance through time, which provides a more accurate reflection of yield growth to use as a basis for projection.

Figure A1 *Time-series of tons produced, hectares sown, and yield for wheat grown across several towns of Australia's Northern Grains Region. The charts highlight how area sown and productivity are affected by high inter-year variability in climatic conditions, including intense drought periods.*



Appendix B. Measuring food insecurity in Australia

McKay et al. (2019) reviewed 57 studies measuring food insecurity in Australia. They show that measures of food insecurity are heavily influenced by the method chosen, the population group studied, and location. Their review provides several insights into past measures of food insecurity. First, it is difficult to quantify the prevalence of food insecurity in Australia because of the differing methodologies between studies. The use of the single-item measure ("In the last 12 months was there any time you have run out of food and not been able to purchase more?") nationally has consistently measured around 5% in the two instances that national food insecurity has been measured (2005 and 2012), although the studies reviewed indicate the single-item measure underestimates food insecurity by at least 5%. Similar studies on the general public reported food insecurity of 8% in Melbourne and 7% in South Australia. It is likely that 5% prevalence of food insecurity in Australia's general population is a minimum for that measure, with a more correct answer being in the vicinity of 10%, and much higher for disadvantaged groups such as Indigenous Australians. Secondly, the USDA HFSSM method provides higher measures of food insecurity than studies using the single-item measure in general, but it remains a better way to measure food insecurity (albeit not perfect). For example, a Victorian study on food insecurity in the general public using the USDA method reported 29% food insecurity, over 3 times more than the single-item method. There was only one study reviewed that used the USDA method on the general public. Similarly, the HFNSS method (Kleve et al. 2018) reports higher prevalence of food insecurity again at 57%. This is likely due to the fact the HFNSS considers more dimensions of food insecurity than affordability (Kleve et al. 2018).

The review shows prevalence of food insecurity in vulnerable populations is far greater than the general population. The general public in socially disadvantaged areas of Sydney have a food insecurity prevalence of 16% (single item) or 22% (USDA). Urban Indigenous Australians are estimated to be 20-25% insecure, whereas remote Indigenous Australians are 76% insecure (both using single-item measures). This is 4 to 15 times more than the general population. Other groups that show the same trend include youth at risk or homeless, children, refugees, university students and people on low incomes.

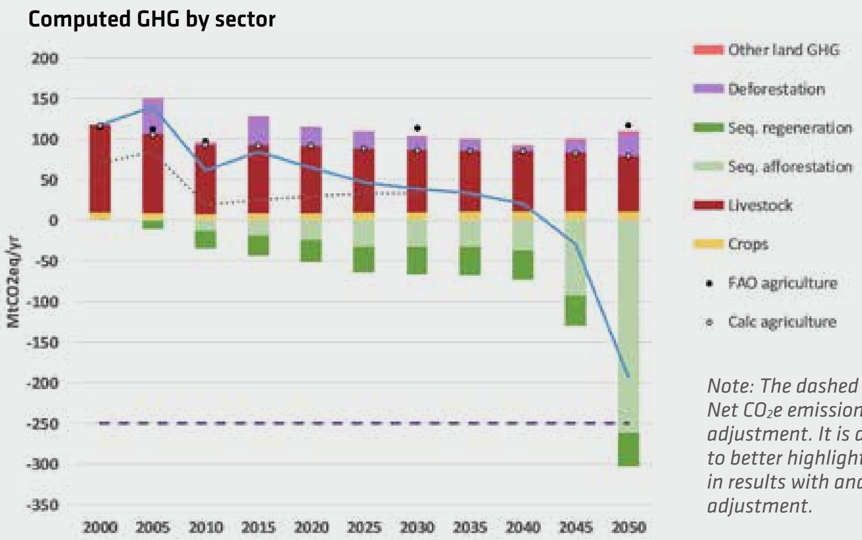
Appendix C. Other impacts of trade adjustment

GHG emissions

Trade adjustment produces a small variation in total GHG emissions (Figure C1). The 40% drop of beef exports compared to pre-trade-adjustment results causes a reduction in production which leads to total livestock emissions in 2050 to be 52 Mt CO_2eq/year, which is 25% less than the pre-trade-adjustment figure.

The decrease in pasture land (mirrored by increase in other land) produces an increase in regenerative sequestration of 50% relative to the pre-trade-adjustment scenario in 2050 (61 Mt CO_2e vs. 41 Mt CO_2e).

Figure C1 *Impact of trade adjustment on GHG emissions from agriculture and land use change*



Note: The dashed line shows the Net CO_2e emissions without trade adjustment. It is displayed here to better highlight the difference in results with and without trade adjustment.

Biodiversity

The growth in SLB conservation is faster from 2015 onwards than in the pre-trade-adjustment scenario (Figure C2). This causes every subsequent period to show a slightly larger percentage of SLB than the previous results, and it culminates in a 10% larger SLB area by 2050.

Figure C2 *Impact of trade adjustment on the share of total land which could support biodiversity conservation*