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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

The Food, Agriculture, Biodiversity, Land-Use, and Energy (FABLE) Consortium is convened as part of the Food and Land-Use Coalition (FOLU). It is led by the International Institute for Applied Systems Analysis (IIASA) and the Sustainable Development Solutions Network (SDSN), working closely with EAT, the Potsdam Institute for Climate Impact Research (PIK), and many other institutions.

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List of Acronyms

AFOLU	Agriculture, Forestry and Other Land Use
BAU	Business As Usual
DEFRA	Department for Environment, Food and Rural Affairs
CBD	Convention on Biological Diversity
CCC	Committee on Climate Change
COP	Conference of the Parties
DDPP	Deep Decarbonization Pathways Project
EU	European Union
FABLE	Food, Agriculture, Biodiversity, Land-Use, and Energy Consortium
FAO	Food and Agricultural Organization
FOLU	Food and Land-Use Coalition
G20	Group of 20 countries (Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, México, Russia, Saudi Arabia, South Africa, Korea, Turkey, the United Kingdom, United States and European Union)
GFW	Global Forest Watch
GHG	Greenhouse Gas
GLOBIOM	Global Biosphere Management Model
IAM	Integrated Assessment Model
IIASA	International Institute for Applied Systems Analysis
IDDRI	Institut du Développement Durable et des Relations Internationales
INDC	Intended Nationally Determined Contributions
IPCC	Intergovernmental Panel on Climate Change
LEDS	Low (greenhouse gas) Emission Development Strategies
LULUCF	Land Use, Land-Use Change, and Forestry
MAgPIE	Model of Agricultural Production and its Impact on the Environment
MDER	Minimum Dietary Energy Requirement
NDC	Nationally Determined Contributions
PIK	Potsdam Institute for Climate Impact Research
R&D	Research and Development
RoW	Rest of the World regions, covering countries that do not currently participate in the FABLE Consortium
SDG	Sustainable Development Goals
SLB	the Share of Land which can support Biodiversity
SDSN	Sustainable Development Solutions Network
SSP	Shared Socioeconomic Pathways
UNFCCC	United Nations Framework Convention on Climate Change

Contents

Preface

The Food, Agriculture, Biodiversity, Land-Use, and Energy (FABLE) Consortium is a collaborative initiative, operating as part of the Food and Land-Use Coalition, to understand how countries can transition towards sustainable land-use and food systems. In particular, we ask how countries can collectively meet associated Sustainable Development Goals (SDGs) and the objectives of the Paris Agreement. These objectives include food security and healthy diets for all, decent rural livelihoods, keeping the rise in average global temperatures to well below 2°C above pre-industrial levels, halting and reversing the loss of biodiversity, ensuring sustainable water use, and containing the pollution of water and air, including through excessive use of fertilizers. These objectives must be met in the context of the need for socioeconomic development and other competing demands on land for urbanization, industrial development, and infrastructure. In many countries indigenous peoples' land rights are being undermined by other groups. Moreover, countries need to consider the spillover effects of their food and land-use systems on other countries since trade has become a leading driver of environmental degradation and rising greenhouse gas emissions.

Meeting these targets at local, national, and global levels will require a profound transformation of land-use and food systems in every country. Such a transformation must cover many different sectors and proceed over the long-term, at least through to the middle of the century. The aim of the FABLE Consortium is to understand how such long-term transformations can be designed, what knowledge gaps must be filled, and how the transformations can guide shorter-term strategies towards sustainable land-use and food systems.

The international community has recognized the need for such long-term strategies. Governments around the world are preparing their mid-century, low-emission development strategies that were adopted in the Paris Agreement (Article 4.19). Our work directly supports these strategies. Members of the Consortium seek ways to raise the level of ambition in every country by demonstrating the feasibility of rapid progress towards the SDGs and the Paris objectives.

The FABLE Consortium currently comprises research teams from 18 countries, including the European Union. The teams are independent, so the analysis presented in this report does not necessarily reflect the views of their governments. Each country team develops the data and modeling infrastructure to promote ambitious, integrated strategies towards sustainable land-use and food systems. In particular, every team is preparing integrated, long-term "pathways" that describe the changes needed to achieve mid-century objectives. Collectively, consortium members aim to ensure alignment of these pathways with the global objectives under the 2030 Agenda for Sustainable Development and the Paris Agreement, as well as additional national objectives.

International trade leads to spillover effects which may increase or reduce the long-term sustainability of food and land systems. The strength of the FABLE Consortium lies in its capacity to consider the role of trade between a large number of countries and to test for alternative trade pathways that are compatible with national and global goals.

The FABLE project is led by the International Institute for Applied Systems Analysis (IIASA) and the Sustainable Development Solutions Network (SDSN), working closely with EAT, the Potsdam Institute for Climate Impact Research (PIK), and many other institutions. Members of the FABLE Consortium provide training and technical support to each other, and they collaborate to fill knowledge gaps in building FABLE pathways.

This first report was written collectively by members of the FABLE Consortium to outline initial findings. These include a shared approach towards framing and analyzing integrated strategies for land-use and food systems, an initial set of global targets to be achieved by mid-century, as well as preliminary country pathways for achieving these targets. The country pathways do not yet achieve all global targets, and we have identified the need for substantial improvements in data and analytical methods. In spite of its preliminary nature, the report represents the first coordinated effort by researchers from most G20 countries and other nations to chart long-term pathways towards sustainable land-use and food systems.

This report focuses on the feasibility of long-term transformation. It does not aim to address the policies needed to implement these transformations. These and other issues will be addressed in the global report of the Food and Land-Use Coalition, which will be released in New York in September 2019.

Over the coming years, members of the FABLE Consortium will improve data systems, analytical tools, and analyses of policy options for land-use and food systems. As part of the Food and Land-Use Coalition, we are working with interested governments to help improve policies and to develop long-term transformation strategies, including low-emission development strategies required under the Paris Agreement. Our work shows that these strategies need to target a range of objectives, including net-zero greenhouse gas emissions and protecting and restoring biodiversity. We plan to issue a second global report in 2020 in the run-up to the Conference of the Parties (COP) of the Convention on Biological Diversity (CBD) in China and the COP of the UN Framework Convention on Climate Change, when countries will submit their long-term low-emission development strategies.

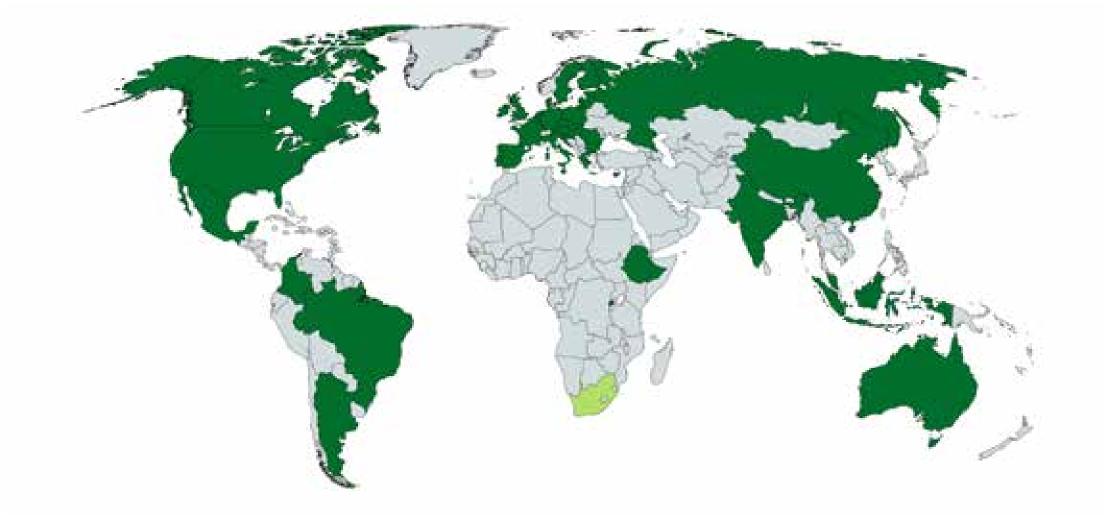
We welcome comments and suggestions for improving the work presented in this first report. And we invite research teams and other partners to join this consortium.

Executive Summary

The Food, Agriculture, Biodiversity, Land-Use, and Energy (FABLE) Consortium is a new knowledge network comprising research teams from 18 countries, including the European Union, that operates as part of the Food and Land-Use Coalition (www.foodandlandusecoalition.org). The FABLE project is led by the International Institute for Applied Systems Analysis (IIASA) and the Sustainable Development Solutions Network (SDSN), working closely with EAT, the Potsdam Institute for Climate Impact Research (PIK), and many other institutions. Each FABLE country team is responsible for its own analysis, and all coordinate to share lessons, ensure consistent trade flows, and align the sum of national pathways with the Sustainable Development Goals (SDGs) and the objectives of the Paris Agreement. A critical focus of the Consortium is to strengthen country teams' capacity to advise their governments on the design and implementation of long-term strategies towards sustainable land-use.

This first report by the FABLE Consortium presents preliminary pathways towards sustainable land-use and food systems prepared by the 18 country teams from developed and developing countries, including the European Union. The aim of these pathways is to determine and demonstrate the technical feasibility of making land-use and food systems sustainable in each country. They can also inform mid-century low-emission development strategies under the Paris Agreement on Climate Change. FABLE country teams have aimed for consistency with the SDGs and the Paris Agreement objectives. At this early stage, not all target dimensions have

FABLE country teams contributing to this report. A South African team has recently joined the Consortium but did not contribute to this report.



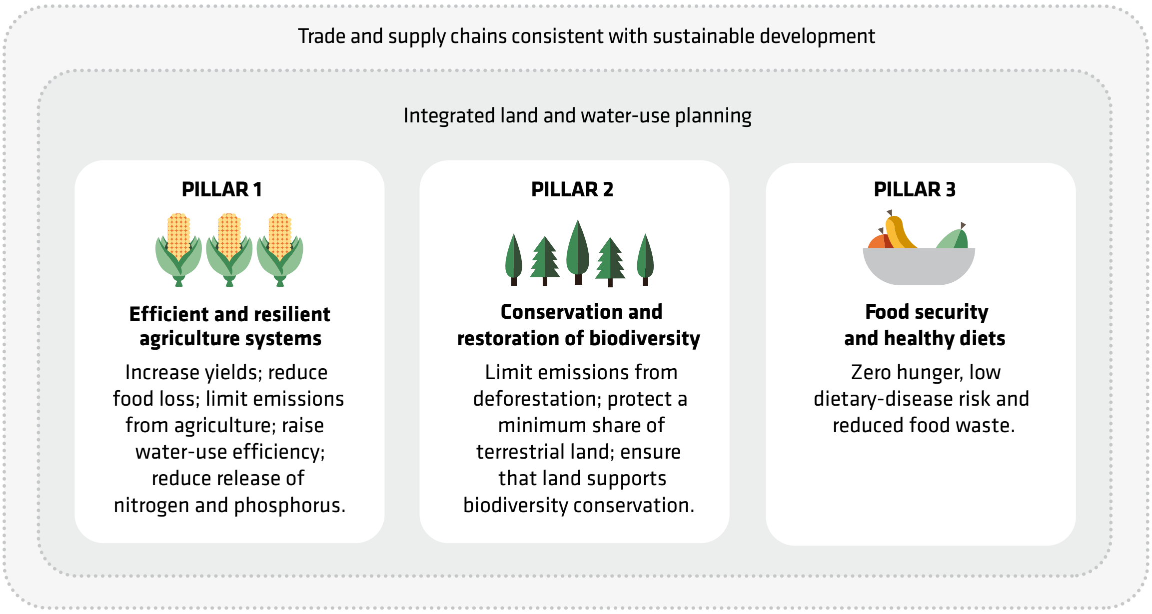
been considered. The report does not discuss policy options for transforming these systems, their implementation, or associated costs and economic benefits. These critical issues will be addressed in the global report by the Food and Land-Use Coalition, which will be published in September 2019 ahead of the Climate Summit convened by UN Secretary-General António Guterres.

This executive summary outlines the need for long-term pathways towards sustainable land-use and food systems and why a global FABLE network is needed. It then presents the FABLE approach, summarizes key findings, and describes the way forward.

The need for global pathways towards sustainable land-use and food systems

Today's land-use and food systems are unsustainable in developed and developing countries alike. Countries face an environmental crisis resulting from rapid biodiversity loss, greenhouse gas emissions, excessive nutrient outflows, chemical pollution, and water stress caused by today's land-use and food systems. The food system does not produce healthy nutrition. More than 820 million people are undernourished while 2 billion are overweight or obese, creating a health crisis. At the same time, predominant systems of agriculture and fisheries do not provide sustainable livelihoods, particularly for many farmers, herders, and fishermen. Finally, land-use and food systems are highly vulnerable to climate change, which threatens food supplies and ecosystem services in many countries.

Three pillars for integrated land-use and food systems must be assessed in the context of integrated land-use planning and sustainable international supply chains (Schmidt-Traub et al., 2019).



Solutions exist, but the transformation of land-use and food systems requires long-term strategies, as called for in the Paris Agreement. While there is a great urgency to act, short-term strategies alone cannot address the drivers of change and are indeed likely to lock countries into unsustainable practices, as has been well documented in the case of energy systems. Recognizing this, Article 4.19 of the Paris Agreement invites governments to submit long-term low-emission development strategies by 2020, which should in turn inform shorter-term strategies, including the Nationally Determined Contributions. Countries need two connected long-term strategies. One for energy systems, as described by the Deep Decarbonization Pathways Project, and a second one for land-use and food systems, which is the focus of the FABLE Consortium. Without these long-term strategies, countries will be unable to align short-term policies and investments with the long-term objectives of the SDGs and the Paris Agreement.

Countries need an integrated framework to understand and address challenges to their land-use and food systems. Following extensive consultations with the FABLE country teams and other experts, the FABLE Consortium proposes three pillars for action: in the figure "*Performance metrics of the computed pathways across the three FABLE pillars*" (1) efficient and resilient agriculture systems, (2) conservation and restoration of biodiversity, and (3) food security and healthy diets. They must be complemented by integrated land- and water-use planning to address competing demands on land and water (e.g. from urbanization, industry, and infrastructure). International trade can have profound implications on countries' land-use and food systems, so international supply and demand must be considered in framing national strategies. Each component of this framework is equally important, and all are interdependent and synergistic. They must also operate over the near and long-term. Naturally, the pillars should be tailored to each country, taking into account local constraints and priorities.

The FABLE Consortium has identified global mid-century targets for sustainable land-use and food systems, that are based on existing international commitments and the latest science. We do not propose national-level targets, since these will need to be determined by countries themselves. Instead we focus on global benchmarks that must be met in order to ensure that food and land-use systems around the world become sustainable. Most of the proposed targets are biophysical in nature because they define a safe operating space for social and economic objectives which are highly country specific and which should become a globally compatible national narrative of change. Meeting all the targets will require profound transformations in every country's land-use and food systems in a short period of time. As the work of the FABLE Consortium progresses, members aim to ensure that the sum of their national pathways will achieve all targets outlined in the table "*Proposed global targets for sustainable land-use and food systems*".

Long-term pathways are a method for problem solving for countries to understand how the targets can be achieved and to build consensus for strategies to achieve them. Pathways work backwards from the mid-century targets and specify the interventions needed to achieve them. They help in three critical ways: (1) they provide a framework for engaging stakeholders (governments, businesses, civil societies and the scientific community), to review, pose questions and suggest improvements for how to achieve the targets, which can build a societal consensus for the transformations; (2) without a long-term perspective countries risk locking themselves into unsustainable infrastructure and land-use systems, which would make achieving the mid-

Proposed global targets for sustainable land-use and food systems.

AREA	GLOBAL TARGET
Food security	**Zero hunger** *Average daily energy intake per capita higher than the minimum requirement in all countries by 2030*
	Low dietary disease risk *Diet composition to achieve premature diet related mortality below 5%*
Greenhouse gas emissions	**Greenhouse gas emissions from crops and livestock compatible with keeping the rise in average global temperatures to well below 1.5°C** *Below 4 $GtCO_2e$ yr^{-1} by 2050*
	Greenhouse gas emissions and removals from Land Use, Land-Use, Land-Use Change, and Forestry (LULUCF) compatible with keeping the rise in average global temperatures to below 1.5°C *Negative global greenhouse gas emissions from LULUCF by 2050*
Biodiversity and ecosystem services	**A minimum share of earth's terrestrial land supports biodiversity conservation** *At least 50% of global terrestrial area by 2050*
	A minimum share of earth's terrestrial land is within protected areas *At least 17% of global terrestrial area intact by 2030*
Forests	**Zero net deforestation** *Forest gain should at least compensate for the forest loss at the global level by 2030*
Freshwater	**Water use in agriculture within the limits of internally renewable water resources, taking account of other human water uses and environmental water flows** *Blue water use for irrigation <2453 km^3yr^{-1} (670-4044 km^3yr^{-1}) given future possible range (61-90%) in other competing water uses*
Nitrogen	**Nitrogen release from agriculture within environmental limits** *N use <69 Tg N yr^{-1} total Industrial and agricultural biological fixation (52-113 Tg N yr^{-1}) and N loss from agricultural land <90 Tg N yr^{-1} (50-146 Tg N yr^{-1}) by 2050*
Phosphorous	**Phosphorous release from agriculture within environmental limits** *P use <16 Tg P yr^{-1} flow from fertilizers to erodible soils (6.2-17 Tg P yr^{-1}) and P loss from ag soils & human excretion <8.69 Tg P yr^{-1} flow from freshwater systems into ocean by 2050*

century targets far more costly if not impossible; (3) they help identify mid-term technology benchmarks needed to achieve the targets, such as increases in agricultural productivity or efficiency gains in livestock, which can then guide business action and innovation challenges. Long-term pathways are critical for success, and FABLE's mission is to develop the tools to prepare them.

Why the FABLE network is needed

A global network of national knowledge institutions is needed to support countries in making their land-use and food systems sustainable. Three major challenges stand out for why we have come together as the Food, Agriculture, Biodiversity, Land-Use, and Energy

(FABLE) Consortium as part of the Food and Land-Use Coalition.

First, countries need to build domestic capacity to develop integrated pathways covering the three pillars. Strategies and long-term pathways towards sustainable land-use and food systems must integrate across agronomy, nutrition, ecology, hydrology, climatology, economics, infrastructure engineering, the social sciences, and of course the local politics. Yet, most countries do not have such integrated policies and to our knowledge none have long-term pathways towards sustainable food and land-use systems covering all three pillars. Many lack the analytical tools to understand the complex synergies and trade-offs across these areas and to determine which short-term measures must be undertaken in order to achieve long-term objectives. Just as it is impossible to design and implement economic policies without sound macroeconomic models, countries will not be able to make their land-use and food systems sustainable without robust tools to model the integrated impacts of policies. Some countries undertake isolated measures, but these do not add up to a strategy for making land-use and food systems sustainable.

Second, national strategies must consider international markets for food and non-food commodities since these can have major implications for national land-use choices as well as the affordability of food and animal feed. For example, rising international demand for feed, particularly from Asia, has been driving large-scale land-use change across much of Latin America. Similarly, US and European domestic biofuel mandates are seen as a major driver of the expansion of palm oil plantations in South-East Asia. For country teams to better understand these drivers they need to be part of a global network involving their major bilateral trading partners.

Third, knowledge on the technologies and policies that can make food and land-use systems sustainable must be shared across countries. To develop long-term pathways towards sustainable food and land-use systems, countries need to access deep expert knowledge from a broad range of fields. A global knowledge network of national institutions can share lessons and deepen the understanding in every country of how its food and land-use systems can be transformed to meet the SDGs and implement the Paris Agreement.

The FABLE approach

The FABLE Consortium supports country teams to develop rigorous, transparent pathways towards sustainable land-use and food systems. We aim to demonstrate the feasibility of rapid progress and help raise the level of ambition towards the SDGs and the objectives of the Paris climate agreement. To this end, the consortium pursues three broad sets of activities

1. **Capacity development and sharing of best practices** for data management, simplified models of the three pillars that facilitate engagement with stakeholders, and more complex, spatially-explicit models that cover the three pillars, other uses of land, as well as international trade.

2. **Development of mid-century national pathways** that can collectively achieve the jointly agreed global targets and have consistent trade assumptions.

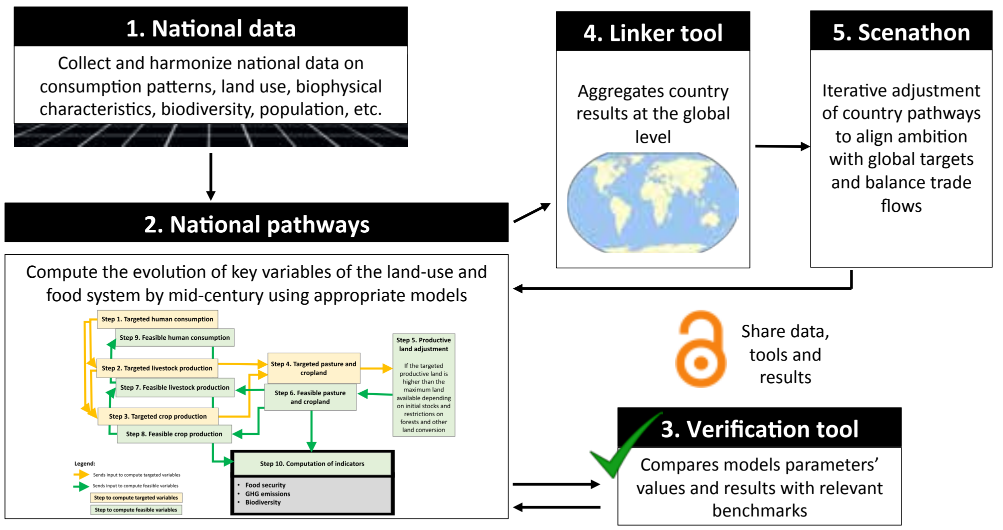
3. **Analysis of national policy options and support to national and international policy processes** will be undertaken over the coming year.

We have developed a new method for preparing national pathways that are consistent with global targets and ensure trade flows balance across countries. It involves five steps described in the figure "*Major steps in the FABLE method for developing national pathways*" country teams prepare national data (1) on their food and land-use systems. They develop national pathways (2) using a simplified Excel-based tool, the publicly available FABLE Calculator, or more advanced spatially-explicit partial-equilibrium tools, such as IIASA's Global Biosphere Management Model (GLOBIOM) or PIK's Model of Agricultural Production and its Impact on the Environment (MAgPIE) models. Following validation of the data and results (3) the national results are aggregated with a Linker tool (4) to determine whether the sum of projected exports for each commodity equals the sum of imports. The Linker Tool also checks if the sum of national pathways achieves the global targets for sustainable land-use and food systems. (5) In an iterative process ("Scenathon") country teams adjust their assumptions and pathways to ensure balanced trade flows and to aim towards achieving the global targets.

Key findings and policy implications

This is the first time that a broad group of country teams have collaborated to develop integrated national pathways towards sustainable land-use and food systems that are consistent with global objectives. To ensure global coverage, results have been computed as the sum of results extracted from the 18 national FABLE Calculators and seven Rest of the World regions. Using the Linker tool trade imbalances were identified and adjusted through a "Scenathon" involving all FABLE country teams.

Major steps in the FABLE method for developing national pathways.



Though preliminary and incomplete, our findings show that tremendous progress can be made towards the FABLE targets. The pathways presented in this report suggest that it is feasible to achieve four out of the five targets considered: average energy intake can be above the minimum dietary energy intake in all FABLE countries by 2030; zero net global deforestation can be achieved from 2030 onwards; by 2050 net greenhouse gas emissions from land use change can be negative; and more than 50 percent of the global terrestrial land can be spared to conserve and restore biodiversity. This first iteration of country pathways makes insufficient progress towards reducing greenhouse gas emissions from agriculture. Closing this achievement gap will be a major priority of future work by the FABLE Consortium.

The feasibility of rapid progress towards the FABLE objectives is driven largely by six factors: (1) large gains in agricultural productivity; (2) shifts in diets towards less meat consumption, with reductions in food overconsumption; (3) a

Performance metrics of the computed pathways across the three FABLE pillars.

Trade consistent with sustainable development

Integrated land use planning

PILLAR 1

Efficient and resilient agriculture systems

Average productivity growth in kcal/ha agricultural land:
+ 56% between 2010 and 2050 globally

Global GHG emissions from crops and livestock:
6 Gt CO2e in 2050

Global GHG emissions from land use change:
-1.6 Gt CO2e in 2050

PILLAR 2

Conservation and restoration of biodiversity

Global deforestation:
1.6 Mha/year in 2050

Net global forest cover change:
+1.6 Mha/year in 2050

Cumulated global afforested land:
191 Mha in 2050

Share of total land which could support biodiversity:
57% of global land in 2050

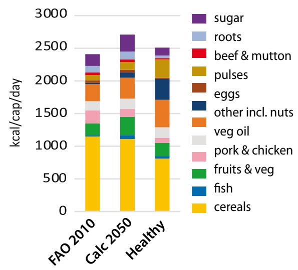
Range across FABLE countries 16% - 82%

PILLAR 3

Food security and healthy diets

Food security:
Average energy intake > minimum requirement from 2030 onwards in all FABLE countries

Average diet in FABLE countries:



slow-down in population growth; (4) reduced food loss; (5) stable per-capita demand for non-food products including bioenergy production; and (6) the resulting fall in demand for pasture and cropland at the global level. These shifts allow for both greater conservation and restoration of ecosystems with resultant impacts on increased carbon sequestration, biodiversity conservation and restoration. It is notable that country teams individually vary in the assumptions they make about the feasibility and desirability of changes to their food systems. For example, teams make different assumptions about desirable and feasible dietary changes across countries, reflecting local traditions, customs, and resource endowments. This demonstrates the importance of country-driven analyses of land-use and food systems as presented in this report.

Our initial results show that it is possible to achieve sustainable land-use and food systems, but countries need to address all three pillars and adopt a long-term perspective. The figure "*Performance metrics of the computed pathways across the three FABLE pillars*" highlights key performance metrics for efficient and resilient agricultural systems, conservation and restoration, and food security and healthy diets. The country teams consider these changes feasible, but they are highly ambitious and will require strong policies and greater investments in food and land-use systems. Results from the FABLE Consortium also show that governments must design analytical instruments and policies to develop their land-use with a long-term perspective to avoid locking themselves into unsustainable land-use and food systems that would be very difficult and costly to reverse later.

The results also demonstrate the critical impact of trade on both importing as well as exporting countries. Relatively small changes in one country's policies can have a profound impact on land-use and food systems in other countries. Therefore, countries will need to consider trade in their medium and long-term strategies. This, in turn, requires an understanding of what is happening within the national settings of major bilateral trading partners, which the FABLE Consortium provides.

Spatially-explicit analyses are needed to understand and manage competing uses of land from agriculture, livestock, forestry, industry, urban development, disaster risk reduction, and ecosystem services, including biodiversity and the retention and capture of carbon for climate change mitigation.

Countries will have an opportunity to promote integrated strategies for climate and land-use at the September 2019 Climate Summit convened by UN Secretary-General Antonio Guterres. Since food systems and land-use change account for just under one third of greenhouse gas emissions, governments that are developing long-term low-emission strategies under the Paris Agreement will need to consider all three pillars for sustainable land-use and food systems alongside the decarbonization of energy systems. China's recently adopted Ecological Conservation Redlines and its Agricultural Redlines provide an example of the type of spatial policies that should be included in mid-century climate strategies.

Next steps for the FABLE Consortium

Launched some 18 months ago, the FABLE Consortium has become a unique global network of country teams focused on understanding how countries can develop long-term strategies towards sustainable land-use and food systems. With other members of the Food and Land-Use Coalition we have made substantial progress in understanding how this can be achieved. We now also see more clearly how to strengthen in-country capacity for developing the strategies. The Food and Land-Use Coalition will describe policy options in a global report to be launched in New York in September 2019.

The FABLE Consortium will pursue five steps to strengthen its work and support governments and other stakeholders in making food and land-use systems sustainable.

1. **Build capacity in countries to improve national pathways using advanced, spatially-explicit data and models, including GLOBIOM, MAgPIE, or other tools.**

2. **Engage stakeholders at national and sub-national levels around the design of long-term pathways and supporting policies towards sustainable land-use and food systems.**

3. **Support country teams in applying their models to test policies and improve their design by simulating the impact of policy options across the three pillars of sustainable land-use and food systems.**

4. **Improve the scope and methodology of the FABLE Scenathon.**

5. **As part of the Food and Land-Use Coalition, work with partners around the world to launch a Food and Land-Use Action Tracker that helps countries benchmark their policies against those pursued elsewhere and to learn from experiences in other countries.**

1. The challenge of unsustainable land-use and food systems

Countries have made tremendous progress in growing more food. Per capita food availability has risen sharply since the middle of the last century despite a more than doubling of the global population (Willett et al., 2019). Yet, today's food and land-use systems face a crisis with at least four dimensions – often invisible and sometimes outside countries' own borders – that are rarely connected and mostly underappreciated by governments, business, and the public. These include (1) an environmental crisis, including climate change, (2) a health crisis driven by poor nutrition and unhealthy food, (3) a rural livelihoods crisis in many countries, and (4) food systems that are highly vulnerable to climate change. These crises are driven by population growth and rising demand for food and feed, high food waste and losses in supply chains, poor technological choices, greenhouse gas emissions, poor or inexistent national policy frameworks, corporate actions that are not aligned with the Sustainable Development Goals (SDGs), and a lack of effective international cooperation and standards.

1.1. The environmental crisis

Food production and the farming of cotton, biofuels, and other non-food products from agriculture and forestry are the biggest drivers of environmental degradation in developed and developing countries. Half the world's tropical forests have been cleared, and we continue to lose about 18 million hectares per year – an area the size of England and Wales. Biodiversity loss now occurs at 1000 times the normal background rate (De Vos et al., 2015), and populations of major species have fallen by some 60 percent since 1970 (WWF, 2018). Rising per capita demand for meat and dairy products increases human demand for land further, yet as the world population increases from 7.6 billion to an estimated 11 billion by the end of the century, there is little room to expand agriculture further without undermining critical environmental and climate objectives.

Intensive farming methods, including the growing reliance on chemicals, are key drivers of the loss of some 80 percent of insects in Germany since the late 1980s (Vogel, 2017). Similar trends have been reported around the world (Sánchez-Bayo and Wyckhuys, 2019). Agriculture, food processing, and the resulting land-use change are responsible for just under a third of global greenhouse emissions (Poore and Nemecek, 2018). Humans also catch unsustainable volumes of wild fish with a third of commercial fisheries classified as over-fished. In little over half a century, humans have wiped out 90 percent of the populations of top predator fish, such as tuna, swordfish, and sharks. And destructive fishing techniques, such as bottom trawling, cause massive damage to coastal and marine ecosystems (McCauley et al., 2015).

Half the world's population is expected to experience high water stress by 2030, and agriculture accounts for two thirds of water use (FAOSTAT, 2019). Since irrigation is particularly common in water scarce regions, the sector is responsible for 90-95 percent of scarcity-weighted water use (Poore and Nemecek, 2018). Finally, the food system drives at least three quarters of nitrogen release that drives algae blooms and dead zones in freshwater ecosystems and the ocean. It has been estimated that the release of reactive nitrogen is already twice the maximum sustainable level (Steffen et al., 2015), and similar concerns apply to phosphorous. Increased nutrient concentration in the oceans combined with other water pollution and rising temperatures from climate change put high stress on marine ecosystems. During a heat wave in 2016-2017, some 90 percent of the Great Barrier Reef was affected, and half the corals died (Ortiz et al., 2018).

1.2. Today's food makes people sick

Today's food systems do not provide adequate and healthy nutrition to many people. Dietary risks account for 20 percent of premature mortality globally, and more than 820 million people are undernourished (FAO, IFAD, UNICEF, WFP and WHO, 2019). Over 160 million children under the age of five are stunted and suffer from permanent cognitive underdevelopment. Inadequate food has become the leading cause of human mortality through increased obesity, cardiovascular diseases, cancer, Type II diabetes, and other health conditions. Some 2 billion people suffer from micronutrient deficiencies, and an estimated 41 million children under the age of five are now overweight (Afshin et al., 2019; (FAO, IFAD, UNICEF, WFP and WHO, 2019).

The contrast between the food we produce globally with what humans ought to be eating is stark. For example, we produce almost five times too much red meat and about 50 percent too much starch, compared with the Planetary Health Diet (Willett et al., 2019). While patterns of over and under consumption of meat are highly regional, there is a nearly universal underconsumption of protective foods, including whole grain, nuts and seeds, fruits, and vegetables. The discrepancies between healthy and actual diets are even more extreme in some regions and countries.

1.3. The livelihoods crisis

An estimated 767 million people continue to live on less than US$1.90 per day (World Bank, 2016). Most of the world's extreme poor and vulnerable live in rural areas (Olinto et al., 2013), where many depend on food production and the harvesting of natural resources for their livelihoods. Poverty tends to be particularly high among smallholder farmers and the landless. Low productivity of smallholder agriculture, limited access to markets, and high vulnerability to extreme weather events make it impossible for many rural poor to escape extreme poverty – a problem that has not markedly improved with increasingly international agricultural value chains.

If unsustainable land-use and food systems are a big part of the rural livelihoods crisis, they can also be a big part of the solution. Many examples exist of large-scale improvements in rural livelihoods through more productive, more diverse, and more ecological approaches to farming. Examples are the Zero Budget Natural Farming program in Andhra Pradesh (India) and the work of the One Acre Fund across much of sub-Saharan Africa. Some companies, such as Unilever and Olam, have also started to integrate smallholder farmers into their supply chains. A critical question therefore is whether and how such efforts can be replicated and scaled up to improve rural livelihoods.

1.4. Highly vulnerable food system

The food system is also uniquely vulnerable to global warming and other environmental change. Every decade, global warming pushes climate zones towards the poles by over 50km (Masson-Delmotte et al., 2018). The changing climate will disrupt pollination and pest regulation services provided by biodiversity. This may have severe health implications, since increasing the production of the protective foods, fruits, nuts, and vegetables, called for by the public health community, is particularly sensitive to pollination services (Chaplin-Kramer, Dombeck et al. 2014). Increased droughts, storms, and floods threaten food production in many parts of the world.

Average yields, particularly in warmer climates, are expected to fall sharply under a business-as-usual scenario, though it is difficult to predict the magnitude (Masson-Delmotte et al., 2018).

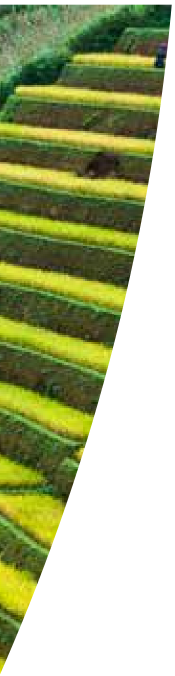
A different form of vulnerability derives from decarbonizing energy systems. Many pathways towards net-zero greenhouse gas emissions from energy presented by the Intergovernmental Panel on Climate Change (Masson-Delmotte et al., 2018) recommend a massive expansion of power generation from biofuels – sometimes in conjunction with carbon capture and storage – and other mitigation strategies that demand land. Such strategies threaten to add to the pressures on land-use and food systems by increasing demand for agricultural land, irrigation water, and chemical pollution (Obersteiner et al., 2018).

1.5. How FABLE is addressing each crisis

Over time the FABLE Consortium aims to address all four crises. Owing to the long-term focus of our initial analysis, we have for now concentrated on the environmental and the health/nutrition crisis. Curbing greenhouse gas emissions from agriculture and land-use change, and increasing carbon sequestration through nature-based solutions, will make a major contribution towards reducing the vulnerability of the food system. Additional measures will be needed, which FABLE country teams will consider in the future, as well as more granular analyses of their countries' food and land-use systems.

Finally, the livelihood crisis is the result of poor policy choices and insufficient investments in land-use and food systems, but it is also driven by the lack of urban-based jobs and global oversupply for certain agricultural commodities. The challenges are highly diverse across countries, and countries vary in their objectives. Depending on the value chains and geographies which are prioritized, the transformation of the agricultural sector might rely on smallholder farms, larger landholdings or both, and will require different types of investment (Caron et al., 2018). Agriculture accounts for a large share of the economy in many developing countries, yet in other countries it accounts for a very small share of employment, and in some cases these jobs are heavily subsidized. For these reasons, it is difficult to agree on global targets for livelihoods, and analytical tools need to differ from one country to the next. In future iterations of the FABLE work, we aim to strengthen analytical tools that investigate the relationship between rural livelihoods and the biophysical land-use systems, so that interested countries can more clearly understand options for improving livelihoods.

2. Organizing the transformation of land-use and food systems

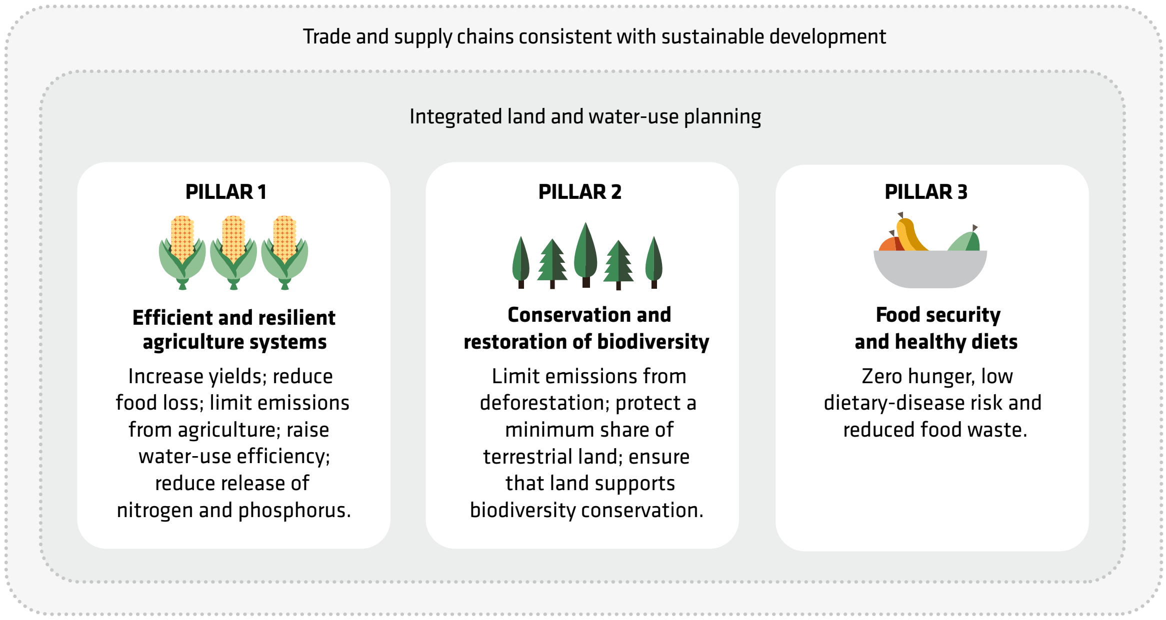


The good news is that solutions exist to address the four interconnected crises of land-use and food systems, which include non-food crops, such as fibers and animal feed. Success will require integrated strategies that are mindful of trade-offs, as they may occur between, for example, increasing agricultural production and environmental sustainability. Piecemeal approaches that focus, say on agricultural productivity without regards to environmental impact cannot work. So, first, countries need a shared, integrated framework for organizing their strategies. They also need time-bound targets to help guide long-term action and mobilize stakeholders. And finally, countries require pathways as a method for problem solving on the way towards sustainable land-use and food systems. We briefly describe these three components in this section.

2.1. An integrated framework for action

The FABLE Consortium has identified three pillars for designing integrated strategies to achieve sustainable land-use and food systems (Figure 1). Each pillar covers essential priorities in transforming food and land-use systems that require profound changes from business-as-usual practices. Each is equally important, and all are interdependent and synergistic. They must also operate over the near and long-term. Naturally, the pillars should be tailored to each country, take account of local constraints, and be complemented with local priorities.

Figure 1 *Three pillars for integrated land-use and food systems must be assessed in the context of integrated land-use planning and sustainable international supply chains (Schmidt-Traub et al., 2019).*



Pillar 1: Efficient and resilient agricultural systems and fisheries that support livelihoods.
Major increases are needed in yields and resource efficiency (nutrients, water, greenhouse gas emissions, chemicals, post-harvest losses) of cropping systems, livestock, aquaculture, fisheries, forestry, and biofuel production. In some cases, efficiency may be sacrificed for multifunctionality. For example, certain forestry and livestock production systems may be more compatible with climate, biodiversity, and water objectives but have lower efficiencies and yields. Agricultural production systems must also reduce their environmental impact by becoming more regenerative, increase resilience and adaptive capacity to climate change, and support livelihoods of farmers through intercropping, agroforestry, creating habitat, more careful use of chemicals, and other regenerative measures.

Pillar 2: Conservation and restoration of forests, terrestrial and marine biodiversity.
Forests, soils, peatlands, wetlands, savannahs, inland water systems, coastal marine areas, and oceans all deliver vital ecosystem services, including biodiversity. Collective action is needed to reduce or halt land conversion and the loss of terrestrial and marine biodiversity, conserve and restore forests, grasslands, wetlands, and other degraded ecosystems, improve soil carbon, and unlock the mitigation, sequestration, and ecosystem service potential of these lands.

Pillar 3: Healthy diets, nutrition, and reduced food waste.
Countries, companies, and consumers need to reduce food waste and shift towards healthy diets (e.g. healthy meat consumption; greater fruits, nuts, vegetables, and whole grain consumption) to end undernutrition, malnutrition, and obesity across all population segments; improve health; reduce food overconsumption. Increasing dietary diversity, smaller portion sizes, better access to and affordability of healthy foods can help drive the transition to healthy diets. Plant-based proteins can substitute for animal proteins (beans, lentils, and nuts) in countries where meat is overconsumed to reduce the environmental footprint and improve health outcomes.

Trade and supply chains consistent with sustainable development.
Trade can enhance national food security and promote sustainable development across national boundaries. This can be achieved, for example, by ensuring that commodities are produced in line with national standards and international agreements, and that environmental, social and economic costs are fully factored into the prices of commodities. Moreover, exporting and importing countries need better information on long-term trends in demand and supply of key agricultural commodities to identify risks and opportunities from trade.

Integrated land-use planning and water management approaches.
Countries need to anticipate and manage competition and trade-offs across different land and water uses through integrated approaches to the planning, allocation, and regulation of the use of land and water for sustainable development. Such approaches must include agriculture, energy, infrastructure, industry, cities, environmental protection, and other priorities.

These pillars contribute directly to the achievement of the SDGs, as described in The World in 2050 (TWI2050, 2018). Several SDG priorities fall outside the immediate scope of sustainable land-use and food systems, but they are interdependent. Examples include decarbonization of energy systems, demography and urbanization, broader health outcomes, and educational attainment. Others, such as extreme poverty or gender equality, are indirectly affected by changes to food and land-use systems.

2.2. Targets for sustainable land-use and food systems

Time-bound, quantitative benchmarks can guide long-term action and help ensure that all three pillars are pursued equally at global, national, and local levels. Ultimately, national policies and local action will drive the shift towards sustainable land-use and food systems, so these need to be anchored in and directed towards national targets. The sum of national targets must be consistent with ensuring the stability of the Earth system. Some authors refer to such global benchmarks as planetary boundaries (Rockström et al., 2009; Steffen et al., 2015).

This report does not propose national-level targets, as these will need to be determined by countries themselves. Instead we focus on global benchmarks that must be met in order to ensure that food and land-use systems around the world become sustainable. Since the SDGs do not specify quantitative benchmarks for sustainable land-use and food systems, the targets must be derived from science.

Following a careful review of the scientific literature and extensive discussions among FABLE Consortium members, we propose four criteria for selecting global targets:

1. **As few targets as possible:** Land-use and food systems are highly context specific with major difference resulting from agroecology, geography, economic development, culture, history, and countless other factors. Yet, meeting multiple targets simultaneously is highly complex. To allow for maximum flexibility at the country level, targets should be parsimonious. Each country can select additional target variables to meet its specific needs.

2. **Focus on mid-century targets:** The target date 2050 is sufficiently distant so that complex transformations can be tackled, yet near enough to be meaningful for national policy discussions and to inform key policy priorities, such as technological change, with sufficient rigor and granularity.

3. **Ideally use science-based targets that have been politically agreed:** Global targets for sustainable land-use and food systems need to be informed by science, but experience with science-based targets shows that setting targets involves an element of discretion. Where possible, we have used politically agreed goals that are grounded in currently available science, such as the Paris Agreement objective on climate change mitigation. Where such politically agreed targets do not exist, we specify target values based on a review of the scientific literature, of international agreements, and intensive discussions within the FABLE Consortium.

4. **Scalable targets:** Making land-use and food systems sustainable will require deep changes at local, national, regional, and global levels. Local action drives land-use at the landscape level, but many agricultural and forestry products are traded internationally, international demand can have profound implications for national land-use decisions. As one example, land-use in New Zealand has been affected heavily by China's demand for dairy products. Hence targets need to be framed in such a way that they can be scalable from the local to the global level.

Table 1 summarizes the targets adopted by members of the FABLE Consortium. To address the four challenges of unsustainable land-use and food systems, these targets need to cover several areas: food security, greenhouse gas emissions,

Table 1 *Proposed global targets for sustainable land-use and food systems. Select references included in the table.*

AREA	GLOBAL TARGET	JUSTIFICATION
Food security	**Zero hunger** *Average daily energy intake per capita higher than the minimum requirement in all countries by 2030*	Based on SDG 2 and literature review (Springmann et al., 2016; Laborde et al., 2016)
	Low dietary disease risk *Diet composition to achieve premature diet related mortality below 5%*	EAT-Lancet and Global Burden of Disease Collaboration reports (Afshin et al., 2019; Willett et al., 2019)
Greenhouse gas emissions	**Greenhouse gas emissions from crops and livestock compatible with keeping the rise in average global temperatures to below 1.5°C** *Below 4 $GtCO_2e$ yr^{-1} by 2050*	Based on literature review: 3.9 Gt for non-CO_2 emissions and 0.1 for CO_2 emissions (Hadjikakou et al., in preparation)
	Greenhouse gas emissions and removals from Land-Use, Land-Use Change, and Forestry (LULUCF) compatible with keeping the rise in average global temperatures to below 1.5°C *Negative global greenhouse gas emissions from LULUCF by 2050*	Based on literature review (Griscom et al., 2017; Rogelj et al., 2018; Popp et al., 2017). Due to large uncertainties and lack of clarity on the sources of LULUCF emissions/removals which are accounting for in the different articles, we prefer not using precise number at this stage.
Biodiversity and ecosystem services	**A minimum share of earth's terrestrial land supports biodiversity conservation** *At least 50% of global terrestrial area by 2050*	(Dinerstein et al., 2017; Noss et al., 2012; Wilson, 2016)
	A minimum share of earth's terrestrial land is within protected areas *At least 17% of global terrestrial area by 2030*	Aichi Target 11 and Maron et al. (2018)
Forests	**Zero net deforestation** *Forest gain should at least compensate for the forest loss at the global level by 2030*	Aichi Target 5; SDG 15; New York Declaration on Forests
Freshwater	**Water use in agriculture within the limits of internally renewable water resources, taking account of other human water uses and environmental water flows** *Blue water use for irrigation <2453 km^3yr^{-1} (670-4044 km^3yr^{-1}) given future possible range (61-90%) in other competing water uses*	Based on literature review (Hadjikakou et al., in preparation)
Nitrogen	**Nitrogen release from agriculture within environmental limits** *N use <69 Tg N yr^{-1} total Industrial and agricultural biological fixation (52-113 Tg N yr^{-1}) and N loss from agricultural land <90 Tg N yr^{-1} (50-146 Tg N yr^{-1}) by 2050*	Based on literature review (Hadjikakou et al., in preparation)
Phosphorous	**Phosphorous release from agriculture within environmental limits** *P use <16 Tg P yr^{-1} flow from fertilizers to erodible soils (6.2-17 Tg P yr^{-1}) and P loss from ag soils & human excretion <8.69 Tg P yr^{-1} flow from freshwater systems into ocean by 2050*	Based on literature review (Hadjikakou et al., in preparation)

biodiversity and ecosystem services, forests, freshwater, nitrogen and phosphorous. We are grateful to members of the Australian FABLE team for their contribution to developing these targets. biodiversity and ecosystem services, forests, freshwater, nitrogen and phosphorous.

The proposed targets are mainly biophysical in nature because they define a safe operating space for social and economic objectives which are highly country specific. For example, some countries have large and growing numbers of smallholder farmers that lack income opportunities outside of agriculture, while others experience a fall in the rural population and pressure to merge farms. In our view, it is not possible to frame economic objectives at a global level, so this should be done by countries. The SDGs span of course the biophysical, social, and economic domains, which makes them a critical framework for the FABLE work.

The FABLE targets are very ambitious, and there are trade-offs between some of the objectives. Meeting all the targets will require profound transformations in every country's land-use and food systems in a short period of time. Today's rates of progress are not only too low, but most countries are moving in the wrong direction on the key target domains: food security and diets (Afshin et al., 2019; Willett et al., 2019), greenhouse gas emissions (Le Quéré et al., 2018), biodiversity (WWF, 2018; IPBES, 2019), freshwater (FAO, 2019), nitrogen (Stevens, 2019), and phosphorous (Steffen et al., 2015).

We do not subscribe to the view held by some that it is impossible to achieve these targets and that they should therefore be weakened or dropped altogether. There is strong evidence that feeding 11 billion people a healthy diet within environmental limits is completely possible (Springmann et al., 2018; Willett et al., 2019). Success will require national pathways that are globally consistent (Schmidt-Traub et al., 2019). The aim of this report is to contribute to our understanding of how these targets can be met globally and in every country.

2.3. Pathways as a method for problem solving

In Article 4.19 of the Paris Agreement countries committed to prepare and present, by 2020, low-emission development strategies for meeting sustainable development objectives (Box 1), including keeping the rise of global temperatures to well below 2°C above pre-industrial levels. In practice, this will require two sets of closely connected but distinct strategies. One will need to focus on energy systems, including power generation, transmission, transport, buildings, and industry (Davis et al., 2018), while the other will need to focus on sustainable land-use and food systems (Schmidt-Traub et al., 2019), using the pillars described in Figure 1. Both sets of pathways are connected and must be coordinated, notably though the possible use of bioenergy and net-zero emission technologies for decarbonizing energy systems. Similarly, nature-based solutions, such as reforestation or soil carbon sequestration, are an important element of overall decarbonization strategies. Yet, both sets of pathways involve sufficiently distinct communities, so it is more practical to tackle them through distinct but coordinated strategies.

The Deep Decarbonization Pathways Project (Sachs et al., 2016; Waisman et al., 2019) has demonstrated the need for and use of long-term national pathways in the energy sector. In several ways long-term pathways are a method for problem solving around making land-use and food systems sustainable:

- **Develop a shared understanding and buy-in for the transformations:** Achieving the FABLE targets (Table 1) will require unprecedented problem solving and profound changes to land-use and food systems. Such changes can only be made on the basis of a strong societal consensus on targets. Transparent pathways or low-emission development strategies provide a framework for engaging stakeholders (governments, businesses, civil societies and the scientific community), to review, pose questions and suggest improvements for how to achieve the targets. As one example, the pathways can help identify potential losers from a transformation, such as companies engaged in deforestation or unsustainable fishing practices and invite stakeholders to propose strategies for compensating them, which in turn can help raise the level of ambition of the strategy (Sachs et al., 2016). Pathways can also estimate the long-term impact and financing needs of different policy options, which enables governments to raise the level of ambition and take better informed decisions.

- **Ensure coherence with long-term objectives:** If countries pursue long-term objectives, such as reducing greenhouse

Box 1 *The role of land use and food systems in mid-century low-emission development strategies.*

Countries have developed climate strategies through to 2025 or 2030, which are known as Nationally Determined Contributions (NDCs). Importantly, but less well known, the Paris Agreement introduces mid-century pathways as a second tool for national climate policies (Article 4.19). By 2020, Parties are invited to present long-term "low greenhouse gas emissions development strategies" (LEDS).

The Paris Agreement's objective to keep climate heating well below 2°C above pre-industrial temperatures implies net-zero greenhouse gas emissions by mid-century (Masson-Delmotte et al., 2018). National LEDS therefore need to map out how each country will reduce net greenhouse gas emissions to zero.

To date, 12 countries have submitted their LEDS: Benin, Canada, the Czech Republic, Fiji, France, Germany, Japan, Mexico, Republic of the Marshall Islands, Ukraine, the United Kingdom, and the United States[1]. Many others are preparing their LEDS for submission by 2020. The 2050 Pathways Platform (www.2050pathways.org) provides an important multi-stakeholder forum for exchanging lessons and building capacity for designing these strategies.

Today's LEDS focus primarily on decarbonizing energy systems with some consideration of avoided deforestation. They do not cover land-use and food systems, as summarized in our three pillars (Figure 1, page 21), even though these systems constitute just under one third of greenhouse gas emissions (Poore and Nemecek, 2018). Countries should, therefore, consider a two-pronged approach comprising energy decarbonization and sustainable land-use and food systems when designing their LEDS. The FABLE pathways described in this report provide a very initial and incomplete analytical foundation for developing the second prong. They show that it should address the three pillars of sustainable land-use and food systems: efficient and resilient agricultural systems, the conservation and restoration of biodiversity, and food security and healthy diets.

The September 2019 UN Climate Summit provides a critical opportunity for countries to reaffirm their commitment to submit LEDS by 2020 and to pledge to integrate sustainable land-use and food systems into such strategies. This would require, for example, the inclusion of spatially-explicit national policy frameworks for managing biodiversity, such as China's recently adopted Ecological Conservation Redlines, which would make an important contribution towards the 2020 Kunming COP of the Convention on Biological Diversity.

1 https://unfccc.int/process/the-paris-agreement/long-term-strategies

gas emissions to zero through rolling five or ten-year strategies they will focus on "low-hanging fruits" instead of tackling the transformations needed to achieve the goals. As a result, countries will lock themselves in with unsustainable infrastructure or land use, which will make it impossible to meet the goals later. Such lock-in effects are well known in the energy sector (Sachs et al., 2016), but they are perhaps even more salient in food and land-use systems where decisions taken today can lock-in land and water use for centuries to come (Figure 3).

- **Set up innovation challenges and provide sector benchmarks:** To achieve the FABLE targets (Table 1), the development and deployment of improved technologies for agriculture, livestock, food processing, biodiversity management, and other areas must be accelerated. Long-term pathways can help identify time-bound technology benchmarks, as is now common in the energy sector (Kuramochi et al., 2018). For example, there's now widespread acceptance that in order to meet the objective of the Paris Agreement, the internal combustion engine must be replaced with zero tailpipe emissions by 2035 at the latest, which in turn helps guide R&D activities in the automotive industry. Similar technology benchmarks might help guide the transformation of food and land-use systems. Examples might be sustainability standards for key crops relating to input use efficiency and other environmental impacts. Critically, such benchmarks require a systems perspective covering all three pillars of land-use and food systems (Figure 1).

Figure 2 *Long-term impact of land-use decisions. Land use in Steiermark/Austria today (right hand photo from 2006) remains highly aligned with land-use zoning from 1823 (left side).*

3. The FABLE approach to developing pathways

Strategies and long-term pathways towards sustainable land-use and food systems must integrate across agronomy, nutrition, ecology, hydrology, climatology, economics, infrastructure engineering, the social sciences, and of course the local politics. Yet, most countries do not have such integrated policies and to our knowledge none have long-term pathways towards sustainable food and land-use systems covering all three pillars (Figure 1). Even worse, they lack the analytical tools to understand the complex synergies and trade-offs across these areas and to determine which short-term measures are required to achieve long-term objectives.

Notably, developed and developing countries alike lack these tools, and most lack integrated policy processes to address the challenges of unsustainable land-use and food systems at the right scale. Indeed, we have found that some of the most compelling lessons for better design and implementation of integrated strategies come from developing countries.

In the absence of comprehensive analytical and policy frameworks, some countries undertake isolated measures, but these do not add up to a comprehensive strategy. And they are not configured to fix broken food systems. Just like it is impossible to design and implement economic policies without sound economic models, countries will not be able to make their land-use and food systems sustainable without robust tools to model the impacts of policies. While many international collaborations exist on modeling elements of the food and land-use system, the Food, Agriculture, Biodiversity, Land-Use, and Energy (FABLE) Consortium is unique in strengthening in-country capacity for integrated modeling and policy analyses covering all three pillars of sustainable land-use and food systems.

Moreover, national strategies must consider international markets for food and non-food commodities, since these can have major implications for national land-use choices as well as the affordability of food and animal feed. For example, rising international demand for feed, particularly from Asia, has been driving large-scale land-use change across much of Latin America. Similarly, US and European domestic biofuel mandates are seen as a major driver of the expansion of palm oil plantations in South-East Asia. For country teams to understand these issues they need to be part of a global network involving their major bilateral trading partners. This is what FABLE aims to provide, and it is another unique feature of our approach.

3.1. The FABLE Consortium

Businesses, civil society organizations, researchers, and international organizations have come together in 2017 to launch the Food and Land-Use Coalition. The coalition aims to draw greater political attention to the challenges of land-use and food systems, promote integrated strategies, and mobilize action. As part of the coalition, the FABLE Consortium has been created as a global network of researchers from 18 developed and developing countries[2] to build tools and analyses for integrated land- and water-use planning (Figure 3).

The FABLE Consortium draws on lessons from the Deep Decarbonization Pathways Project (DDPP) (Waisman et al., 2019), which coordinated country teams in 17 G20 countries to develop

2 Argentina, Australia, Brazil, China, Canada, Colombia, Ethiopia, European Union, Finland, India, Indonesia, Malaysia, Mexico, Russia, Rwanda, Sweden, UK, and the United States.

long-term integrated pathways for decarbonizing energy systems (Box 2). The DDPP has had significant policy impact in the run-up to the Paris Agreement, notably by facilitating the China-US Joint Presidential Statements of November 2014 and September 2015. Its central recommendation to develop long-term pathways that inform short-term policies has been enshrined in Article 4.19 of the Paris Agreement, which is central to helping ensure that the NDCs are consistent with the Agreement's long-term objective.

FABLE is inspired by experiences from land-use policy impact assessments carried out in a range of countries, including the European Union, USA, and Australia. In particular, FABLE draws on Brazil's experience in implementing the GLOBIOM land-use model, which is now used to formulate and implement ambitious policies (Box 3). This has allowed the government to build broad cross-ministerial and public support for its ambitious pledge to reduce deforestation, which in turn helped build momentum towards a successful Paris Agreement – though the current government has undone some of the ambitious pledges.

The Consortium supports country teams to develop rigorous, transparent pathways towards sustainable land-use and food systems that demonstrate the feasibility of rapid progress and help raise the level of ambition towards the SDGs and the objectives of the Paris Agreement. To this end, the Consortium pursues three broad sets of activities

1. **Capacity development and sharing of best practice** for data management and modeling of the three pillars. The analytical approach and tools are described further below.

2. **Development of mid-century national pathways** that can collectively achieve the jointly agreed global targets and have consistent trade assumptions.

Figure 3 *FABLE country teams contributing to this report. A South African team has recently joined the Consortium but did not contribute to this report.*

3. **Analysis of national policy options and support to national and international policy processes** will be undertaken over the coming year.

3.2. Data and tools for pathways towards sustainable land-use and food systems

To develop coherent policies for sustainable land-use and food systems, we recommend that countries consider three sets of complementary tools and data, which we describe further

Box 2 *Lessons from the Deep Decarbonization Pathways Project.*

In 2013, IDDRI and the SDSN convened the Deep Decarbonization Pathways Project (DDPP) involving national research teams from 17 G20 countries. Two years before the Paris climate conference, the teams discovered that hardly any countries had clarity of what an energy system consistent with 2°C might look like or how it might be achieved. While many global models and pathways were available, they lacked the granularity and – critically – local ownership to inform national policy decisions. All agreed that in the absence of detailed national pathways for decarbonizing energy systems, government leaders would struggle to commit seriously to decarbonizing their energy systems.

In response each national team participating in the DDPP committed to develop a long-term pathway towards decarbonizing its energy system. Project participants agreed to pursue three pillars of deep decarbonization: (1) energy efficiency, (2) zero-carbon power, and (3) electrification and other fuel switching (Williams et al., 2012). They also committed to collectively stay within the global carbon budget identified by the Intergovernmental Panel on Climate Change (IPCC). Results from the national pathways were consolidated in a global dashboard, so that every country team could see how others tackled the decarbonization of their energy systems. This generated discussions on technology and policy options across the consortium, which helped teams see how to achieve a greater level of ambition.

The DDPP has had significant policy impact in the run-up to the Paris Agreement, notably by facilitating the China-US Joint Presidential Statements of November 2014 and September 2015. Its central recommendation to develop long-term pathways that inform short-term policies has been enshrined in Article 4.19 of the Paris Agreement. In this article, countries commit to submit mid-century "low greenhouse gas emission development strategies" that will be central to ensuring that the shorter-term Nationally-Determined Contributions are consistent with the long-term objective of "well below 2°C".

The DDPP has demonstrated the feasibility and importance of long-term pathways as a method for problem solving on how to decarbonize energy systems. Such analyses need to be locally developed to build trust and inform national policy processes. Long-term analyses are required to understand the system transformations and to avoid lock-in. Without them countries will not know which measures are needed over the short-term to achieve long-term objectives. Many DDPP members have demonstrated how pathways can be a tool for mobilizing stakeholders around a shared vision for decarbonization. They provide a framework for stakeholders to identify shortcomings and propose better ways to meet the targets. Finally, long-term pathways can also help build trust across nations, as they outline how each country aims to achieve the long-term objectives of the Paris Agreement. It is therefore important that all signatories of the Paris Agreement have committed to submit by 2020 their mid-century "low greenhouse gas emission development strategy".

The objectives and organization of the FABLE Consortium are informed by lessons from the DDPP. Notably, FABLE members have developed a shared framework for organizing strategies to make food and land-use systems sustainable (the three pillars in Figure 1; they pursue national-level pathways that are aggregated through a Linker Tool to ensure consistency with global sustainability objectives and international trade; they organize technology and policy roundtables to advance members' understanding on where and how the level of ambition can be increased.

More information on the DDPP is available, see SDSN and IDDRI (2015), Bataille et al. (2016), Sachs et al. (2016), and Waisman et al. (2019).

Box 3 *Lessons from Brazil.*

Experiences in Brazil provide lessons for how the FABLE approach can be put into practice. Since 2012, researchers from Brazil's National Institute for Space Research (INPE) and the Institute for Applied Economic Research (IPEA) have been developing a regional version of the GLOBIOM model (Box 5), in collaboration with IIASA (Camara et al., 2016). With a series of refinements that reflect specific needs in Brazil, GLOBIOM-Brazil simulates the competition for land between the agricultural, the forestry, and the bioenergy sectors of the Brazilian economy. The model integrates data on agricultural production systems, land-cover, biodiversity, and transport infrastructure to project how various policies might change domestic consumption and global demand for products such as soy, sugarcane, beef, bioethanol and timber. It can project the impact of different policy measures, such as the Forest Code, on food production, deforestation, biodiversity loss, and many other dimensions (Soterroni et al., 2018).

In the run up to the Paris climate conference, Brazilian policymakers were struggling to produce an appropriate mix of policies that could reconcile agricultural production with targets for the country's greenhouse emissions, which in Brazil are driven largely by land use and land-use changes. Working closely with stakeholders in the capital Brasília and the country's top climate negotiators, GLOBIOM-Brazil model developers ran different emission scenarios that provided clear, science-based evidence for defining Brazil's NDC, eventually submitted to the Paris COP-21 in 2015. In a historic step forward, Brazil's NDC pledges an absolute decrease in greenhouse emissions, a first among major developing countries, with a cut of 37 percent below 2005 levels by 2025, and of 43 percent by 2030.

Unfortunately, the full suite of policies has not been implemented. The rate of deforestation has nearly doubled since 2012 and Brazil is set to miss its Paris targets (Rochedo et al., 2018). Yet, this experience demonstrates the need for integrated, long-term analyses of food and land-use systems to promote joined-up policymaking and to raise the level of ambition. Clearly, these tools on their own are not enough to affect large-scale system change, but without them countries cannot chart a course towards implementing the Paris Agreement and achieving the SDGs.

below: (1) simplified assessments of land-use and food systems for stakeholder engagement ("FABLE Calculator"); (2) spatial biophysical and socioeconomic data to support policymaking; and (3) integrated, geospatially-explicit modeling of land-use and food systems.

3.2.1. The FABLE Calculator

Owing to the complexity of food and land-use systems, simplified tools are required to consolidate national data across the three pillars as well as international trade in agricultural products. Such tools can identify major imbalances in and threats to national food and land-use systems without the need for complex geospatial data or optimizations. The FABLE Consortium has developed an Excel-based model (the 'FABLE Calculator'), which is available to interested researchers and policymakers.

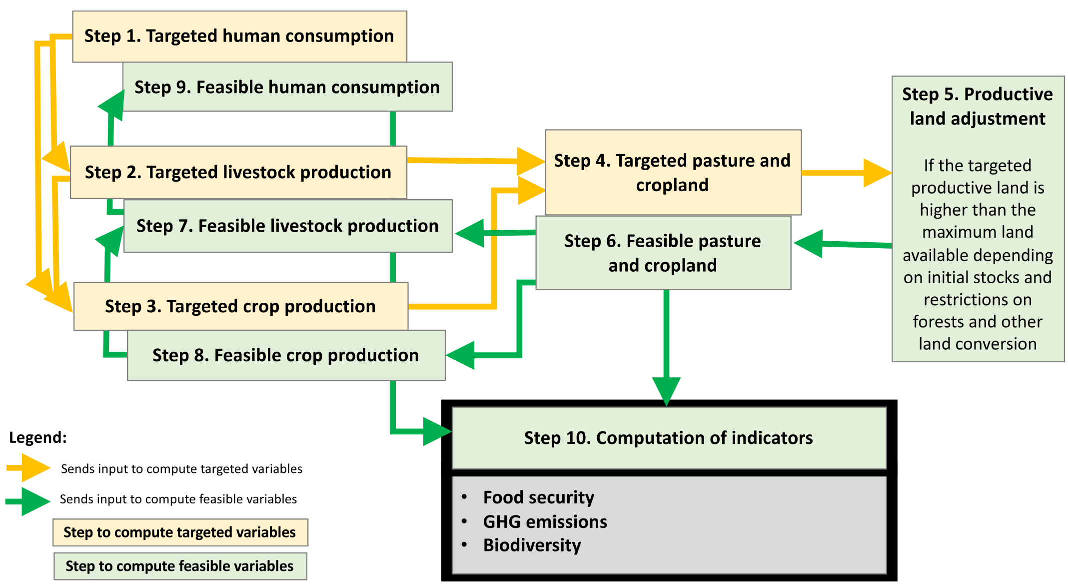
The FABLE Calculator can quickly generate pathways towards sustainable land-use and food systems using national-level data. It can also operate at sub-national levels. While the Calculator does not allow for geospatial disaggregation or for dynamic optimization, it ensures maximum transparency. Users can develop scenarios quickly and use them for stakeholder engagement, as assumptions can be changed easily and transparently (Box 4). Several FABLE country teams are looking into using the FABLE Calculator for national and sub-national stakeholder dialogues to build a greater understanding among stakeholders of food and land-use system challenges and buy-in into solution pathways. The tool also provides a benchmark for more complex modelling. As described further below, all FABLE country teams have used the FABLE Calculator to develop the first generation of pathways towards sustainable land-use and food systems which are presented in this report.

The FABLE Calculator focuses on agriculture as the main driver of land-use change and biodiversity habitat loss at the global scale. It includes 76 agricultural and forest products including crops, livestock products, vegetable oils, oilseed cakes and refined sugar (see online documentation). In its current form, the Calculator addresses all FABLE targets (Table 1) with the exception of targets related to water use, nitrogen, and phosphorous. We aim to include these targets in later versions of the Calculator and FABLE reports.

In each 5-year time step, the level of agricultural activities and the impact on land use change is computed. Some policies can be implemented to either increase the natural area through afforestation or reforestation or prevent conversion of forests and other natural land to agriculture. These policies could target rich carbon area to reduce national greenhouse gas emissions from land use change, and/or rich biodiversity area for biodiversity conservation. In the FABLE Calculator, abandonment of agricultural land can also increase carbon sequestration and biodiversity conservation. Key shortcomings of the tool are that it computes results at the national level, the use of national carbon stocks per land cover type, and rough biodiversity indicators based on broad national-level land-cover classes. Moreover, the Calculator does not currently address biodiversity inside agricultural production systems.

As described in Figure 4, the Calculator applies eight computational steps to develop pathways:

Figure 4 *Overview of the FABLE Calculator.*



1. **Targeted demand for each product.** Annual demand is driven by the population projection, the evolution of the average per capita consumption of each product (food diets and non-food demand), and changes in food waste.

2. **Targeted livestock production.** Once the demand for livestock products has been defined in Step 1, the size of the livestock herd, total feed demand by crop, and the required pasture area are calculated using the following information: the evolution of exports and imports per livestock product[3], the contribution of different animal types and production systems to the total production, the evolution of the production level by livestock unit, the evolution of the feed requirement per product by livestock unit, and the ruminant density per hectare of pasture.

3. **Targeted crop production.** Once the demand for food and feed has been computed in Steps 1 and 2, additional information is used to compute the harvested area for each crop. This includes the evolution of exports and imports per crop, the evolution of crop productivity per hectare, post-harvest losses, and the conversion coefficient of processed commodities. The total cropland is the sum of all harvested areas by crop, adjusted for the average number of harvests per year when relevant.

4. **Total land balance.** By tallying up total land use, adjustments in cropland and pasture use can be made, as necessary, to ensure that productive land use does not exceed land availability. Once the targeted pasture area has been computed in Step 2, and targeted cropland has been computed in Step 3, additional information is used to compute the area of each land cover class at the end of each time-step, including the evolution of urban areas, afforestation/reforestation, land which is potentially available for conversion, and the share of the productive land expansion which goes to each non-productive land cover class. Land availability is both determined by the initial stock of land by land cover type, and scenarios which could restrict productive land expansion e.g. protected areas, zero-deforestation policy, etc.

5. **Feasible livestock production.** When the land area used for pasture needs to be adjusted following Step 4, ruminants herd size needs to be reduced. This will in turn reduce the livestock production, feasible exports, and demand for feed.

6. **Feasible crop production.** When the cropland area needs to be adjusted following Step 4, harvested area is reduced proportionally for each crop. This in turn reduces overall production volumes.

7. **Feasible human consumption.** Using feasible crop production from Step 6 and feasible livestock production and feed demand from Step 5, exports and human consumption are adjusted to ensure market balance between production, domestic consumption, and trade.

8. **Computation of indicators to monitor the achievement of FABLE targets and national objectives.** In a final step the Calculator computes key indicators using as input the feasible variables computed during the last steps. These include daily kilocalorie consumption per capita; greenhouse gas emissions from land-use change and agriculture; and the share

3 There cannot be both imports and exports in the calculator: only net trade is represented. For the historical period, it is computed as the difference between total exports and total imports. If the net is positive, the difference represents exports and imports are set to zero and if the net is negative, the difference represents imports and exports are set to zero.

of total land area used for biodiversity conservation. Other available indicators include water footprint and species loss. This list of computed indicators will be expanded in the future.

The focus of the FABLE Calculator is to determine feasible pathways towards sustainable land-use and food systems. The Calculator does not cover economic dimensions such as prices. The structure of the Calculator is kept simple, though some complexity arises from the large number of products and years (76 products multiplied by eleven 5-year time steps from 2000 to 2050) and a large number of parameters. All countries can apply the Calculator using internationally available data, as provided by the FAO for example. Alternatively, they can use national data from governments or other sources.

Box 4 *Testing pathways: Ensemble envelopes.*

To better understand how the level of ambition of the country pathway compares with the range of possible pathways which could be implemented in the FABLE Calculator, we use an ensemble envelope analysis. The technique is based on a common method for testing the stability of system dynamics models. For this we select the extreme assumptions for each scenario parameter (Table 2) and generate combination matrices for each country team's FABLE Calculator, which yield tens to hundreds of thousands of possible unique scenario combinations. Using an Excel macro, we then run through all of these combinations, which generates thousands of potential pathways. The maximum and minimum boundaries of these pathways are called ensemble envelopes, which help country teams test and understand the boldness of their assumptions and their impact on the pathways. Some of these envelope analyses have been included among the results plots in the country chapters.

3.2.2. Spatial biophysical and socioeconomic data

Most governments lack adequate biophysical and socioeconomic data across the three pillars. Where data exists, it can be difficult to access, or it may not be available in harmonized and integrated formats that are needed to support policymaking. Improved collection and integration of spatial data on land use, soil and water resources, agricultural production, biodiversity, carbon stocks, transport infrastructure, climate impacts, consumption patterns, and food waste are required to improve the formulation and assessment of policies. A particular data challenge relates to the measurement of biodiversity and ecosystem functions. Data on food consumption also tends to be of low quality and have limited temporal as well as spatial resolution.

Major challenges exist in harmonizing, curating and integrating these data to make them useful for policymaking and integrated modelling. These processes are often highly knowledge and time intensive and insufficiently funded. One example is India, which thanks to its own space program has large volumes of high-quality remote sensing data, but these data are not used for policymaking. Many countries have geo-tagged household survey data, but these data are rarely integrated with biophysical data.

To fill this gap, FABLE aims to support countries in building sophisticated databases that curate and update geospatially-explicit biophysical and socio-economic data relating to food and land systems. As one example, countries may draw inspiration from China's successful generation and curation of high-resolution geospatial data in relation to its 'redlines' for agriculture, water use, biodiversity, and ecosystem services (Bai et al., 2016). We see great potential for building harmonized data infrastructure and mapping tools to reduce the cost of building integrated data systems in each country.

FABLE aims to build an open-access portal for model-ready data that will serve the needs of policymakers and the community of global and national modelers of food and land-use systems. To this end, data will be harmonized and consolidated from global and national databases. This will enable the use of higher-quality national data for global policy analyses. To further enhance transparency, FABLE aims to standardize and release the data processing routines which lead to the final, harmonized product, allowing researchers to easily improve existing routines.

The data portal will cover model input and output data from policy impact assessments carried out under FABLE. It will also support new modeling approaches at national and international level with high standards of quality control. The FABLE data initiative will build on the accomplishments and experiences for the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP), led by PIK, which has greatly enhanced the quality, availability, and consistency of climate change data.

3.2.3. Integrated, geospatially-explicit modeling of land-use and food systems

Spatial alignment of policies targeting the land-use and food sectors is a formidable challenge. FABLE supports countries to develop dynamic, geospatially-explicit models that cover all three pillars as well as international trade and other demands on land. To enable the testing of policy options and development of long-term pathways, as required under the UNFCCC (Waisman et al., 2019), such models must allow for integrated assessment of land-use choices, taking account of biophysical constraints and competing uses (e.g. land availability, water resources, biodiversity, or climate impacts). We have found partial-equilibrium economic models with high geospatial and thematic resolution to reach acceptance in policy processes in many countries.

Such models are complex, require a lot of high-quality input data, and are therefore challenging to implement. Yet, they offer a number of important features and some advantages over the FABLE Calculator or computable general equilibrium economic models:

- Integrate large numbers of heterogeneous data layers that allow for integrated decision-making across all relevant variables at high resolution;

- Allow for a range of policy assessments, including optimal land-use decisions based on economic criteria (e.g. which crops generate the highest economic return given soil, climate, and hydrological conditions?) that can consider environmental criteria (e.g. areas of high biodiversity and carbon density that need to be protected to ensure ecological functionality) and social metrics (e.g. dietary health, food security, employment);

- Integrate across food production and consumption, infrastructure development, urbanization, biological carbon sequestration, biodiversity, other ecosystem services, and other forms of land as well as water use; and

- Integrate international trade flows into national decision making.

Two prominent examples of geospatially-explicit partial-equilibrium models are the Global Biosphere Management Model (GLOBIOM) (Box 5) developed by IIASA and the Model of Agricultural Production and its Impact on the Environment (MAgPIE) (Box 6) from the Potsdam Institute for Climate Impact Research (PIK). The FABLE Consortium is promoting a wide variety of advanced modeling platforms by country teams that allow for adequate geospatial resolution, incorporate international trade, and cover critical food and land-use challenges. It promotes reviews and comparisons of different modeling approaches and encourages modelling innovations to better represent land and food systems. FABLE promotes transparency and reproducibility by encouraging open access data, tools, and results.

3.3. Developing national pathways consistent with global objectives

Members of the FABLE Consortium develop country pathways that collectively (i.e. by adding up all pathways) aim to achieve the global targets outlined in Table 1. Moreover, the pathways need to have consistent assumptions about trade, so the sum of exports for each commodity must equal

Box 5 *The Global Biosphere Management Model (GLOBIOM).*

GLOBIOM (www.globiom.org) is a partial equilibrium model of the global agricultural and forestry sectors (Havlík et al., 2014). Crop and livestock production are represented at the level of Simulation Units (SimU) going down to 5x5 minutes of arc. Different production and management systems are represented at SimU level considering differences in natural resource and climatic conditions as well as differences in cost structure and input use. The model explicitly covers 18 major crops produced in four management systems (subsistence, low input - rainfed, high input – rainfed, and high input - irrigated) whose input structure is defined by Leontief production functions. Production functions are parameterized using the bio-physical crop growth model EPIC (Environmental Policy Integrated Model). In the livestock sector, four species aggregates (bovines, small ruminants, pigs, and poultry) are distinguished. Ruminants can be produced in eight alternative production systems and monogastrics in two. The parameterization of the livestock sector is based on the RUMINANT model (Herrero et al., 2013). The forestry sector in GLOBIOM represents the source for logs (for pulp, sawing and other industrial uses), biomass for energy, and traditional fuel wood, which are supplied from managed forest or short rotation plantations (SRP) (Lauri et al., 2014). Harvesting cost and mean annual increments are informed by the G4M global forestry model (Kindermann et al., 2006). GLOBIOM represents a comprehensive set of greenhouse gas mitigation options for food and land-use systems. For the agricultural sector the model represents structural options based on different management systems and technical non-CO_2 mitigation options. In the forest sector, G4M provides mitigation potentials for afforestation and reforestation, reduced deforestation and forest management.

Demand in GLOBIOM is modelled at the level of 37 aggregate economic regions and income elasticities are calibrated to mimic FAO projections. Prices are endogenously determined at the regional level to establish market equilibrium to reconcile demand, domestic supply and international trade. Land and other resources are allocated to the different production and processing activities to maximize a social welfare function which consists of the sum of producer and consumer surplus. Changes in socioeconomic and technological conditions, such as economic growth, population changes, and technological progress, lead to adjustments in the product mix and the use of land and other productive resources. By solving the model in a recursive dynamic manner for 10-year time steps, decade-wise detailed trajectories of variables related to supply, demand, prices, and land use are generated.

Afforestation, deforestation, wood production in managed forests and respective CO2 emissions are estimated by the geographically explicit (0.5x0.5 deg) model G4M that is connected with GLOBIOM. Afforestation and deforestation decisions are calculated by comparing net present values of agriculture and forestry land uses. Afforestation occurs where it is more profitable than the agriculture and the environmental conditions are suitable for forest growth. Deforestation, in contrast, happens where agriculture net present value plus profit from one-time selling of deforested wood exceeds the net present value of forestry. The net present values are estimated by taking into account agriculture land rents and wood prices obtained from GLOBIOM and price of carbon stored in biomass. The land transitions in G4M are harmonized with GLOBIOM agriculture land demand. G4M simulates forest management aimed at sustainable production of wood demanded by GLOBIOM on regional scale. Introduction of carbon price creates an alternative for forest owners to make profit of wood production or carbon accumulation that, generally makes rotation time in managed forests longer.

Box 6 *The Model of Agricultural Production and its Impact on the Environment (MAgPIE).*

MAgPIE (https://doi.org/10.5281/zenodo.1418752) is a modular open-source framework for modeling global land systems (Dietrich et al., 2019). Based on a regional demand for agricultural products and biophysical endowments on a regular geographic 0.5° by 0.5° grid resolution, the model generates optimal land use patterns by minimizing global production costs. The recursive dynamic nature of the model is reflected in a multi-year optimization (usually using 5-10-year time-steps), where optimal land use patterns from the previous period are taken as a starting point for the current period. The initial period is calibrated to the arable area reported by the FAO.

Most of the economic constrains in MAgPIE are defined at the level of socioeconomic regions. By default, MAgPIE operates using 12 world regions, but the number and definition of regions can be changed. The demand for food is regionally defined and given as an income-elastic, endogenous trend to the model, encompassing 13 plant-based staple products, five plant-based processed products, and six animal-based products. The estimates for calorie intake for each region are obtained from a country cross-section regression analysis on population and GDP (Bodirsky et al., 2015). In addition to food, the agricultural demand consists also of feed, material and bioenergy demand. Feed demand is based on feed baskets defined for each livestock production activity and depends on regional efficiencies, while material demand is implemented in proportion with food demand.

The supply side in MAgPIE is determined by different production costs, biophysical crop yields and availability of water. The information on rain-fed and irrigated crop yields, water availability and water requirements for every grid-cell are by default provided by the LPJmL (Lund-Potsdam-Jena with managed Land) model (Müller and Robertson, 2014). The objective function of the optimization process is to minimize global agricultural production costs. The main decision on how to allocate land for cropping activities is based on four types of production costs and interregional restrictions on trade. In the MAgPIE model several types of costs are defined, including factor requirements, technological change, land conversion and transport costs.

Factor requirements costs are defined per ton of produced crop type and differentiated between rainfed and irrigated production systems. They represent costs of capital, labor and intermediate inputs (such as fertilizers and other chemicals) and are implemented at the regional scale using the cost-of-firm data from the Global Trade Analysis Project (GTAP). Crop production can be increased in a region by investing in technological change that increases yields, or by expansion of agricultural production into other non-agricultural areas suitable for plant cultivation. Land conversion from forest and natural vegetation into arable land comes at region-specific costs. Transport costs are calculated from the GTAP database and assure paying for a quantity of goods transported to the market in a unit of time needed for covering the distance.

All MAgPIE regions fulfil part of their demand by domestic production, which is founded on regional self-sufficiency ratios. If domestic production does not cover regional demand, goods are imported from regions with excess production. Export shares and self-sufficiency ratios are calculated from the FAOSTAT database for the initial year (1995). Trade between regions can be liberalized in future time periods by relaxing the trade barrier, and thus allowing for a certain share of goods freely traded, based on regional comparative advantage. In every time step, trade is balanced at the global level.

the sum of imports. In other words, to develop national pathways, country teams need to consider the actions of other country teams. This requires collaboration across country teams, which can only be ensured through a global network, such as FABLE.

The FABLE Consortium has developed the process involving five steps (Figure 5): First, country teams identify and harmonize national data, including spatially-explicit metrics. Second, every country team develops national pathways towards sustainable land-use and food systems using the FABLE Calculator – later more advanced geospatially-explicit partial-equilibrium models, such as GLOBIOM (Box 5) or MAgPIE (Box 6), will be used. Third, a verification tool assesses the model's ability to reproduce past trends and compare the model's results with available benchmarks. Fourth, results are aggregated at the global level using a dedicated aggregation tool ("Linker tool"), which determines if trade flows are balanced for each commodity and identifies possible imbalances that must be resolved. The tool also computes if the sum of the country outcomes adds up to the global targets (Table 1). And fifth, trade imbalances and discrepancies between global targets and the sum of outcomes of the country pathways are addressed iteratively by the country teams using a "Scenathon".

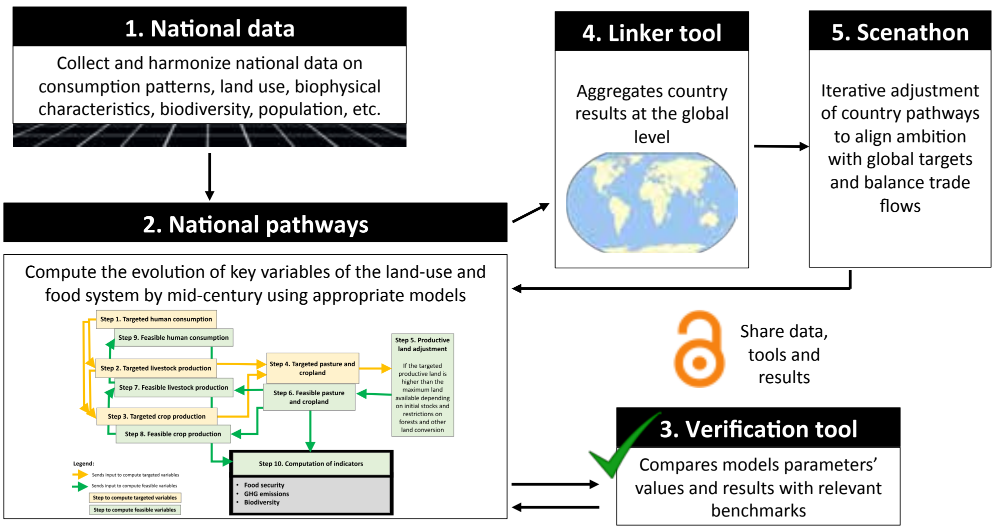
3.3.1. Preparation of national data

As described in section 3.2.2 countries prepare data from national statistics and other sources for use in the FABLE Calculator or partial-equilibrium models. In many instances, we encounter inconsistency between international data sources and national data. Resolving these inconsistencies is critical and often involves discussions with the data providers. Geospatial data from different sources often come in different formats that require harmonization and careful cross-checking. As described above, the FABLE Consortium aims to build a data initiative to improve the consistency and accessibility of national and global data on land-use and food systems.

3.3.2. Development of national pathways

Using either the FABLE Calculator or partial-equilibrium models (collectively referred to as "models"), the country teams then develop mid-century pathways towards sustainable food and land-use. All pathways cover the three pillars for sustainable land-use and food systems identified by the FABLE Consortium (Figure 1), including international trade in harmonized agricultural and

Figure 5 *Major steps in the FABLE method for developing national pathways.*



forest product categories. To cross-check data quality and the consistency of assumptions, it is critical that national pathways estimate historic trends – typically this is done going back to the year 2000. The implementation of scenarios starts in 2015.

For the results reported in the next chapter, national FABLE Calculators were prepopulated with data from FAO and default scenarios for changes in GDP per capita, population, diets, imports and exports, livestock, crop productivity, afforestation and reforestation. Country teams then adapted their Calculator to national circumstances with each change carefully documented. Examples for additional dimensions added by some country teams include changes in ruminant density or in the average cropland harvesting intensity per year to allow for inter-cropping or multiple growing seasons per year. For each dimension of the scenario, country teams selected an alternative parameter, e.g. low growth, stable growth or high growth scenarios. Detailed justifications of the choices made by each country team are provided in the country chapters.

The 18 FABLE countries account for some 60 percent of the world population. To allow for a global aggregation, the national FABLE Calculators were complemented by seven regional "rest-of-the-world" (RoW) Calculators covering countries that do not currently participate in the FABLE Consortium (including European countries not part of the European Union, rest of Central Asia, rest of Asia, rest of Africa, rest of America, rest of Pacific, and rest of the Middle East). These regional Calculators were managed by the FABLE Secretariat. To ensure that RoW pathways do not drive overall results, the default selection for all RoW regions uses middle-of-the-range projections on population and GDP (taken from the Shared Socioeconomic Pathways - SSP2); no changes to diets, food waste, productivity growth, and import shares for each commodity; free expansion of productive land within the total land boundary; no afforestation and reforestation targets.[4] Collectively, the FABLE country teams aim to meet the global targets (Table 1). Discrepancies between these targets and the sum of national targets achieved by the country teams are identified through the Linker Tool and addressed through the Scenathon described below.

3.3.3. Verification tool to check model results

Our verification process involves three steps. The first step is to agree on which parameters and variables to monitor. The second step is to agree on the data sources for benchmarks used in the quality control. By benchmarks, we refer to elements of comparison that allow users to check if model inputs and key outputs fall within realistic ranges. The third step is to set up threshold values for each benchmark. If a value falls beyond that threshold, alerts are sent to a modeling team or reviewer. In this way, large deviations from benchmarks can be scrutinized to determine if they are genuine or perhaps due to data inconsistencies or errors in the model. In this way, the verification process can:

- Highlight priority areas for further model improvements,
- Highlight data gaps or inconsistencies,
- Increase the general understanding of models for users and reviewers, and
- Foster the discussion around the results.

3.3.4. Aggregation using Linker Tool

Aggregation of country-level data and results is needed to address two challenges. First, trade flows in agricultural and forest products must be consistent globally. This becomes particularly challenging when different country teams aim to meet ambitious social and environmental objectives. Trade can then appear as a simple

4 For some regions, due to large natural grassland area, the current average ruminant density per hectare is very low. Projected changes in ruminant meat and milk domestic production lead to large changes in pasture area and conversion or abandonment of natural land. In order to minimize the impacts on the global results, in Central Asia and in Africa we have computed the ruminant density per hectare of pasture which would allow keeping constant the pasture area over time. The average ruminant density per hectare of pasture increases from 0.09 in 2015 to 0.14 in 2050 in Central Asia and from 0.26 to 0.41 in Africa.

means to externalize some of the negative aspects of food and land-use. For example, a country might undertake large-scale afforestation to meet the climate goal and in turn plan to import greater volumes of food. Or it might choose to import meat to reduce its domestic flows of nitrogen. However, such strategies can of course not be successful if pursued by all countries. Countries' projected trade flows must be carefully considered and compared.

Second, countries vary in their comparative advantage for the production of food and other agricultural and forest products on the one hand, and the production of environmental goods, such as carbon sequestration or biodiversity conservation, on the other hand. This will generate both local as well as internationally tele-connected trade-offs between FABLE-specific food production and environmental protection targets. For this reason, the combined performance of FABLE

Box 7 *Trade and the FABLE targets: The case of China.*

China is the world's largest importer of soy and many other agricultural commodities, and on current trends, its import demand for feed is projected to exceed today's total trade several times over (Ma et al., 2019). In response to rising living standards, shifts in diets, and the outsourcing of some of the environmental costs of food production (particularly related to animal protein), the country is projecting a massive increase in imports of food, forest products, and non-food products (including biofuels). As a result, China is increasingly driving land-use change and infrastructure development in many exporting countries. For example, land-use decisions in New Zealand are heavily influenced by China's demand for dairy products (Bai et al., 2018), and Chinese timber imports are a major driver of deforestation in Southeast Asia.

It is unknown and unlikely that China's projected increases in imports are consistent with exporting countries' commitments to implement the Paris Agreement and achieve the SDGs. Trade-offs are likely across many FABLE targets, including greenhouse gas emissions, food security, biodiversity protection, and water quality and scarcity. Available analyses of these challenges are either national and do not consider the needs of exporting countries or are based on global trade models that lack vetting and credibility both in China and its major trading partners. As a result, the magnitude of the challenge posed by rising demand for Chinese imports is unclear and not appreciated by most policymakers in China and its trading partners. Similar challenges exist in other countries, such as India and several African economies, that are projected to become major sources of demand for agricultural and forest commodities.

Countries need better analyses to understand these challenges, engage policymakers, and test policy options. To this end, the Chinese FABLE country teams – in collaboration with FABLE country teams representing major exporters to China, including Australia, Argentina, Brazil, Canada, the European Union, Indonesia, Russia, and the United States – along with researchers from New Zealand are engaging in a collaborative exercise to determine the sustainability of China's projected trade in agriculture and forestry products.

Using the FABLE Calculator, as well as geospatially-explicit partial equilibrium models such as GLOBIOM (Box 5), Chinese import projections by commodity type will be compared with projected exports from each major bilateral trading partner. Findings from this work will identify areas where Chinese exports exceed what countries are reasonably willing or able to export after taking account of domestic needs, exports to countries other than China, and competing demands on land-use and food systems, notably in the context of the Paris Agreement and the SDGs. Based on these initial analyses, the Chinese and other country teams will determine iteratively what changes would need to be made to supply and demand of agricultural and forestry products in order to ensure that country pathways are globally consistent with the SDGs and the Paris Agreement and politically feasible within country. The novelty presented by this approach is to go beyond available global trade models and draw on national analyses compiled by national teams who are closest to the data, the policy environment, and local stakeholders. Initial findings will be available towards the end of 2019 with a final policy report due out by early 2020.

countries must be considered against each of the targets, the totality of all targets, and the overall trade balance for all commodities.
FABLE country teams have agreed on a minimum set of "reporting variables" that must be produced by every national model and submitted at each iteration to the web-based Linker Tool. This tool sums up the performance of all countries and RoW regions, measuring the advance towards the global FABLE targets through an online, interactive graphical dashboard. It also displays national and regional reporting variables for comparison across countries. This may identify opportunities for greater ambition in some countries, highlight common trends across all countries, and help identify mistakes or inconsistencies. The Linker Tool adds countries' net trade volumes and determines whether projected exports and imports match for each product category. Finally, it could also support communication between country teams – for example, to address major imbalances in trade flows.

3.3.5. Scenathon

Scenathons aim at collectively solving complex, large-scale multi-objective problems. FABLE has applied the Scenathon process to allow country teams to iteratively and collaboratively align national pathways with the global FABLE targets and to balance trade flows. To our knowledge this represents the first time that a large number of country teams have collaborated in such a process to develop their own national pathways. Developing and testing the Scenathon methodology has required a major development effort and many iterations among the country teams to gradually increase the complexity and realism of the Scenathon.

Following aggregation of the country pathways using the Linker Tool, possible inconsistencies in trade flows and the gap between the sum of national ambitions and the global targets are communicated to each country team. On the basis of this information, country teams submit new pathways aiming to close the gap between the sum of all pathways and the global targets (Table 1).
In subsequent iterations, country teams will have access to the assumptions used by other teams, as well as detailed performance metrics for countries' land-use and food systems. This will allow each team to benchmark their pathway against others, which in turn helps to identify opportunities for increasing ambition or strengthening coherence. This process also flags knowledge gaps, which the Consortium will then seek to address through Technology and Policy Roundtables (Section 3.4).

In addition to closing the ambition gaps to the global targets, Consortium members collaborate to balance trade flows for every commodity and time step. In some cases, the Linker Tool does indeed report that the sum of all imports deviated substantially from the sum of all exports. In such instances we use a simple approach to balance trade flows: For each commodity and each time step, we determine the difference between the sum of global exports and imports. We then estimate balanced trade flows for each commodity, time-step, and country. If the sum of exports exceeds the sum of imports, then exports are reduced proportionally for every exporting country to equal imports. If imports exceed exports, then imports are reduced proportionally to equal exports. FAO data over the period 2000-2010 show trade imbalances for many commodities that are presumably the result of incomplete data or reporting errors. To account for this possibility, we allow for up to 20 percent deviation between imports and exports. Each country team then introduces the adjusted trade flows into its Calculator and submits the updated results to the Linker Tool.

The country chapters in this report are based on a Scenathon, which considered five FABLE targets: (1) zero net deforestation from 2030 onwards,

(2) zero net emissions from land-use change by mid-century, (3) a maximum of 4 Gt CO_2e per year by 2050, (4) a minimum of 50 percent of the terrestrial land that could support biodiversity conservation, and (5) average energy daily intake per capita higher than the minimum requirement (Table 1). While incomplete, these targets capture some of the most important potential trade-offs inherent in land-use and food systems, notably between increasing agricultural production, curbing greenhouse gas emissions, and protecting and restoring biodiversity. Five iterations were run for this Scenathon in order to reduce the gap between the sum of all pathways and the global targets and balance trade.

Initial experiences with the Scenathon and a careful review of the results by the country teams provide a proof-of-concept for the approach and its application to pursue multiple simultaneous targets with significant potential for trade-offs. During the Scenathon, country teams made substantial progress towards the global targets and in making trade assumptions consistent. We believe that the same approach can be used to pursue the full set of FABLE targets as well as results from a heterogeneous set of models applied by country teams, including spatially-explicit partial-equilibrium models. The resulting pathways are each country team's best attempt to chart a course towards simultaneously meeting the FABLE targets considered in this Scenathon. For this reason, country pathways may deviate from what might be optimal for meeting individual targets on their own. Such modeling results will need to be reviewed with domestic policymakers and other stakeholders.

3.4. Technology and policy roundtables

The national pathways and the modeling that underpins them require country teams to assess the feasibility of faster progress in areas ranging from dietary shifts to foods waste, agricultural production, or greenhouse gas emissions from many different types of sources. In many instances, improved technologies or policies must be developed and/or diffused to accelerate progress. Yet, these technologies and policies cover a very broad spectrum, and expert knowledge about them tends to be in the hands of a small number of experts.

To help fill knowledge gaps on the scope for the application of improved technologies and policies, the consortium organizes roundtables where technology and policy experts from business, government, civil society, and science present the state of the art in their areas of expertise and outline the scope for advances over the long-, medium-, and short term. In this way, FABLE technology and policy roundtables aim to develop a shared understanding and common assumptions across country teams on cost curves and technical feasibility of improved technologies and policies.

By way of illustration, initial roundtables have been held on dietary shifts, improved livestock management, and nutrient cycling, as well as enteric methane formation in ruminants. While it is too early to draw definitive conclusions from these initial roundtables, the discussion around policy and technology options has been well received by members of the Consortium. Over time, we expect the roundtables to allow country teams to substantially improve the quality and robustness of their modeling and raise the level of ambition of the pathways.

4. Key findings from FABLE pathways

This section summarizes the results from the Scenathon and highlights commonalities and differences across country pathways. As described earlier, 18 country teams participated in the Scenathon process. Each country team developed a pathway towards a sustainable land-use and food system by 2050 as defined by the global FABLE targets (Table 1) and complementary national objectives. The Rest of the World (RoW) was included in the Scenathon exercise as seven aggregated regions using standardized assumptions. Global results are computed as the sum of results extracted from 25 standalone FABLE Calculators – one for each country and region. The Linker Tool identifies trade imbalances, which are then addressed by revising national pathways.

The findings described in this section show that tremendous progress can be made towards the FABLE targets. The pathways presented in this report suggest that it is feasible to achieve four out of the five targets considered: average energy intake can be above the minimum dietary energy intake in all FABLE countries by 2030; zero net global deforestation can be achieved from 2030 onwards; by 2050 net greenhouse gas emissions from land-use change can be negative; and more than 50 percent of the global terrestrial land can be spared to conserve and restore biodiversity. The sum of country pathways makes insufficient progress towards reducing greenhouse gas emissions from agriculture. Closing this achievement gap will be a major priority of future work by the FABLE Consortium.

The feasibility of rapid progress towards the FABLE objectives is driven largely by six factors: (1) large gains in agricultural productivity; (2) shifts in diets towards less meat consumption, combined with reductions in food overconsumption; (3) a slow-down in population growth; (4) reduced food loss; (5) stable per capita demand for non-food products, including bioenergy production; and (6) the resulting fall in demand for pasture and cropland, which can store carbon and protect as well as restore biodiversity.

In the following, we review the principal assumptions made by the country teams in developing their pathways and describe how they shape the global results. In section 4.2, we compare the global results with the five mid-century FABLE targets and describe the contributions made by FABLE countries to these. Next, we discuss strengths and weaknesses of this preliminary assessment and outline opportunities for improvement. Finally, in section 5 we summarize the policy implications of our results. The country chapters in Section 6 describe the national pathways and assumptions in detail.

4.1. Key country-level drivers

4.1.1. Population

Based on assumptions by the country teams (Table 2), world population is expected to increase by 30 percent between 2015 and 2050, reaching 9.2 billion inhabitants by 2050. This is in between the low variant and medium variant estimates of the UN Population Division projections, which vary from 8.9 billion to 9.7 billion inhabitants by 2050 (UN DESA, 2017). The lower global population estimate is driven by the fact that the SSP2 scenario has been used for the RoW regions and, even if SSP2 also represents a "middle-of-the-road" scenario, projections are lower than in the

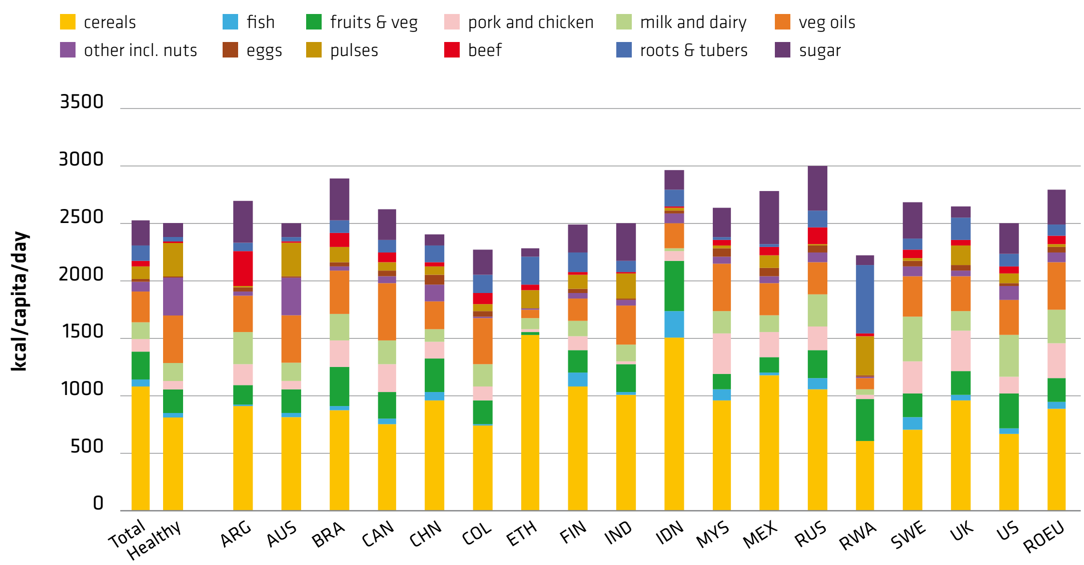
UN medium-variant, mainly because of different assumptions on female education attainment and different levels of education-specific fertility in Africa (KC and Lutz, 2017). Based on our assumptions, some 44 percent of this increase occurs in Asia, 37 percent in Africa, and 7 percent in the Middle East.

The total population projection from FABLE countries only is 4 percent higher than the UN medium-variant. Among the FABLE countries, the largest absolute population increase is in India, accounting for one-fourth of the total projected population increase between 2015 and 2050. We notice that only Colombia, Ethiopia, Indonesia, and Mexico have assumed lower population projections than the median fertility variant by the United Nations and Russia is the only FABLE country which expect its population to fall below 2015 level by 2050 (by 1.7 million). Yet, several countries project a reduction in population numbers, starting in 2025 in Russia, 2030 in China, 2035 in Colombia, and 2040 in the European Union.

4.1.2. Dietary shifts

Some countries project significant changes in per capita food intake, as well as the composition of their average diets, in order to achieve dietary health and sustainable food and land systems by 2050 (Table 2). Five countries aim to lower animal-based calorie intake between 2015 and 2050 (Australia, China, Finland, the UK, and the US). Except China, these countries have some of the highest animal-based energy intake per capita, so shifting away from excessive meat consumption promises to enhance health outcomes as well (Afshin et al., 2019; Willett et al., 2019). Projections in China would reverse recent trends, as the

Figure 6 *Assumptions on average diet composition in 2050 by FABLE country compared to recommended diet.*



Note: *"Total" is a weighted average of FABLE countries and RoW assumed diets by 2050; "healthy" diet is based on the EAT-LANCET report (Willett et al., 2019).*

country's per capita intake of animal-based energy increased by 35 percent from 2000 to 2010 (FAOSTAT, 2019). Starting mostly from a very low base, Ethiopia, India, Indonesia, and Malaysia project increases in per capita consumption of animal-based proteins through to 2050, but this will remain within recommendations for healthy diets (Willett et al., 2019). The other country teams assume stable energy intake per capita, both in total and in composition.

Overall, the global average daily caloric intake rises by 5 percent between 2015 and 2050. At the aggregated level, we project large increases in the average per capita consumption of nuts, fish, pulses, fruits, and vegetables. Compared to the EAT-LANCET and Global Burden of Disease recommendations, consumption of nuts and pulses should increase even further in most FABLE countries compared to our current assumptions for 2050 (Figure 6). The environmental implications of these nutritional shifts have not been fully explored. For example, depending on production location, the shift towards greater nut, fruits, and vegetable consumption might affect water demand for food production, which is not yet taken into account in the FABLE Calculator. In the US, for example, most nuts are produced in California's Central Valley, which is already very water scarce.

4.1.3. Food loss

Eleven out of 18 FABLE countries project a fall in food losses at the household level by 2050 compared to 2015 levels (Table 2). Food losses encompass losses during production, handling and storage, processing, distribution and market, and consumption. In the FABLE Calculator, food losses are split into two categories: post-harvest losses and consumption losses. The scenario targets only consumption losses, while the share of the production which is lost after harvest by crop and by country is assumed constant at 2010 levels based on FAOSTAT statistics. The default assumption in the FABLE Calculator is that food consumption losses represent 10 percent of total food consumption. This is close to the current estimated level in Europe and industrialized Asia (Lipinski et al., 2013). In the reduced food loss scenario, this share is assumed to be cut by half in 2050. Using national estimates, the Chinese team assumes that food losses will drop from 13.5 percent in 2015 to 11.8 percent in 2050 in China. We hope that more country teams will be able to improve this parameter in the future, but data on current levels of consumption losses is scarce.

4.1.4. Crop and livestock productivity

On the supply side, most FABLE country teams assume significant gains in productivity for agriculture and livestock over the next decades (Figure 7), which we measure as the total calories produced per hectare of agricultural land, including both cropland and pasture area. On average, total agricultural land productivity is projected to increase by 56 percent between 2010 and 2050 in FABLE countries (corresponding to annual compound growth rate of 1.1 percent). This productivity increase is significant but substantially lower than the 40 percent increase observed between 1990 and 2010 (corresponding to 1.7 percent annual compound growth) (FAOSTAT, 2019).

As productivity growth is measured in calories per hectare, changes in crops can affect productivity. For example, shifting towards crops with a higher energy content per hectare will increase overall productivity levels. In part, this explains high variations on productivity growth assumed across FABLE country teams. At the high end, Australia, Russia, and the UK assume more than a doubling of total productivity between 2010 and 2050.

At the product level, some country teams assume large yield increases. Projected yield increases are particularly ambitious for corn (Argentina, Australia, Indonesia, Malaysia, Rwanda), rapeseed

(Canada, Ethiopia, the UK), soybean (Canada), sugarcane (Australia, Colombia, Ethiopia, US), wheat (Argentina, Mexico, the UK), and oil palm fruit (Malaysia). For livestock, the land productivity depends on both the cattle density per hectare of pasture and the productivity per animal. Pasture intensification is a key component of the overall agricultural land intensification strategy for Brazil, Mexico, and the UK (Table 2). The country teams from Australia, Russia, Ethiopia, and Rwanda project higher milk and meat production per animal head. As highlighted in the country chapters, productivity growth for key crops will require significant investment in research and development, as well as uptake of new technologies by farmers.

4.1.5. Constraints on land-cover change

Argentina, Brazil, and Colombia project that deforestation will be halted by 2030. Afforestation targets are set by almost all FABLE country teams (Table 2). Across all FABLE countries, some 105 million hectares are afforested by 2030 and 191 million hectares by 2050. This comes close to meeting the Bonn Challenge (107 million hectares by 2030) (Dave et al., 2017) by FABLE countries. As discussed in the country chapters, these projections demonstrate what could be the impacts of greater afforestation and do not constitute a forecast of what will happen in countries. Many FABLE country teams have assumed that afforestation/reforestation efforts will continue after 2030. Finally, China is the only country that has set up a formal constraint to avoid cropland area reduction over 2015-2050. Meanwhile, India and Mexico assume no further expansion of agricultural land beyond the area covered in 2010.

4.1.6. Agricultural trade

When expressed in calories equivalent, FABLE countries represent almost 90 percent of world

Figure 7 *Average land productivity change by commodity groups across FABLE countries from 1990 to 2050 with 2010 data set at 0 percent. Historical trends from FAOSTAT (2019); data for 2010-2050 from FABLE country team projections.*

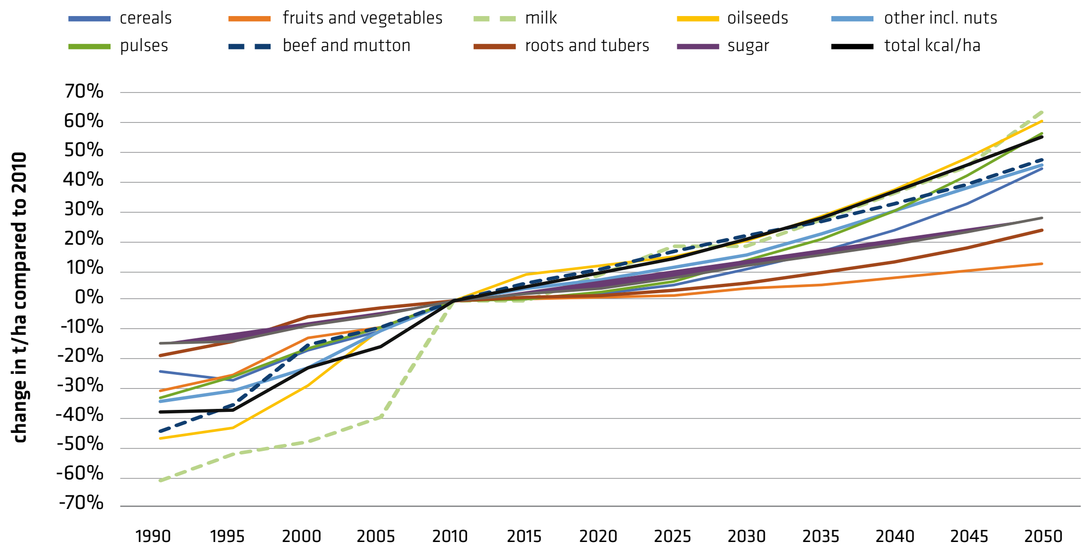


Table 2 *Summary of the main assumptions of FABLE pathways.*

		POP	FOOD				TRADE		PRODUCTIVITY			LAND	
		Population (millions)	Total energy intake (kcal/cap/day)	Plant based energy intake (kcal/cap/day)	Animal based energy intake (kcal/cap/day)	Food Loss (% consumption)	Targeted Imports (kcal)	Targetd exports (kcal)	Livestock (kcal/TLU)	Crop (kcal/ha)	Pasture (TLU/ha)	Constraints on agriculture expansion	Afforestation over 2000- 2050 in Mha
		2050 compared to 2015 (2015=1)											
FABLE COUNTRIES	ARG	1.3	1.0	1.0	1.0		1.,3	2.7	1.4	2.0	1.0	ND 2030	1.9
	AUS	1.6	1.0	1.2	0.4		1.7	1.8	1.9	1.5	1.1		15.8
	BRA	1.1	1.1	1.1	1.0		1.1	1.7	1.3	1.5	1.5	ND 2030	11.4
	CAN	1.3	1.0	1.0	1.0	R	1.3	1.6	1.2	1.2	1.0		
	CHN	1.0	1.0	1.0	0.7	R	0.8	1.3	1.0	1.0	1.0	MC	41.3
	COL	1.0	1.0	1.0	1.0	R	0.9	3.3	1.0	1.2	1.0	ND 2030	1.9
	ETH	1.7	1.1	1.0	1.3	R	2.5	1.3	2.1	2.9	1.0		14.3
	FIN	1.1	1.0	1.3	0.3		1.3	0.6	1.2	0.9	1.0		0.3
	IND	1.4	1.2	1.2	1.3	R	2.2	1.6	1.4	1.9	1.0	NE 2010	2.0
	IDN	1.4	1.2	1.2	1.3	R	1.6	2.7	1.5	1.5	1.0		1.9
	MYS	1.4	1.0	0.9	1.7		1.7	1.8	1.2	1.4	1.0		1.9
	MEX	1.2	1.1	1.1	1.1	R	1.5	1.2	1.3	1.5	1.4	NE 2010	4.2
	RUS	1.0	1.1	1.0	1.0	R	0.9	4.9	2.3	2.2	1.0		
	RWA	1.9	1.2	1.1	1.8	R	3.3	1.4	2.9	1.9	1.0		
	SWE	1.3	1.1	1.0	1.1		1.3	1.8	1.1	1.2	1.0		1.8
	UK	1.2	1.0	1.0	0.8	R	1.0	1.0	1.4	1.6	1.3		1.5
	US	1.2	0.9	1.0	0.8		1.4	1.9	1.6	1.4	1.0		38.0
	ROEU	1.0	1.0	1.0	1.0	R	1.0	1.6	1.2	1.2	1.0		10.1
ROW	RASI	1.2	1.0	1.0	1.0		1.2	1.7	1.3	1.4	1.0		
	RAFR	1.8	1.0	1.0	1.1		1.8	1.6	1.3	1.4	1.5		
	RAME	1.3	1.1	1.1	1.1		1.3	1.6	1.4	1.4	1.4		
	RCAS	1.5	1.1	1.1	1.1		1.6	1.8	1.0	1.5	1.5		
	RMID	1.6	1.1	1.0	1.1		1.9	1.7	1.5	1.6	1.0		
	RPAC	1.3	1.0	1.0	1.0		1.3	1.4	1.6	1.2	1.0		
	RNEU	1.1	1.1	1.1	1.1		1.1	1.2		1.3			

Scenarios: R: *Reduced food loss compared to current level;* ***ND 2030:*** *No-deforestation beyond 2030;* ***NE 2010:*** *No agricultural land expansion beyond 2010 level;* ***MC:*** *Minimum Cropland area* ***FABLE country teams:*** *ARG: Argentina; AUS: Australia; BRA: Brazil; CAN: Canada; CHN: China; COL: Colombia; ETH: Ethiopia; FIN: Finland; IND: India; IDN: Indonesia; MYS: Malaysia; MEX: Mexico; RUS: Russia; RWA: Rwanda; SWE: Sweden; UK: United Kingdom; US: United States of America; ROEU: Rest of European Union.* ***Rest of the world regions:*** *RASI: Rest of Asia; RAFR: Rest of Africa; RAME: Rest of America; RCAS: Rest of central Asia; RMID: Rest of Middle East; RPAC: Rest of Pacific islands; RNEU: Rest of Europe (non-EU).*

Magnitude of the changes --> darker shade for strong change - both extremes exports of crops and livestock but only 50 percent of total imports. Except Finland and the UK, all FABLE countries have assumed an increase in their agricultural exports in calories equivalent between 2015 and 2050 (Table 2). Export projections are particularly ambitious for Argentina, Australia, Brazil, Canada, Colombia, India, Indonesia, Malaysia, Russia, Sweden, the US, and the rest of the EU. Except China, Colombia, Russia, and the rest of the EU, FABLE country teams also assume higher total imports for many products. African FABLE countries (Ethiopia and Rwanda), India, Mexico, Malaysia, and Finland assume a faster growth of agricultural imports compared to their exports.

4.2. Performance against global FABLE targets

In this section we review how the sum of all FABLE country and region pathways performs against the global FABLE targets described in Table 1 (page 24). The performance of the pathways against the targets relies, to a large extent, on the change in agricultural land between 2015 and 2050. Over this period, we project a cropland reduction by 77 Mha and pasture land by 524 Mha, globally equivalent to 5 percent reduction of current cropland area and 16 percent of current pasture area. By 2050 the global cropland area will return close to its 2010 level, and the pasture area will fall below the 2000 level. The reduction in land used for agriculture is made possible by two factors: (1) higher productivity growth per hectare of agricultural land (56 percent between 2010 and 2050; see Section 4.1.4) than the growth in demand for agricultural products (48 percent between 2010 and 2050); and (2) the reduction of food consumption losses.

The reduction in agricultural land is even more pronounced in FABLE countries: total cropland area decreases by 13 percent, and grassland by 30 percent, between 2015 and 2050, resulting in a reduction of 23 percent of total agricultural land. There is significant heterogeneity across FABLE countries both in magnitude of this change and in timing. The UK, Brazilian, Australian, Mexican, and Russian country teams project a reduction in total agricultural land by more than 30 percent compared to 2015 levels, but the Canadian, Colombian, Indonesian, Rwandan, and Swedish teams project a slight increase (less than 10 percent). Some country teams project reductions in both cropland and pasture starting as early as 2025 (Mexico, rest of the EU, the UK).

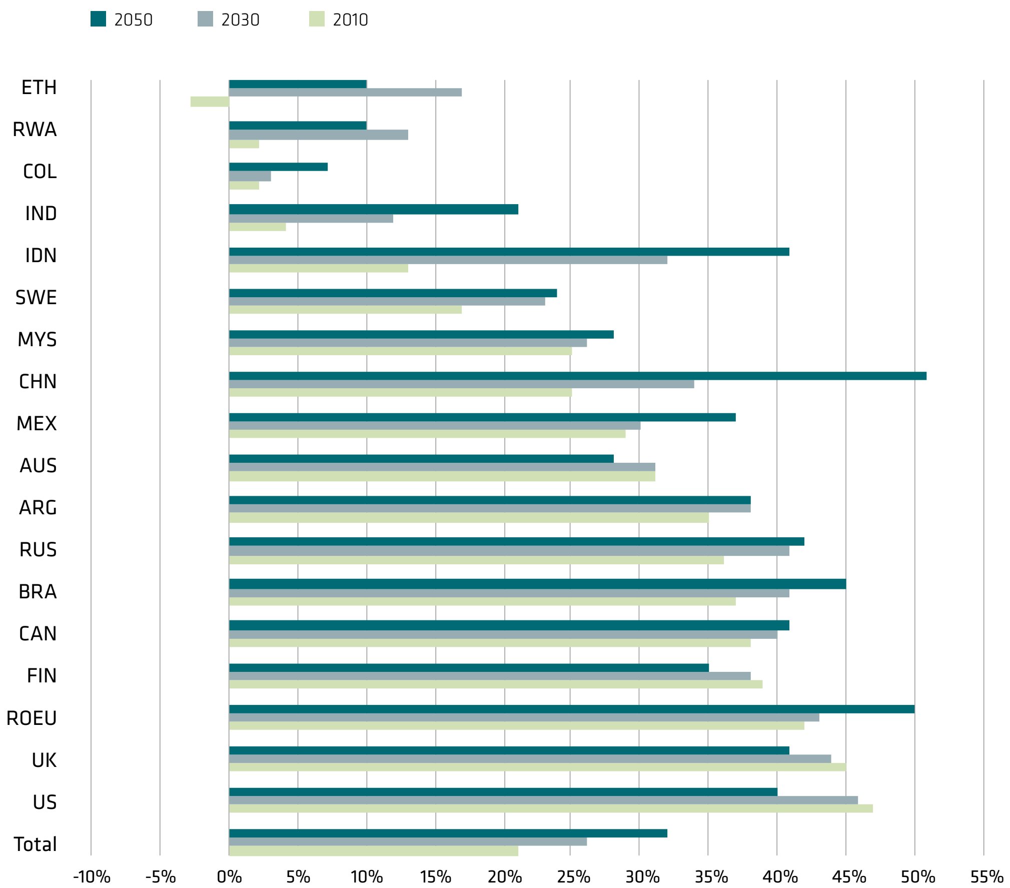
4.2.1. Food security

Target 1: Average daily energy intake per capita above the minimum daily energy requirement (MDER) by 2030 onwards in all countries

By 2030 and 2050, all countries achieve an average daily energy intake per capita that exceeds their respective Minimum Daily Energy Requirement (MDER) (Figure 8). The MDER is computed as a weighted average of energy requirement per sex, age class, and activity level (U.S. Department of Health and Human Services and U.S. Department of Agriculture, 2015) and the population projections by sex and age class (UN DESA, 2017) following the FAO methodology (Wanner et al., 2014). Computed MDER at the national level varies between 2000 and 2100 kcal per capita per day in 2050 in FABLE countries. The largest increases in energy intake occur in Ethiopia, India, and Indonesia – the FABLE countries that have among the highest rates of undernourished population. In contrast, Australia, Finland, the UK, and the US project a reduction in the surplus average energy intake, consistent with high obesity rates in these countries. Overall, projected average energy intakes per capita increase faster than the MDER in most FABLE countries. As a result, the surplus in average energy intake rises from 24 percent in 2015 to 28 percent in 2050. This leaves additional room for reducing demand for food, particularly in Brazil, the EU, and Mexico, which project a rise in the surplus from an already high base today.

In interpreting national and global results, it is important to note that the country pathways presented in this report focus on national averages. So even if the average energy intake is above the MDER in a country, it may be possible that significant parts of the population over- or under-consume key commodities. In particular, poor and marginalized populations may struggle to improve their nutritional status. More disaggregated analyses are needed to investigate these inequalities.

Figure 8 *Difference between the computed average daily energy intake per capita and the Minimum Daily Energy Requirement (MDER) for each FABLE country, sorted by 2010 surplus (from lowest to highest).*

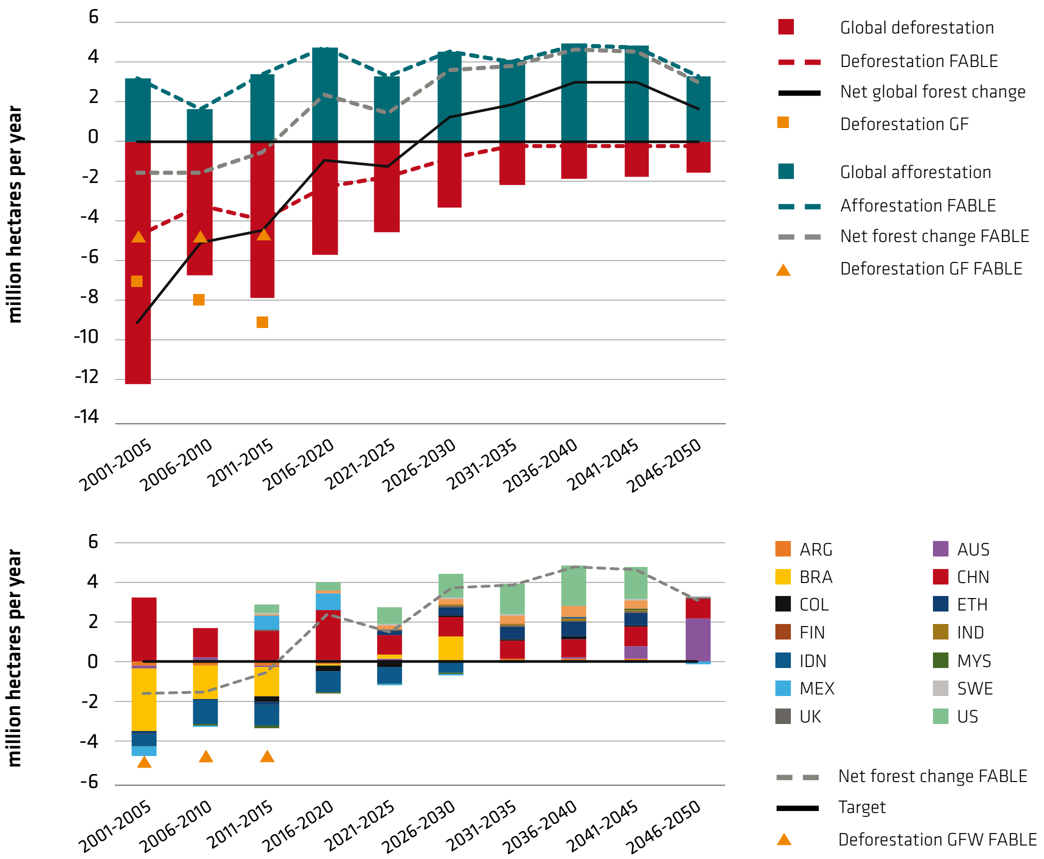


Note: Energy intake also includes the 2010 consumption level of animal fat and alcohol reported by FAO, as these are not computed in the calculator in 2050. These two items represent 6 percent of average calorie intake in FABLE countries. A surplus indicates that the computed energy intake is higher than the MDER at the national level, while a negative number indicates a deficit compared to the MDER.

4.2.2. Zero net deforestation

Target 2: Zero net deforestation by 2030 onwards
Our results show that this target could be achieved already by 2016-2020 for FABLE countries as a group, and by 2026-2030 globally. We obtain a net increase in forest area that fluctuates between 2 and 3 million hectares per year after 2030 (Figure 9, top). Our results still show some deforestation over the whole period of simulation, but four times lower than the net deforestation computed for the period 2011-2015. At the global level, most of the estimated deforestation after 2030 comes from the Rest of Africa. There are large uncertainties related to the level of future deforestation in Africa, and this result should therefore be interpreted with care, as conservative assumptions have been made for the region.

Figure 9 *Computed forest cover change globally (top) and in FABLE countries (bottom).*



Note: Our computation includes only deforestation caused by the expansion of cropland, pasture and urban areas. For comparison with our estimates for the historical period we use deforestation from commodity expansion, urban expansion and shifting cultivation from Global Forest Watch (GFW) database (GFW, 2019). Dashed lines represent computed results for FABLE countries only, as well as the triangles for GFW historical deforestation.

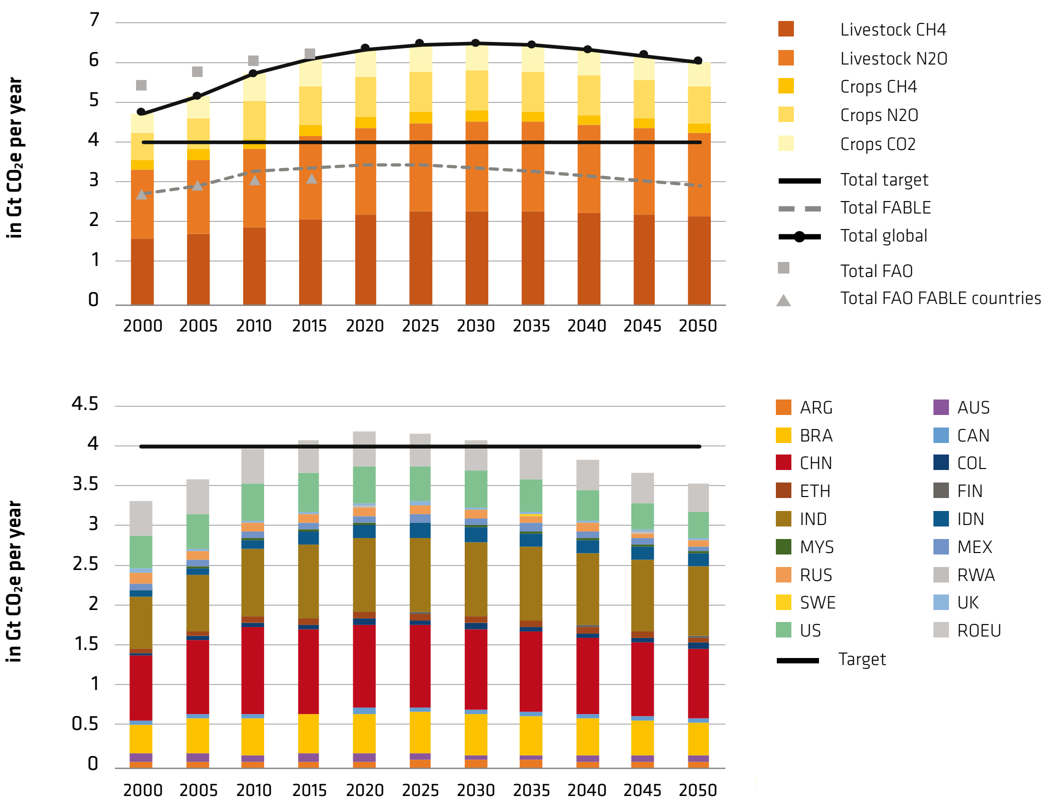
FABLE countries account for a large share of historical deforestation. This share reduces after 2015, and FABLE countries reach zero deforestation after 2030. As each country team defines and implements its afforestation target over different time scales, the total afforested area fluctuates over the period considered in the Scenathon. The total afforested/reforested area peaks at 5 million hectares per year (Figure 9, bottom). China is reducing its historical rate by some 50 percent and the US emerges as the single largest contributor to future accumulated afforestation with 38 million hectares afforested by 2050.

4.2.3. Greenhouse gas emissions reduction

Target 3: Greenhouse gas emissions from crops and livestock below 4 Gt CO_2e by 2050

The sum of FABLE countries and RoW pathways considered in this Scenathon do not achieve this target. By 2050, computed emissions from crops and livestock amount 6 Gt CO_2e per year, i.e. 50

Figure 10 *Computed greenhouse gas emissions from agriculture globally (top) and in FABLE countries (bottom).*



Note: Since CO_2 emissions from energy use in crop cultivation are not available for 2015, we use the same emission level as reported for 2010 in the total FAO emissions.

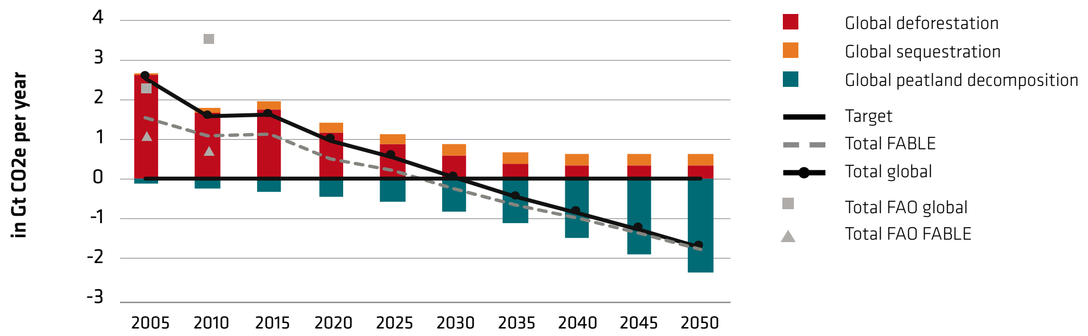
percent above the target (Figure 10, top). This is mostly driven by increases in emissions from the livestock sector. Projected emissions from agriculture only start to decline after 2035, and at a pace which remains too slow to reach the target.

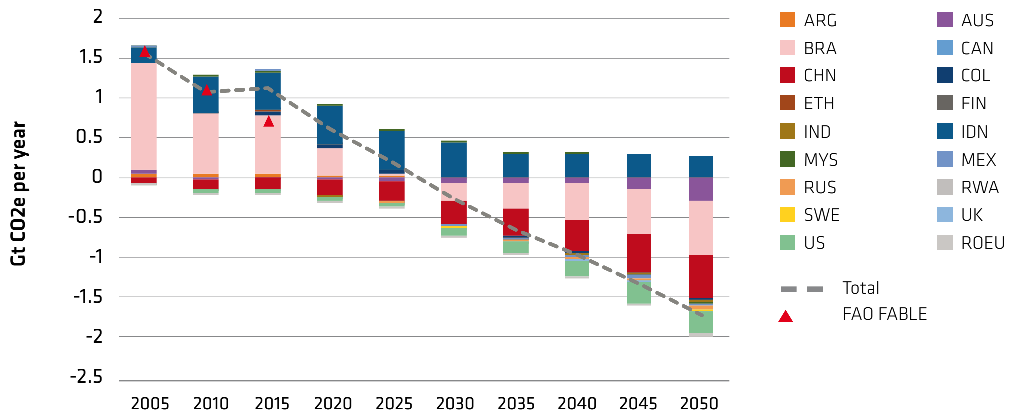
FABLE countries represent 70 percent of total emissions from agriculture in 2010, and this share is projected to fall to 60 percent by 2050. India and China contribute a large share of global greenhouse gas emissions from agriculture, representing about half of the total from the FABLE countries (Figure 10, bottom).

Target 4: Zero or negative greenhouse gas emissions from land use change by 2050

Results from the FABLE countries and RoW pathways generate net negative emissions from land-use change in the range of 1.7 Gt CO_2e per year by 2050 (Figure 11, top). Emissions from land-use change start to turn negative around 2030, largely as a result of slowing deforestation, an increase in afforestation, and an increase in abandoned cropland and pasture where natural vegetation regrowth can lead to carbon sequestration.

Figure 11 *Computed emissions from land-use change globally (top) and in FABLE countries (bottom).*





Among FABLE countries, the only significant source of emissions from land-use change after 2030 comes from peatland decomposition (Figure 11, bottom) in Indonesia, the only FABLE country team to consider this emission source in the FABLE Calculator. The country's pathway projects that no new peatland will be converted after 2030, but emissions remain large since drained peatland continues emitting greenhouse gases for decades (Murdiyarso et al., 2010). Brazil accounts for a large share of greenhouse gas sequestration due to natural vegetation regrowth on abandoned agricultural land and some afforestation over 2020-2030. In Australia, China, and the US, net carbon sequestration is achieved through a combination of afforestation and the abandonment of agricultural land.

4.2.4. Biodiversity

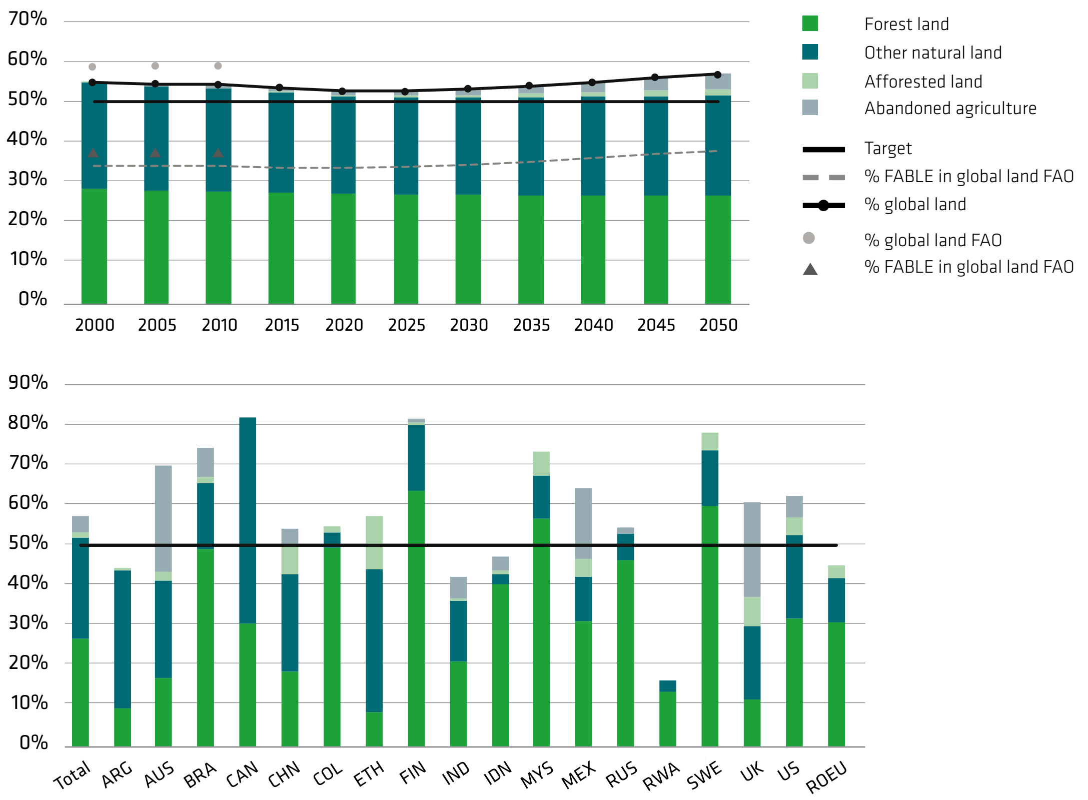
Target 5: At least 50 percent of the terrestrial land could support biodiversity conservation by 2050

Progress towards this target has to be tracked through proxies, since the FABLE Calculator does not use spatially-explicit data. The area of land that could support biodiversity conservation is estimated as the sum of the land covered by forest, other natural land classes defined at the national level, as well as agricultural land that has been afforested or abandoned. One shortcoming of this approach is that different areas within the same broad land cover type can support different levels of biodiversity. For example, a hectare of tropical rainforest cannot be compared with a hectare of boreal forest. Moreover, the other natural land category can be very heterogeneous within the same country, i.e. including degraded land, desert areas or savannah-forest transition areas.

With these important caveats in mind, our global results suggest that it might be possible to leave 50 percent of terrestrial land for biodiversity conservation (Figure 12, top). The land available declines before 2020, and then rises from 2020 to 2050. Restored and afforested land, particularly if it was previously degraded, generates biodiversity very slowly and may never reach biodiversity levels of comparable pristine land, or at least not on human time scales. Yet, even if restored and afforested land is excluded from our analysis, then the land area which could support biodiversity would stabilize just above 50 percent of total land by 2050.

Fourteen countries reach the target in 2050, but six of these only reach the target thanks to afforestation and the abandonment of agricultural land (Figure 12, bottom). Among the FABLE country teams, Rwanda is projecting the greatest loss of biodiversity due to projected agricultural land expansion, and Argentina, India, Indonesia, and the EU also do not reach the target by 2050. Our projections do not reflect the large reforestation efforts which are underway in Rwanda (The Ministry of Natural Resources of Rwanda, 2014). Agroforestry has been identified as the greatest opportunity for restoration in the country as it allows afforestation and agricultural production in the same area, but this is not represented in the Calculator, i.e. afforested land excludes agricultural production. In these circumstances, the implementation of the Bonn Challenge commitment would have led to too low food production and consumption in Rwanda.

Figure 12 *Computed share of total land which could support biodiversity conservation globally (top) and change in total area which could support biodiversity between 2000 and 2050 by country and region (bottom).*



4.3.Impacts of trade adjustment

Before the trade adjustment, the sum of exports projected by FABLE countries exceeded total imports for soybean, rapeseed, cassava, palm oil, beef, corn, sweet potato, oats, and – to a lower extent – wheat and rice. In other words, there was surplus production of these products at the global level. On the other hand, imports exceeded projected exports for most fruits, vegetables, nuts, tea, coffee, and sugar. Following the trade adjustment, trade volumes exhibit a steady increase between 2015 and 2050. By 2050, the share of the total production which is traded internationally remains below 30 percent for all agricultural products except cocoa (50 percent). The trade adjustment does not significantly affect countries' performance against the global FABLE targets, but significant impacts are observed on land use in some countries and for some key commodities (see country chapters).

We illustrate the implications of the trade adjustment with two examples: the evolution of the international market for beef and Chinese imports of soybean and milk.

4.3.1. International market for beef

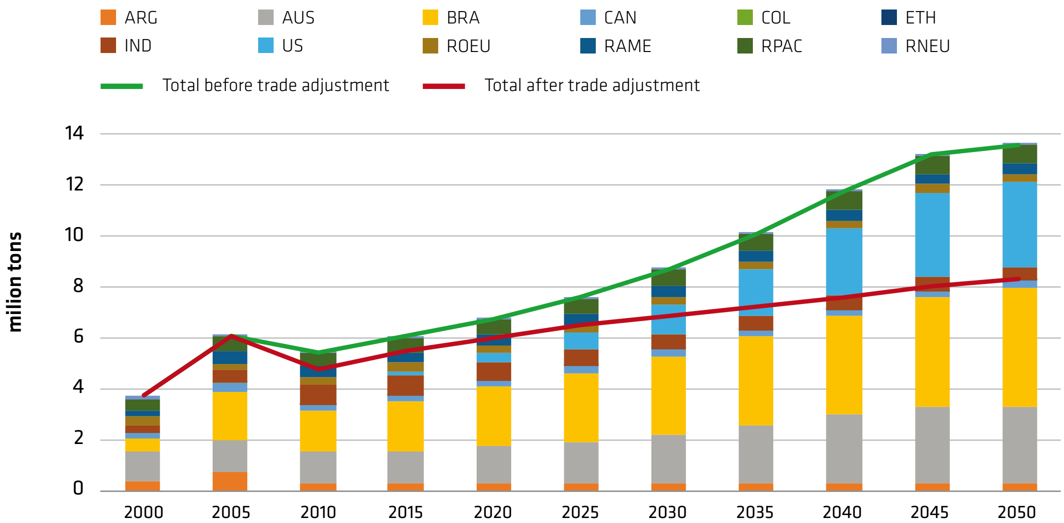
Based on projections by the FABLE country teams, total beef exports exceed imports before the trade adjustment by a substantial margin. The Rest of the World regions represent more than half of total imports, followed by Russia, UK, China, Mexico, Malaysia, and Indonesia. Total beef imports are projected to increase by 50 percent between 2015 and 2050, especially due to a doubling of imports from the Middle East, Africa, Malaysia, and Mexico.

Two substantial changes to exports are forecasted by the FABLE country teams. Indian beef exports are projected to fall, while US exports increase sharply, making the country the second largest exporter by 2050 after Brazil and before Australia (Figure 13). US exports rise even though US beef production in 2050 is lower than 2015 because US domestic beef consumption is projected to halve by 2050. Higher exports thereby cushion a reduction in US beef production and associated pasture area. A trade adjustment was conducted to align beef imports with exports. It led to a cut in overall export volumes by 26 percent in 2050. Owing to the large rise in US exports (prior to the trade adjustment), export shares of some traditional beef exporters, such as Australia, fall significantly, which has raised concerns among the respective country teams. This highlights the importance of the trade adjustment process, as well as the need for careful analyses of international demand and how to address trade imbalances.

4.3.2. Chinese imports

The rapid rise in Chinese imports of agricultural products has had profound implications on agricultural production systems around the world. For example, soybean imports from China increased from almost zero in 1997 to more than 60 million tons in 2013 (USDA Production,

Figure 13 *Evolution of beef exports by exporting country, and impact of the trade adjustment on total exports.*



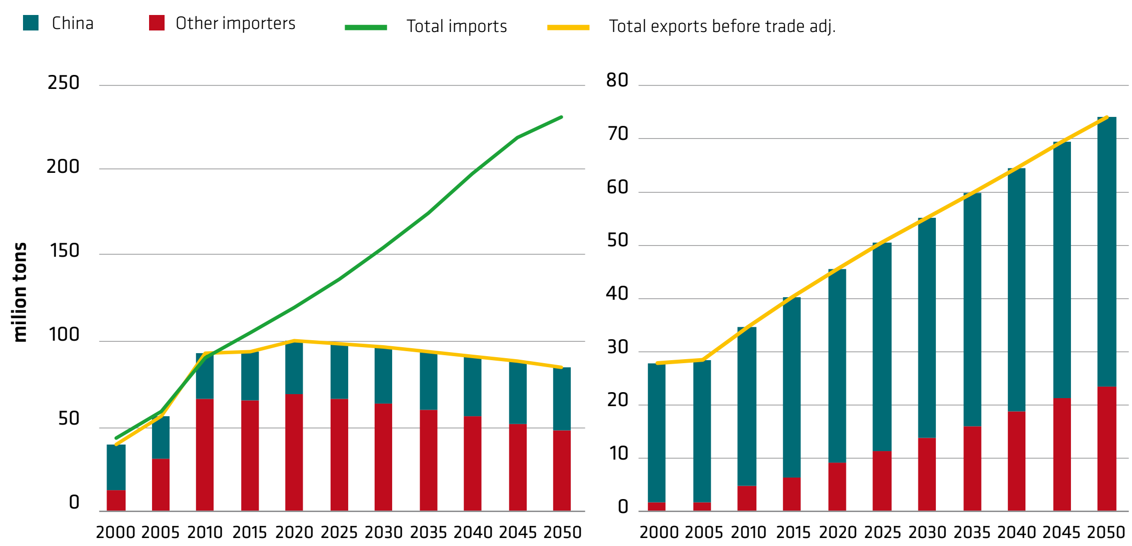
ROEU: Rest of European Union; RAME: Rest of America; RPAC: Rest of Pacific Islands; RNEU: Rest of Europe (Non-EU)

Supply and Distribution database). Initially, the FABLE country teams from China's major trading partners had assumed that current trends would continue. However, our results show a substantial reduction in the global demand for soybean imports after 2020 (Figure 14). This reduction in demand is driven by projected dietary changes in China, leading to a stabilization of ruminant meat demand and a reduction in pork and chicken meat consumption. Overall, the Chinese team projects a reduction in the number of pigs and chicken, which in turn translates into a reduction in soybean demand for animal feed. During the trade adjustment, total exports of soybean therefore had to be reduced by more than half to match global imports in 2050.

The dietary change in China is also characterized by an increase in milk and in vegetable oil consumption per capita. Increases in domestic production largely satisfy this demand, but higher imports are also required to fill the gaps. Our results show that Chinese milk imports increase by a factor of five between 2015 and 2050 (Figure 14). This comes in addition to higher milk imports by other countries, particularly in Africa and the Middle East. This increase in global milk demand matches the anticipation of FABLE teams from countries that export milk (Argentina, Australia, and EU).

Chinese demand will have profound implications for other commodity markets. For vegetable oils, China would need to increase its imports or reduce its consumption, especially if the domestic processing of soybean is reduced. Imports of palm oil, soybean oil, and sunflower oil might increase significantly. This might be met by increased exports of sunflower oil as forecasted by Russia, and increased exports of palm oil as forecasted by Indonesia and Malaysia.

Figure 14 *Evolution of soybean imports (left) and milk imports (right) from China and from the rest of the world.*



FABLE country teams are exploring the most cost-effective and sustainable trade strategy for China. Detailed results will be presented in early 2020 (Box 7 on page 41).

4.4. Discussion of results

As discussed above, the average energy intake in all FABLE countries exceeds the MDER by 2050. In fact, many countries face large surpluses of the average energy intake compared to the MDER, but inequalities in food access might mean that some parts of the population still suffer from hunger. For instance, to reduce the risk of hunger, Searchinger et al. (2018) recommends using an average national target of 3000 kcal per capita per day, which is far higher than the 2100 kcal based on MDER (Section 4.2.1). Of particular importance is adequate nutrition during the first three years of childhood to ensure children reach their full potential for cognitive ability (Bhutta et al., 2013; Willett et al., 2019). To address these distributional issues and to assess the impact of policies on the most vulnerable, household survey data can be combined with economic models (Laborde et al., 2016). Another analytical challenge concerns the quality of diets. As highlighted by Nelson et al. (2018) and the EAT-Lancet report (Willett et al., 2019), providing nutritious diets to all will be a greater challenge than providing enough calories by 2050. We will investigate how to expand food security indicators in the FABLE analysis to cover more dietary deficiencies.

Our results on greenhouse gas emissions are in the range of previous published results from Integrated Assessment Models. Using five such models, Popp et al. (2017) estimate that, to be compatible with the 1.5°C limit by 2100, annual CO_2 emissions from Land-Use, Land-Use Change, and Forestry (LULUCF) will need to be in the range of -12.4 to 2.9 Gt CO_2 in 2050. A net sequestration of 2.3 Gt CO_2 in 2050 is estimated using MESSAGE-GLOBIOM (Rogelj et al., 2018). In this report, we estimate a net sequestration of 1.7 Gt CO_2 in 2050 from land use and land-use change only. It is difficult to compare these estimates due to a lack of transparency on the estimated emissions and sequestration from the different components of the LULUCF sector. For instance, carbon sequestration in managed forests is not taken into account in the FABLE Calculator, but it is included in some Integrated Assessment Models. Some models also consider carbon in dead organic matter and soil organic carbon, which are not accounted for in the FABLE Calculator.

The target on greenhouse gas emissions from agriculture is not reached in the Scenathon results presented in this report. Emissions rise to 6 Gt CO_2e in 2050 compared to the target of 4 Gt CO_2e. Yet, even these results fall within the range of IAM results compatible with a 1.5°C target by 2100. These estimates vary between 2.2 and 11.1 Gt CO_2e in 2050 (Popp et al., 2017). Indeed, our results are close to the BAU emissions from Frank et al. (2019) which reach between 7.1 and 8 Gt CO_2e per year in 2050.

Reducing greenhouse gas emissions from agriculture will be a priority for forthcoming FABLE work. In particular, we will include mitigation options for agriculture; currently, the emissions from agriculture can only be reduced by lowering production volumes or increasing productivity. Frank et al. (2019) estimate that improved rice management, animal feed supplements, fertilization techniques or anaerobic digesters are among the most promising technologies to reduce emissions from crops and livestock. Climate-smart agriculture is an interesting approach as it pursues higher productivity for better livelihoods and the reduction of emissions at the same time (Campbell et al., 2014). We will explore how to include these in future versions of the Calculator. Other models with a better representation of these production systems, such as GLOBIOM and MAgPIE, might also join the Scenathon in the future.

Our results on biodiversity offer a very preliminary and incomplete assessment. As discussed above, reaching the FABLE target is necessary, but far from sufficient for ensuring that biodiversity can be protected. Improving the analysis will require spatially disaggregated modeling tools that consider the spatial heterogeneity of biodiversity richness, including on agricultural land. Some production systems, such as shade-grown coffee, cocoa, and agroecology, can have high carbon stocks and biodiversity values (Jezeer et al., 2017; Tscharntke et al., 2005; Bioversity International, 2019). In addition to ensuring spatially disaggregated biodiversity analyses, the biodiversity assessment should also consider ecoregions.

The FABLE methodology has a number of advantages, but also limitations. One clear advantage over global modeling approaches is that country teams develop pathways for their own countries. They have a far deeper understanding of national specificities, as can be seen from the country chapters. This can result in divergent assumptions, as can be seen, for example, in relation to the meat consumption in Latin America compared with other parts of the world. The FABLE Calculator has the advantage of transparency, allowing country teams to implement pathways that can strongly depart from current trends.

Additional functionalities that can be built into the FABLE Calculator include a better representation of the forestry sector, water use, nutrient flows, and climate impacts on land-use and food systems. We will also broaden the Scenathon to allow for the participation of partial equilibrium models, such as GLOBIOM (Box 5) or MAgPIE (Box 6). Another important aspect would be to include more indicators related to the first FABLE pillar, "Efficient and resilient agricultural systems and fisheries that support livelihoods." The share of employment in agriculture is declining almost everywhere, but it is still high in China (27 percent), India (44 percent), and Indonesia (31 percent), so the employment and livelihood dimensions of the transformation towards sustainable land-use and food systems is critical.

The Scenathon has demonstrated how many different country teams can contribute to a global target. It proved challenging to balance trade flows for each commodity, but this step underscored the interdependencies across all countries. Every country needs to consider demand and supply from other countries in developing its own pathways towards land-use and food systems. The FABLE Consortium will further improve the methodology to balance trade by taking into account more economic variables and more extensive exchanges across country teams. Another avenue of exploration is the role of cooperation between country teams. This would allow us to further explore the effects of cooperation or non-cooperation between countries on the Scenathon outcomes.

5. Policy implications and next steps

Launched some 18 months ago, the FABLE Consortium has become a unique global network of country teams focused on understanding how countries can develop long-term strategies towards sustainable land-use and food systems. With other members of the Food and Land-Use Coalition (FOLU), we have made substantial progress in understanding how this can be achieved. We now see more clearly how to strengthen in-country capacity for developing the strategies. The Food and Land-Use Coalition will describe policy options in a global report to be launched in New York in September 2019. Meanwhile, this first report by the FABLE Consortium has consolidated preliminary results from 18 country pathways, developed through a collaborative process which we call a Scenathon, to achieve time-bound global targets summarized in Table 1 (page 24).

The results described in the preceding section show that the ambitious FABLE targets can be achieved under reasonable assumptions. We did not find anything that would make achieving the FABLE targets seem impossible, with two caveats. First, more work is needed on the target to reduce greenhouse gas emissions from agriculture. Second, the water and nutrient targets still need to be incorporated into the analysis.

It is notable that country teams vary in the assumptions they make about the feasibility and desirability of changes to their food systems. For example, teams make different assumptions about desirable and feasible dietary changes across countries, reflecting local traditions, customs, and resource endowments. This demonstrates the importance of county-driven analyses of land-use and food systems.

Nevertheless, the projected changes to land-use and food systems are profound and will require deep, long-term changes across the three pillars, which in turn depend on ambitious policies, greater investments from the public and private sectors, and tremendous innovation. Figure 15 summarizes key benchmarks that are achieved.

Our preliminary results show that action on one pillar is not sufficient to achieve the transformation unless backed by action on all other pillars. Since food systems and land-use change account for just under one third of countries' greenhouse gas emissions (Poore and Nemecek, 2018), governments that are developing long-term, low-emission strategies under the Paris Agreement will need to consider all three pillars alongside the decarbonization of energy systems. The most important changes by pillar include:

- **Efficient and resilient agricultural systems.** Our sustainable pathways rely on crop productivity growth by 56 percent in FABLE countries through 2050, which corresponds to an annual improvement of 1.1 percent per year. This rate is significantly lower than the 1.7 percent observed over the last 25 years, but it will nevertheless represent a major challenge in the face of high baseline productivity and the impacts of climate change and land degradation. To achieve these productivity levels, countries will need to invest in research and development, as well as enabling conditions for the deployment and application of improved varieties and farming practices. Infrastructure investments and access to high-quality inputs will also play an important role, particularly in poor countries.

The flipside of rising productivity, though, has to be far greater resource efficiency. This will be a major direction of future research for the FABLE Consortium.

- **Conservation and restoration of biodiversity.** As a top priority, countries need to enforce measures against deforestation. A combination of command and control policies and incentives, such as payment for environmental services, might be desirable. Ensuring robust national forest monitoring systems in order to produce high-quality data on forests and forest ecosystem services, and to track forest changes, is critical and may require international transfer payments. Countries also need to promote afforestation/reforestation measures in line with the Bonn Challenge. The contribution of afforested areas to biodiversity restoration will require significant technical know-how and investments in nurseries of native flora, breeding centers of wild animals, and the prevention of the occupation of invasive

Figure 15 *Performance metrics of the computed pathways across the three FABLE pillars.*

Trade consistent with sustainable development

Integrated land use planning

PILLAR 1

Efficient and resilient agriculture systems

Average productivity growth in kcal/ha agricultural land:
+ 56% between 2010 and 2050 globally

Global GHG emissions from crops and livestock:
6 Gt CO2e in 2050

Global GHG emissions from land use change:
-1.6 Gt CO2e in 2050

PILLAR 2

Conservation and restoration of biodiversity

Global deforestation:
1.6 Mha/year in 2050

Net global forest cover change:
+1.6 Mha/year in 2050

Cumulated global afforested land:
191 Mha in 2050

Share of total land which could support biodiversity:
57% of global land in 2050

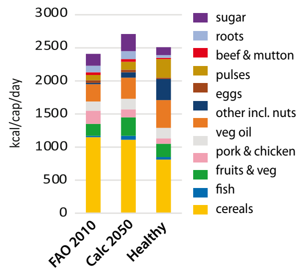
Range across FABLE countries 16% - 82%

PILLAR 3

Food security and healthy diets

Food security:
Average energy intake > minimum requirement from 2030 onwards in all FABLE countries

Average diet in FABLE countries:



species to the detriment of native ones (Fernandez et al., 2017).

- **Food security, healthy diets, and lower food losses.** One of the most important levers of change is to reverse the current trend towards imbalanced diets that are high in starchy food, animal protein, and sugar (Willett et al., 2019). This requires large changes in food consumption habits, food processing, and food marketing. Improved diets need to go hand-in-hand with lower food losses.

- **The critical role of trade.** The results also demonstrate the critical impact of trade on both importing as well as exporting countries. Relatively small changes in one country's policies can have a profound impact on land-use and food systems in other countries. This has been powerfully illustrated by the increase in China's demand for dairy products, which transformed land use in New Zealand (Bai et al., 2018). Our results show that slight changes in the balance between demand and supply of meat in the United States could have profound impacts on other countries. Countries will therefore need to consider trade in their medium and long-term strategies. This, in turn, requires an understanding of what is happening with major bilateral trading partners, information that the FABLE Consortium provides. As one example, the Consortium is currently undertaking an in-depth assessment of the long-term impacts and sustainability of trade in agricultural and other commodities between China and its major trading partners. Findings and policy implications will be available towards the end of this year.

- **Integrated land and water-use planning frameworks.** Our results also underscore the need for spatially-explicit design of land-use and food systems by governments working with business, private land owners, and other stakeholders. Competing uses of land come from agriculture, livestock, forestry, industry, urban development, disaster risk reduction, and ecosystem services, including biodiversity and the retention and capture of carbon for climate change mitigation. All of these claims on land are location specific. For example, land in the vicinity of cities is most vulnerable to conversion. Results from the FABLE Consortium show that governments must design analytical instruments and policies to design their land-use with a long-term perspective. The upcoming global report by the Food and Land-Use Coalition will describe how this can be done.

In 2020, governments will convene for the Kunming conference of the Convention on Biological Diversity to adopt new targets for protecting nature and, later, for the climate COP, where they aim to increase the level of ambition of national climate strategies and present mid-century low-emission development strategies towards net zero greenhouse emissions (Box 1, page 25). Our results show clearly that strategies for protecting nature, curbing human-induced climate change, and promoting climate change adaptation require integrated approaches for managing all three pillars of sustainable land-use and food systems, complemented by dedicated strategies to decarbonize energy systems.

One urgent opportunity for countries to enhance the level of ambition and to promote the integration of their national strategies towards pursuing the Sustainable Development Goals and implementing the Paris Agreement comes at the September 2019 Climate Summit convened by UN Secretary-General Antonio Guterres in New York. Governments have the opportunity to reaffirm their commitments to submit low-emission development strategies by 2020, as provided by the Paris Agreement, and to include integrated strategies for efficient and resilient agricultural systems, the conservation and restoration of biodiversity, and food security and healthy diets. This would require, among other priorities, the inclusion of spatially-explicit national policy frameworks for managing biodiversity, such as China's recently adopted Ecological Conservation Redlines or South Africa's long-standing biodiversity management strategies, into the low-emission development strategies under the climate convention. Such a simple step would go a long way towards integrating national strategies for food and land-use systems, which our results show to be urgently needed.

Members of the FABLE Consortium have developed an ambitious five-point work program to improve our work and support governments and other stakeholders in making food and land-use systems sustainable. First, we are building country-level capacity to improve national pathways with the use of advanced, spatially-explicit data and models. Most FABLE country teams have identified spatially-explicit partial-equilibrium models, such as GLOBIOM (Box 5, page 36) or MAgPIE (Box 6, page 37), as necessary for supporting the design of national pathways and engagement with stakeholders. Over the coming year, most Consortium members will apply such models to their countries. In the run-up to the Kunming biodiversity COP in 2020, we will work with the Nature Map Consortium (www.naturemap.earth) and other partners to integrate biodiversity into these analyses. A key challenge for our future work will be to enhance our understanding of the social and economic costs, as well as the benefits, arising from the design and implementation of long-term strategies towards sustainable land-use and food systems. In particular, we will consider implications on rural livelihoods.

Second, FABLE Consortium members will engage stakeholders in their countries around the design of long-term pathways and supporting policies for sustainable land-use and food systems. As part of the Food and Land-Use Coalition, we will work with governments, civil society, business, and science to use pathways as a method for problem solving for making land-use and food systems sustainable, as described in Section 2 above. Several country teams will use the FABLE Calculator to engage stakeholders at national and sub-national levels on the feasibility of the needed transformations. We aim to organize our work to support interested governments in developing ambitious long-term strategies, including the low-emission development strategies intended to achieve the long-term objective of the Paris Agreement. All our tools are made available publicly for other countries and partners to use freely.

Every major infrastructure project requires environmental and social impact assessments, but this is not systematically the case with national policies that can have a far greater impact on long-term patterns of land-use and food systems. So, third, FABLE Consortium members will use their models and pathways to help simulate the impact of policy options across the three pillars of sustainable land-use and food systems. For example, these analyses will help governments quantify the intended consequences of changes to forest codes, biofuel mandates, or school feeding programs on agricultural production systems, greenhouse gas emissions, biodiversity, and the health of the population. Importantly, these analyses will also help governments and other stakeholders identify unintended consequences of policies so that their impacts can be considered as part of the decision-making process. We recognize that such policy assessments are highly complex, but experiences from each of the FABLE countries suggests that tremendous progress can be achieved in a relatively short period of time.

Fourth, we will improve the scope and methodology of the FABLE Scenathon to (1) cover a greater number of targets, including for water management and fertilizer run-off (nitrogen and phosphorous); (2) enhance the way in which trade is covered in the Scenathon; (3) include spatial aspects of land-use and food systems through the use of spatially-explicit partial-equilibrium models and results of sub-national applications of the FABLE Calculator; and (4) improve the quality and range of data used in the analyses, including through the data hub (Section 3) and the data produced by the Nature Map Consortium.

Finally, as part of the Food and Land-Use Coalition we will work with partners around the world to improve our understanding of how countries are transforming their food and land-use systems. Building on the successful experience of the Climate Action Tracker, which tracks and assesses policies to decarbonize energy systems, we aim to launch a Food and Land-Use Action Tracker to help countries benchmark their policies against those pursued elsewhere and to learn from experiences in other countries. To this end, members of the FABLE Consortium and other partners plan to inventory national targets, policy frameworks, and budgets across the three pillars of sustainable land-use and food systems. With adequate funding, we hope to develop and test a robust methodology for the FOLU Action Tracker and present initial results by the summer of 2020, in time for the landmark biodiversity and climate conferences later that year.

We, the members of the FABLE Consortium, have been encouraged by what we have learned since the start of this project. We have seen that every country – rich or poor – faces tremendous challenges in making its land-use and food systems sustainable. We have seen that far more knowledge needs to be applied to understanding the challenges and devising solutions that work over the long-term. We have found the concept of long-term strategies to be a highly useful concept for the problem-solving that must happen at global, national, and local scales involving governments, civil society, business, and science. Above all, we have experienced tremendous collaboration among all members of the FABLE Consortium to better understand the issues and build the capacity that is needed to tackle them and encourage others to join this work.

Having spent the last year and a half preparing this initial report, we are convinced of the feasibility of transforming land-use and food systems to better meet the needs of present and future populations. But we also see how complex and difficult it will be to design and implement these transformations in every country. As outlined in this section, we plan to improve, deepen, and expand our work to help governments and their partners chart their ways forward. The September global report of the Food and Land-Use Coalition will outline an action agenda for this transformation.

6. Country Analyses and Pathways

6

Argentina

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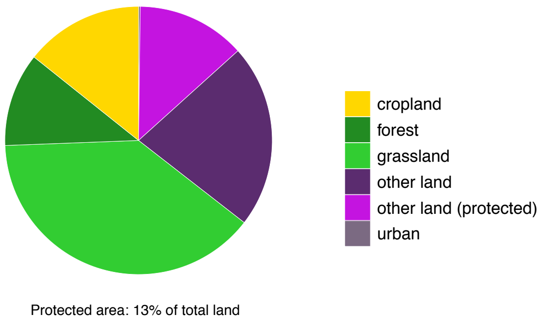
Land and food systems at a glance

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

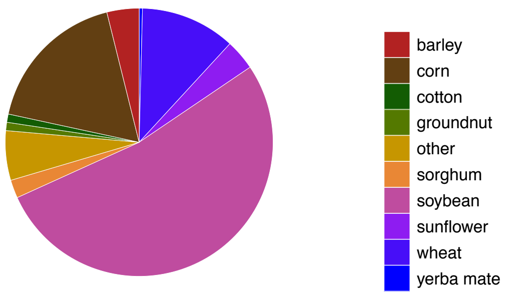
Land & Biodiversity

Fig. 1 | Area by land cover class in 2015



Source: FAO (2019), agroindustria.gob.ar (2019)

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



Source: agroindustria.gob.ar (2019)

Annual deforestation in 2015:
159 kha (half of it illegally) =
0.6% of total forest area

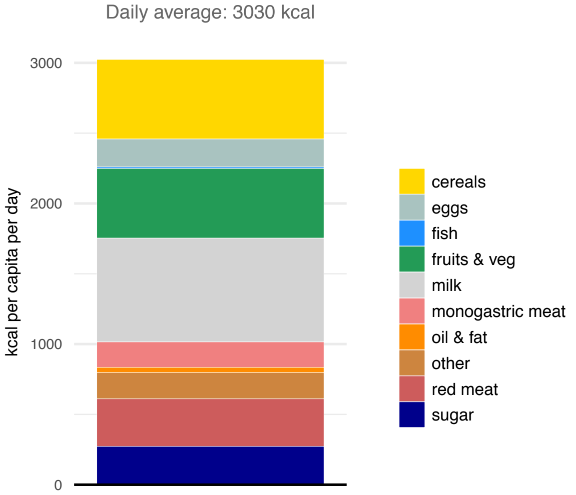
(Greenpeace, 2019; Presidencia de la Nación, 2017)

Endangered species:
564 (104 in danger, 149 threatened, and 311 vulnerable)

(AGN, 2019)

Food & Nutrition

Fig. 3 | Daily average intake per capita at the national level in 2010



Source: FAO (2019), INTA (2015)

Share of undernourished in 2015:
Children: 8.2%

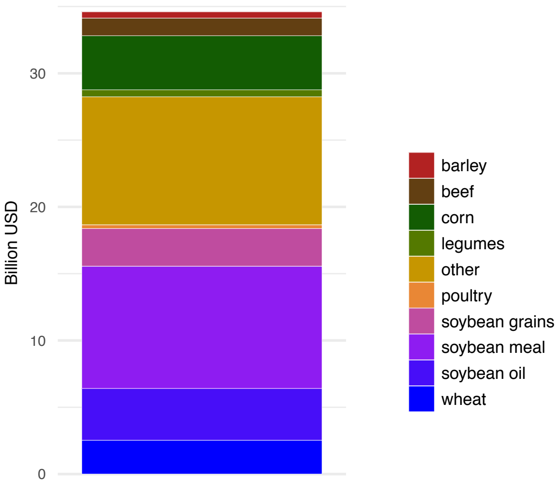
(FAOSTAT, 2019)

Share of obese in 2015:
Children: 10%
Adults: 28%

(FAOSTAT, 2019)

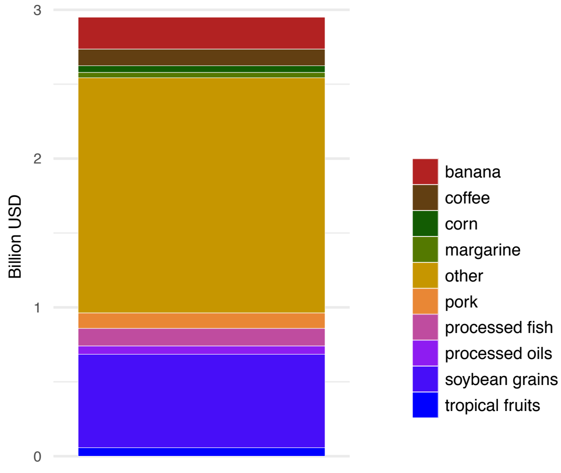
Trade

Fig. 4 | Main agricultural exports by value in 2017



Source: Observatory of Economic Complexity (2019)

Fig. 5 | Main agricultural imports by value in 2017



Source: Observatory of Economic Complexity (2019)

Surplus in agricultural trade balance in 2015: USD 33.45 bln

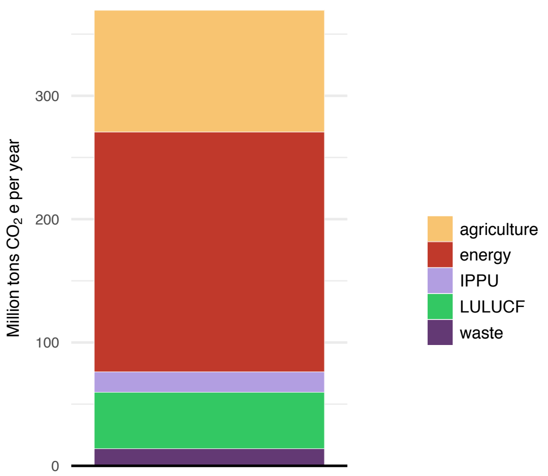
(OEC, 2019)

#1 exporter of soybean meal and oil. 5% of world grain and 15% of grain and byproducts

(Lopez-Dardaine, 2018)

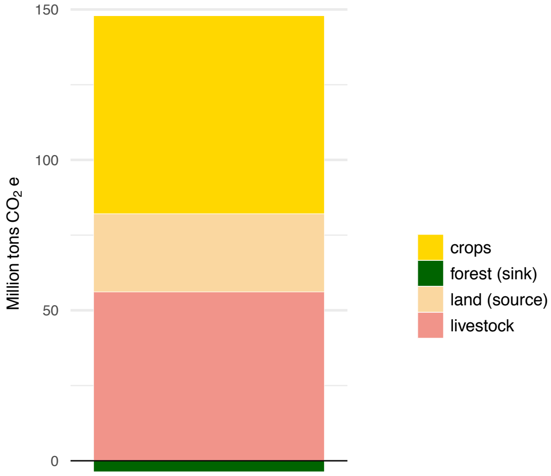
GHG Emissions

Fig. 6 | GHG emissions by sector in 2014



Source: Second BUR Argentina (2014)

Fig. 7 | GHG emissions from agriculture and land use change in 2014



Source: Second BUR Argentina (2014)

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 (large change)	Population (large change)
Scenario definition	GDP is expected to increase more than twofold, from USD 458 bnl in 2015 to USD 1 tln in 2050 (SSP3 scenario selected).	Population is expected to increase by 33% between 2015 and 2050 from 43 mln to 57 mln (SSP3 scenario selected).
Scenario justification	Based on the linear extrapolation of 1990-2017 potential GDP (Baumann Fonay et al., 2018).	Based on combined extrapolations from INDEC (2019) and Baumann Fonay et al., (2018).

TRADE

	Imports (no change)	Exports (large change)
Scenario definition	The share of total consumption which is imported decreases: - from 72% in 2010 to 36% in 2050 for bananas. The share of total consumption which is imported remains constant at 2010 level for the other products.	The exported quantity increases: - from 17 Mt in 2010 to 71 Mt in 2050 for corn, - from 13 Mt in 2010 to 54 Mt in 2050 for soybean, - from 5 Mt in 2010 to 20 Mt in 2050 for soy oil, - from 25 Mt in 2010 to 100 Mt in 2050 for soy cake, and, - from 2 Mt in 2010 to 8 Mt in 2050 for milk. The exported quantity remains constant at 2010 level for the other commodities.
Scenario justification	The selection of lower imports and higher exports is in line with the continuation of BAU tendencies on exports and imports.	The selection of lower imports and higher exports is in line with the continuation of BAU tendencies on exports and imports.

LAND

	Land conversion	Afforestation (large change)
Scenario definition	We assume that deforestation will be halted beyond 2030.	We assume total afforested/reforested area to reach 2 Mha by 2050 (based on the Bonn Challenge).
Scenario justification	We have made our choice based on the existence of a new law that establishes forest protection (Forest Law, 2017). As there are no other laws restricting land use changes, we have not selected another scenario.	Argentina's national commitment to the Bonn Challenge is to restore 1 Mha by 2020 (Bonn Challenge, 2014).

Scenario signs (=) no change (→) small change (↗) large change

BIODIVERSITY

	Protected areas (no change)
Scenario definition	The protected areas remain constant at 6.6 Mha between 2015 and 2050.
Scenario justification	The Administration of National Parks has issued a plan to double the current area in the near future, but not at the expense of highly productive areas. Therefore, we have not taken this into consideration to inform our pathway.

FOOD

	Diet (no change)	Food waste (no change)
Scenario definition	Between 2015 and 2050, the average daily calorie consumption per capita increases from 2,824 kcal to 2,855 kcal (SSP1 scenario was selected).	Between 2015 and 2050, the share of final household consumption which is wasted remains stable at 10%.
Scenario justification	We selected SSP1 scenario on diets, mainly because so far, we prioritized other variables. The impact of this assumption is yet to be determined.	Argentina wastes 16 Mt/year of food (Roulet, N, 2018, unpublished data). No projections on this issue were found.

PRODUCTIVITY

	Crop productivity (large change)	Livestock productivity (large change)	Pasture stocking rate (no change)
Scenario definition	Between 2015 and 2050, crop productivity increases: - from 8 t/ha to 21 t/ha for corn, - from 3 t/ha to 5.6 t/ha for soybean, and - from 3.7 t/ha to 10.4 t/ha for wheat.	Between 2015 and 2050, the productivity increases: - from 76 kg/TLU to 90 kg/TLU for beef, and - from 5.9 t/TLU to 6.9 t/TLU for cow milk.	The average livestock stocking density remains constant at 0.32 TLU/ha of pastureland between 2015 and 2050.
Scenario justification	The estimated yield gap in Argentina is 100% for corn, 140% for wheat, 130% for soybean (Global yield gap atlas, 2019).	The estimated yield gap in Argentina is 54% for cow-calf and 60% for finishing (Rearte, 2010).	This is a conservative assumption. Rearte (2010) estimates that it could increase by 15-20% with better management of forage resources only.

Scenario signs = no change → small change ↗ large change

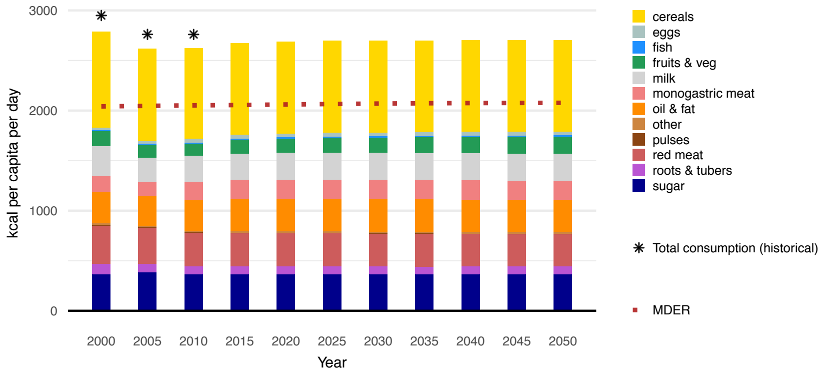
Results against the FABLE targets

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.



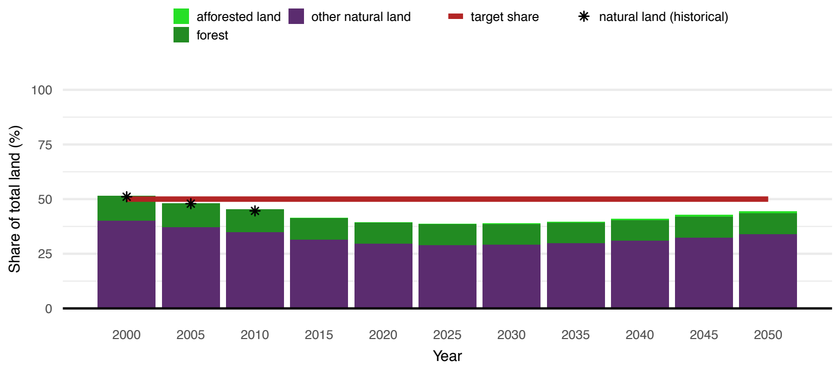
Historical data source: FAOSTAT

Our results show average daily energy intake per capita remains stable throughout the period, and near 20% higher than the MDER at the national level in 2050.

In relation to the recommended diet, our results show highest consumption of cereals, meat, sugar and oil and fat. Our results suggest that meeting national food security objectives will be easily attainable. However, the challenge will be linked to the distribution, ensuring that it reaches every person.

Biodiversity

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



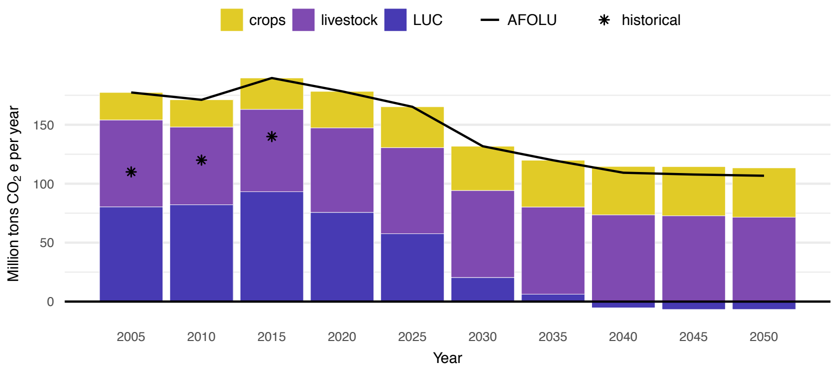
Historical data source: FAOSTAT

Our results show that the Share of the Land which could support Biodiversity conservation (SLB) decreases between 2000-2015 from 52% to 48%. To our knowledge, there are no statistics on past land use change to compare this estimate.

Compared to the global target of having at least 50% SLB by 2050, our results are below the target. However, we think that it does not reflect the reality since two-thirds of Argentina's territory are covered by native grasslands currently accounted for in the Calculator as pastures, while in reality they could also support for biodiversity conservation. Rewilding actions will be needed to restore native flora and fauna.

GHG emissions

Fig. 10 | Computed GHG emissions from land and agriculture



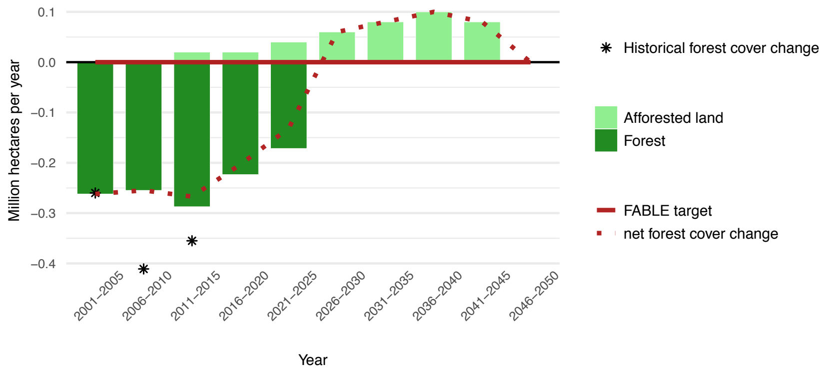
Historical data source: Second BUR Argentina (2014)

Our results show annual GHG emissions between 90 and 200 Mt CO_2e/year over 2000-2015 which decrease over time. The calculated values are lower than those expected by FAO's estimations. Peak GHG emissions from AFOLU are computed for 2015 at 145 Mt CO_2e/year. This is mostly driven by GHG emissions from land-use change (LUC). Argentina's Biennial Update Report (BUR) (Ministerio de Medio Ambiente y Desarrollo Sustentable, 2017) indicates 144 Mt CO_2e/year: 56 Mt from livestock, 45 Mt from land use, and 42 Mt from direct and indirect N_2O emissions. This is very close to our estimates even if carbon sequestration in forests and grasslands is only considered in the BUR. In our results, positive net emissions from AFOLU by 2050 are explained by livestock and crops while emissions from LUC become negative.

Compared to the global target, our GHG emissions from agriculture do not reduce over time but we do reach negative GHG emissions from LUC by 2050.

Forests

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



Source historical data: globalforestwatch.org (2019), Greenpeace (2019)

For the period 2001-2017, forest loss was estimated at 5.6 Mha (GFW, 2019), while the Calculator estimates 4.9 Mha for the period 2000-2020. Deforestation peak is computed for 2011-2015 at 1.5 Mha. This is in line with official statistics which report 1.7 Mha for that period (GFW, 2019). However, unofficial reports (e.g. Greenpeace) state that actual deforestation is much higher (twice the reported number). Deforestation is mostly driven by soybean, either directly (by increasing the area necessary for increasing its production) or indirectly, by pushing cattle production to areas which used to be forest previously. Our results show that annual deforestation stops in 2030. Deforestation values are expected to decrease as more provinces comply with the new Forest Code (Forest Law, 2017).

Compared to the global target of having zero or positive net forest change after 2030, our results are slightly above the FABLE target with net afforestation after 2030. However, our results do not meet our national commitment of having 1 Mha restored by 2020.

Other relevant results for national objectives

Table 1 | Other Results

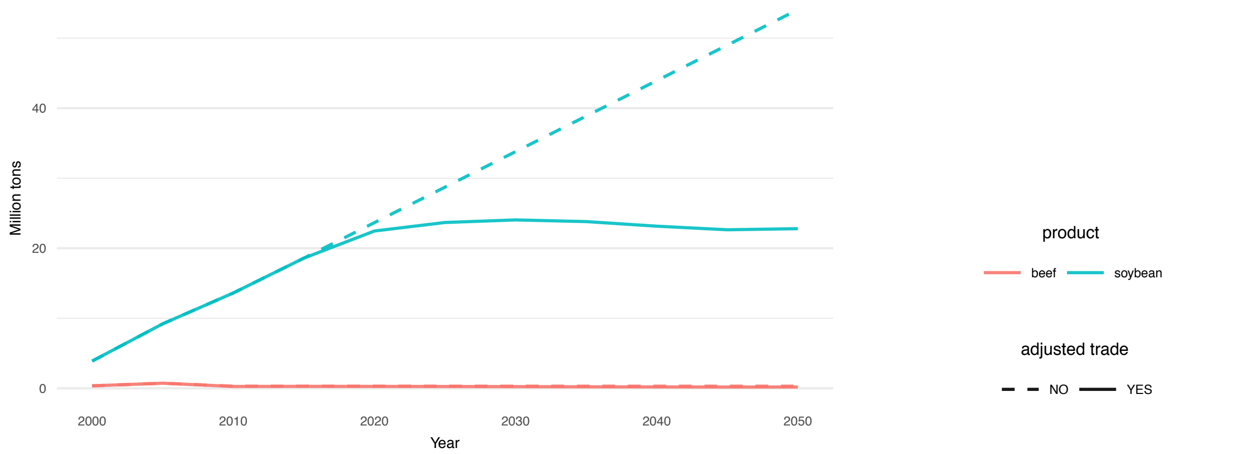
Variable	Unit	2000	2005	2010	2015	2020	2030	2040	2050
Virtual water use									
Green Water (historical)	10^9 m^3/year	241.0	250.0	256.0					
Green Water (calculated)	10^9 m^3/year	190.9	241.4	285.4	345.4	416.7	558.9	700.7	842.4
Blue Water (calculated)	10^9 m^3/year	4.7	5.1	5.5	6.0	6.6	7.6	8.6	9.6
Grey Water (calculated)	10^9 m^3/year	5.1	5.2	6.4	6.9	7.9	9.9	11.9	13.9
Share of virtual water used for exports									
Green Water (calculated)	%	46.0%	50.0%	45.7%	49.6%	50.9%	52.5%	53.5%	54.1%
Blue Water (calculated)	%	0.5%	0.6%	0.5%	0.5%	0.4%	0.4%	0.4%	0.4%
Grey Water (calculated)	%	1.4%	1.2%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%

Source of historical data: Frank (2014)

The results on virtual water use in the historical period are compatible with a local estimation available in Frank (2014). The evolution of water footprint is in line with the changes expected in land use and production of agricultural commodities. As a rainfed-agriculture producing country, it is expected that Argentina has a very large green water footprint, and very low blue and grey. The fact that more than 90% of the water footprint is green is a very good news, since rainfall rarely competes with other possible uses for fresh water (use it or lose it). Moreover, most of the recurrent flooding in the central part of the country are related to lower water use (water transpiration from soybean is lesser than that of maize and legumes). Our results show that half of the water used to produce food is exported.

Changes to Results arising from Trade Adjustments

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

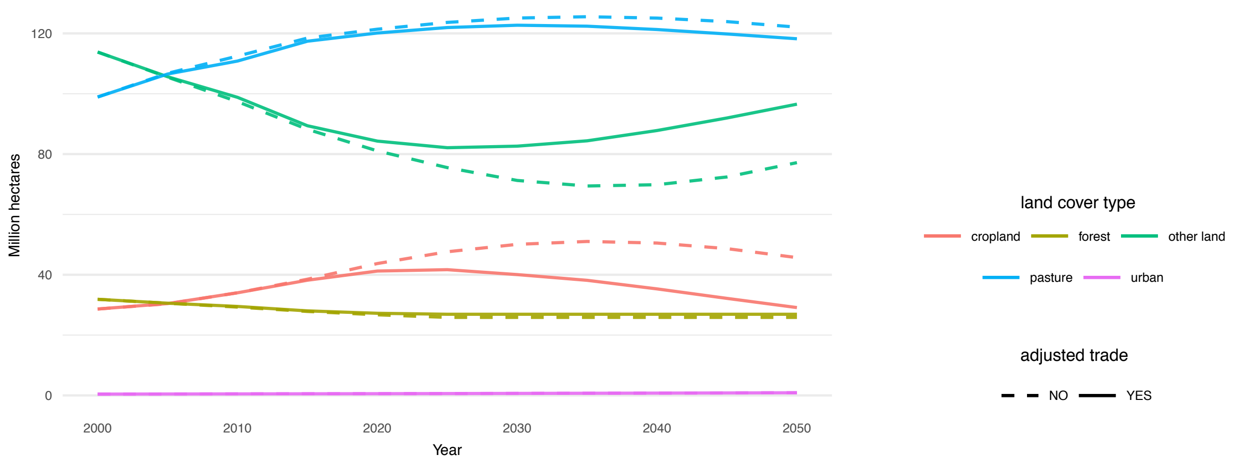


We observe a strong impact of the trade adjustment on soybean. We initially assumed a strong growth of soybean exports up to 50 Mt in 2050 but after the trade adjustment, exports peak at around 20 Mt in 2020 and then they slightly decrease until 2050 (historical value for 2017 is around 12 Mt).

The impact of the trade adjustment on beef exports is lower. We initially assumed stable beef exports over 2015-2050 at approximately 300 kt. After the trade adjustment, exports peak at 274 kt in 2015 and then reduce until 184 kt in 2050 (historical value for 2018 is around 500 kt).

Trade adjustment makes absolutely no change in imports. This is not surprising since Argentina's contribution to global trade is always on the supply side.

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



Land use by types of land cover area is the basis for analyzing the rest of the variables, and the easiest way to check if projections make any sense.

Cropland is the land cover class which is the most impacted by the trade adjustment. It is reduced by 35% in 2050 compared to pre-trade adjustment levels (dashed lines). This is mainly due to lower soybean exports: the land used for soybean productions represents more than half of the country's cropland area. Even though beef exports are also limited, this does not affect pasture area (less than 5% change). Since crops expansion occurs on other land, the impact of trade adjustment increases this class.

During the computed period, cropland area increases, but then decreases, ending in 2050 at a similar level as in 2000. Pasture area increases and then stabilizes. There are no strange or abrupt changes in tendencies, overall, it looks like there is almost no land use change.

Discussion and next steps

A central objective of the FABLE Consortium is to support the preparation of integrated national pathways towards sustainable land-use and food systems that are consistent in their trade assumptions (i.e. all trade flows have to balance out) and consistent with countries' sustainable development objectives (including the Paris Climate Agreement and the SDGs). The use of the FABLE Calculator has allowed for a sound representation of such a sustainable pathway for Argentina.

The pathway presented in this chapter can be summarized as a compromise between development and environmental objectives. Land use changes necessary to attain this pathway by 2050 are moderate. There is an increase in cropland area in the first years, but then this tendency changes, resulting in approximately the same cropland area in 2050 as in 2000. Pasture area increases by 20%, but this includes both native grasslands and sowed pastures. Forest area decreases during the period, but at less than 20%, and at a slower rate than the previous deforestation. These small changes, plus the technological improvements that will reduce yield gaps, lead to reaching the food production objectives of the country. Moreover, they allow for an increase of more than twofold in exports of food products and avoid the need for imports. It is safe to say that the target of zero hunger could be easily achieved.

The environmental impacts of pursuing this pathway are not of great concern as it could be expected from a pathway that increases production. Greenhouse gas emissions increase at first, but end in values closer to those of 2000, with emissions from deforestation disappearing after 2030. The global target was set at 4 Gt of CO_2e from crops and livestock and negative or zero from land use changes by 2050. Argentina's CO_2e contribution from crops, livestock, and land use change represents only 2.5% of that figure. The target of zero net deforestation is met by 2030, which leads to also fulfilling the zero net emissions target from land use change.

Biodiversity is another issue. The target set at 50% of land supporting biodiversity is not achieved at any time during the period. The final value is around 45%, considering that the country exports a great amount of food, its negative contribution to this target is negligible. Protected areas cover nowadays around 12%, so the 17% target is not so far away and could be easily fulfilled. To achieve these targets there are at least three necessary actions: 1) strengthen the function of protected areas as sources of reproduction of native species, 2) minimize the deterioration of natural areas that are not yet legally protected, and 3) establish rewilding plans to recover biodiversity. The latter is the most expensive and inefficient, so we believe actions 1 and 2 should be prioritized.

Increase in water use is also important to mention, since this pathway leads to doubling the water consumption to produce food. However, unless irrigation increases dramatically in the future, more than 95% of this corresponds to green water, not actually competing with other uses, hence not compromising the target of less than 2,500 km^3 per year. Further developments of this newly added indicator of the FABLE Calculator is necessary to address, for example, changes in irrigation.

Regarding the strongest limitations of the use of the FABLE Calculator to design and represent a sustainable pathway for Argentina, the first worth mentioning is biodiversity. Needless to say, it is very difficult to represent such a complex issue in a non-spatially explicit way. The idea of "land supporting biodiversity" is a fair proxy, since it is universal, but it disregards completely the biodiversity present in agricultural areas (cropland and pastures). Besides, this approach does not take into account the actual conservation status of agricultural areas, ignoring both the different negative impacts of agricultural activities on biodiversity, and the conservation value of pastures and some of the crops.

Related to this, but also to livestock production, separating native grasslands from sowed pastures is crucial. These two land covers are very different in terms of biodiversity, soil carbon storage, productivity, and management, at the very least. Moreover, in Argentina great portions of forest areas are filled with cattle as well. At this point, pasture area is estimated from cattle stocks and stocking rates, but in reality, cattle forages on pastures, native grasslands, and forests.

Another limitation of the FABLE Calculator worth mentioning relates to food distribution. Despite overachieving the target, there is the fear of not providing everyone with sufficient and healthy food. According to these results, there is plenty of food (or the capacity to grow it) yet, if there is still hunger, it is because food is not distributed equally. This raises the need for an indicator that addresses this problem, for example, by "correcting" food supply by its unequal distribution.

The use of the FABLE Calculator is a continuous process. Each iteration on the Scenathon, exchanges during global FABLE Consortium meetings, or even remote participation in FABLE coordination calls bringing together the FABLE country teams represent opportunities for further improvement. Until now, country teams have updated their FABLE country Calculator almost 20 times, from minimal corrections to the inclusion of new indicators and scenarios. With this in mind, there are several improvements and further developments that should be addressed by the Consortium in the future:

- Biodiversity present in agricultural lands and impacts of agriculture on biodiversity,
- Scenarios on the evolution of protected areas,
- Separating native grasslands from pastures,
- Food distribution inside the countries,
- Scenarios on water use and irrigation, and
- Other indicators to assess other targets (e.g. nutrients).

One of the most important steps that the FABLE Argentinian country team is pursuing is the integration of the FABLE Calculator with other available tools. Advances have been made in using the results from the Calculator (primary production only) to feed into other models, such as the Long-range Energy Alternatives Planning system, to estimate GHG emissions throughout the supply chain of the food system. As an example, the case of soybean and all of its byproducts has been analyzed and presented in a report to the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH on behalf of the German Federal Ministry for Economic Cooperation and Development (BMZ) in 2019.

In parallel, another national ambition that can be explored in the framework of the FABLE analysis is the potential for Argentina to shift from being a producer of commodities to being a producer of high agricultural value products, which would also include an improvement of the internal market, and the promotion of environmentally friendly agricultural practices, such as agroecology. Besides considering the political, technological, and economic feasibility of such a shift, the Calculator should be modified to include these aspects. On the other hand, the technological intensification paradigm appears as one of the most hopeful alternatives to achieve sustainability, especially in the production of food. This would mean increasing productivity per hectare, production of new forms of food, new technologies in food transportation, and depending on the policies of future governments, the incentive or disincentive to develop technological packages aimed at adding value to primary production.

Beyond the analytical development of a sustainable pathway by the FABLE Argentinian country team that is in line with the FABLE global targets and is as realistic as possible, the implementation of such a pathway is challenging, mainly with regards to "selling it to decision makers". The main challenges for implementing this sustainable pathway in Argentina are the pressure exerted by agricultural lobbies (e.g. promoting soybean monoculture which rely on an important use of Glyphosate), corruption, weak law enforcement, lack of interest, etc. Besides, recurring changes of direction in decision making regarding land use, foreign trade policies, and commodity market are expected to continue. Being part of the FABLE Consortium for over a year, with our preliminary results in hand, Argentina's country team should explore how to address this issue right away. None of the technical limitations and flaws mentioned here should be an excuse to stop the continuous work of making use of the FABLE Calculator and its development, in parallel to exploring ways to effectively present and discuss its results with stakeholders.

Another issue of great importance to the country team are "spillover effects", understood here as the effects of the decisions taken in one country on other countries. For example, the positive (income) and negative (deforestation, herbicide pollution, GHG emissions, etc.) effects of China's soybean imports from Argentina (also estimated and discussed in the previously mentioned GIZ report). This phenomenon can be observed in richer countries, where they buy food for their internal consumption from abroad to enable the country to get closer to achieving the SDGs on its territory, thus creating spillover effects on the producing countries. We believe these effects should be discussed in greater detail within the Consortium.

Nowadays, Argentina is basically a soybean exporter, with a very linear and simple system (exporting mainly to China). This simplification makes Argentina very vulnerable to any change in global foreign trade networks. The pressure of Argentina's external debt, together with possible free trade agreements establishes a lock on the future, making it difficult to move towards a paradigm shift: a diversified system with high added value and job creation, prioritizing food security over the entire surface of the country and establishing foreign trade agreements with a multiplicity of countries, multiplying the redundancy, alternative channels and strengthening the country's position in the global system.

If the FABLE project can be used to prove that a more intricate system of food-trade relationships between Argentina and other countries could be achieved using economically and environmentally sustainable means, an important step towards Argentina's achievement of the SDGs will definitely be taken.

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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Australia

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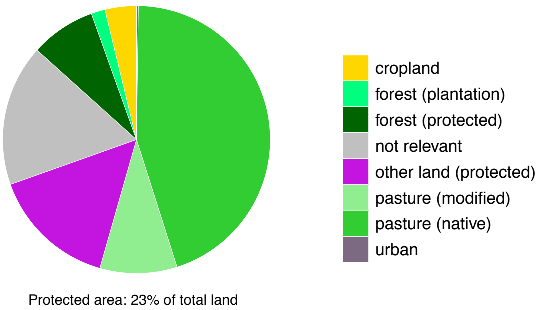
Land and food systems at a glance

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

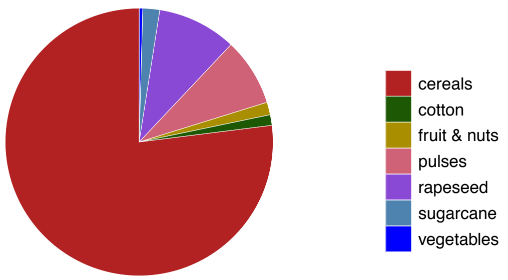
Land & Biodiversity

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)

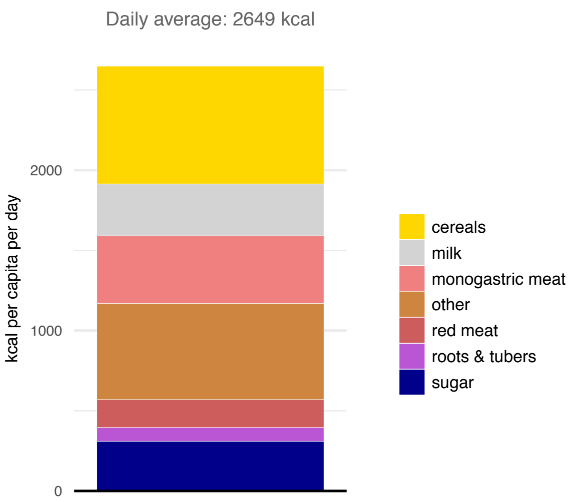
(Metcalfe and Bui, 2017; Montreal Process Implementation Group for Australia and Committee, 2018)

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)

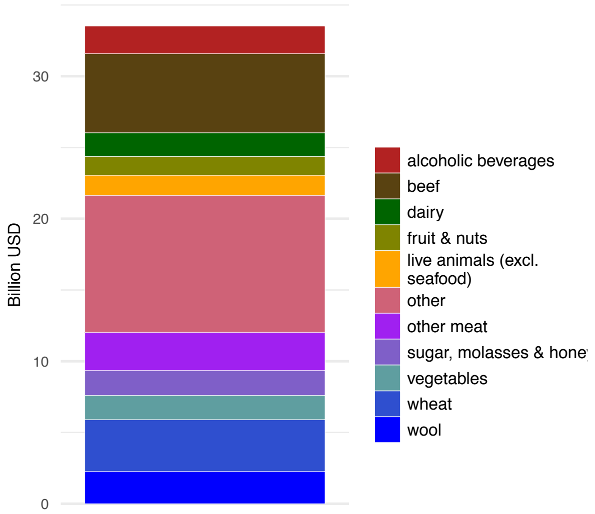
Share of obese and overweight in 2017
31% obese (very similar share male vs. female) and 36% overweight in 2017

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

(ABS, 2018a)

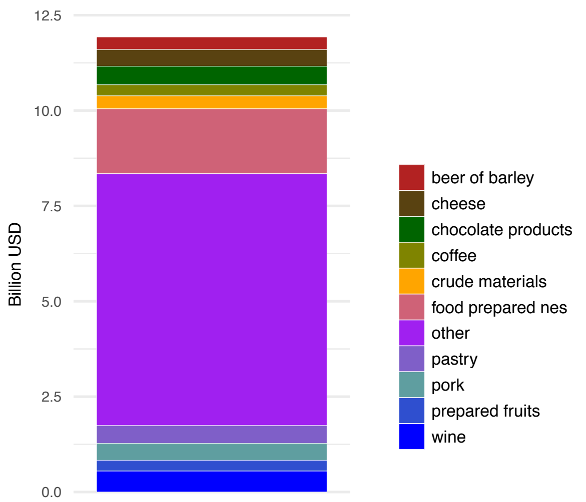
Trade

Fig. 4 | Main agricultural exports by value in 2016



Source: DFAT (2017)

Fig. 5 | Main agricultural imports by value in 2016



Source: FAOSTAT

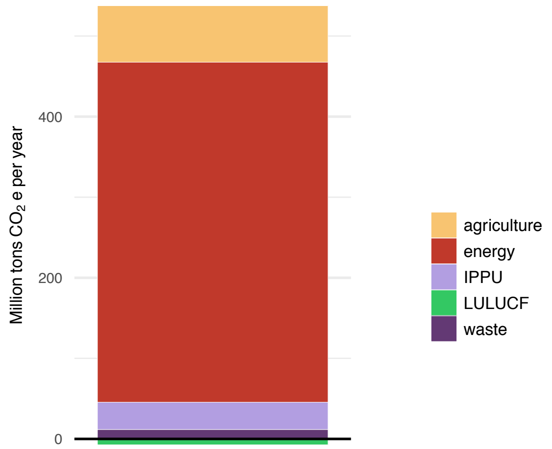
Surplus in agricultural trade balance in 2015: USD 18,550 million

(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)

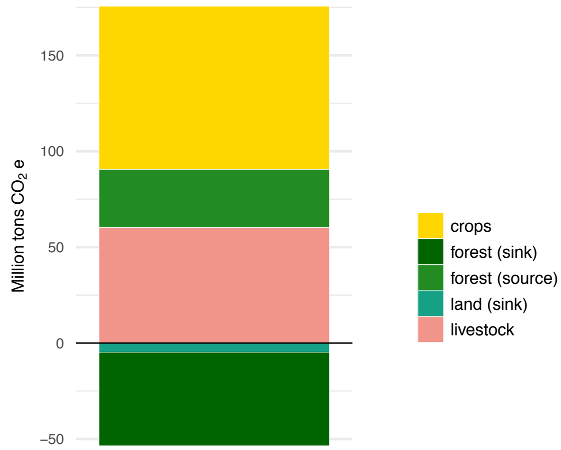
GHG Emissions

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

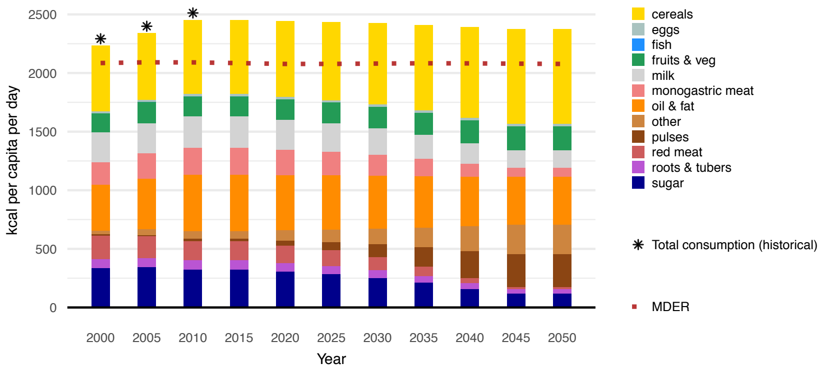
Results against the FABLE targets

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.



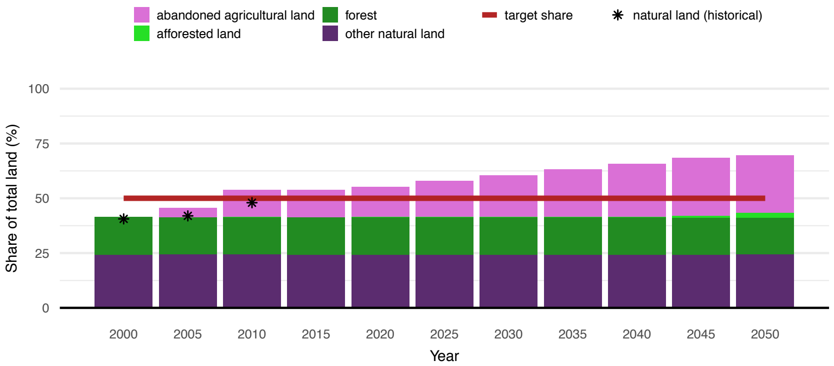
Historical data source: FAOSTAT

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



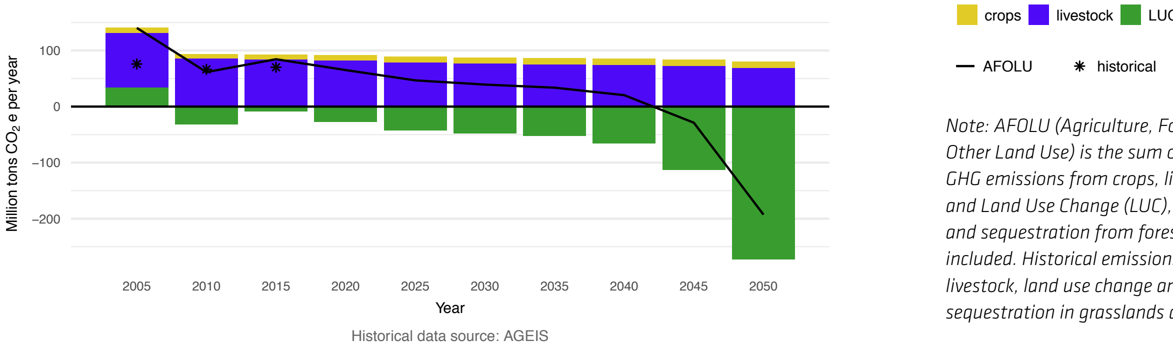
Historical data source: ABARES (2016)

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



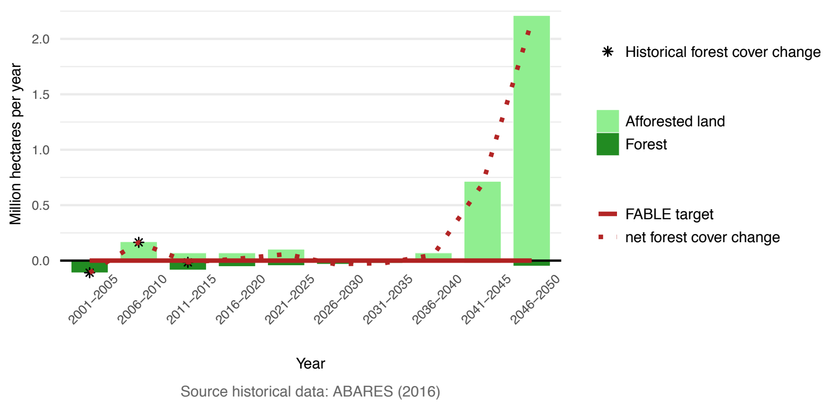
Note: AFOLU (Agriculture, Forestry and Other Land Use) is the sum of computed GHG emissions from crops, livestock and Land Use Change (LUC), emissions and sequestration from forestry are not included. Historical emissions include crops, livestock, land use change and carbon sequestration in grasslands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

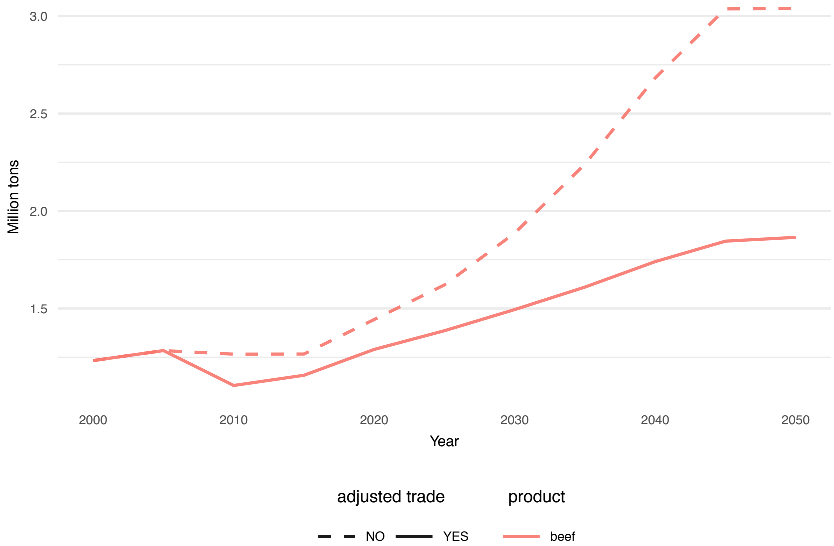
FAOSTAT's yearly reported values of permanent pastures show that there are temporary increases in total grazing land, but a declining long-term trend remains. For the year 2016 ABS reports a slightly larger amount of total grazing land than FAOSTAT (340 Mha vs. 325 Mha) (ABS, 2018b). The yearly values 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

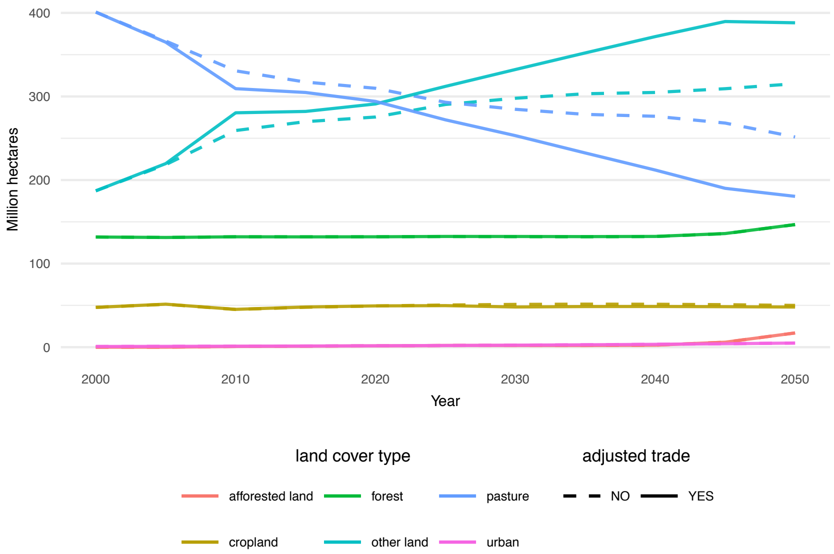
Fig. 12 | Impact of global trade harmonization on main exported/imported commodities over 2000-2050



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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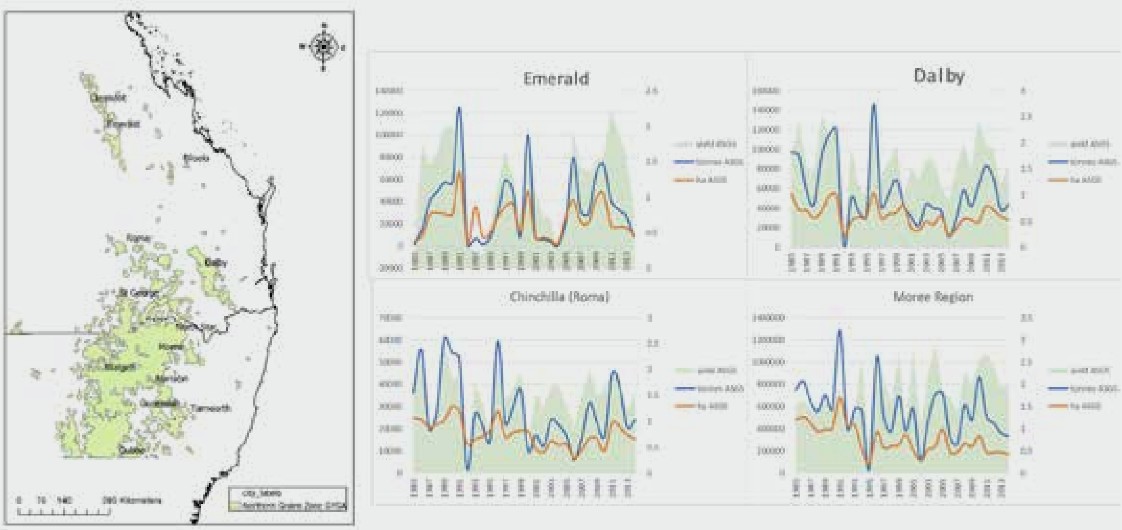
Appendix A. Spatially explicit modelling of crop productivity

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.

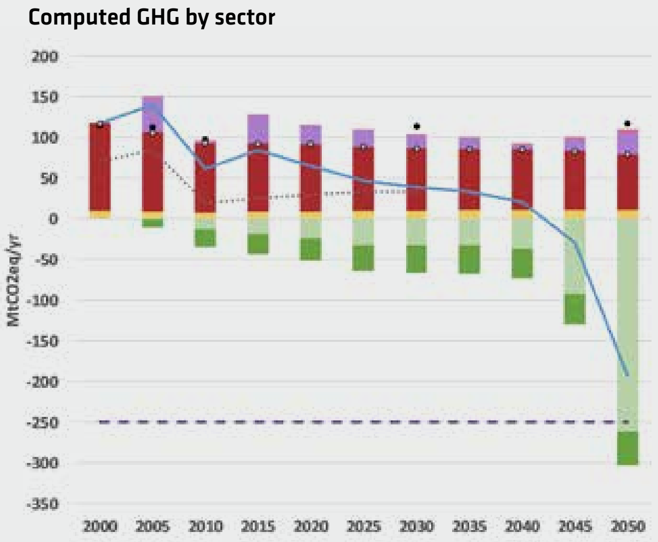
Appendix C. Other impacts of trade adjustment

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*

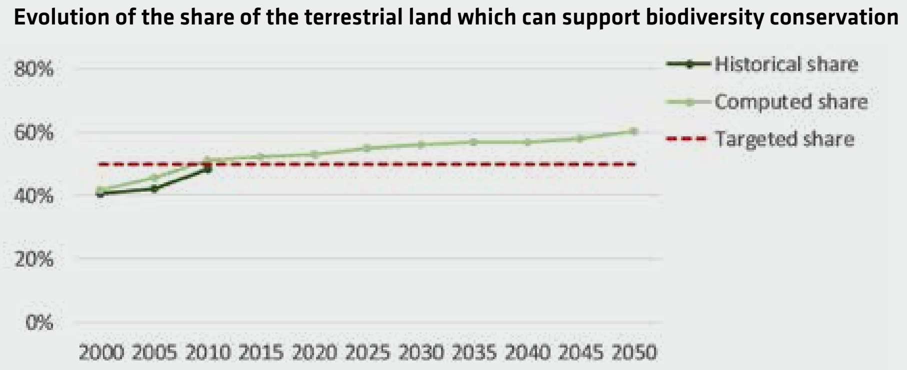


Note: The dashed line shows the Net CO_2e emissions without trade adjustment. It is displayed here to better highlight the difference in results with and without trade adjustment.

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*



Brazil

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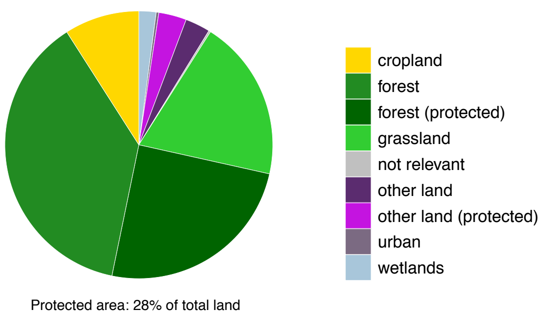
Land and food systems at a glance

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

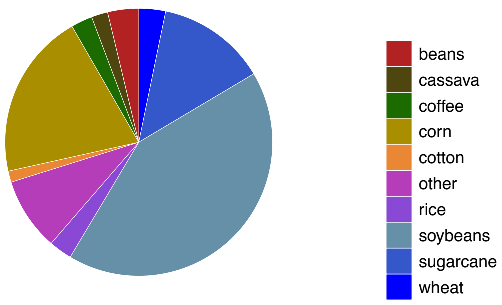
Land & Biodiversity

Fig. 1 | Area by land cover class in 2015



Source: MapBiomas

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



Source: Municipal Crop Production survey (PAM/IBGE)

Annual deforestation in the Amazon Biome (2015):
0.62 Mha = 0.12% of total forest area

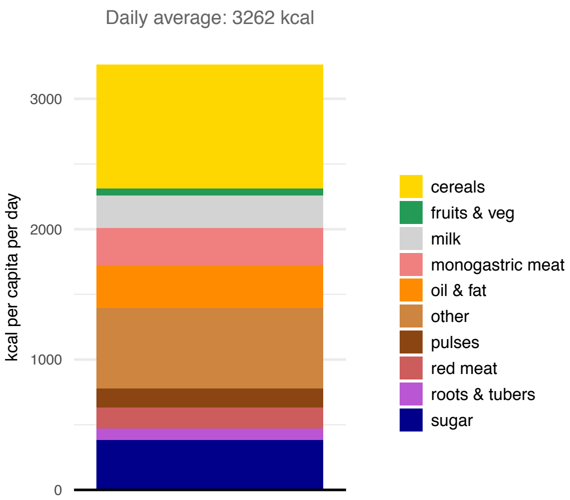
(PRODES/INPE, 2019)

Endangered species in 2018: 1,173 (448 vulnerable, 406 endangered, 318 critically endangered, and 1 extinct in the wild)

(ICMBio, 2018)

Food & Nutrition

Fig. 3 | Daily average intake per capita at the national level in 2013



Source: FAOSTAT

Share of undernourished in 2015:
2.5%

(World Bank, 2019)

Share of obese in 2015:
18.9%

(Ministério da Saúde, 2015)

Trade

Fig. 4 | Main agricultural exports by value in 2015

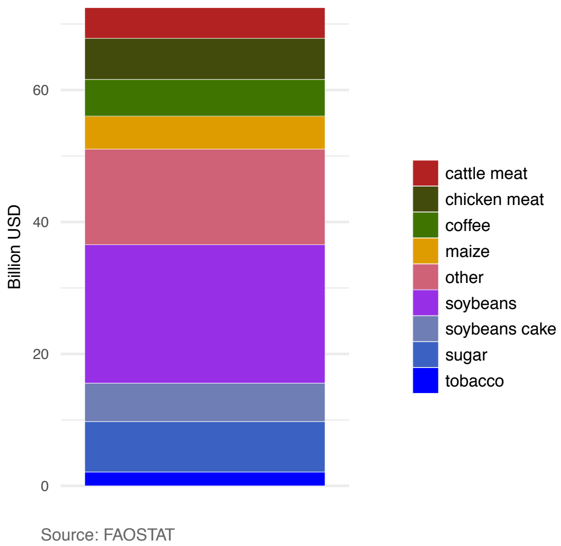
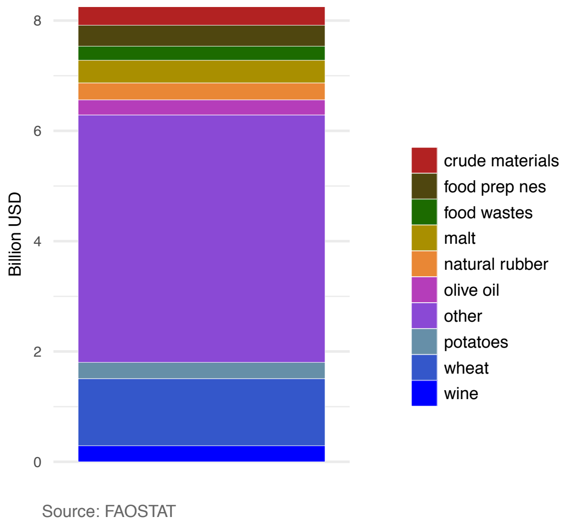


Fig. 5 | Main agricultural imports by value in 2015



Surplus in agricultural trade balance in 2015: USD 75 bln

(MAPA, 2019)

The largest soybean exporter in the world in 2015

(FAOSTAT, 2019)

GHG Emissions

Fig. 6 | GHG emissions by sector in 2015

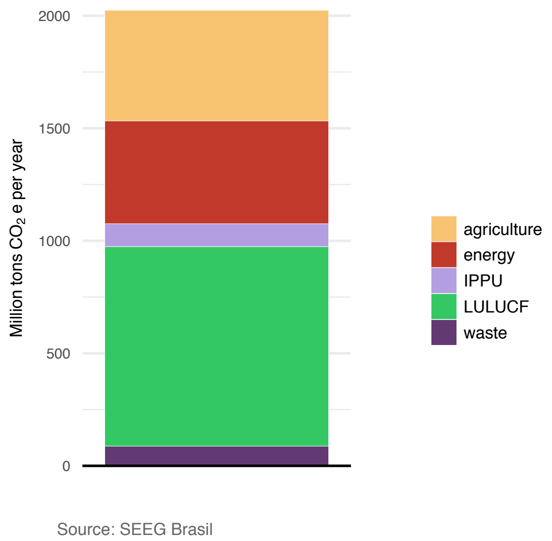
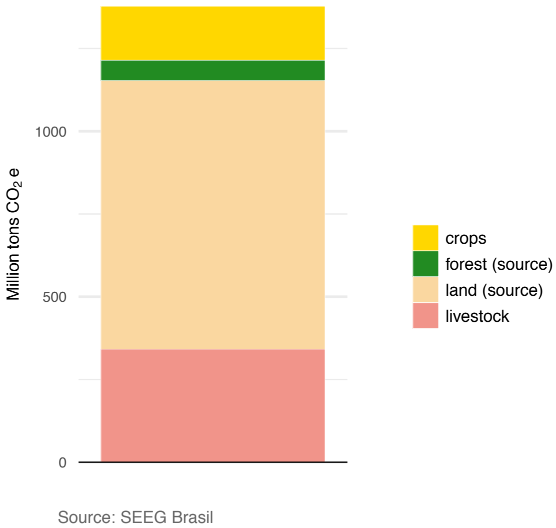


Fig. 7 | GHG emissions from agriculture and land use change in 2015



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 (large change)	Population (small change)
Scenario definition	GDP per capita is expected to increase by 109% from USD 11,313 in 2015 to USD 23,697 in 2050 (SSP2 scenario selected).	The population is expected to increase by 14.5% between 2015 and 2050 from 206 mln to 236 mln (SSP2 scenario selected).
Scenario justification	According to OECD (2019), GDP will reach 5.78 tln by 2050 which would be equal to USD 24,807 per capita using population projections from the Brazilian Institute of Geography and Statistics (IBGE, 2019), of which the closest scenario is SSP2.	Brazil's population will peak around 233 mln by 2050, according to data from IBGE (2019).

TRADE

	Imports (no change)	Exports (large change)
Scenario definition	The share of total consumption which is imported is assumed constant at 2010 level.	The exported quantity increases: - from 57 Mt in 2015 to 133 Mt in 2050 for soybean, - from 1.6 Mt in 2015 to 2.3 Mt in 2050 for beef, - from 17 Mt in 2015 to 36 Mt in 2050 for corn.
Scenario justification	Brazilian wheat imports in 2028 do not differ much from 2018 numbers (-2.1%), according to projections from MAPA (2018). Hence, we choose a scenario that reflects that trend.	The following projections are from the MAPA report (2018): soybean exports increase from 70 Mt in 2017/18 to 96.5 Mt in 2027/28 (assuming the same growth rate, it is expected to be 148 Mt in 2050).

Scenario signs no change small change large change

LAND

	Land conversion	Afforestation (large change)
Scenario definition	We assume that deforestation will be halted by 2030.	We assume total afforested/reforested area to reach 12 Mha by 2030.
Scenario justification	In line with Brazil's NDC (Brazil, 2018) which commits to strengthen its policies and measures with a view to achieve zero illegal deforestation in the Brazilian Amazonia by 2030. This target goes beyond the Brazil's NDC which assumes zero illegal deforestation. This target also goes beyond the 2012 Brazil's Forest Code (FC). The FC is not a zero deforestation law and it allows deforestation according to the levels of protections defined in the legal reserve requirements (e.g. 20% of private properties in the Amazon biome can be legally deforested while 80% must be preserved).	In 2015, the Government of Brazil pledged to reforest 12 Mha by 2030 under its NDC. Restoring 12 Mha of deforested land is also a commitment Brazil made for the Bonn Challenge (Bonn Challenge, 2014; Brazil, 2018).

BIODIVERSITY

	Protected areas (no change)
Scenario definition	The protected areas remain constant at 243 Mha between 2015 and 2050.
Scenario justification	Brazil has 243 Mha of protected areas including federal, state, and municipal conservation units and indigenous land. The Amazon biome holds the highest percentage of protected areas, as it concentrates more than 80% of the total area, followed by the Cerrado (approximately 10%) (MMA, 2019a; FUNAI, 2019).

Scenario signs no change · small change · large change

FOOD

	Diet (small change)	Food waste (large change)
Scenario definition	Between 2015 and 2050, the average daily calorie consumption per capita increases from 2,735 kcal to 2,831 kcal. Per capita consumption: - increases by 47.3% for fruits and vegetables, - decreases by 7.5% for roots, - increases by 1.5% for cereals, - decreases by 10% for pulses, - for the other food groups, there is no large shift in consumption. We assumed a middle level of activity of the population to compute the MDER.	Between 2015 and 2050, the share of final household consumption which is wasted decreases from 10% to 5%.
Scenario justification	The scenario for diets follows FAO projections at the horizon of 2050 (Ministério da Saúde, 2014; FAO, 2018).	There is little research on food waste in Brazil. According to FAOSTAT (2019), the Brazilian food waste in 2000 was approximately 12.6% of the total production. We assume the share of waste in final household consumption decreases from 10% in 2015 to 5% in 2050 in order to follow the sustainable pathway scenario.

PRODUCTIVITY

	Crop productivity (large change)	Livestock productivity (small change)	Pasture stocking rate (large change)
Scenario definition	We assumed the same productivity growth as over 2000-2010. Between 2015 and 2050, crop productivity increases: - from 2.98 t/ha to 3.99 t/ha for soybeans, - from 4.45 t/ha to 7.88 t/ha for corn.	Between 2015 and 2050, the productivity per head: - remains stable at 100 kg/TLU for cattle meat, - increases from 1.9 t/TLU to 2.5 t/TLU for cattle milk.	The average cattle ranching stocking density increases from 0.71 TLU/ha to 1.04 TLU/ha pasture between 2015 and 2050.
Scenario justification	This is based on the following projections from the MAPA (2018) report: soybean increases from 3.33 t/ha in 2017/18 to 3.45 t/ha in 2027/28 (assuming the same productivity improvement rate, then it is expected to be 3.72 t/ha in 2050), and corn increases from 5.35 t/ha in 2017/18 to 6.38 t/ha in 2027/28 (assuming the same productivity improvement rate, then it is expected to be 9.08 t/ha in 2050).	The "Plano Mais Pecuária" aims to increase the cattle meat production by 40% and productivity by 100% up to 2024 (EMBRAPA, 2014; MAPA, 2014).	Cattle ranching in Brazil is commonly referred to as a driver of deforestation. The sustainable intensification of beef production serves as a conservation tool (Cohn et al., 2014; Strassburg et al., 2014). Cattle ranching intensification should spare land for cropland expansion and decrease the deforestation (Soterroni et al., 2018). Therefore, there should be a stocking rate increase from the current amount to follow any sustainable pathway scenario.

Scenario signs = no change → small change ↗ large change

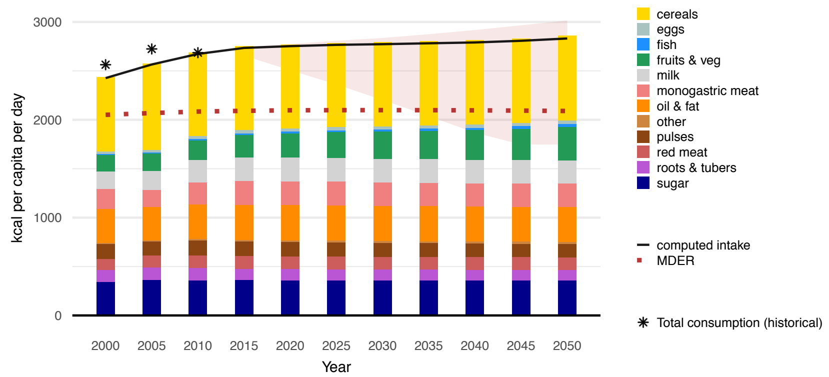
Results against the FABLE targets

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.



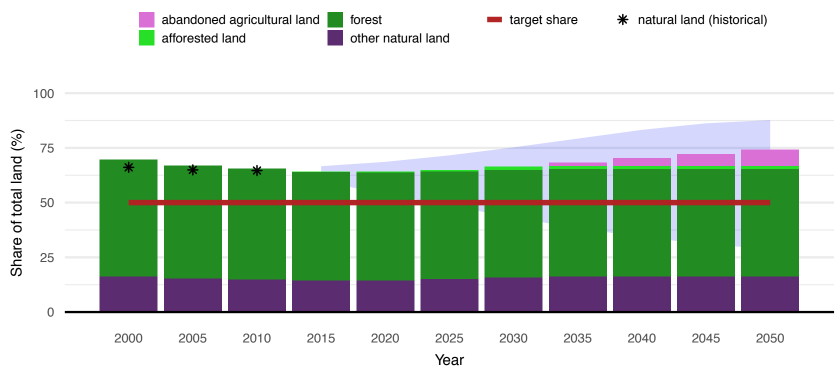
Historical data source: FAOSTAT

Our results show average daily energy intake per capita increases from 2,426 to 2,735 kilocalories between 2000-2015. The value in 2015 is 18.1% lower than the value from FAO for 2013 (FAOSTAT, 2019) because we are not taking into account some products in our calculations. Over the last decade, 31% of the food intake came from cereals. Calorie intake reaches 2,782 over the period 2031-2035 and 2,8301 over the period 2046-2050. In terms of recommended diet, our results show higher consumption of fruits and vegetables. The computed average calorie intake is 35.5% higher MDER at the national level in 2050.

Our results show that national food security objective of having 2,000 kcal/capita/day is reached during the whole simulation period.

Biodiversity

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



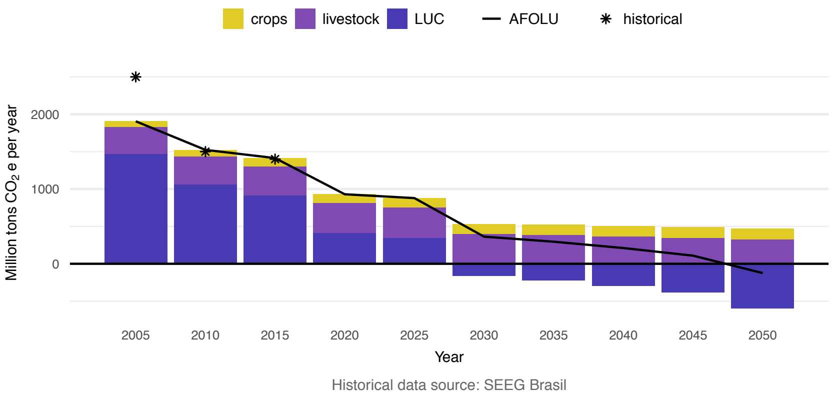
Historical data source: FAOSTAT

Our results show that the Share of total Land which could support Biodiversity conservation (SLB) decreased between 2000-2015 from 72.1% to 65.7%. The lowest SLB is computed for the period 2010-2015 at 65.7% of total land. This is mostly driven by deforestation and the conversion of other non-managed land to cropland and pastureland. SLB reaches 74.1% over the last period of simulation, 2046-2050. The difference is explained by a higher conversion of other land.

Compared to the global target of having at least 50% SLB by 2050, our results are above the target. Our results are not consistent with national CBD biodiversity commitments by 2020: the rate of loss of all natural habitats, including forests, should be at least halved and where feasible brought close to zero, and degradation and fragmentation should be significantly reduced.

GHG emissions

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



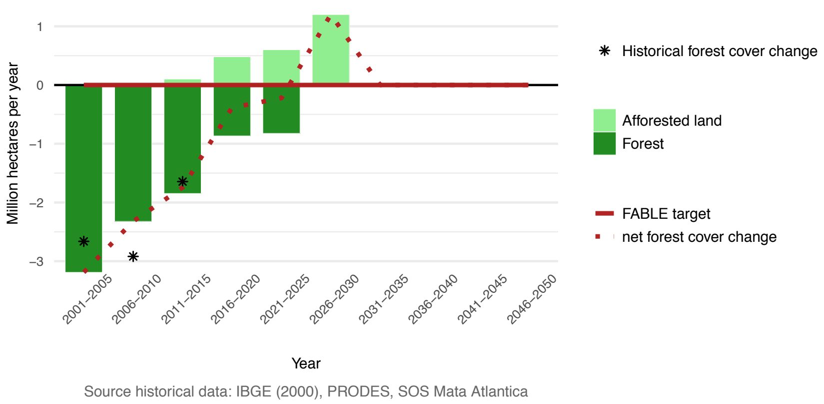
Note: AFOLU (Agriculture, Forestry and Other Land Use) is the sum of computed GHG emissions from crops, livestock and Land Use Change (LUC), emissions and sequestration from forestry are not included. Historical data only include positive emissions from crops, livestock, land use change.

Our results show annual GHG emissions from the AFOLU sector decreasing from 1.9 Gt CO2e to 1.4 Gt CO_2e during the period 2005-2015. Although our values are lower than the estimates from SEEG (2019) in 2005 (2.5 Gt CO_2e/year), they capture a decreasing trend and the estimates for the year 2015 are equal. The emissions from the AFOLU sector reach -124 Mt CO_2e over the period 2046-2050: 472 from agriculture and -596 from LUC. Negative emissions from LUC by 2050 are mainly explained by passive restoration as a result of pasture and cropland areas abandonment.

Compared to the global target of reducing emissions from agriculture and reaching zero or negative GHG emissions from LULUCF by 2050, our results meet the target for LULUCF emissions.

Forests

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



Our results show accumulated deforestation of 36.79 Mha between 2001 and 2015. This amount is lower compared to PRODES Amazon and PRODES Cerrado which estimate an average of 44.95 Mha over the same period. Deforestation peak is computed for the period 2001-2005 at 15.9 Mha. Zero deforestation is reached over the period 2025-2030 because we assume no deforestation by 2030 in our sustainable scenario, which leads to a positive net forest cover change over the same period.

Compared to the FABLE target of having zero or positive net forest change after 2030, our results are above the target. Our results meet the national objectives of having 12 Mha of forest reforestation until 2030 as defined in Brazil's Bonn Challenge commitment, and the Brazil's NDC.

Other relevant results for national objectives

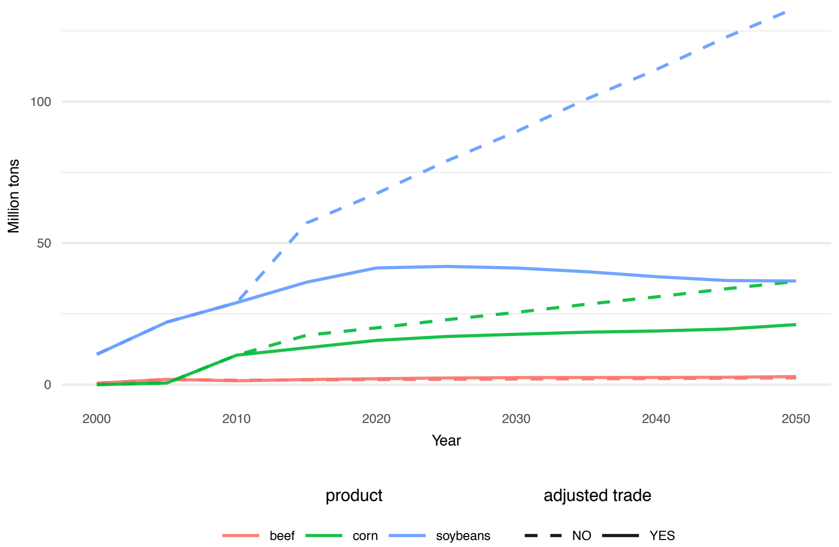
Table 1 | Other Results

Variable	Unit	2000	2005	2010	2015	2020	2030	2040	2050
Cropland	Mha	48.1	62.6	63.6	75.6	79.6	84.2	83.5	78.9
Pasture	Mha	200.1	208.2	223.1	221.8	214.1	190.4	159.4	128.1
Urban	Mha	5.4	6.6	8.0	9.7	11.7	17.2	25.2	30.0
Forest	Mha	461.7	445.8	434.2	425.0	420.6	416.5	416.5	416.5
Afforested land	Mha	0.0	0.0	0.0	0.5	2.9	11.9	11.9	11.9
OtherLand	Mha	141.3	133.4	127.8	124.0	127.6	136.4	160.0	191.1

In summary, there is no deforestation in Brazil after 2030. Pasture areas decrease by 32.7% and croplands also decrease by 6.2% between 2030 and 2050. On the other hand, other natural land is increasing by 40% during the same period.

Impacts of trade adjustment to ensure global trade balance

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



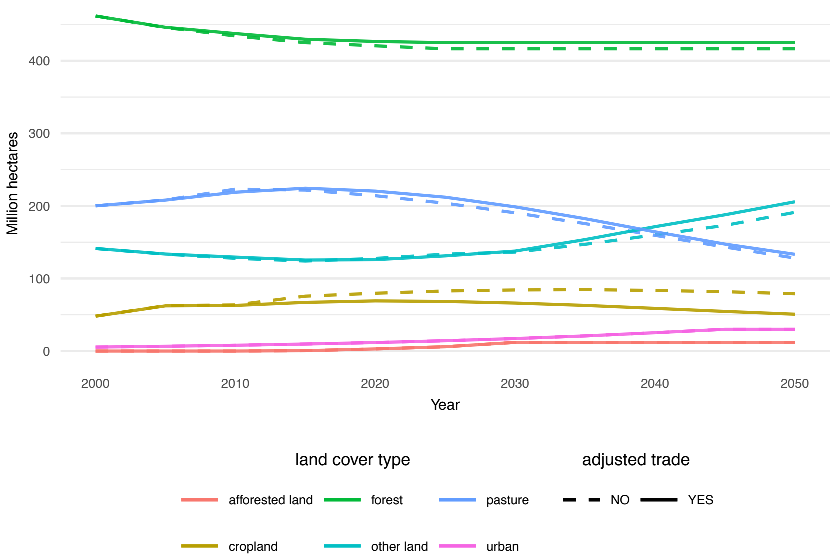
With the trade adjustment, soybean export quantities, started to change by 2015 with a reduction of 37% and a peak of 73% reduction in 2050 compared to no trade adjustment.

For corn export quantities, the results computed with the trade adjustment started to change by 2015 with a reduction of 25%, with a peak of 42% reduction in 2045 compared to no trade adjustment.

For beef export quantities, the results with the trade adjustment started to change by 2010 with a reduction of 13%. From 2020, the exports started to increase compared to no trade adjustment.

It is important to note that the main Brazilian imports are not affected by the trade adjustment.

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



Comparing the evolution of land use with and without trade adjustment, differences in pasture, cropland and other land classes can be observed from 2030 onwards. The cropland area is the land use class with the highest change when compared to the no trade adjustment, with a reduction of 36% by 2050.

Discussion and next steps

Brazil is one of the 17 megadiverse countries in the world with 45,678 plant species, 720 mammals, 1,024 amphibians, 1,924 birds, 761 reptiles, 4,538 species of freshwater fish, and 105,881 species of invertebrates. Within this set, 1,173 animal species and 2,113 plant species are under threat of extinction largely due to habitat loss from agriculture expansion (MMA, 2019b, 2019c). Two-thirds of the Amazon rainforest are located in the Brazilian territory with 48% having some kind of protection including conservation units and indigenous lands. Between 2004 and 2012, Brazil made great progress on protecting natural resources – the deforestation in the Brazilian Amazon decreased by 83% during this period. This sharp reduction was possible thanks to a combination of factors including the expansion of the protected areas network, improvements on national satellite monitoring systems, the implementation of supply chain agreements, the implementation of credit restrictions to farms located in municipalities with high levels of deforestation, among others. Nevertheless, Brazil remains one of the countries with the highest deforestation rates in the world (Weisse and Goldman, 2019).

Since 2012, the area deforested in the Brazilian Amazon has been increasing reaching 7,900 km^2 in 2018, the worst annual deforestation figures in a decade (PRODES/INPE, 2019). The rates of deforestation in the Cerrado – the richest savanna formation on earth and a biodiversity hotspot – have exceeded those of the Amazon over several years in the last decade (Carneiro-Filho and Costa, 2016). It is estimated that less than 20% of the Cerrado biome remains undisturbed (Strassburg et al., 2017). On the other hand, Brazil is a top producer and exporter of several commodities including soybeans and beef, which are well-known drivers of tropical deforestation. These commodities are produced to meet both internal consumption and global demand, which are poised to increase in the next decades (Alexandratos and Bruinsma, 2012; Lapola et al., 2013; Lambin et al., 2013). In 2015, approximately 60% of Brazilian soybean exports went to China and another 17% arrived in the European Union (TRASE, 2015).

Even with these two conflicting interests of increasing food production and preserving the environment, Brazil's COP21 pledge was to cut its GHG emissions by 37% below 2005 levels by 2025 and to reach a 43% reduction by 2030 (Brazil, 2018). The largest source of emissions in Brazil is by far from the land-use change and the forestry (LUCF) sector. In 2017, emissions from agriculture and LUCF sectors (AFOLU) accounted for almost 70% of the country's emissions. Since 50% of forests and native vegetation in Brazil are located in private properties (Soares-Filho et al., 2014), regulating land-use change in those areas is key for the country to achieve its emissions reduction goals. The most important environmental law that regulates land use and environmental management on private properties in Brazil is the Forest Code, which dates from 1965 and underwent a major revision in 2012. The Forest Code sets a minimum percentage of native vegetation to be preserved or restored on each property. It is not a coincidence that among the key measures of Brazil's NDC the enforcement of the Forest Code and the control of illegal deforestation in the Amazon biome are listed. The restoration of 12 million hectares of forests and native vegetation is also an important commitment to increase the land that can support biodiversity as well as contribute to negative emissions through carbon uptake of young forests.

In this study, the scenario implemented in the FABLE Calculator assumes a series of targets to promote a sustainable food and land-use system. Since the transformation towards a sustainable future in Brazil is mainly connected to strategies for managing land-use, the most important goals are the crop and livestock productivities increase, food waste reduction, zero deforestation after 2030, and 12 million hectares of forest restoration. In summary, the FABLE Calculator projects, between 2015 and 2050, a decrease in pasture areas, a slight increase in croplands, and a forest increase due to forest regrowth on abandoned pasture. Although the soybean area in 2025 is very close to OECD-FAO projections (only 1.4% smaller), the FABLE Calculator projects a higher area of rice by 35% and a lower area of sugarcane by 13% when compared to OECD-FAO outlook numbers (OECD-FAO, 2018). This might happen because of different assumptions on crop productivity over time that will need to be reviewed in the future. In addition, the calculation does not include bioenergy demand for products such as sugarcane ethanol, of which demand is expected to increase in Brazil (Empresa de Pesquisa Energética, 2018) with a direct impact on sugarcane area expansion. These refinements might be the next steps for improving the FABLE Calculator results for Brazil.

In terms of emissions, between 2046 and 2050, the average emissions from the AFOLU sector are projected to reach -25 $MtCO_2e$ per year at the national level. According to the Calculator, in the next 35 years the emissions from cropland are projected to increase by 28% (from 22 $MtCO_2e$ per year in 2015 to 28.2 $MtCO_2e$ per year in 2050) while the emissions from livestock decrease by 16% (from 78.9 $MtCO_2e$ per year in 2015 to 66 $MtCO_2e$ per year in 2050), and the emissions from land-use change and forest (LUFC) sector decrease by 169% (from 182.2 $MtCO_2e$ per year in 2015 to -125 $MtCO_2e$ per year in 2050). This negative emissions value is achieved largely due to the ban on deforestation combined with carbon uptake from natural vegetation regrowth and afforestation.

The targets of the sustainable pathway scenario implemented in this study are challenging, especially the zero-deforestation assumption. A more realistic but still challenging scenario is the rigorous enforcement of Brazil's Forest Code, which allows the clear cut of native vegetation surpluses in private properties while completely banning illegal deforestation everywhere in Brazil's six biomes. Under the Forest Code the two conflicting goals of agricultural production growth and environmental protection are likely to be achieved (Soterroni et al., 2018). Recently, the Brazilian Government has abandoned command-and-control policies to stop deforestation and environmental protection measures are being systematically weakened (Rochedo et al., 2018). When the governance is weak, supply chain agreements can play an important role in halting deforestation (Soterroni et al., 2019). However, the risk of leakage to other regions and commodities not covered by this type of sectoral agreement might fail in stopping overall deforestation (Lambin et al., 2018). Ideally, a mix of public-private policy with a focus on halting deforestation is needed for Brazil to become more resilient to political turmoil and for increasing the effectiveness of supply-chain agreements.

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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Canada

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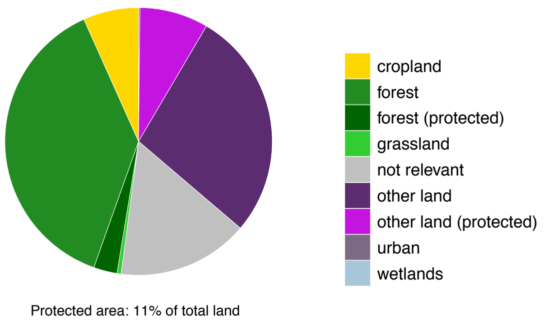
Land and food systems at a glance

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

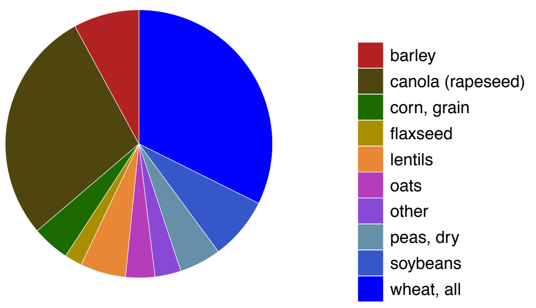
Land & Biodiversity

Fig. 1 | Area by land cover class in 2010



Source: Canadian Council on Ecological Areas, Statistics Canada (2015)

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



Source: Agriculture and Agri–Food Canada (2015)

Annual deforestation in 2015:
40 kha = 0.02% of total forest area

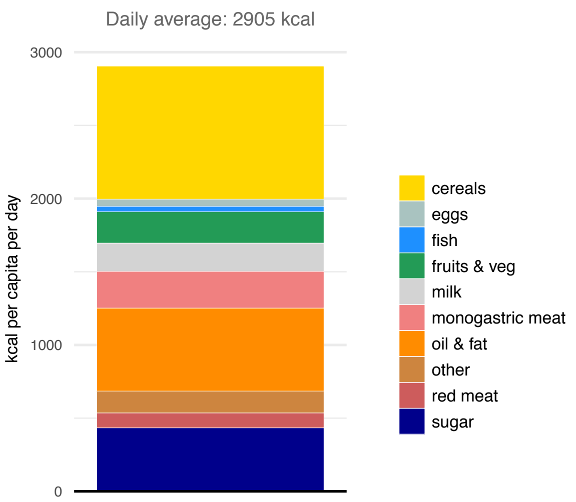
(Dyk et al., 2015)

Endangered species: 13

(Canadian Endangered Species Conservation Council, 2016)

Food & Nutrition

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



Source: Statistics Canada, FAOSTAT

Share of households that are food insecure:
1 in 8

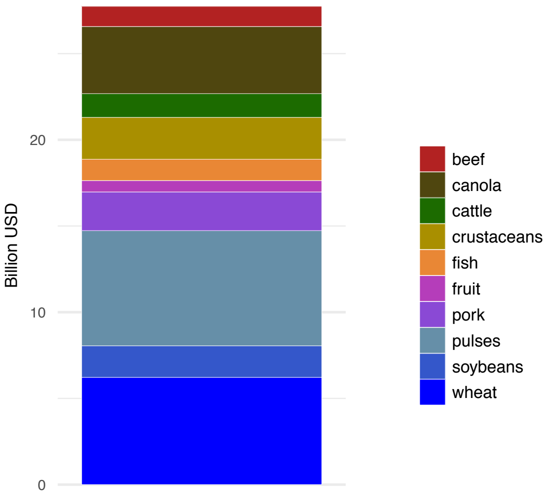
(Tarasuk et al., 2016; Health Canada, 2015)

Share of obese in 2015:
26.7%

(Health Canada, 2015)

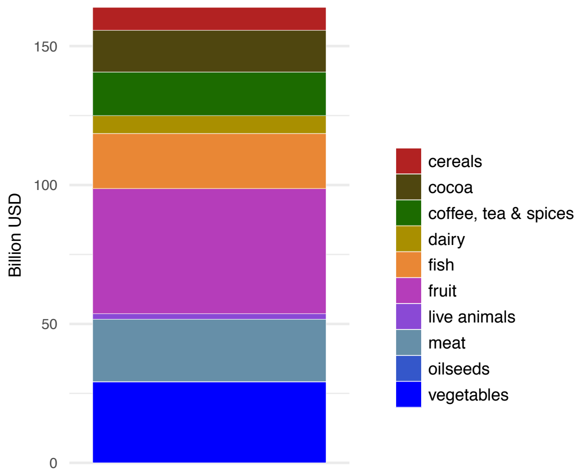
Trade

Fig. 4 | Main agricultural exports by value in 2015



Source: UN Comtrade Database

Fig. 5 | Main agricultural imports by value in 2015



Source: UN Comtrade Database

Surplus in agricultural trade balance in 2015: USD 13,542 mln

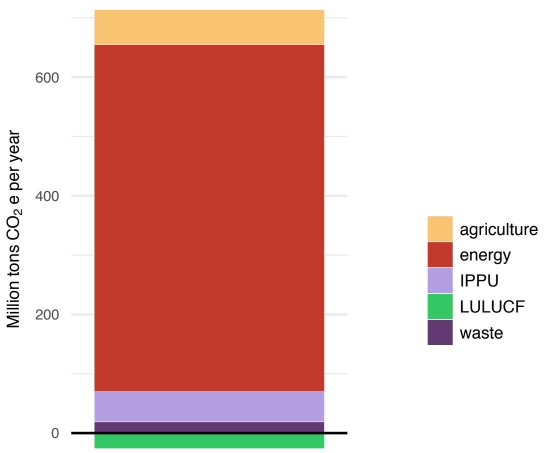
(Statistics Canada, 2019a)

#1 lentil and dry pea exporter in the world in 2015

(Statistics Canada, 2016)

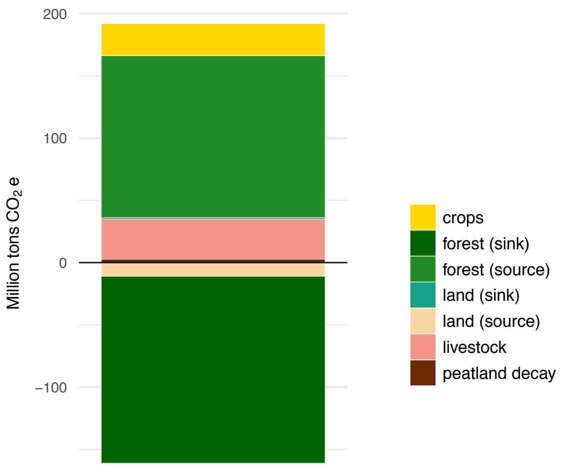
GHG Emissions

Fig. 6 | GHG emissions by sector in 2015



Source: Environment and Climate Change Canada (2018)

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



Source: Environment and Climate Change Canada (2018)

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 (large change)	Population (large change)
Scenario definition	GDP per capita is expected to increase from USD 50,070 in 2015 to USD 83,545 in 2050. The SSP2, "Middle of the Road" scenario was selected, assuming a medium economic growth with little deviation of social, economic and technological trends from historical patterns.	The population is expected to increase by 31.5% between 2015 and 2050 from 35.9 mln to 47.2 mln. The SSP2, "Middle of the Road" scenario was selected, which assumes medium fertility, medium mortality, medium migration, medium education and extension of current trends in urbanization. The population variation expected in this scenario is 1.54.
Scenario justification	Based on OECD Real GDP long-term forecast for Canada up to 2050. This publication was chosen because it contains useful and relevant forecasts and analysis of economic situations of the OECD member countries and formed the basis for scenario selection (OECD, 2018).	Based on Statistic Canada Population Projections for a medium-growth scenario. Statistics Canada has several medium growth scenarios which all roughly match the chosen scenario (Statistics Canada, 2018).

TRADE

	Imports (no change)	Exports (large change)
Scenario definition	The share of total consumption which is imported stays constant at 2010 levels.	The exported quantity increases: - from 18.4 Mt in 2010 to 36.8 Mt in 2050 for wheat, - from 7.4 Mt in 2010 to 14.8 Mt in 2050 for rapeseed, - from 2 Mt in 2010 to 4 Mt in 2050 for barley, - stays constant for the other products.
Scenario justification	Based on the Medium Term Outlook for Canadian Agriculture 2018 which assesses a historical agri-food domestic sales growth of 2.7% over the past 12 years and a 3.5% annual growth rate going forward. The domestic sales of agri-food products are expected to meet increased demand as a result of domestic growth, thus maintaining the share of consumption which is imported (Agriculture and Agri-Food Canada, 2018)	Based on the Medium Term Outlook for Canadian Agriculture 2018 which assesses a historical agri-food annual export growth of 6.5% over the past 12 years and forecasts 2% annual growth going forward. The growth of exports is indicated to come from multiple commodities but largely from the main exports, wheat and rapeseed (Agriculture and Agri-Food Canada, 2018).

Scenario signs no change small change large change

LAND

	Land conversion	Afforestation
Scenario definition	We assume that there will be no constraint on the expansion of the agricultural land outside beyond existing protected areas and under the total land boundary.	We assume no active afforestation and/or reforestation over the period of simulation.
Scenario justification	Based on the Statistics Canada Land Cover Data which is collected from land surveying and geospatial analysis. Canada has not committed to any deforestation schemes and there are currently no land-use change constraints other than regional zoning laws (Statistics Canada, 2019b).	Based on the Canadian Forest Service which does not track afforestation but does track regeneration (either through area planted or seeded) with new trees. In 2015, 425,000 hectares were regenerated through planting or seeding (Natural Resources Canada, 2018).

BIODIVERSITY

	Protected areas (=)
Scenario definition	The protected areas remain the same over 2000-2050.
Scenario justification	The scenario does not reflect the 6th National Report to the Convention on Biological Diversity (CBD) by Biodivcanada which sets a 20% target for protected areas for 2020. Canada currently has 11% of its land under protection including parks, biosphere reserves, conservation areas and other protected areas (Biodivcanada, 2018).

Scenario signs (=) no change (→) small change (↗) large change

FOOD

	Diet (small change)	Food waste (large change)
Scenario definition	Between 2015 and 2050, the average daily calorie consumption per capita increases from 2,590 kcal to 2,618 kcal. Per capita consumption: - increases by 13% for fruits and vegetables, - increases by 20% for fish, - increases by 17% for other (includes nuts), - decreases by 15% for pulses. For the other food groups, there is no large shift in consumption.	Between 2015 and 2050, the share of final household consumption which is wasted decreases from 10% to 5%.
Scenario justification	Based on recommendations made in the recently released Canada Food Guide which recommends increasing the intake of fruits and vegetables and reducing intake of protein from meat. The food guide does not provide prescriptive recommendations but rather encourages eating a mostly plant based diet with whole grains and minimal processed foods (Health Canada, 2018).	Based on the Second Harvest Food Waste Roadmap, this publication lays out the roadmap for Canada to reduce avoidable food waste and loss through a 2018-2022 plan (Nikkel et al., 2019).

PRODUCTIVITY

	Crop productivity (large change)	Livestock productivity (large change)	Pasture stocking rate (no change)
Scenario definition	Between 2015 and 2050, crop productivity increases: - from 2.84 t/ha to 3.83 t/ha for wheat, -- from 5.69 t/ha to 9.06 t/ha for rapeseed (canola).	Between 2015 and 2050, the productivity per head increases: - from 103 kg/TLU to 115 kg/TLU for beef cattle, - from 600 kg/TLU to 900 kg/TLU for pork, - from 8.3 t/TLU to 9.3 t/TLU for cow milk.	The average livestock stocking density remains constant at 0.8 TLU/ha of pasture land between 2015 and 2050.
Scenario justification	Based on the Medium Term Outlook for Canadian Agriculture 2018, which forecasts an annual yield growth rate between 0-0.4% for wheat and 1.1-1.6% for rapeseed (canola) (Agriculture and Agri-Food Canada, 2018).	Based on the Medium Term Outlook for Canadian Agriculture 2018, which forecasts that herd sizes for dairy cows, beef cattle, and swine will increase slightly due to higher prices and demand. Relatively inexpensive feed is forecasted to contribute to farmers producing animals with higher average carcass weight (Agriculture and Agri-Food Canada, 2018).	Based on the report "Grazing Management in Canada" from Statistics Canada and based on data collected in the Farm Environmental Management Survey. There is a large amount of variation in livestock density by province which is expected to continue but the aggregate pasture stocking rate is expected to remain stable due to the large pasture land base (Rothwell, 2005).

Scenario signs = no change → small change ↗ large change

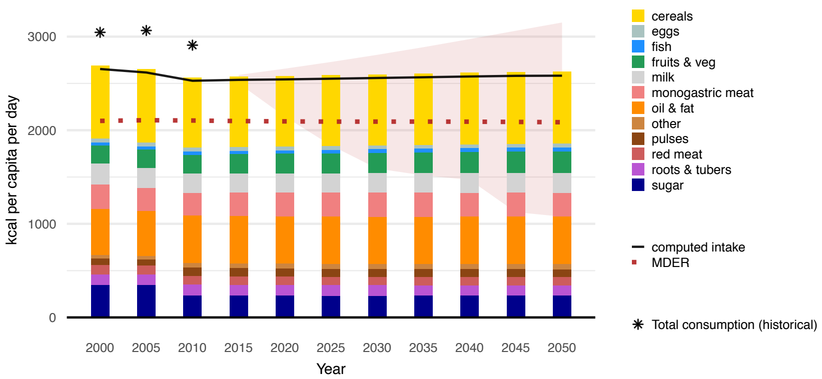
Results against the FABLE targets

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

Food security

Figure 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.



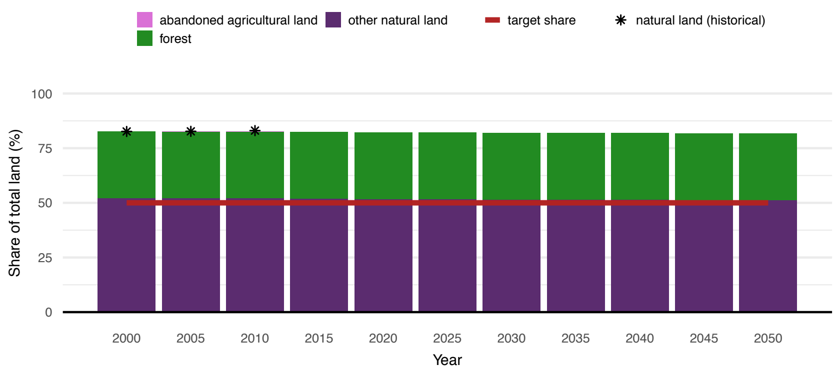
Historical data source: FAOSTAT

Our results show average daily energy intake per capita remains stable between 2,500 and 2,600 kcal from 2000-2015. This is 24% lower than Health Canada (2015) data due to some categories not being taken into account in our calculation. Over the last decade, 29% of the food intake came from cereals. Calorie intake reaches 2,600 kcal over the period 2031-2035 and remains stable over the period 2046-2050. In terms of recommended diet, our results show higher consumption of fruits and vegetables.

The computed average calorie intake is 23% higher than the Minimum Dietary Energy Requirement (MDER) at the national level in 2030 and 2050. Our results suggest that meeting national food security objectives will be attainable.

Biodiversity

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



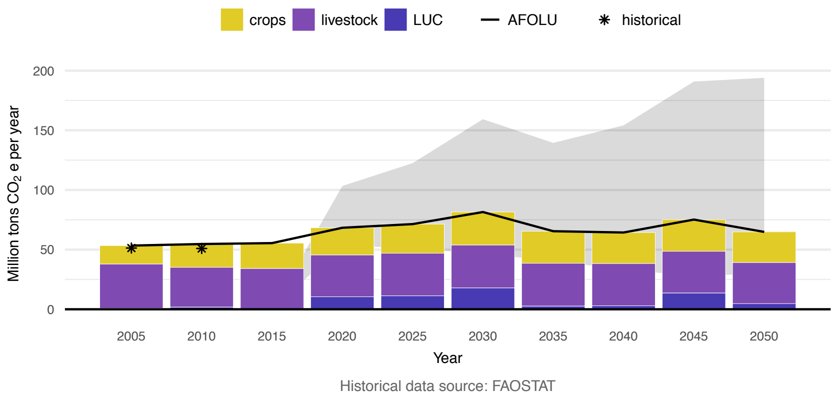
Historical data source: FAOSTAT

Our results show that the Share of Land which could support Biodiversity (SLB) remained stable between 2000-2015 at 83%. This number is similar to estimates based on Statistics Canada (2019b) land cover statistics. SLB remains stable over the whole period of simulation in the absence of significant land use change.

Compared to the global target of having at least 50% SLB by 2050, our results are above the target.

GHG emissions

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



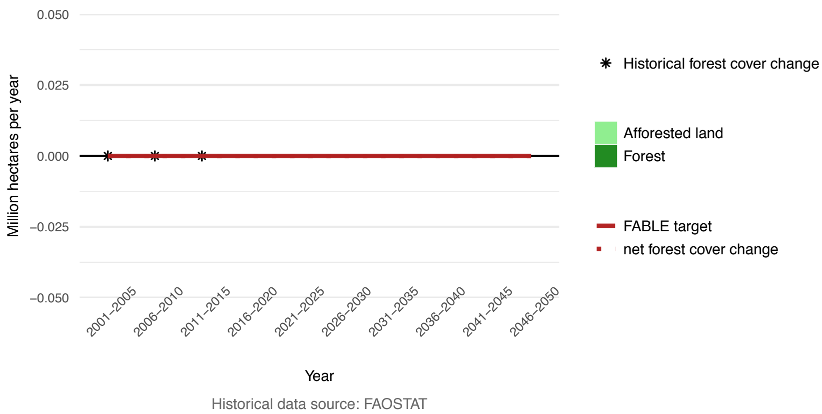
Note: AFOLU (Agriculture, Forestry and Other Land Use) is the sum of computed GHG emissions from crops, livestock and Land Use Change (LUC), emissions and sequestration from forestry are not included. Historical emissions include crops and livestock.

Our results show annual GHG emissions between 50 and 52 Mt CO_2e/year over 2000-2015 which increased over time. These are consistent with FAO statistics for GHG emissions from agriculture but this is higher than the Canada National Inventory Report which estimates a maximum of 26 Mt CO_2e/ year over the same period and a stable trend. Peak AFOLU GHG emissions are computed for the period 2030 at 80 Mt CO_2e/year. This is mostly driven by GHG emissions from LUC and crops. AFOLU GHG emissions reach 65 Mt CO_2e over the period 2046-2050: 60 from agriculture and 5 from land use change (LUC). Positive net emissions from LULUCF by 2050 are explained by the conversion of other natural land to urban area.

Compared to the global target of reducing emissions from agriculture and reaching zero or negative GHG emissions from LULUCF by 2050, our results are below the target. Our results show that AFOLU could contribute to as much as 5% of the total GHG emissions reduction objective of Canada (Environment and Climate Change Canada, 2018).

Forests

Figure 11 | Computed forest cover change over 2001-2050

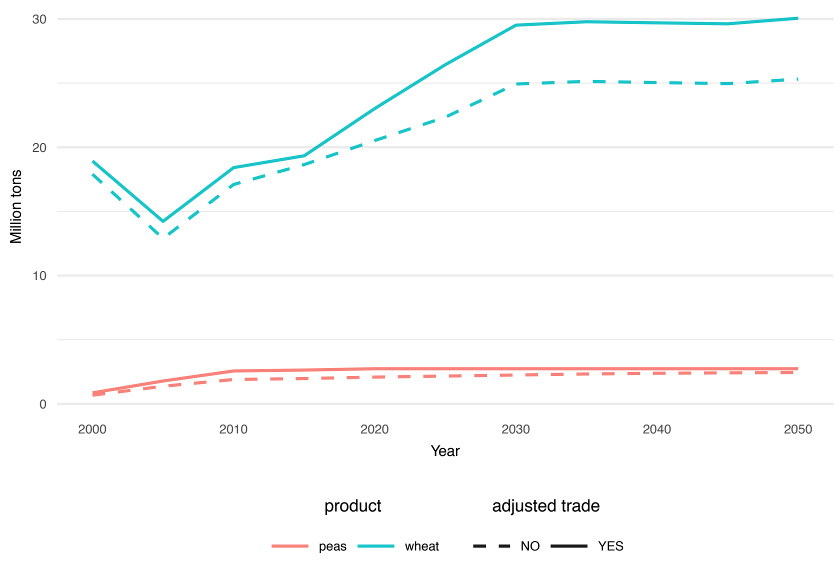


There is no deforestation computed from 2000-2015 which remains stable over time. This is consistent with FAO statistics but lower compared to the Canadian Forest Service (Natural Resources Canada, 2018) which estimates a maximum deforestation of 40 kha/year over the same period and a decreasing trend.

Compared to the global target of having zero or positive net forest change after 2030, our results are at the target. Our results meet national objectives of having less than 0.05% net forest cover change.

Impacts of trade adjustment to ensure global trade balance

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

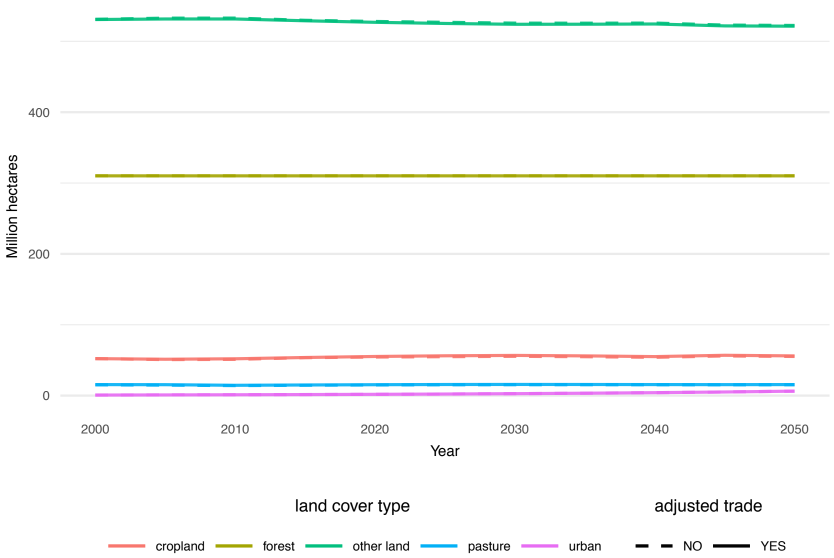


Trade adjustment leads to an increase of exported quantity for peas by 11.94% and for wheat by 18.76% by 2050.

Change in imports compared to no trade adjustment for fruits in 2050: +20%.

Change in imports compared to no trade adjustment for vegetables in 2050: +21%.

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



Trade adjustment does not lead to significant impacts on land use in Canada: cropland is reduced by 1.45% in 2050. By 2050, total AFOLU GHGs are reduced by 3.43% after trade adjustment.

Discussion and next steps

In developing a sustainable pathway for Canada, it was important to consider the advantages Canada has been conferred. As a land and resource giant with a small population, Canada is in the fortunate position of having low land-use impact due to the sheer size of the country and thus easily meets many sustainability targets such as low deforestation. Therefore, it was important to set challenging goals for Canada to meet in 2050 to ensure that achieving them was a result of substantial systemic change and did not end up being "business-as-usual".

Scenarios for the future were based on "middle of the road" projections for population and GDP growth, resulting in projections in 2050 with a population of 47 million and 120% growth in GDP. A sustainable diet was chosen that resulted in daily energy intake per capita remaining stable between 2,500-2,600 kilocalories with lower consumption of ruminants meats and sugars and higher consumption of fruits, vegetables and fish, which is consistent with the broad dietary recommendations set out in the latest Canada Food Guide (Health Canada, 2018).

A ambitious goal for reducing food waste was targeted as Canada is one of the worst countries in the world at wasting food with an average of 396 kilograms of food wasted per capita (Nikkel et al., 2019). In the FABLE Calculator, food waste in Canada is reduced from 10% to 5% by 2050. While this is an ambitious target, there are several agencies working in Canada on this issue and they have developed a comprehensive roadmap that could be a means by which to meet this goal.

Sustainable land-use targets included full compliance with Canada's commitment to the Convention on Biological Diversity, with 17% of terrestrial ecosystems and 10% of coastal and marine areas protected as well as keeping deforestation rates below 0.05%. As there is such a large land base, no restrictions on land conversion were enacted in this pathway through the FABLE Calculator, which resulted in very little land being converted between land use classes in the Calculator.

As Canada already has highly productive crops and livestock, productivity rate improvements were kept similar to current growth rates, with medium improvements seen in the yields of major crops (wheat, canola, pulses), and in the beef and dairy production rate. The results of the Calculator closely mirrored the expected government agricultural outlooks for the country, with quality parameters gaining increasing importance over quantity, particularly in the beef sector. Improvements in technology and germplasm as well as longer growing seasons and increased heat units are expected to increase crop yields in Canada, but there will also likely be yield penalties due to increased biotic and abiotic stress resulting from climate change and shifting agro-ecological zones.

The last part of the sustainable pathway was on developing scenarios for trade, and for Canada it was assumed that the share of consumption which is imported would remain stable (as part of the sustainable diet and meeting domestic demand with locally sourced products) and that exports would increase due to Canada continuing to play a role as a major exporter of agricultural products to Asia, the Middle East, and Europe. Adjusting for trade increased Canada's imports of key foodstuffs (fruits and vegetables, on which Canada is heavily reliant on imports) but also decreased exports of key commodities between 10-20%. Adjusting for trade had little impact of cropland area or total GHG emissions from land.

While using the FABLE Calculator has yielded interesting results and provided a pathway to a more sustainable future in Canada, there are several components not featured in the methodology that are important to the Canadian land and food systems. On average 2.5 million hectares of forest area burn every year in Canada and in 2016 over 15.5 million hectares of forest had been defoliated by insects and contained beetle-killed trees. These statistics show that the actual extent of forest cover loss in Canada is much higher than deforestation or harvesting rates suggest. Natural forest disturbance from fire and pests, its acceleration due to climate change and its contribution to GHG emissions and reducing forest stocks are all important considerations when considering the future of Canada's landscapes and are not currently captured by the Calculator.

Another component of the Calculator that could be improved is the methodology for assessing biodiversity. The current calculation only includes land that could potentially support biodiversity, which is remarkably high in Canada (83%) due only to the vast wilderness and uninhabitable parts of the country. A more accurate calculation should consider biodiversity at the eco-region level to account for the differing amounts of protected land needed in the unique biospheres of world. Improvements could also come from including industrial crops, their contribution to energy systems as well their competition for land. Currently 25% of Canada's renewable energy comes from solid biomass, bioethanol, or biodiesel and this sector is expected to grow with the enactment of renewable fuels regulations and government commitments to 100% renewable energy as early as 2025.

Other useful considerations for the Calculator would be to include the emissions (or carbon sequestration) of different agriculture practices and cropping systems. Over 75% of the land area of the Canadian Prairies, the major agriculture region in the country, is in reduced or no-till which has been shown to improve biodiversity while reducing greenhouse gas emissions. Alternative cropping systems such as organic production are becoming increasingly common and have different land-use, biodiversity, and crop productivity outcomes that should be considered as part of a more holistic look at agriculture production at a country level.

The FABLE Calculator has set ambitious objectives for Canada to reach by 2050 in terms of increasing agriculture output while reducing carbon and land-use footprints. Technological innovation, such as the wide-scale adoption of precision agriculture, will likely be key in optimizing input and water use, reducing soil compaction, improving yields, and increasing overall productivity. While the implementation of precision agriculture still has a long way to go, adoption of some key technologies has been shown to be widespread among Canadian farmers including GPS guidance and yield monitoring on combines (Steele, 2017).

The implementation of sustainable pathways for Canada will require political action and buy-in at the local, provincial, and federal levels, as well as reconciling the economic incentives of resource-extraction with sustainability initiatives. Challenges to the realization of a more sustainable future are further constrained by the lack of data on the evolution of land and food systems, as this data is controlled by the national statistics body of Canada and not available at finer scales. Modelling future land-use scenarios will require this data as well as better tracking of other land-use statistics including afforestation efforts. The disconnect between environmental, natural resource, and agricultural policymakers on sustainability issues is another challenge that needs to be addressed in the Canadian context in order for the sustainable pathways to be implemented.

Recommendations to develop integrated policies to address these challenges include increasing forest replanting to offset AFOLU GHG emissions, enacting policies to further protect natural land, pasture and agricultural land from land-use change, developing climate change adaptation plans for shifting agri-ecological zones, and making agriculture and land-use microdata available for better modelling and land-use planning. Canada is fortunate to have the political will and the means to enact many of the changes needed to put the country on a path to sustainability and now has (at least partially) a roadmap to do so.

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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China

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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 2015

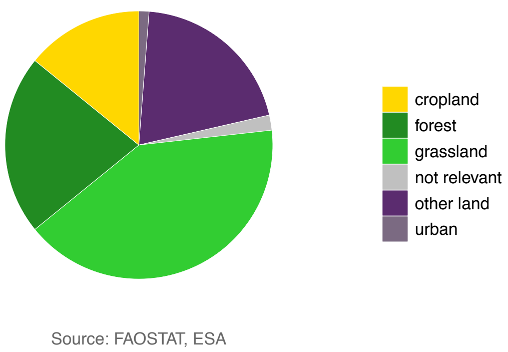
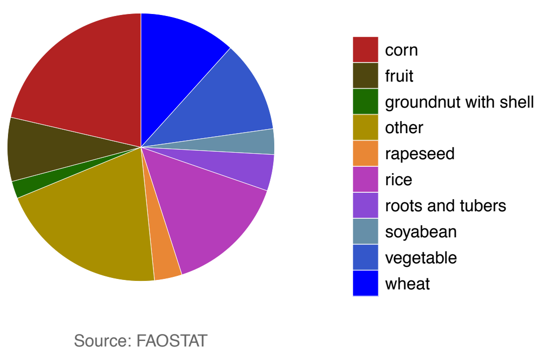


Fig. 2 | Share of harvested area by crop in 2015



Annual afforestation in 2015:
1.5Mha = 0.74% of total forest area

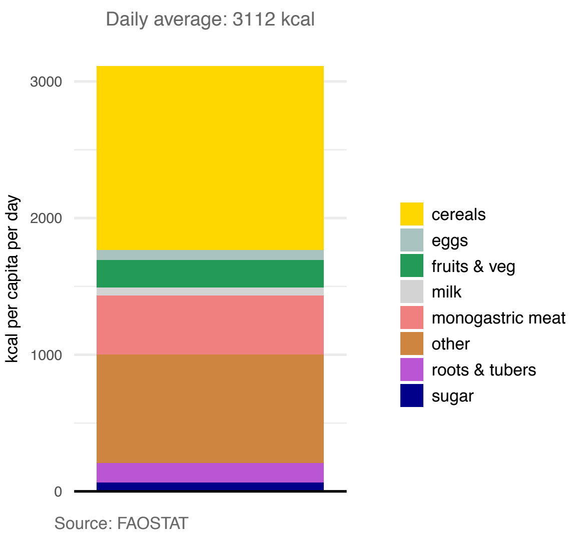
(FAOSTAT, 2019)

Endangered species: 795

(World Bank, 2019)

Food & Nutrition

Fig. 3 | Daily average intake per capita at the national level in 2013



Share of undernourished in 2015:

8.8%

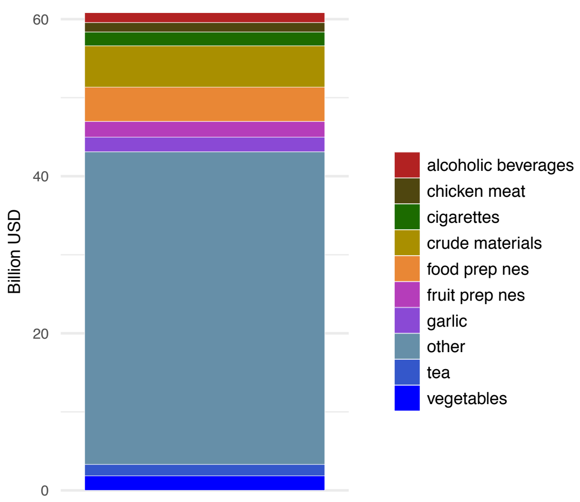
(FAOSTAT, 2019)

Share of obese in 2015:
11.9% of adults over the age of 18
6.4% of children and teenagers between the ages of 6 and 17

(National Health and Family Planning Commission, 2015)

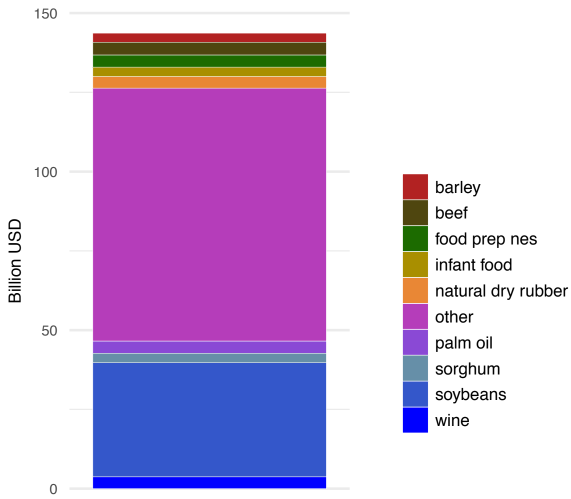
Trade

Fig. 4 | Main agricultural exports by value in 2015



Source: FAOSTAT

Fig. 5 | Main agricultural imports by value in 2015



Source: FAOSTAT

Deficit in agricultural trade balance in 2015: USD 83 bln

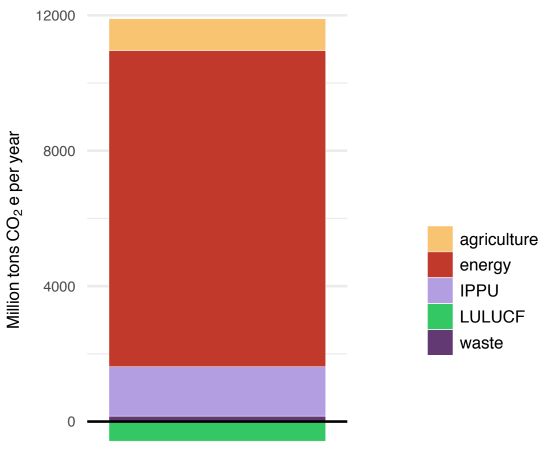
(FAOSTAT, 2019)

#1 soybean importer in the world in 2015

(FAOSTAT, 2019)

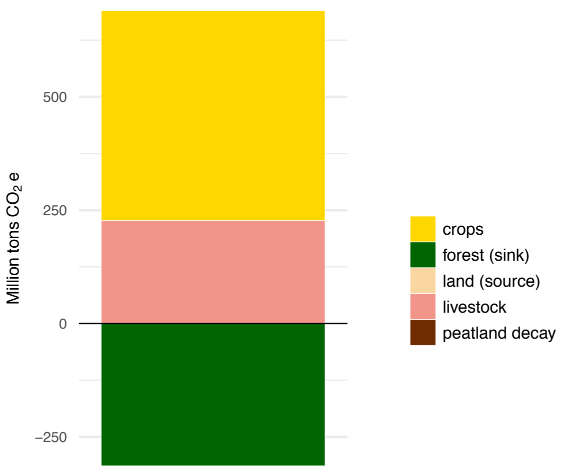
GHG Emissions

Fig. 6 | GHG emissions by sector in 2012



Source: National Leadership Group on Climate Response, Energy Conservation & Emissions Reduction (2016)

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



Source: FAOSTAT

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 (large change)	Population (small change)
Scenario definition	GDP per capita is expected to increase by 260% from USD 6,378 in 2015 to USD 21,063 in 2050 (SSP1 scenario selected).	Population is expected to decrease by 2% between 2015 and 2050 from 1.39 bln to 1.36 bln (Family Planning scenario selected).
Scenario justification	This is based on 2050 being close to the 100th Anniversary of the Founding of the People's Republic of China when, according to our national objective, China will be a great modern socialist country. By 2050, China would reach the third quartile of a middle and high income country, therefore economic growth should be kept around 3.4% from 2017-2050, which is close to SSP1 (Center for China in the World Economy, 2017; O'Neill et al., 2014).	Based on China's two child policy, the birth rate will increase in short term, and total population will increase first and peak during 2025-2030 (Jing et al., 2018; Qi et al., 2016).

TRADE

	Imports (large change)	Exports (no change)
Scenario definition	The share of total consumption which is imported increases: - from 2% in 2015 to 10% in 2050 for pork, - from 5% in 2015 to 10% in 2050 for beef, - from 4% in 2015 to 10% in 2050 for poultry meat, - from 3% in 2015 to 10% in 2050 for mutton, - from12% in 2015 to 20% in 2050 for milk. The share of total consumption which is imported remains constant at 2010 levels for the other commodities.	The exported quantity remains constant at 2010 levels for all products.
Scenario justification	Based on China's current food security policy, as well as trends in recent years for imports of agricultural products, which requires that the self-sufficiency rate of staple foods, such as rice, wheat, and maize, remain above 90%. Meanwhile, the central government would like to increase imports of animal products, but maintain the current self-sufficiency rate for soybean and palm oil (Ma et al., 2019).	Based on China's lack of land available for agricultural production, it is reasonable to reduce or maintain current levels of food exports (Ma et al., 2019).

Scenario signs no change small change large change

LAND

	Land conversion	Afforestation (large change)
Scenario definition	We assume that arable land should be higher or equal to 2010 extent i.e. 120 Mha, over the whole period of simulation.	Total afforested area is expected to reach 72.6 Mha by 2050.
Scenario justification	Based on China's determination to "hold the rice bowl in our own hands" i.e. to guarantee grain self-sufficiency (State Council of China, 2017).	Based on the central government's regular emphasis of the importance of afforestation and our national territorial plan, which clearly states that the forest cover rate should reach 24% by 2030. Therfore, we assume the forest cover rate could reach 26% in 2050 (State Council of China, 2017).

BIODIVERSITY

	Protected areas (no change)
Scenario definition	Protected areas remain at their 2010 level, representing 14.8% of total land area.
Scenario justification	This does not take into account the plan to expand protected areas to 25% of China's total land area according to the Ecological Conservation Redline (Ministry of Ecology and Environment, 2016; Gao, 2019).

FOOD

	Diet (large change)	Food waste (small change)
Scenario definition	The share of total consumption which is imported increases: - from 2% in 2015 to 10% in 2050 for pork, - from 5% in 2015 to 10% in 2050 for beef, - from 4% in 2015 to 10% in 2050 for poultry meat, - from 3% in 2015 to 10% in 2050 for mutton, - from 12% in 2015 to 20% in 2050 for milk. The share of total consumption which is imported remains constant at 2010 levels for the other commodities.	Between 2015 and 2050, the share of final household consumption which is wasted decreases from 13.5% to 11.8%.
Scenario justification	While there is no policy in China that forces people to change their diet, we assume that Chinese people will tend to follow a healthier lifestyle in the future (Chinese Nutrition Society, 2016).	Based on recent government policies that show the feasibility and positive impacts of reducing food waste through, for example, the clean the plate campaign in Chinese universities (Ma et al., 2019).

Scenario signs = no change → small change ↗ large change

PRODUCTIVITY

	Crop productivity	Livestock productivity	Pasture stocking rate
Scenario definition	Between 2015 and 2050, crop productivity per year increases: - from 6.7 t/ha to 7.3 t/ha for wheat, - from 6.1 t/ha to 6.8 t/ha for rice, - from 7.7 t/ha to 8.2 t/ha for corn.	Between 2015 and 2050, the average productivity per year remains constant: - at 44.4 kg/head for beef, - at 95.6 kg/head for pork, at 3.3 t/head for cow milk.	The average livestock stocking density remains constant at 0.32 TLU/ha of pasture land between 2015 and 2050.
Scenario justification	An average of 11% increase in crop yield was achieved between 2005 and 2015 for millions of small household farms in China due to the implementation of better nutrient management practices. Chen et al (2014) also show that the productivity of wheat, rice, and corn could be increased by 45%, 17%, and 69%, respectively, compared to 2010 levels through integrated soil and crop nutrient management, extension services, and closing the yield gap. Therefore, we assume China could achieve 9.6%, 16%, and 7.3% yield increases for wheat, rice, and corn between 2015 and 2050 (Cui et al., 2018; Chen et al., 2014).	This is a conservative estimate made to avoid a sharp decline in pasture area by 2050.	Based on one of the core missions of land-use planning in China, which includes controlling the degradation of grassland (State Council of China, 2017).

OTHER

	Crop harvesting Intensity
Scenario definition	Between 2015 and 2050, average crop harvesting intensity per hectare per year remains constant at 1.4, this is a conservative estimation due to future climate change. However, we assumed there will be constant havesting index if the increase in temperature stays below 1.5 degrees.
Scenario justification	

Scenario signs no change small change large change

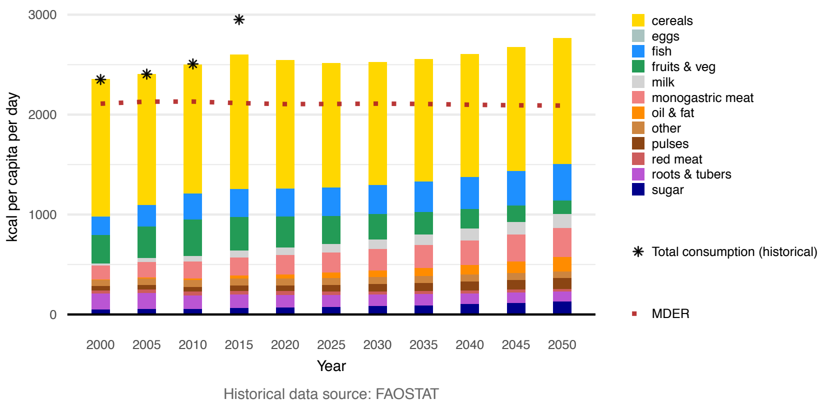
Results against the FABLE targets

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.

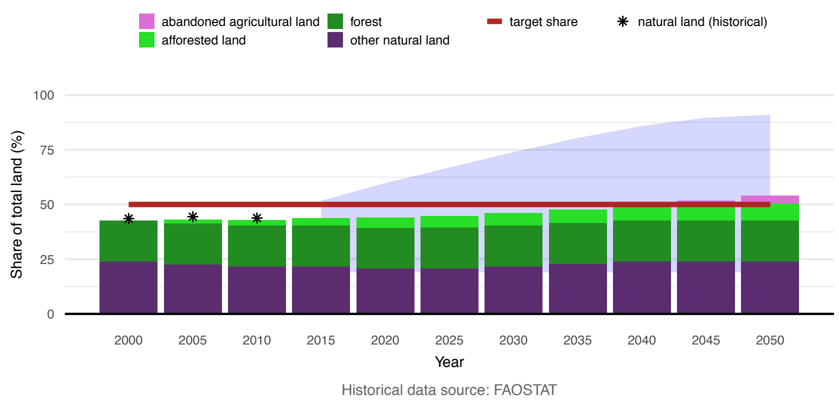


Our results show average daily energy intake per capita increases from 2,355 and 2,617 kcal/cap/day between 2000-2015. Over the last decade, 50% of the food intake came from cereals. Calorie intake reaches 2,617 over the period 2031-2035 and 2,950 kcal/cap/day over the period 2046-2050. In terms of recommended diet, our results show lower consumption of meat, while other food consumption increases for other animal products and pulses. The computed average calorie intake is 41% higher than the Minimum Dietary Energy Requirement (MDER) at the national level in 2050.

Our results suggest that meeting national food security objectives of having zero huger by 2030 will be attainable.

Biodiversity

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

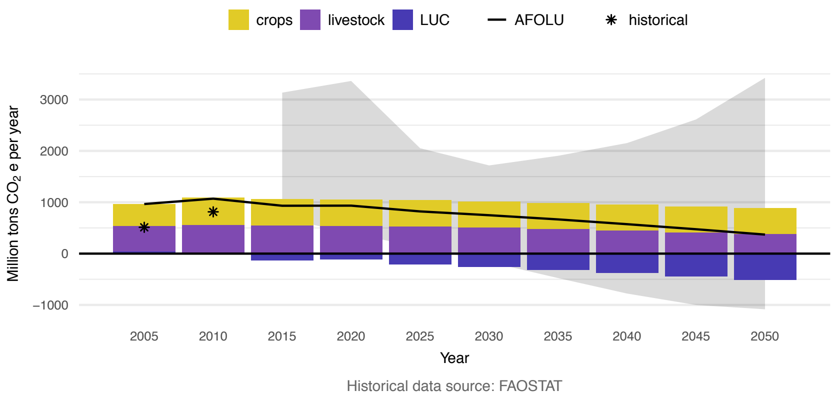


Our results show that the Share of Land which could support Biodiversity conservation (SLB) increased between 2000-2015 from 42.9% to 43.9%. This number is close to historical levels based on FAO land-cover statistics. The lowest SLB is computed for the period 2005-2010 at 43.2 % of total land. This is mostly driven by other non-managed land conversion to pasture. SLB reaches 53.6 % over the last period of simulation, 2046-2050. The difference is explained by high afforestation and the reduction of pasture area where we assume natural vegetation regrowth.

Compared to the global target of having at least 50% SLB by 2050, our results are above the target.

GHG emissions

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



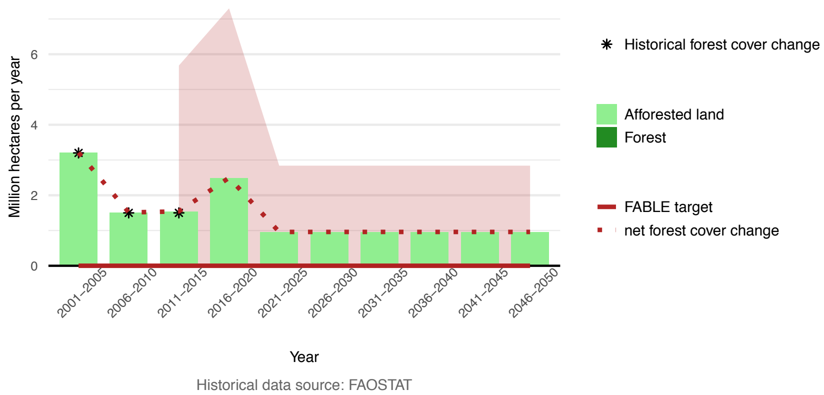
Note: AFOLU (Agriculture, Forestry and Other Land Use) is the sum of computed GHG emissions from crops, livestock and Land Use Change (LUC), emissions and sequestration from forestry are not included. Historical emissions include crops and livestock.

Our results show annual GHG emissions between 807 $MtCO_2e$/yr and 932 $MtCO_2e$/yr over 2000-2015 that increased and then decreased over time, whereas FAO estimates a maximum of 813 $MtCO_2e$/yr over the same period. This is mainly due to different GHG emission parameters used in the FABLE Calculator and FAO GHG emission database. For example, the FAO database does not include GHG emissions by energy use of agricultural machinery. Also, the FABLE Calculator calculated GHG emissions based on the average GHG emissions per head of livestock category, whereas FAO GHG emissions from livestock production includes enteric fermentation, manure management, and manure applied to soil and pastures. Peak AFOLU GHG emissions are computed for the period 2005-2010 at 1,070 $MtCO_2e$/yr. This is mostly driven by GHG emissions from livestock. AFOLU GHG emissions reach 370 $MtCO_2e$ over the period 2046-2050: +883 from agriculture and -513 from LULUCF. Positive net emissions from LULUCF by 2050 are mainly explained by higher agricultural emissions than afforestation can reduce.

GHG emissions per unit of gross domestic product: Compared to the global target of reaching zero or negative GHG emissions from LULUCF by 2050, our results meet the target. The central government of China has committed that average GHG emissions per GDP in 2020 will be 40-45% lower compared to 2005 levels. Our results show that AFOLU could reduce the average GHG emissions per agricultural GDP by 44%, which is in the range of the national target (Ministry of Foreign Affairs, 2011).

Forests

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



Our results show high afforestation from 2001-2005 at about 3.2 Mha/year, which then stabilizes between 2006-2015 at 1.5 Mha/year. This trend is consistent with FAO statistics. Peak afforestation is computed for the period 2016-2020 at 2.5 Mha/year and reaches 950 kha/year over the period 2031-2050. We assume no deforestation between 2000-2050, which leads to a positive net-forest cover change of 72.6 Mha.

Compared to the global target of having zero or positive net forest change after 2030, our results are above the target with 0.96 Mha/year net forest cover increase by 2030.

Other relevant results for national objectives

Table 1 | Other Results

Variable	Unit	2000	2005	2010	2015	2020	2030	2040	2050
Rice									
Production (historical)	Mt	126.6	121.4	131.5					
Production (calculated)	Mt	125.1	119.8	130.5	138.1	136.1	132.3	129.0	125.9
Imports (calculated)	Mt	0.0	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Wheat									
Production (historical)	Mt	99.6	97.4	115.2					
Production (calculated)	Mt	97.9	96.4	116.9	117.1	115.2	111.8	108.8	105.9
Imports (calculated)	Mt	2.1	4.3	2.3	2.3	2.3	2.1	1.9	1.7
Beef									
Production (historical)	Mt	5.0	5.7	6.6					
Production (calculated)	Mt	4.9	5.6	6.4	6.3	6.2	5.6	4.9	4.1
Imports (calculated)	Mt	0.1	0.1	0.3	0.3	0.4	0.4	0.5	0.5
Milk									
Production (historical)	Mt	12.4	32.0	41.1					
Production (calculated)	Mt	12.1	31.4	40.2	46.3	52.8	63.5	70.9	74.9
Imports (calculated)	Mt	1.5	1.6	4.6	6.0	7.6	11.3	15.1	18.8
Soyabean									
Production (historical)	Mt	15.4	16.4	15.1					
Production (calculated)	Mt	15.7	18.0	17.0	12.1	11.7	11.1	10.5	10.0
Imports (calculated)	Mt	12.7	31.8	67.5	65.9	64.5	59.0	51.6	43.4

Source of historical data: FAOSTAT for production, CEH LCM for land cover

Our results show small changes for rice production over the period 2000 to 2010. According to Dietary Guidelines for Chinese Residents 2016, the consumption of rice will continue to decrease between 2015-2050, so the production quantity will also go down. Our government highly values cereals production, and is determined to ensure self sufficiency, so rice imports will remain low in the future, our results show the net import rate close to 0% during the whole period.

Our results show that the production of wheat increased by 15% between 2000 and 2010. Similarly to rice, the consumption of wheat will decline by around 40% between 2010 and 2050. Net imports of wheat are low and remain within the lower bound. The reduction of wheat production and harvested area could contribute to the objective for reducing groundwater depletion.

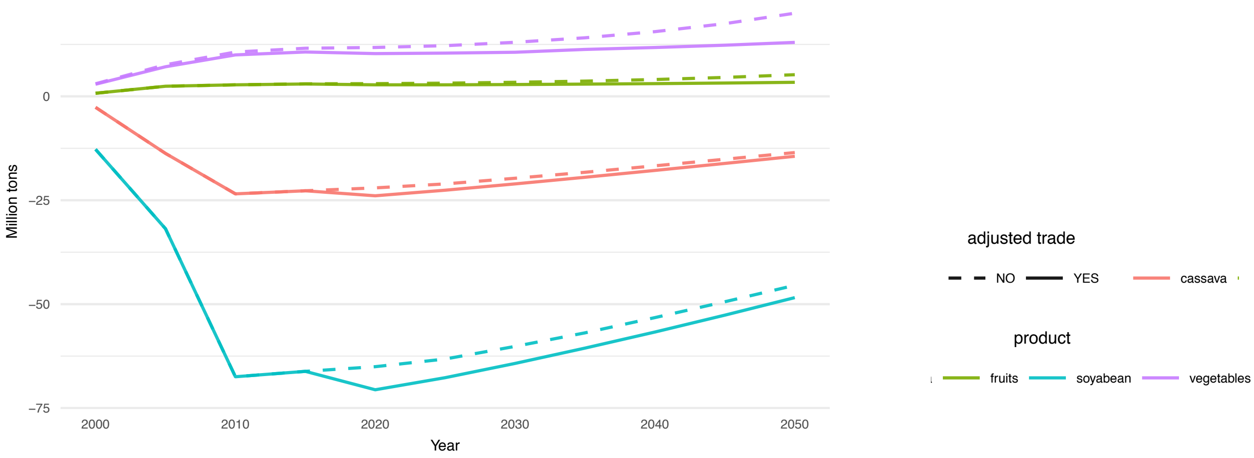
Our results show that the production of beef increased by 31% from 2000 to 2010. The targeted production quantity is projected to decline due to future dietarty shifts, reaching 4.1 Mt in 2050, which is much lower than the level in 2000. Net imports of beef will remain constant at around 450 kt, which will account for 10% of production in 2050.

Our results show that the production of milk increased by more than a factor of 2 between 2000 to 2010. The targeted production quantity is projected to further increase by 30% between 2010 and 2050, due to dietary changes. Meanwhile, milk imports will also increase, reaching 22 Mt in 2050 or 25% of total production. There is a national plan to increase milk consumption, especially for students and the central government would like to increase the self-sufficiency rate of milk in the future (Bai et al., 2013; General Office of the State Council of China, 2018).

Our results show that the production of soybean remains stable between 2000 to 2010. The targeted production quantity is projected to decline, reaching 7.9 Mt in 2050 which is much lower than the level in 2000. Soybean imports will steadily decrease between 2010 to 2050. A decline in soybean production does not align with current policy, which seeks to increase soybean production. The harvest area of soybean will reach 10 Mha in 2022 and may continue to increase in the future (Ministry of Agricultural and Rural Affairs, 2019).

Impacts of trade adjustment to ensure global trade balance

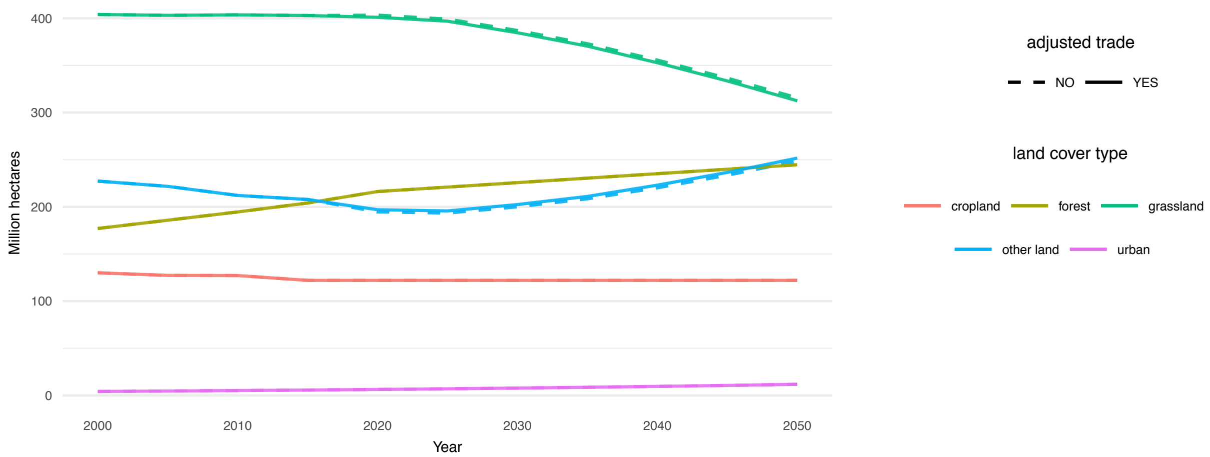
Fig. 12 | Impact of global trade harmonization on main exported/imported commodities over 2000-2050



For fruits, the change is apparent starting in 2020. Exports first increase, then decrease starting in 2015, before increasing again after 2025, and finally peaking at 3,400 kt in 2050. When trade is not adjusted, exports increase, first quickly, before slowing down and picking back up starting in 2030, and finally peak at about 3,700 kt in 2050. For vegetables, the change is apparent starting in 2005 and follows a similar trend to fruits with and without the trade adjustment, peaking at 13,000 kt and 14,000 kt in 2050, respectively. Lower exports after the trade adjustment may be due to other countries exporting more than we had anticipated and/or importing countries importing less than anticipated.

Soybean and cassava are two of the most important imports for China. They have the same trend before and after the trade adjustment. When trade is adjusted, they first increase between 2000-2010, then decrease between 2010-2015, then increase and peak in 2020, before falling until 2050. Imports peak in 2020 at 24,000 kt for cassava and 71,000 kt for soybean, respectively. When trade is not adjusted, both products peak in 2010 (23,500 kt for cassava and 67,000 kt for soybean), after which imports steadily decline. Similar to the case of exports, China will need more imports in the future based on our assumption that the population will peak between 2020-2030.

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



There is no significant impact of trade adjustment on land cover which is explained by the fact that trade still represents 10% maximum of total consumption for most of the agricultural commodities and the impact of trade adjustment on Chinese traded commodities is relatively small.

Discussion and next steps

Under this pathway, China achieves zero hunger, no deforestation and the increase of land for biodiversity, however total GHG emissions from AFOLU remain positive in 2050. The main underlying assumptions for this sustainable pathway are shifts towards healthier diets and reductions in food waste, as well as strict afforestation policies and increasing imports of agricultural products from abroad. These two strategies greatly contributed to achieving sustainable agricultural production.

According to recommendations made by the Chinese Nutrition Society on healthy diets, average consumption per capita should decrease by 22% for cereals, 59% for pork and poultry, and increase by 89% and 68% for milk and pulses, respectively. Overall, average daily calorie consumption per capita increases from 2,617 to 2,950 kilocalories per capita per day between 2015 and 2050. This is a relatively optimistic estimate, since average meat consumption per capita in China is already relatively low compared to other developing countries (FAOSTAT, 2019). In 2050, we assume a relatively high increase in GDP per capita, which would mean a continuous reduction in the consumption of animal protein with an increasing GDP per capita between 2015 and 2050. This will require a joint effort from scientists, government, consumers, producers, and retailers to develop healthly and nutritious food, linking nutrition, diet, food waste, and behavioral subsidies, building clear information and sound extension services, incentives for vegetarian food production, taxes on meat consumption, acceptance of healthly diets, and training for environment protection, etc. (Ma et al., 2019). Meanwhile, reducing food waste could also supplement decreasing demand for agricultural products. Here we aimed to reduce food waste from 13.5% to 11.8%. This is a relatively conservative estimate and could be achieved in the near future.

Other measures, such as improving crop productivity and land-use planning also support sustainable agricultural production. In 2050, we assume that the crop productivity of wheat, rice, and corn increase by 9.6%, 16%, and 7.3% compared to 2015. This is could be achieved through Integrated Soil-Crop System Management (ISSM) technology (Chen et al., 2014; Cui et al., 2018). Cui et al (2018) showed that an average 11% increase in crop yield was achieved between 2005 and 2015 for millions of small household farms in China due to the implementation of better nutrient management practices. Chen et al (2014) also showed that the productivity of wheat, rice, and corn could be increased by 45%, 17% and 69%, compared to 2010, through integrated soil and crop nutrient management, closing of the yield gap and greater extension services. Therefore, we assume China could increase wheat, rice, and corn yields by 9.6%, 16%, and 7.3%, respectively, between 2015 and 2050. These improvements have already been achieved in field experiments, experimental farms, and millions of small household farms but will require further integration, testing, and up scaling through, for example, the Science and Technology Backyard program, a program where young students and researchers stay in villages and help farmers adopt technologies needed to close the yield gap and improve nutrient management. This requires the joint efforts of policymakers, researchers, extension services, farmers, citizens, industry, and market organizations to fully understand the levers and barriers of each option.

The Integrated Soil-Crop System Management (ISSM) applied in these studies involved agronomic measures such as planting appropriate crop varieties or hybrids at the right sowing dates and densities and applying fertilizer according to crop demands and soil fertility. ISSM redesigns cropping systems using advanced crop and nutrient management to bring yields closer to their biophysical potential, while optimizing various resource inputs (that is nutrient and water) and minimizing environmental costs. Such agronomic improvements represent a huge underutilized potential in China. Even larger technological improvements should be feasible over the longer term and beyond the 2050 period considered here, including genetic crop improvement and, in the future, more mechanized and automated production technologies for precision field management.

Increased imports of food from abroad is also a sound option for China to achieve domestic SDGs. In this study, we assumed imports of animal products will increase substantially between 2015 and 2050. This could largely reduce the need for domestic livestock production, as well as GHG emissions and demand of land. However, China is a leading livestock producer globally and increasing the proportion of meat imports will greatly transfer the burden of domestic agricultural production to other leading exporting countries, such as Brazil and Argentina, although this may be less likely to happen when these countries embark on a pathway towards SDGs.

The main challenge of the current FABLE Calculator is the lack of geographic analysis, which is important for China due to the highly uneven distribution of human population and agricultural production. Currently, the FABLE Calculator covers most of the policies at the national level in China. In the future, improvements could be made so that the impacts of polices at the regional level could be considered which is important because of the high diversity in agricultural production between regions and the highly uneven distribution of production systems. For example, there are increasingly strict water-use policies in the North China Plain, which may greatly impact wheat and maize production (State Council of China, 2012). There is also a strict water protection rule in southern China, which has impacts on total pig production throughout China (State Council of China, 2015). Furthermore, the Ecological Redline also limits the further expansion of agricultural production. The nutrient management and water requirement for agricultural production may need to be further strengthened, mainly due to decoupled crop-livestock production and severe water shortages, which have already contributed to the severe air and water pollution in China (Bai et al., 2018; Du et al., 2014). These factors are not yet well covered by FABLE Calculator.

Additionally, a coherent framework to ensure a sustainable pathway for land and food systems needs to be developed in the future to help with implementation. This framework should include: (1) incentives to adopt improved agronomic practices and technologies, (2) incentives to support land-based animal production and pasture-based livestock systems, so as to improve manure management and meet water quality standards (which is included in the new Environmental Protection Law of China), (3) subsidy reforms to ensure that subsidies reach their target stakeholders, and (4) education and policies that promote a healthy diet and reduced food waste. Implementing such a strategy also commits China to sound monitoring and evaluation for assessing the impacts of action and enables it to adjust the strategy in a proactive, evidence-based manner, taking constraints and barriers into account. In principle, the ambitious targets embedded in China's new agricultural and environmental strategies appear to be achievable through an integrated transformation of the whole food system (Ma et al., 2019).

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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Colombia

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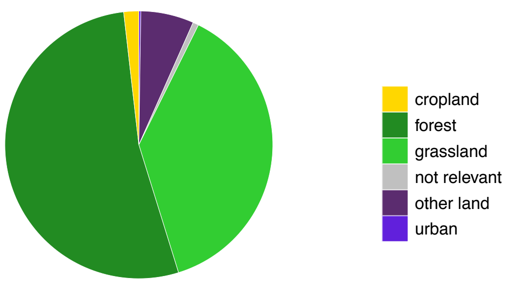
Land and food systems at a glance

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

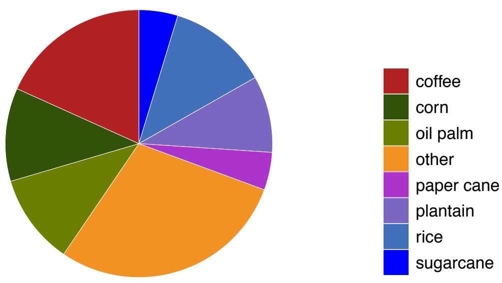
Land & Biodiversity

Fig. 1 | Area by land cover class in 2010-2012



Source: Ideam, Rodríguez & Peña (2013)

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



Source: Min. de Agricultura & Desarrollo (2016)

Annual deforestation in 2015:
124 kha = 0.21% of total forest area

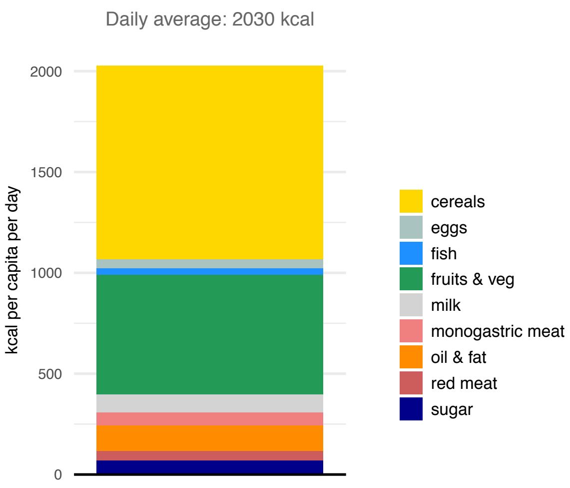
(González et al., 2018)

Endangered species: 1,203 species

(Ministerio de Ambiente y Desarrollo Sostenible., 2019)

Food & Nutrition

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



Source: Min. de la Protección, S., Inst. Nacional de, S., & Uni. de, A. (2011)

Share of undernourished in 2015:

Children age 0-4 years: 10.8%
Children age 5-12 years: 7%
Children age 13-17 years: 10%

(ICBF, 2015)

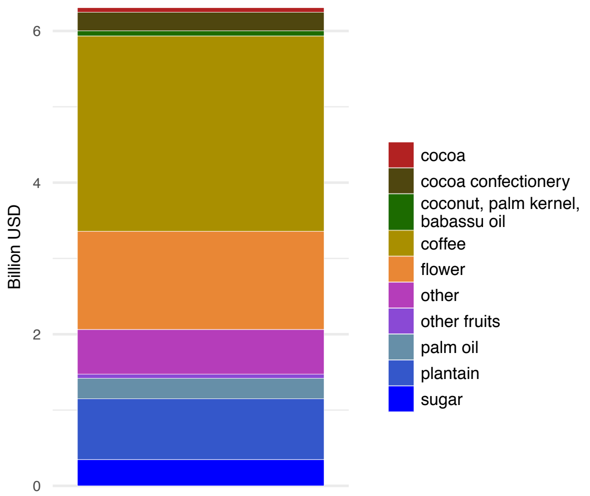
Share of overweight in 2015:

Children age 0-4 years: 6.3%
Children age 5-12 years: 24.4%
Children age 13-17 years: 17.9%
Adult age 18-64 years: 37.7%

(ICBF, 2015)

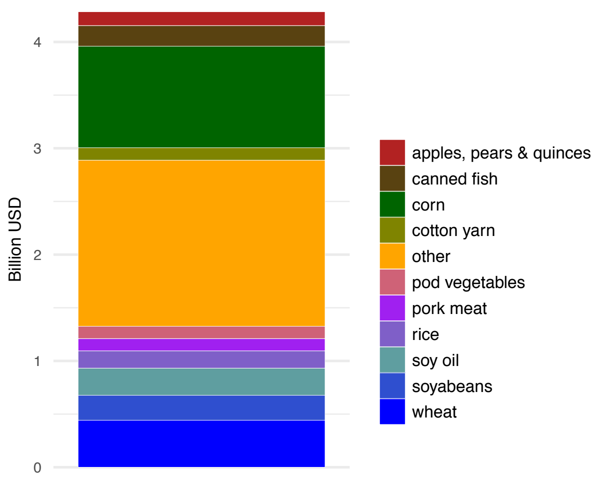
Trade

Fig. 4 | Main agricultural exports by value in 2015



Source: Dian (2018)

Fig. 5 | Main agricultural imports by value in 2015



Source: Dian (2018)

Surplus in agricultural trade balance in 2015: USD 2.6 bln

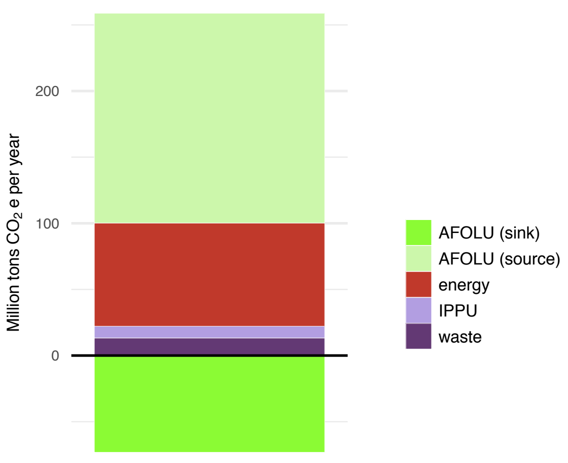
(DANE, 2019)

3rd most important coffee exporter in the world in 2015

(International Coffee Organization, 2019)

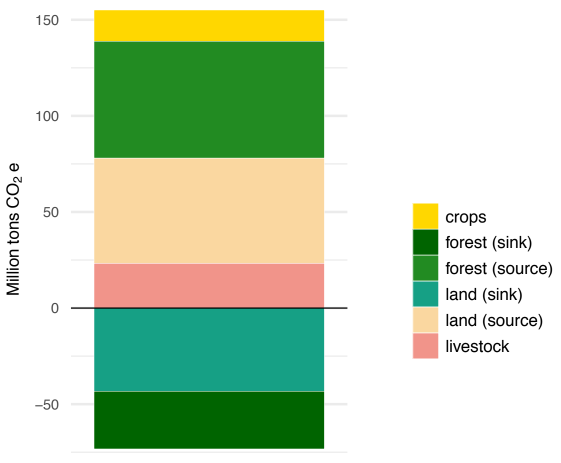
GHG Emissions

Fig. 6 | GHG emissions by sector in 2012



Source: Ideam, Pnud, Mads, Dnp, & Cancilleria (2017)

Fig. 7 | GHG emissions from agriculture and land use change in 2012



Source: Ideam, Pnud, Mads, Dnp, & Cancilleria (2017)

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 (large change)	**Population** (no change)
Scenario definition	GDP per capita is expected to increase by 416% from USD 4,750 in 2000 to USD 16,468 in 2050.	The population is expected to stay quite stable between 2015 and 2050, from 48.2 mln to 48.5 mln (UN low growth scenario was selected).
Scenario justification	Assuming a scenario in which the GDP growth rate is above 4.2% and a population growth close to 1%, an increase in GDP per capita of this magnitude is possible under a very optimistic scenario. However, this choice of scenario contrasts with other scenarios based on historical trends that expect a 70% increasing in GDP per capita by 2050 (Guillemette and Turner, 2018).	Currently, the National Administrative Department of Statistics (DANE) - the governmental office in charge of population censuses in Colombia, is finalizing data processing for the most recent population census (DANE, 2018). As of November 2018, with a geographic coverage of 99.8%, Colombia's population is approximately 45.5 mln (DANE, 2018). This value falls short by around 3 mln with respect to the projected one by UNDESA (2017) for the year 2015 (48.2 mln). Additionally, it is around 5 mln less than the total expected for 2020. Considering the above, the low growth scenario was deemed appropriate (UNDESA, 2017; DANE, 2018).

TRADE

	Imports (no change)	**Exports** (large change)
Scenario definition	The share of total consumption, which is imported stays constant at 2010 levels for crop and livestock commodities.	The exported quantity increases: - from 1.7 Mt in 2015 to 2.4 Mt in 2050 for banana, - from 0.7 Mt in 2015 to 1.1 Mt in 2050 for sugar, and - from 0.2 Mt in 2015 to 1.6 Mt in 2050 for palm oil. The exported quantity remains constant at 2010 levels for the other commodities.
Scenario justification	According to official statistics, Colombia imports a high volume of cereals to satisfy internal demand. Wheat, barley, and approximately 70% of corn have been imported during the last decades (DANE, 2019). It is highly probable that this trend continues in the future. Colombia is unable to produce most cereals at a competitive cost compared to production costs in other latitudes where soil and climatic conditions allow for a more efficient crop production. Hence, the country is, and will be in the near future, highly dependent on food imports.	According to FAO, world production for banana has been increasing at a rate of 3.5%/year during the last 30 years. In Colombia, production for the same period has been increasing at a rate of 4.3%/year. Most of the production in Colombia is intended for export; in 2018 Colombia sent bananas to 31 countries around the world. We can expect that this trend will continue in the years to come. The palm oil crop has been increasing in the last decade in Colombia, from 300 kha in 2007 to ca. 500 kha in 2017. During the same period exports and internal consumption have both increased substantially. Colombian coffee production and exports have been decreasing slightly over the last two decades (FAO, 2017).

Scenario signs no change small change large change

LAND

	Land conversion	Afforestation (large change)
Scenario definition	We assume that deforestation will be halted beyond 2030.	We assume total afforested/reforested area to reach 2 Mha by 2050.
Scenario justification	The changes expected on the deforestation patterns follow the response to current national policies. Colombia's Paris Agreement commitments bound the country to zero deforestation by 2020 (IDEAM et al., 2017; SIAC and Ministerio de Medio Ambiente y Desarrollo Sostenible, 2017).	Colombia's Bonn Challenge commitment is to restore 1 Mha by 2020. Although, the program has had a slow start and many areas are planned to be restored by 2020, current afforestation (restoration) levels are far from the goal with ca 86 kha restored (Ospina et al., 2015; Bonn Challenge, 2014).

FOOD

	Diet (small change)	Food waste (large change)
Scenario definition	Between 2015 and 2050, the average daily calorie consumption per capita decreases from 2,316 kcal to 2,267 kcal. Per capita consumption: - increases by 7% for pig and poultry meat, - decreases by 1.6% for milk, - decreases by 4.7% for eggs, - decreases by 5.4% for vegetable oil, - increases by 1.4% for sugar, and - remains constant for the other food groups.	Between 2015 and 2050, the share of final household consumption which is wasted decreases from 10% to 5%.
Scenario justification	The OECD (2019) expects an increase in meat consumption from 2017 to 2027: - beef and veal: by 7%, from 11.47 kg/cap to 12.34 kg/cap, - poultry: by 10.6% from 28.61 kg/cap to 32.01 kg/cap, and - pork: from 7.09 kg/cap to 8.02 kg/cap.	There are no official statistics nor comprehensive studies on food waste associated to household consumption in Colombia. In 2016, the National Planning Department of Colombia published a study (based on 2007 data) estimating that 16% of food waste in the country occurs from the consumption side, chiefly from households (DNP, 2016). Although, the government of Colombia recognizes the importance of formulating national policies to deal with the problem of food waste, the process is at its very early stages, with no targets and specific policy instruments set in place to tackle the problem (FAO, 2016). Assuming strong commitment from the government and relevant stakeholders for developing comprehensive and ambitious policies on the issue, it would be expected that by 2050 the share of final household consumption should decrease to 5% for the year 2050.

Scenario signs no change small change large change

BIODIVERSITY

	Protected areas
Scenario definition	The protected areas remain constant between 2015 and 2050.
Scenario justification	Protected areas have been recently expanded by 1.5 Mha as referred to in the National Bill 125 from 2015 “Expansion of protected areas in Colombia” (Parques Nacionales Naturales de Colombia, 2018).

PRODUCTIVITY

	Crop productivity	Livestock productivity	Pasture stocking rate
Scenario definition	Between 2015 and 2050, crop productivity: - increases from 18.9 t/ha to 21.2 t/ha for oil palm fruit, - increases from 2.7 t/ha to 4.6 t/ha for corn, - remains constant at 2.8 t/ha for rice, and - remains constant at 0.7 t/ha for coffee.	Between 2015 and 2050, the productivity per head increases: - from 0.8 kg/head to 1.5 kg/head for poultry meat, and - from 1.2 kg/head to 2.6 kg/head for eggs. It remains constant from 2015 to 2050 for the other livestock products.	The average livestock density remains constant at 0.5 TLU/ha of pastureland between 2015 and 2050.
Scenario justification	Corn productivity is expected to increase in the future following historical trends from the last decade according to FAOSTAT (2019a) and national production reports (Ministerio de Agricultura y Desarrollo Sostenible, 2016). Rice productivity is expected to remain constant due to the historical trends and lack of technological development, according to FAO and national production reports (FAOSTAT, 2019; Ministerio de Agricultura y Desarrollo Sostenible, 2016).	We assume there will be an increase in poultry productivity reflecting the trend observed during the last decade interval. For the other livestock products, productivity remains constant, changing only in overall numbers but not in terms of their efficiency (FEDEGAN, 2019).	Livestock density has remained stable (between 0.55-0.6 TLU/ha) during the last 40 years (FEDEGAN, 2019). Additionally, Colombia’s population is expected to remain relatively stable by 2050 as indicated above.

Scenario signs no change small change large change

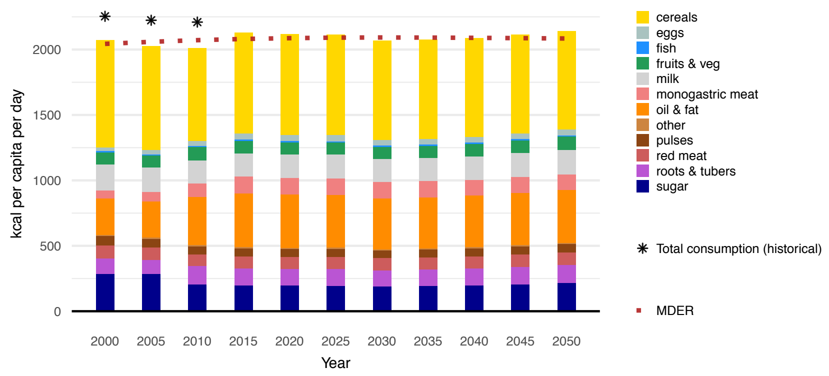
Results against the FABLE targets

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.



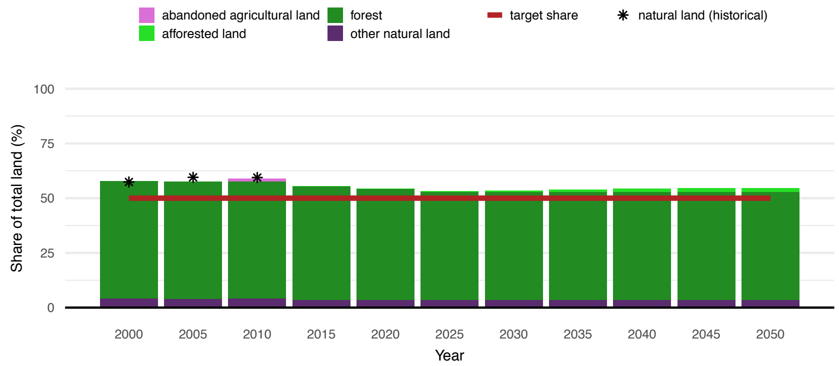
Historical data source: FAOSTAT

Our results show average daily energy intake per capita increases from 2,159 to 2,330 kcal/cap/day between 2000-2015. Calorie intake reaches 2,121 kcal/cap/day over the period 2031-2035 and 2,135 kcal/cap/day over the period 2046-2050. In terms of recommended diet, our results show quite stable diet over 2000-2050.

Our results show that the feasible average daily intake is at the limit of the minimum intake (MDER) which has been computed based on projections of the age and sex composition of the population, average activity level and recommendations. If we would add categories which are not yet included in the FABLE Calculator, the available energy intake would be 3% higher than the MDER in 2030 and 7% of the MDER in 2050.

Biodiversity

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



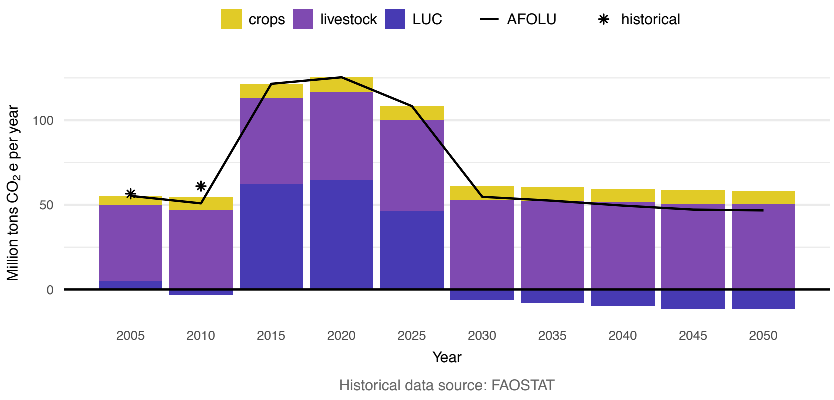
Historical data source: FAOSTAT

Our results show that the Share of Land which could support Biodiversity (SLB) remains relatively constant at 69% between 2000-2010 with a decrease towards 2015 following the deforestation rates for the same period (57%). After the lowest value is reached in 2025 at 55%, SLB slowly increases thanks to the afforestation efforts and reaches 56% over the last period of simulation, 2046-2050.

Compared to the global target of having at least 50% SLB by 2050, our results are above the target. Our results are consistent with national biodiversity conservation targets according to the national biodiversity monitoring program by the Humboldt Institute (Gomez et al., 2016).

GHG emissions

Fig. 10 | Computed GHG emissions from land and agriculture



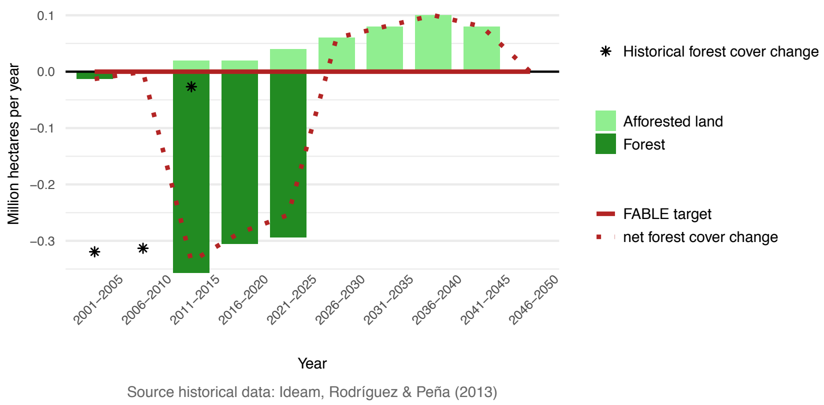
Note: AFOLU (Agriculture, Forestry and Other Land Use) is the sum of computed GHG emissions from crops, livestock and Land Use Change (LUC), emissions and sequestration from forestry are not included. Historical emissions include crops and livestock.

Our results show annual GHG emissions between 44 and 120 Mt CO_2e over 2000-2015 which increase over time. Although, the final values are similar to those observed in the national monitoring program, the trend is misleading. The observed emissions from AFOLU for the country remained relatively stable since 2000 with slight increases until 2012 (IDEAM et al., 2017). Peak AFOLU GHG emissions are computed for the period 2016-2020 at 125 Mt CO_2e/year. This is mostly driven by GHG emissions from deforestation. AFOLU GHG emissions reach 47 Mt CO_2e over the period 2046-2050: 58 from agriculture and -11 from LUC. Negative emissions from LUC by 2050 are mainly explained by the halt of deforestation after 2030 and some abandonment of agricultural land.

Compared to the global target of reaching zero or negative GHG emissions from LULUCF by 2050, our results are above the target. Colombia committed to reduce its emissions to its 2015 level by 2030 with an overall reduction of emissions of 66.5 Mt CO_2e. This can be achieved if the policies to control deforestation and the restoration program (i.e. Bonn Challenge) are fully implemented.

Forests

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



Our results show an annual deforestation of 357 kha/year between 2010-2015. This is above the national estimates reported by the National Forest Monitoring program for Colombia (González et al., 2018). This program reported an average of 350 Mha/year over 2001-2007. Colombia is committed to zero deforestation by 2030. Our deforestation results are mostly driven by pastures for cattle and to a lower extent, cropland expansion due to corn, soybean, and rice expansion. In reality, the expansion of coca also contributes to deforestation, but this crop is not included in the Calculator. Over 2026-2030, we compute that forest regrowth will offset 70% of the deforestation over the period. Since we have implemented a zero-deforestation policy after 2030, afforestation will be the dominant feature of forest dynamics after 2030.

Our results meet the national commitments with a 5 to 10-year delay. Colombia was committed to have zero deforestation by 2020 but the current trends are indicative of a lack of control on deforestation and the inability of the country to stop the social dynamics causing the deforestation hotspots.

Other relevant results for national objectives

Table 1 | Other Results

Variable	Unit	2000	2005	2010	2015	2020	2030	2040	2050
Computed exported quantities of selected commodities									
Banana	Mt	1.5	1.6	1.7	1.6	1.7	2.2	2.3	2.5
Sugar Raw	Mt	1.1	1.2	0.8	0.7	0.8	1.0	1.0	1.1
Palm Oil	Mt	0.1	0.2	0.2	0.3	0.5	1.4	1.5	1.6
Coffee	Mt	0.6	0.6	0.4	0.4	0.4	0.4	0.4	0.4

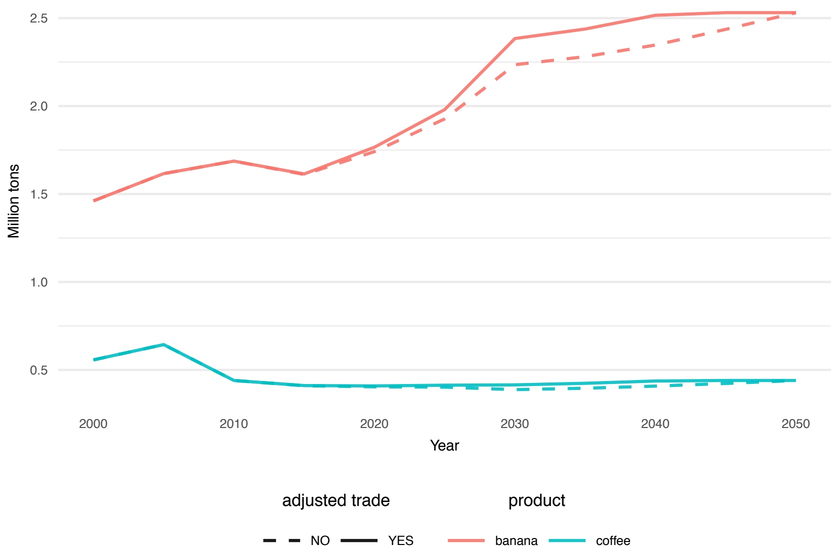
Historical wheat production has fluctuated about a mean quantity of around 15 Mt, which is matched well by the Calculator. Our results suggest that wheat production will increase overall given the scenario assumptions made. This is due to a balance between a reduction in cropland and an increase in yield over the model integration.

The Calculator matches historical beef production data well, as both FAOSTAT (2019) and the Office for National Statistics (2019) indicate a growth from around 700 kt to 900 kt between 2000 and 2015. Beef production decreases over the next 35 years, driven by the shift away from a meat-based to a plant-based diet. The reduction in production is not as severe as the change in pasture land cover would imply due to an increase in both livestock productivity and stocking density.

The Calculator generally matches the historical trends well. We see large changes away from productive land to “other land” and new forest. This is consistent with the high ambition scenario of the CCC Land Use Report (Committee on Climate Change, 2018).

Impacts of trade adjustment to ensure global trade balance

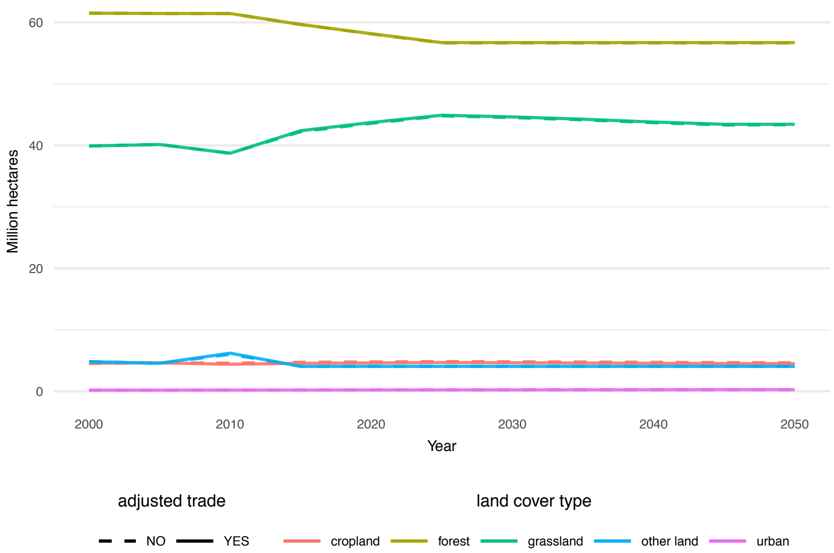
Fig. 12 | Impact of global trade harmonization on main exported/imported commodities over 2000-2050



The trade balance adjustment resulted in small reduction in exported quantities of banana and coffee.

Colombia imports most of its oil and oilseeds such as soy and sunflower oil, soybeans, and sunflower seeds. Another relevant group of imported food are cereals, mostly wheat, corn, and barley. After the trade balance there are no changes in the import quantities for these main products.

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



Trade adjustment does not have significant impacts on land use in Colombia.

Discussion and next steps

In the last decades, the main driver of deforestation in Colombia has been the growing of illicit crops and the low productivity of cattle (pastures) both operating under a strategy of land grabbing not intended for food production. This phenomenon is spatially complex and difficult to control, despite efforts by the Colombian and US governments. Furthermore, we consider that crop production should be planned according to water availability and existing infrastructure for water distribution. The current limitations of crop production at the national level are mostly due to the lack of efficient irrigation. The production costs of crops should include environmental costs such as non-point water pollution and/or land degradation.

In order to develop an accurate long-term pathway for Colombia, a small economy vulnerable to sudden changes in trends, inertia, and a climate-dependent crop production the representation of short-term variability in the FABLE Calculator should be improved.

From the land-use sector and GHG emissions perspectives, electricity generation is an important source of environmental change in Colombia. We consider that future developments of the FABLE Calculator would benefit from the inclusion of this economic dimension.

Colombia faces important food security challenges for the decades ahead as it imports a large proportion of the cereals and oil seeds necessary for human consumption and animal feed. The costs of national production in Colombia given the soil and climatic conditions are not competitive enough compared to the products available on the international trading market to allow for a sufficient national production. In addition, the Colombian food production will be affected by climate variability as most of the national production relies on seasonal rains with a very limited use of irrigation making crops susceptible to droughts (i.e. coffee, sugar cane, oil palm, cacao, and rice).

The FABLE Calculator allows us to understand the challenges that the country faces to feed its own population. The evidence provided by the FABLE Calculator is allowing us to suggest that it is urgent to develop long term policies aimed at promoting food security based on a balanced diet and limiting the competition between land dedicated to food production and to forested areas. The policies should be based on quantitative science-based evidence and not only on short term political expectations. The FABLE Calculator can support the decision-making process led by policy makers by highlighting the impact of different agricultural expansion scenarios and technological development strategies on the rates of greenhouse gas emissions at the national level.

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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Ethiopia

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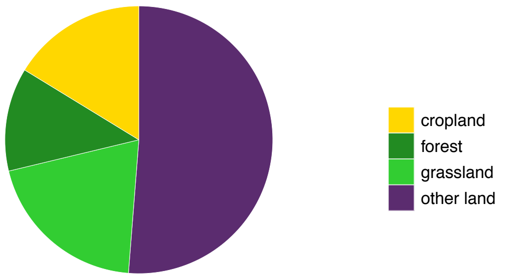
Land and food systems at a glance

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

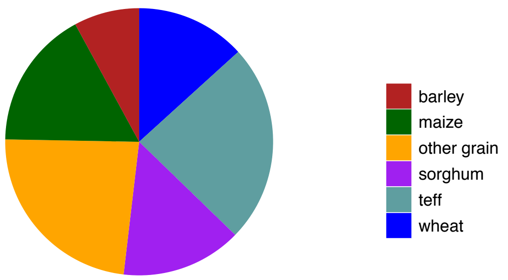
Land & Biodiversity

Fig. 1 | Area by land cover class in 2015



Source: FAOSTAT

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



Source: FAOSTAT

Annual deforestation in 2015:
140 kha = 1% of total forest area

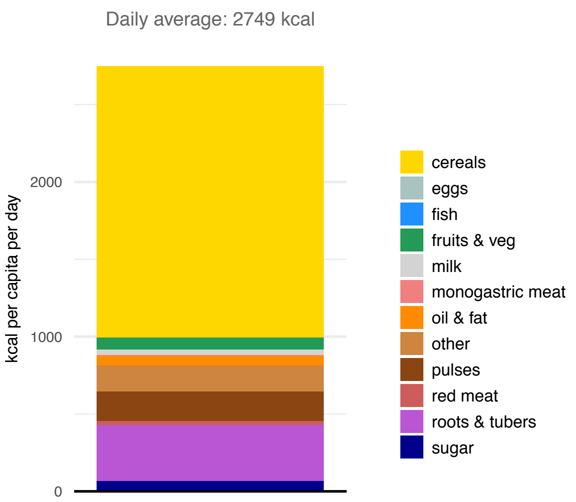
(Bekele, 2001)

Endangered species: 179 threatened species of which 36% are plants, 20% birds, and 20% mammals

(IUCN Red List, 2019)

Food & Nutrition

Fig. 3 | Daily average intake per capita at the national level in 2012



Source: Berhane et al. (2012)

Share of undernourished in 2016:
Children age 0-5 years: 38%

(Gebru et al., 2018)

Share of obese in 2015:
Adult women: 7-8%

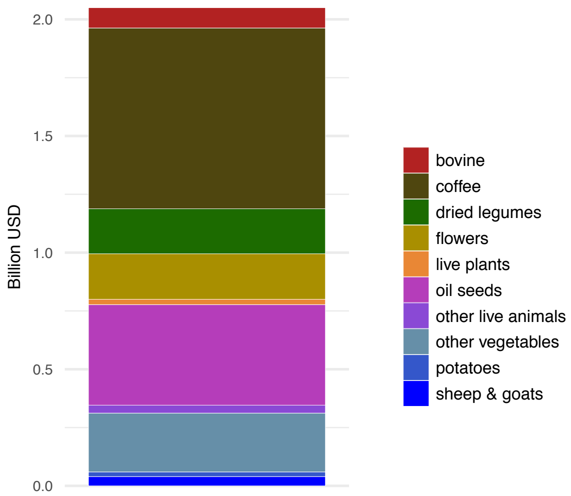
(Gebru et al., 2018)

Adult men: 1.9%

(WHO, 2017)

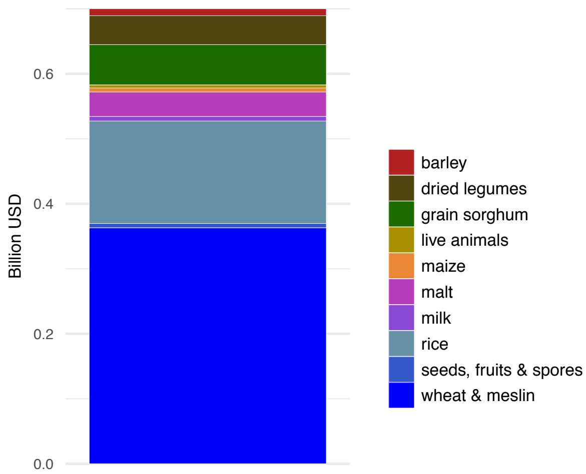
Trade

Fig. 4 | Main agricultural exports by value in 2017



Source: ITC (2016)

Fig. 5 | Main agricultural imports by value in 2017



Source: ITC (2016)

Surplus in agricultural trade balance in 2015: USD 206 mln

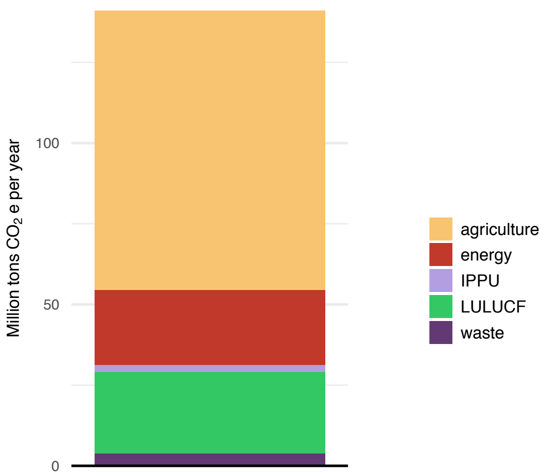
(FAOSTAT, 2019; and authors' computation)

120th/80th most important exporter /importer in the world in 2015

(Central Intelligence Agency, 2017)

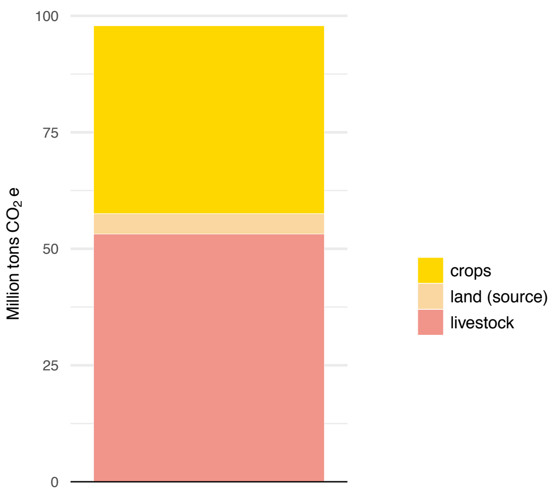
GHG Emissions

Fig. 6 | GHG emissions by sector in 2011



Source: World Resource Institute (2015)

Fig. 7 | GHG emissions from agriculture and land use change in 2013



Source: FAOSTAT

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 is expected to increase from USD 49 bln in 2015 to USD 471 bln in 2050. GDP per capita is expected to increase from USD 487 in 2015 to USD 2,765 in 2050 (a national scenario of high-speed economic growth as set in the five-year plans of the country was selected).	The population is expected to increase by 70.6% between 2015 and 2050 from 99.87 mln to 170.42 mln (UN low growth scenario was selected).
Scenario justification	The GDP figures are based on projections by the Planning and Development Commission for subsequent five-years. Specifically, according to the vision laid out in various government documents such as Ethiopia's second five-year Growth and Transformation Plan (GTP II) and the Climate Resilient Green Economic (CRGE) plan, real GDP is expected to increase by 11 %/year up to 2025 (Federal Democratic Republic of Ethiopia, 2011; National Planning Commission, 2016). Accordingly, we have assumed an annual average GDP growth rate of 6.7%/year between 2015 and 2050. This is lower than Ethiopia's 11.2% average growth rate observed between 2010/11 and 2014/2015 (National Planning Commission, 2016), but it is higher even compared to the SSP1 scenario.	Based on the UN's population projection database (UNPD, 2015). The primary source of population data is the census which was conducted in 1994 and 2007. Accordingly, the average population growth rate is close to 2.5%/year between 1994 and 2007 – corresponding to the two census periods (Central Statistical Agency, 2013). However, this is expected to go down as a result of the government's focus on increasing the contraceptive prevalence rate of up to 66% by 2015 (Central Statistical Agency, 2013). Accordingly, CSA projects the population to reach 122 mln by 2030 (Central Statistical Agency, 2013). The results that are closest to this figure are found using the UN low growth scenario.

TRADE

	Imports	Exports
Scenario definition	Increased imports scenario for wheat, milk, and corn was selected. The share of total consumption which is imported increases: - from 39% in 2010 to 79% in 2050 for wheat, and - from 0% in 2010 to 1% in 2050 for milk. The share of total consumption which is imported stays constant at 2010 levels for the other commodities.	We have assumed that exports of coffee, sesame, and corn increase by a factor of 1.5 by 2050. Accordingly, the exported quantity for these products is expected to increase: - from 212 Mt in 2010 to 317 Mt in 2050 for coffee, - from 228 Mt in 2010 to 342 Mt in 2050 for sesame, and - from 4 Mt in 2010 to 6 Mt in 2050 for corn.
Scenario justification	We have assumed increased import share for wheat following the pattern of import in the country (Olana et al., 2018). As is also indicated in Olana et al (2018), Ethiopia's wheat imports have been growing fast and it is expected to increase in the future given the high population growth and improvements in the standards of living in the country, which in turn is likely to lead to higher demand for wheat products.	The slower export growth assumption is based on the country's small export base as well as slower growth rate of exports of goods which has been observed in recent years (IMF, 2018).

LAND

	Land conversion	Afforestation (large change)
Scenario definition	We assume that there will be no constraint on the expansion of the agricultural land outside beyond existing protected areas and under the total land boundary.	We assume total afforested/reforested area to reach 15 Mha by 2050
Scenario justification	Ethiopia has diverse geographic conditions. Crop production takes place mainly in the highlands and there is little room for cropland expansion in the highlands, but there is potential to expand cropland activities in the low lands (Schmidt and Thomas, 2018). In relation to pastureland, the grey literature identifies the rise in rangeland enclosures (Fekadu Beyene, 2009; Napier and Desta, 2011). Currently, there is no effort that we are aware of aiming to limit agricultural land expansion. Therefore, we have assumed free land expansion to get closer to what is likely to happen in the future.	Considering the commitment towards a Climate Resilient Green Economy that the country has outlined in 2011 and the pledge it has made, we have taken the Ethiopia's Bonn challenge commitment targeting 15 Mha for afforestation by 2020 (Pistorius et al., 2017).

FOOD

	Diet (large change)	Food waste (large change)
Scenario definition	The daily average consumption per capita at the national level is expected to increase from 1,849 kcal in 2010 to 2,246 kcal in 2050. Between 2010 and 2050, the average daily calorie consumption per capita increases: - by 23% for cereals, - by 311% for pig and poultry meat, - by 139% for eggs, - by 42% for milk, - by 30% for oil and fat, - by 3.2% for red meat, - by 5% for pulses, - by 14% for roots and tubers, and - by 49% for sugar. While the daily calorie decreases for ruminant meat and roots, and it increases for pulses and eggs.	Between 2010 and 2050, the share of final household consumption which is wasted decreases from 10% to 5%.
Scenario justification	We have assumed that diets will follow the FAO's projection (Alexandratos and Bruinsma, 2012). This appears to be the best estimate we were able to find.	We have assumed a reduced share of food waste compared to 2010 as many development partners are looking at food waste as a possible area of intervention (Federal Democratic Republic of Ethiopia, 2011).

Scenario signs no change · small change · large change

PRODUCTIVITY

	Crop productivity (large change)	Livestock productivity (large change)	Pasture stocking rate (no change)
Scenario definition	Between 2015 and 2050, crop productivity increases: - from 1.36 t/ha to 4.39 t/ha for teff, - from 1.91 t/ha to 6.51 t/ha for wheat, - from 2.64 t/ha to 8.81 t/ha for corn.	Between 2015 and 2050, productivity per head: - increases from 9.3 kg/head to 17.6 kg/head for cattle meat, - will remain the same at 4 kg /head for sheep and goat meat, - increases from 601.7 kg/head to 7.4t/head for cow milk, and - increases from 41.8 kg/head to 181.8 kg/head for sheep and goat milk.	The average livestock stocking density remains constant at 1.45 TLU/ha of pastureland between 2015 and 2050.
Scenario justification	Despite the assumption of free expansion of agricultural land, we have assumed high crop productivity growth. The reason for assuming high crop productivity growth is based on the country's current relatively low cereal productivity base (Taffesse et al., 2012) and significant improvements in recent years following the government's focus on agricultural transformation through various programs such the agricultural growth program which shows a 16% improvement in yield in five year (World Bank, 2017).	We have assumed a livestock productivity scenario higher than for the period 2000-2010. This is because of the renewed interest among policymakers and development partners towards the livestock sector, as well as the low level of current productivity. Ethiopia's cattle meat production of 14 kg per standing head is lower than neighboring countries like Kenya (21 kg per standing head) and milk production is even less productive 72.5 kg per standing head compared to Kenya's 194.74 kg per standing head (Shapiro et al., 2015).	The livestock density reported by (Tilahun and Schmidt, 2012) is 0.3 TLU/ha but it disregards camel, and donkey.

Scenario signs = no change → small change ↗ large change

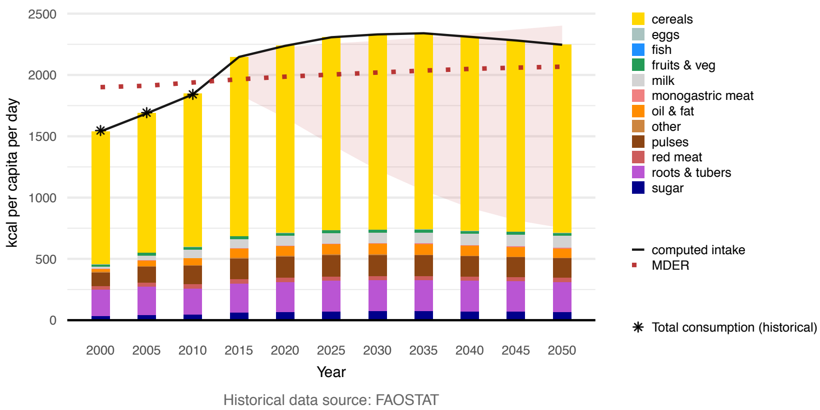
Results against the FABLE targets

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

Food security

Fig. 8 | Computed daily kilocalorie 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.



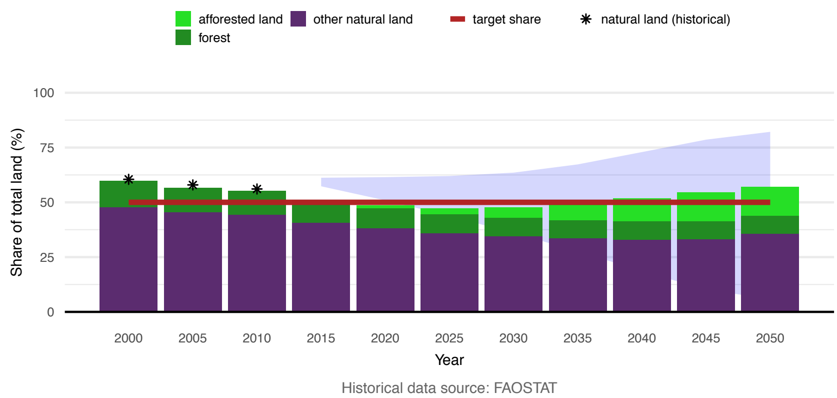
Historical data source: FAOSTAT

Our results show the average daily energy intake per capita increases between 2000 and 2030 and remains stable after that. Calorie intake reaches 2,330 kcal by 2030 and shows a slight decline thereafter. In terms of recommended diet, our results show higher consumption of animal-based proteins, sugar and fat but the initial levels were very low compared to other countries.

The computed average calorie intake is higher than the minimum requirement (MDER) at the national level from 2015 onwards (average calorie intake of 2,246 compared to MDER of 2,067 in 2050). The national nutrition plan aims to reduce the percent of newborns with weights less than 2.5 kg from 11% in 2014 to 5% by 2020 and reduce the number of overweight women of reproductive age from 9% in 2014 to 6% in 2020.

Biodiversity

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



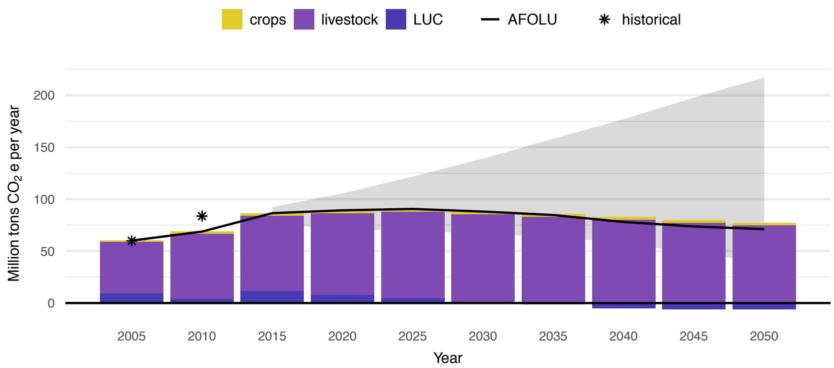
Historical data source: FAOSTAT

Our results show that the Share of Land which could support Biodiversity (SLB) decreased between 2000-2030 from 60% to 47%. After reaching its lowest level of 47% in 2030, the computed SLB increased thereafter reaching above 60% in 2050 thanks to afforested land.

Compared to the global target of having at least 50% SLB by 2050, our results are above the target. As indicated in the Institute of Biodiversity Conservation (2005), the Ethiopian government has established at different levels close to 193,600 km2 of land for wildlife protection.

GHG emissions

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



Historical data source: FAOSTAT

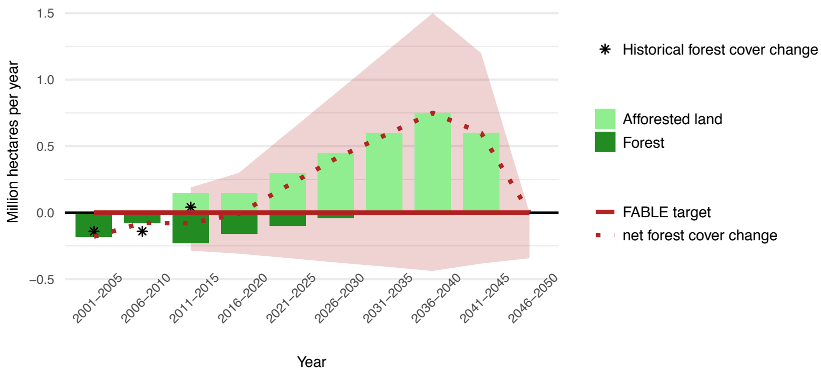
Note: AFOLU (Agriculture, Forestry and Other Land Use) is the sum of computed GHG emissions from crops, livestock and Land Use Change (LUC), emissions and sequestration from forestry are not included. Historical emissions include crops and livestock.

Our results show annual GHG emissions increase from 37 to 91Mt CO_2e between 2000 and 2025. Peak AFOLU GHG emissions are computed for the period 2021-2025 at 91 Mt CO_2e /year. This is mostly driven by GHG emissions from the livestock sector. AFOLU GHG emissions reach 71 Mt CO_2e over the period 2046-2050: 77 from agriculture and -6 from land use change.

Our results meet the target of zero or negative emissions from land use change by 2050 but the reduction in emissions from agriculture is limited. Overall emissions are considerably less than what is estimated by the Climate Resilient Green Economy (CRGE) strategy – 150 Mt CO_2e total GHG emissions as of 2010 of which 130 MtCO_2e is from agriculture and forestry. However, the composition of sectoral contribution is consistent as the agricultural sector is the major contributor to emissions (Federal Democratic Republic of Ethiopia, 2011).

Forests

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



Historical data source: FAOSTAT

Our results show annual deforestation between 80 kha and 230 kha/year from 2000-2015. It decreases over time after 2015. Deforestation peak is computed in 2015 at 230 kha/year. This is mostly driven by pasture expansion and to cropland expansion (until 2025). Deforestation reaches 43 kha/year over the period 2031-2035 and becomes less than 1 kha/year over 2035-2050. Afforestation is computed from 2015-2045 and leads to a positive net forest cover change from 2025 to 2045 with a peak of afforested area over 2036-2040 at 750 kha/year.

Compared to the global target of having zero or positive net forest change after 2030, our results are above the target. Ethiopia has set a target of increasing forest cover from 15.5% in 2014/15 to 20% by 2019/20 (National Planning Commission, 2016). In other words, the plan aims to increase forest cover from the current 17 Mha to 22 Mha (Ethiopia's total land area of 110 Mha) between 2015 and 2020. The model predicts that net forest cover change will still be negative for the year 2020 but very low (i.e. –9 kha/year).

Other relevant results for national objectives

Table 1 | Other Results

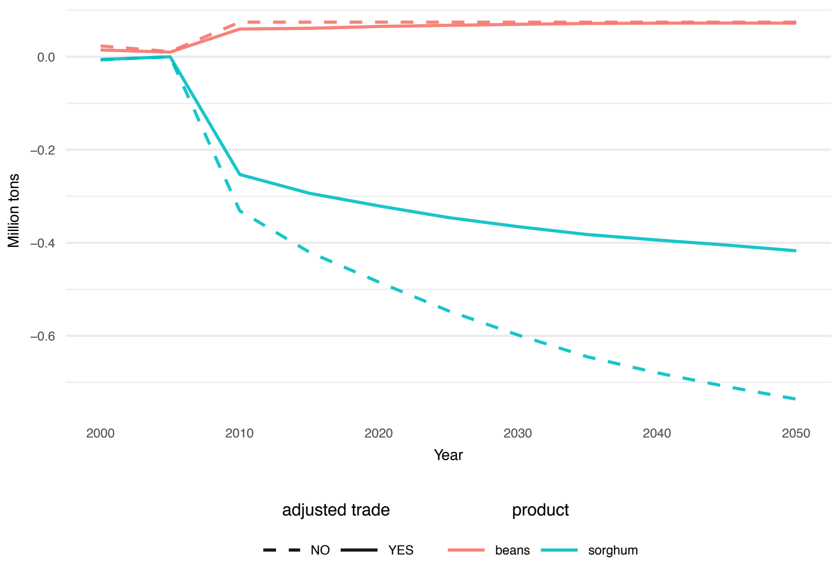
Variable	Unit	2000	2005	2010	2015	2020	2030	2040	2050
Coffee production and export									
Production	kt	229.2	171.6	369.7	316.3	349.0	450.0	465.5	478.6
Export	kt	118.9	172.2	211.7	216.9	238.1	317.5	317.5	317.5
Sesame production and export									
Production	kt	15.6	115.4	327.7	240.6	264.8	352.3	353.2	353.5
Export	kt	26.9	219.0	228.0	233.7	256.5	342.1	342.1	342.1

Although the historical values of annual production of coffee are quite close to the calculated values (370 vs. 371 kt for 2010), both are a bit higher than the 341 kt reported in official statistics (Ministry of Finance and Economic Development, 2010). On the other hand, for 2015, the 316 kt annual production of coffee calculated by the FABLE Calculator is lower than the 419.98 k/t reported in GTP II (for 2014/15 fiscal year) and 431 kt reported by (USDA, 2018). In a country where slightly less than half of the production is locally consumed, the very narrow gap between production and exports observed in 2005 calls for an explanation. In the case of exports, the 2010 annual export of coffee used in the model (211 kt) is lower than the 320 kt indicated in GTP I baseline (2009/2010).
Both the production and the exports of coffee steadily increase between 2015 and 2030. After 2030, while coffee production continues to gently increase reaching 478 kt in 2050, annual exports of coffee remain flat around 317 kt. Given GTP II's target of producing 1 Mt of coffee by 2019/20, the 2050 projected 478 kt is quite small.

The fact that the historical annual export values of sesame are larger than its annual production values in the FAO database (especially in 2005) is puzzling and calls for a need to further check the data (the gap appears to be too big to be justified based on changes in stocks). Projection of sesame production increases between 2015 and 2030 and remains relatively flat thereafter reaching a bit higher than its historical peak in 2010. Given the traditionally low domestic consumption of sesame, the narrow gap between production and exports is expected. The country has a target of increasing its annual production of oilseeds and pulses, which mostly comprises of sesame, from 373 kt in 2014/15 to 925 kt in 2019/20 (National Planning Commission, 2016). Given this target, the projection of annual production/export for sesame only of approximately 340 kt seems reasonable.

Impacts of trade adjustment to ensure global trade balance

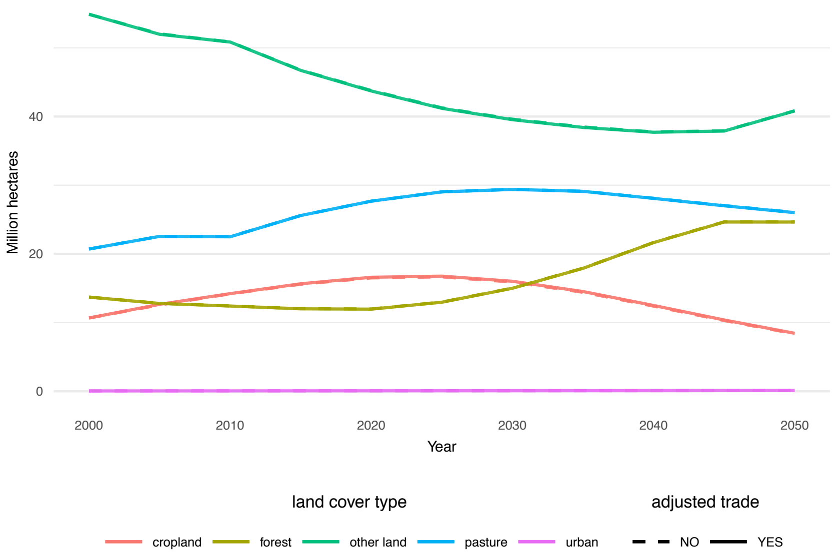
Fig. 12 | Impact of global trade harmonization on main exported/imported commodities over 2000-2050



When we compare trends in Ethiopia's export commodities with and without trade adjustment, no difference appears between exports of the country's major exports (coffee and sesame). However, the evolution of other key export commodities like beans differs when calculated with and without trade adjustment. Specifically, while the trade adjusted exports of beans start out lower than the unadjusted exports, it tends to increase steadily and the two start to converge after 2030. In the case of oilseeds (others), the trade-adjusted evolution of exports remains substantially lower than the export figures calculated without trade adjustment.

When we compare the evolution of key imports like wheat, rice, milk, and palm oil, we do not find any difference between the evolution of imports with and without trade adjustment. However, in the case of two other key import commodities, sorghum and sugarcane, we see import values calculated without trade adjustment are much higher than imports calculated with trade adjustment.

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



Evolution of land use with and without trade adjustment remains almost the same. This is because exports and imports (and hence production) of major commodities are not affected by the trade adjustment.

Discussion and next steps

The assumptions used to develop this sustainable pathway are based on governmental policy documents - Climate Resilient Green Economy (CRGE) strategy, the Growth Transformation Plan II (GTP II), the Bonn Challenge, the Agriculture Growth Program, observed trends in crop and livestock productivity, recent trends in agricultural trade, and governmental focus on postharvest loss reduction. These policy documents highlight the need for Ethiopia's economy to achieve its ambitious growth target while keeping greenhouse gas emissions low. Accordingly, we have assumed high GDP growth and population growth (although the population growth is the UN's low scenario), high improvement in crop productivity, high livestock productivity, high afforestation effort, higher food consumption, and reduced food waste.

Accordingly, our results show calorie intake to be above the Minimum Dietary Energy requirement after 2015. GHG emissions will peak by 2025 and slightly decline thereafter. The major contributor to GHG emission will be the agricultural sector. In particular, livestock will be the major contributor to GHG emissions. In addition, our results show an increased demand for pastureland as a result of higher demand for animal products (e.g. milk). There will be forest loss, however, the new forest will compensate in greater volumes for the loss of old forest. Natural lands will remain above 50% through 2050. We also find that there will be an increased volume of export of agricultural commodities.

During the period 2015/16 to 2019/2020 agricultural production is expected to increase from 270 million quintals to 406 million quintals – a 50% increase in five years. The GTP II has also specified targets on productivity improvement to 27.3 quintals per hectare by 2019/20 from 21.5 quintals per hectare in 2014/15 for major crops. The land area under major crop production was 12.5 million hectares in 2014/15. Assuming the same crop composition, the area under crop production will have to increase to 14.9 million hectares (National Planning Commission, 2016). As it stands, the FABLE Calculator requires an assumption on increases in agricultural productivity as inputs to compute the agricultural land expansion – without tradeoff. If there is an option to create a tradeoff between the two based on past experience, it will help to better capture the dilemma on the ground.

In relation to crop and livestock productivity, productivity changes have been computed based on historical growth rate and they have been implemented linearly up to 2050. However, considering a period of 35 years, linear growth is unrealistic. Therefore, in the future, we will consider alternative evolutions of agricultural productivity. For example, logistic growth will be preferable.

There are suggestions of shifting the dietary mix away from cattle to poultry as recommended in the Climate Resilient Green Economy strategy - which has been criticized for not taking the cultural aspect into account. Innovations and policy options which would be required to improve the dietary mix to achieve a more sustainable pathway in terms of calorie intake, pressure on land and GHG emission will be examined in the future.

Going forward we will be able to provide a better comparison and analysis of the results computed by the FABLE Calculator with the reality on the ground thanks to consultation with experts, dedicated seminar discussions, comparison with alternative scenarios, and better data.

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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European Union

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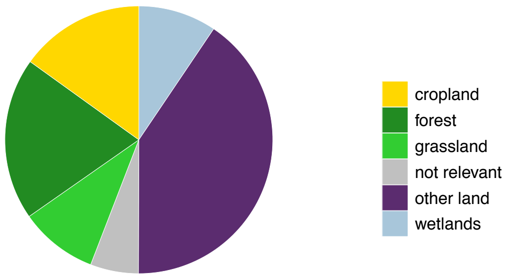
Land and food systems at a glance

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

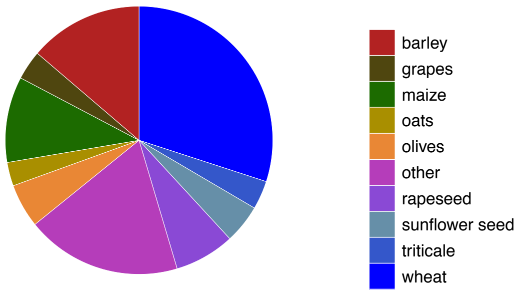
Land & Biodiversity

Fig. 1 | Area by land cover class in 2015



Source: FAO (2019)

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



Source: FAO (2019)

Afforestation in 2015:
370 kha

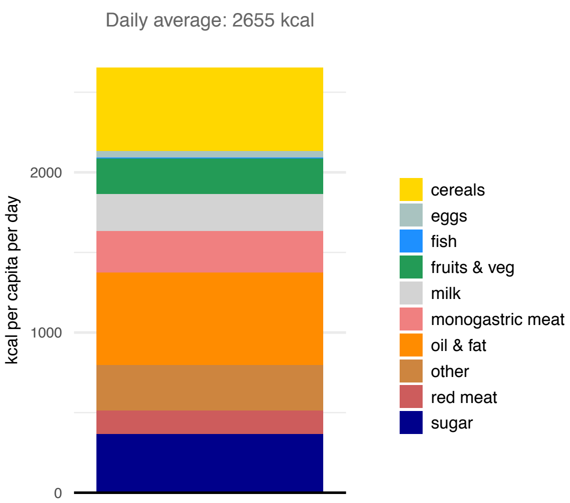
Source: FAOSTAT (2019)

Endangered species: 1677

Source: IUCN Red List (2019)

Food & Nutrition

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



Source: FAO (2019)

Share of undernourished in 2015: < 2.5%

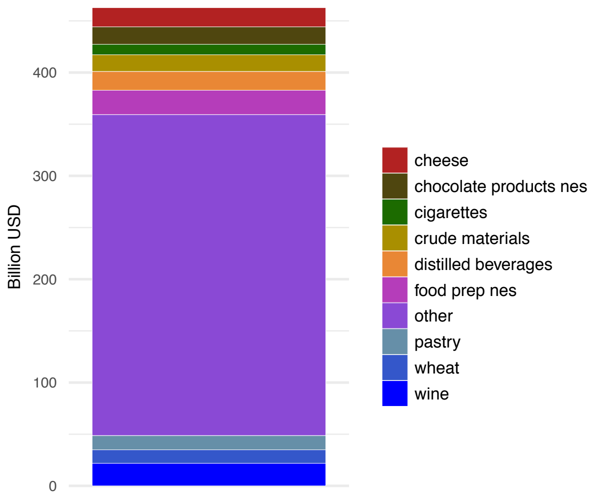
Source: FAOSTAT (2019)

Share of obese in 2015: 24.9%

Source: FAOSTAT (2019)

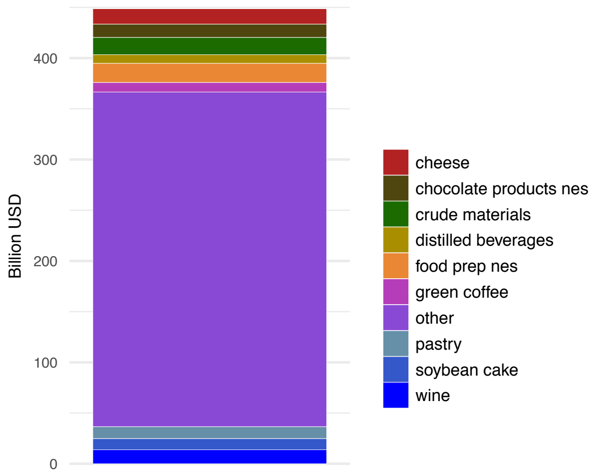
Trade

Fig. 4 | Main agricultural exports by value in 2015



Source: FAO (2019)

Fig. 5 | Main agricultural imports by value in 2015



Source: FAO (2019)

Surplus in agricultural trade balance in 2015: USD 14.10 mln

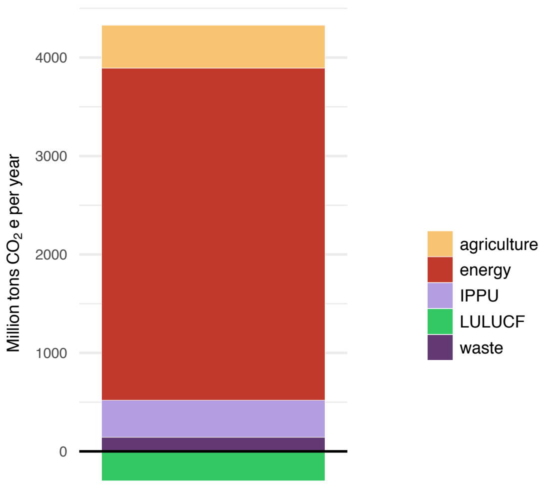
Source: FAOSTAT (2019)

In 2015, the EU was the first exporter of wheat, wheat flour, milk, and pork meat.

Source: FAOSTAT (2019)

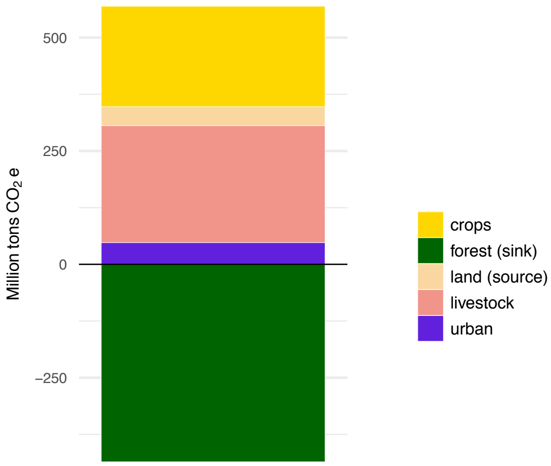
GHG Emissions

Fig. 6 | GHG emissions by sector in 2015



Source: EEA (2019)

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



Source: EEA (2019)

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.

The assumptions and results presented in the rest of the document come from the FABLE Calculator for the Rest of European Union (ROEU), which includes 25 European Union member countries. Sweden, Finland, and the UK are not included, as they are members of the FABLE Consortium and participated individually in the Scenathon using the FABLE Calculator adapted to their respective national contexts.

GDP GROWTH & POPULATION

	GDP per capita (large change)	Population (no change)
Scenario definition	GDP per capita is expected to increase by 60% from USD 34,000 in 2015 to USD 54,000 in 2050.	The population is expected to increase marginally by 0.13% between 2015 and 2050 from 426 mln to 427 mln.
Scenario justification	The evolution of GDP follows the EU Reference Scenario 2016 (Capros et al., 2016).	The evolution of the population follows the EU Reference Scenario 2016 (Capros et al., 2016).

TRADE

	Imports (no change)	Exports (large change)
Scenario definition	The share of total consumption which is imported remains constant at 2010 levels for: - soyabean at 90%, - palm oil at 100%, and - for banana at 93%. It decreases from 92% to 50% for groundnuts.	The exported quantity increases: - from 21 Mt in 2015 to 38 Mt in 2050 for wheat, and - from 19 Mt in 2015 to 33 Mt in 2050 for milk. For the other products, exports remain constant at 2010 levels.

LAND

	Land conversion	Afforestation (large change)
Scenario definition	We assume free expansion of productive land within the total land boundary.	We assume 11 Mha of new forest by 2050.

Scenario signs no change · small change · large change

Scenario definition

BIODIVERSITY

Protected areas

The protected areas remain constant for the entire period 2000-2050.

FOOD

	Diet	Food waste
Scenario definition	Between 2015 and 2050, the daily per capita calorie consumption increases from 2,526 kcal to 2,708 kcal. Per capita consumption: - increases by 23% for fruits and vegetables, - increases by 23% for other, including nuts, - increases by 7% for eggs, and - increases by 7% for sugar.	Between 2015 and 2050, the share of final household consumption which is wasted decreases from 10 to 5% for all food groups.
Scenario justification	The diet projections follow the “Middle of the Road” assumption of the shared socio-economic pathways (SSP2), which are based on projections from FAO.	

PRODUCTIVITY

	Crop productivity	Livestock productivity	Pasture stocking rate
Scenario definition	Between 2015 and 2050, crop productivity increases: - from 5 t/ha to 6.4 t/ha for wheat, - from 4.3 t/ha to 4.8 t/ha for barley, and - from 7.3 t/ha to 12.7 t/ha for corn.	Between 2015 and 2050, the productivity per head increases: - from 5.4 t/TLU to 6 t/TLU for cow milk, - from 150 kg/TLU to 233 kg/TLU for pork meat, and - from 98 kg/TLU to 110 kg/TLU for beef.	The average livestock stocking density remains constant at 1.1 TLU/ha pastureland between 2015 and 2050.

Scenario signs: no change (Protected areas, Pasture stocking rate); small change (Diet, Crop productivity, Livestock productivity); large change (Food waste)

Scenario signs = no change → small change ↗ large change

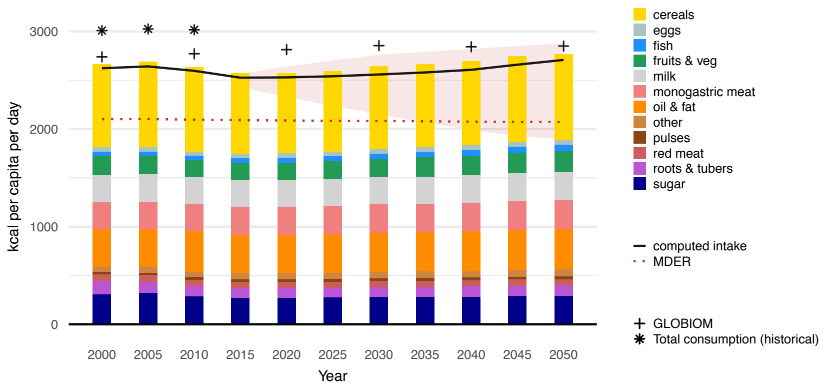
Results against the FABLE targets

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.



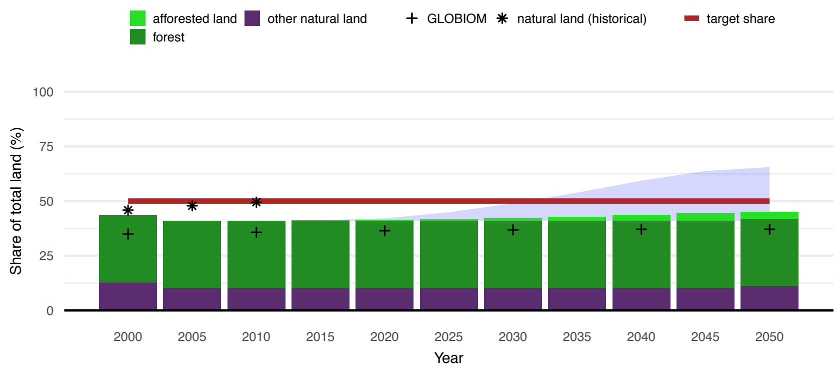
Historical data source: FAO (2019)

The computed average daily energy intake per capita decreases from 2005 to 2040 from 2,641 kcal/cap/day to 2,606 kcal/cap/day. An increase in caloric intake is computed at the end of the period, i.e. 2,659 kcal/capita/day in 2045 and 2,708 kcal/capita/day in 2050. In comparison with the results of GLOBIOM, the FABLE Calculator results have lower values over the entire period; the average difference is around 208 kcal/capita/day. We do not assume significant dietary shifts. Cereals remain the first source of kilocalories for the ROEU region throughout the entire period.

The computed average calorie intake is 24% higher than the Minimum Dietary Energy Requirement (MDER), on average. Our results generally suggest that meeting national food security objectives in the region remains attainable.

Biodiversity

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



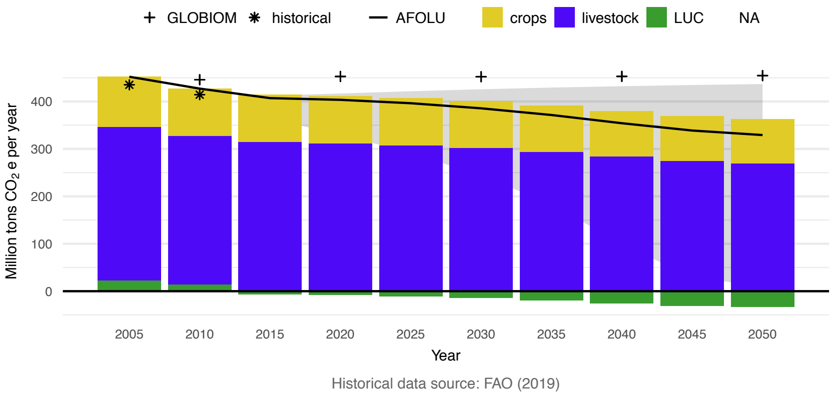
Historical data source: FAO (2019)

Our results show that the Share of Land which can support Biodiversity (SLB) increases between 2000-2015 from 44% to 45%. This number is somewhat lower than the estimates based on FAO land-cover statistics, which calculate a SLB of 49% by 2010. The lowest SLB is computed for the years 2005-2020 at 41% of total land. In comparison to the results of the FABLE Calculator, simulations with GLOBIOM result in a smaller proportion of land for biodiversity conservation. The SLB calculated with GLOBIOM ranges from 35% to 37%. Both the FABLE Calculator and GLOBIOM show relatively stable SLB throughout the period.

Compared to the global target of having at least 50% SLB by 2050, our results are slightly below the target for the region.

GHG emissions

Fig. 10 | Computed GHG emissions from land and agriculture



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 and livestock. Carbon sequestration in forests is not included.

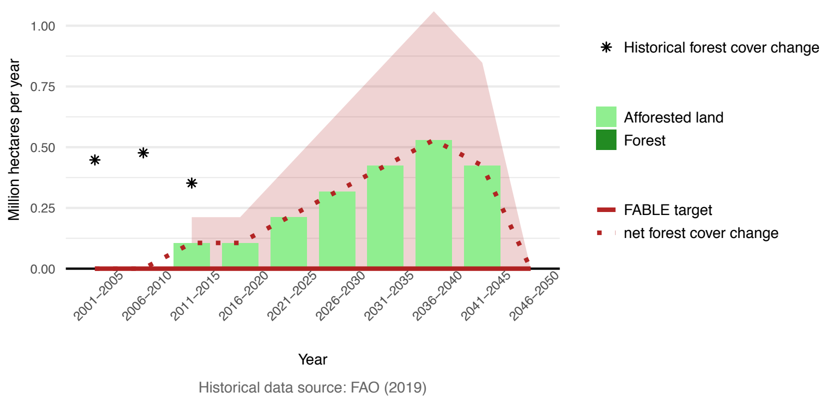
Our results show annual GHG emissions between 452 and 407 Mt CO_2e over 2005-2015, which continue to decrease over time. The calculated results are higher than FAO estimates of 435 Mt CO_2e for the year 2005, even though a decreasing trend is observed. A comparison of the results of the FABLE Calculator with those of GLOBIOM (crops and livestock) show that the latter tend to be higher, with 446 Mt CO2e in 2010 and 453 Mt CO_2e in 2020.

Calculated AFOLU GHG emissions are mostly driven by GHG emissions from livestock. AFOLU GHG emissions amount to 339-329 Mt CO_2e over the period 2046-2050. Negative-net emissions from land-use change by 2050 are mainly explained by zero deforestation throughout the period combined with minor afforestation.

Compared to the global target of reducing emissions from agriculture and reaching zero or negative GHG emissions from LULUCF by 2050, our results are on the target for the region.

Forests

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



Our results show zero annual deforestation for the entire period and afforestation starting over 2006-2012-2015. According to the FAO, afforestation occurred over 2000-2010 and at a higher level: 0.5 Mha/year.

The afforestation projections in the ROEU Calculator are based on the 1.5 °C scenario in IIASA's Global Biosphere Management Model (GLOBIOM). GLOBIOM projects a continued increase in forest area throughout the EU28, in line with historical trends and driven by increasing biomass demand for energy use (European Commission, 2018).

Our results are in line with the global target of having zero or positive net forest change after 2030.

Other relevant results for national objectives

Table 1 | Other Results

Variable	Unit	2000	2005	2010	2015	2020	2030	2040	2050
Milk									
Production (historical)	Mt	135.8	134.7	134.1					
Production (calculated)	Mt	135.2	132.7	127.6	129.7	131.6	135.9	139.9	148.2
Wheat									
Production (historical)	Mt	113.8	118.1	119.9					
Production (calculated)	Mt	112.6	111.4	121.1	122.0	124.6	130.4	136.8	146.6
Area by land cover									
Cropland (historical)	Mha	117.8	112.5	109.4					
Cropland (Calculator)	Mha	117.8	113.8	113.1	112.8	112.4	110.8	107.7	104.8
Cropland (GLOBIOM)	Mha	120.2		116.9		114.7	113.5	117.6	119.7
Pasture (historical)	Mha	60.1	58.6	56.4					
Pasture (Calculator)	Mha	61.2	70.4	69.1	68.9	68.7	67.8	66.0	65.6
Pasture (GLOBIOM)	Mha	76.5		75.0		73.1	71.8	66.0	63.1
Forest (historical)	Mha	100.9	103.0	105.5					
Forest (Calculator)	Mha	100.9	100.9	100.9	100.9	100.9	100.9	100.9	100.9
Forest (GLOBIOM)	Mha	95.1		93.9		93.1	92.4	91.9	91.3
Afforested land (Calculator)	Mha	0.0	0.0	0.0	0.5	1.1	3.7	8.5	10.6
Afforested land (GLOBIOM)	Mha	4.9		8.3		11.5	13.5	14.9	15.5
Otherland (historical)	Mha	49.7	54.1	57.0					
OtherLand (Calculator)	Mha	42.0	33.8	33.8	33.8	33.8	33.8	33.8	35.1
OtherLand (GLOBIOM)	Mha	17.3		17.6		17.7	17.7	17.7	17.7
Urban (Calculator)	Mha	6.5	9.6	11.5	11.5	11.5	11.5	11.5	11.5
Urban (GLOBIOM)	Mha	21.6		23.8		25.4	26.5	27.4	28.2

Source historical data: FAOSTAT

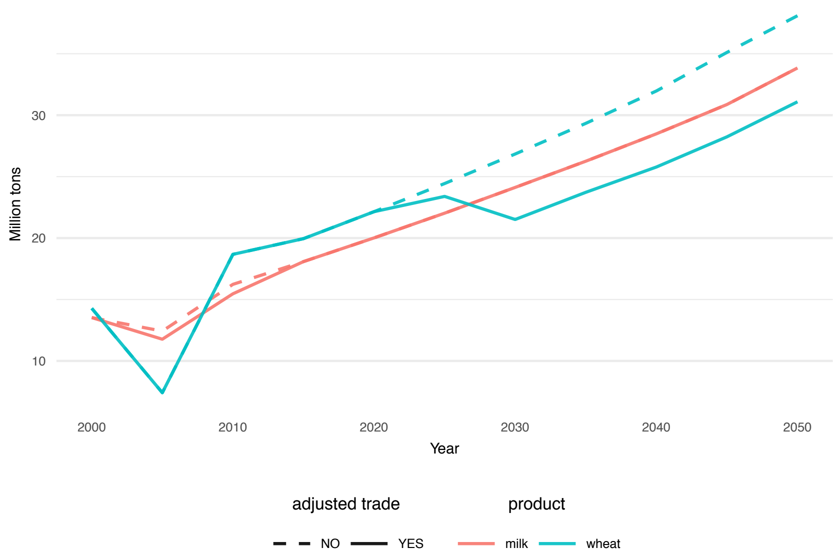
Milk production remains relatively stable over the period, given the scenario assumptions made. A minor decrease in milk production is observed from 2000 to 2015, followed by a slight but continuous increase thereafter. The calculated and projected production quantities range from 127 Mt in 2010 to 148 Mt in 2050.

Historical FAO data is slightly above the calculated production quantities for wheat. The production quantity of wheat in the ROEU region increases throughout most of the period, with values ranging from 111 Mt in 2005 to 147 Mt in 2050.

The cropland, other land and pastureland categories show a slight decrease for most of the period. The other categories show a slight increase in terms of their extension: urban land increases up to 2010 and then remains relatively stable, while afforested land increases at the end of the period. The other land category is higher than reported by the FAO mostly due to urban area, which is taken out of other land in the Calculator. In comparison to the FABLE Calculator results, GLOBIOM results project an increase in cropland after 2030 which is driven by dedicated energy crops, a decrease for forestland throughout the entire period mainly related to the expansion of settlements and a more pronounced decrease in pasture related to higher afforestation, particularly after 2030.

Impacts of trade adjustment to ensure global trade balance

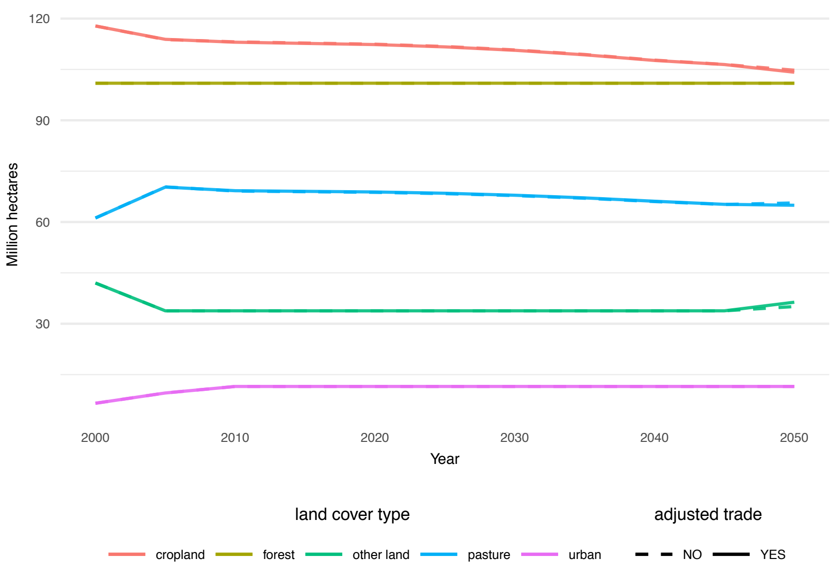
Fig. 12 | Impact of global trade harmonization on main exported/imported commodities over 2000-2050



The change for milk with trade adjustment is minor, differences are only observed for the years 2005 and 2010. For the rest of the period, the exports remain the same.

In contrast to milk, wheat exports from the ROEU region are impacted by the trade adjustment, particularly after 2030. In 2030 the difference is 5.3 Mt, which grows to 7 Mt by 2050.

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



The graph shows the three land-cover indicators that are affected by the trade adjustment: cropland, pasture and other land. As can be seen, however, the impact of the trade adjustment (dashed lines) is minor, with a respective average change of 120, -3, and -116 thousand hectares. For the other land-cover indicators, there is no impact of trade adjustment.

Discussion and next steps

The EU has established a long-term strategy to achieve zero net greenhouse gas emissions by 2050 (European Commission, 2018). The production of sufficient food, feed, and fibers will remain key for the European economy but at the same time, the agriculture and forestry sectors are also expected to contribute to the mid-century carbon neutrality objective. Biomass demand is expected to increase to produce heat, biofuels, biogas, building materials, and sustainable bio-based products such as biochemicals. Increased biomass supply is expected to come from diverse sources in order to ensure the sustainability of the production and the stabilization or enhancement of the carbon sink in existing forests. Reduction of non-CO2 emissions from agriculture will be mainly achieved through innovation e.g. precision farming to optimize the field application of fertilizer and other chemicals, improvement of cattle productivity, and treatment of manure in aerobic digesters. The EU strategy also relies on increasing carbon sequestration on agricultural land through better farming practices including agroforestry techniques, zero-tillage, and the use of cover crops. Finally, afforestation and restoration of degraded ecosystems could contribute to several objectives: CO2 sequestration, biodiversity, soils and water conservation, and biomass production.

We have partly used this long-term strategy from the EU to parametrize the Rest of the European Union (ROEU) FABLE Calculator. In our sustainable pathway scenario, afforestation/reforestation is expected to reach 11 Mha by 2050, crop and livestock productivity is expected to further increase, and the share of the final food consumption at the household level which is wasted is cut by half, allowing for growth in exports of milk and wheat, a stable self-sufficiency ratio for the other products, and a reduction of cropland and pasture area over time. However, some important components of the EU strategy are not yet included.

The FABLE Calculator does not represent bioenergy production, a topic that is central to the projection of EU climate policy up to 2050. The EU has set a target to ensure that 10% of transport fuel in each member state comes from renewable sources, such as biofuels, by 2020 (European Parliament, 2009). These renewable sources should respect some sustainability criteria i.e. bioenergy feedstock should not be grown on areas with high carbon stock or high biodiversity value (Frank et al., 2013). These sustainability criteria also apply to renewable energy produced outside the European Union with limits on high indirect land use change (iLUC) risk biofuels, bioliquids, and biomass fuels (European Parliament, 2018; Valin et al., 2016). Biodiesel is the most widely used biofuel in Europe and it is mostly produced from rapeseed oil. This growing demand for biofuels is not taken into account in the Calculator, which could lead to an underestimation of the cropland area: in our results we project a reduction in cropland area in ROEU but in GLOBIOM-EU the cropland area is projected to increase after 2030. It can also lead to an underestimation of imports for feedstock used for biofuel production.

The Fable calculator currently does not represent timber production from the forestry sector. About 60% of the forest area in the EU is privately owned by small family holdings or large estates owned by companies (European Union, 2011). The forestry sector plays a key role in the EU strategy as biomass demand is expected to increase. Di Fulvio et al (2019) carry out a spatially explicit analysis of the impacts of different biomass demand levels on biodiversity, combining life cycle analysis of various biomass products with GLOBIOM´s overview of the global economy on the AFOLU sectors. They show that the expansion of perennial cultivation for bioenergy might have negative impacts on biodiversity both in the EU and outside the EU through leakage.

Our results do not take into account CO_2 sinks due to carbon sequestration in existing forest ecosystems. The forest CO_2 sink offsets more than half the emissions from agriculture in the EU: emissions from agriculture were 440 Mt CO_2e, while the LULUCF CO_2 sink sequestered, and hence removed, around 249 Mt CO_2 from the atmosphere in 2017 (EEA, 2019). The challenge for the region, therefore, is how to maintain or enhance this carbon sink i.e. through forest restoration or afforestation while increasing biodiversity, guaranteeing food and nutrient security, and promoting other land use activities to reduce emissions in view of the policies that are being set on the table today, such as biomass use.

Despite its current limitations, the added value of a tool such as the FABLE Calculator is that it allows multiple stakeholders to sketch out a range of pathway solutions, highlight tradeoffs, and explore which shared pathway best satisfies national objectives and global targets, such as climate change mitigation, forest and biodiversity conservation.

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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Finland

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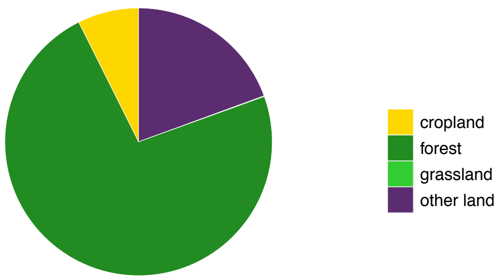
Land and food systems at a glance

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

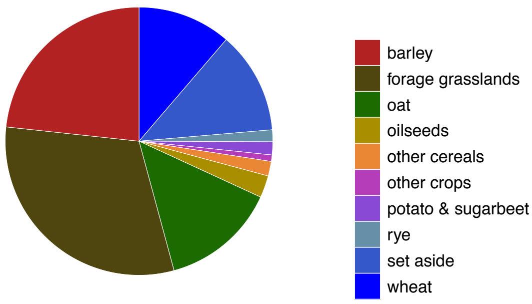
Land & Biodiversity

Fig. 1 | Area by land cover class in 2015



Source: Statistics Finland (2014)

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



Source: Official Agricultural Statistics (2014)

Annual deforestation in 2014:
8.5 kha

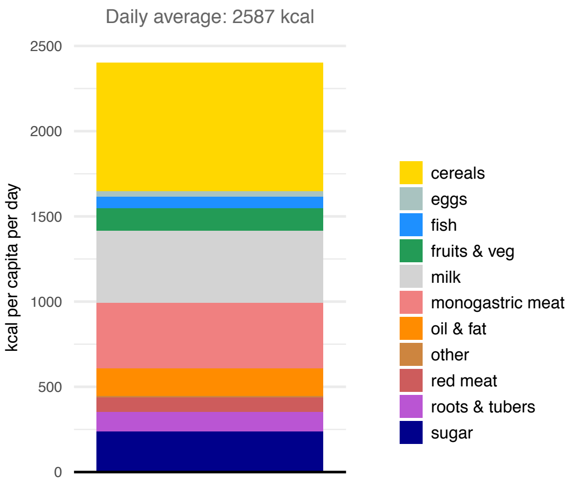
(Statistics Finland, 2019a)

Number of endangered species in 2019: 2,664

(Ministry of the Environment & Finnish Environment Institute, 2019)

Food & Nutrition

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



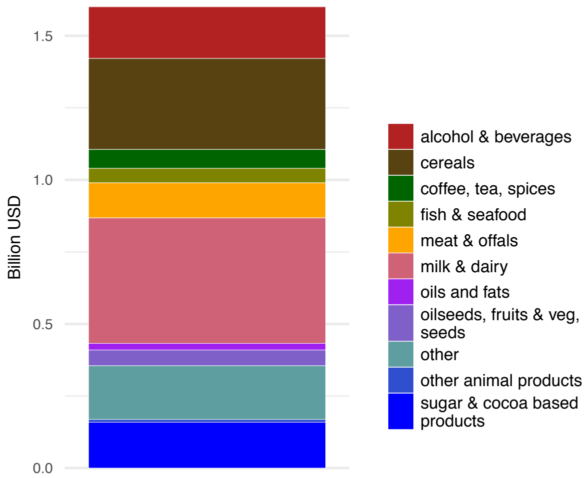
Source: National Institute for Health and Welfare (2017)

Share of obese
(greater than 30 Body Mass Index) in 2017:
Adult men 26.1%
Adult women: 27.5%

(National Institute for Health and Welfare, 2017)

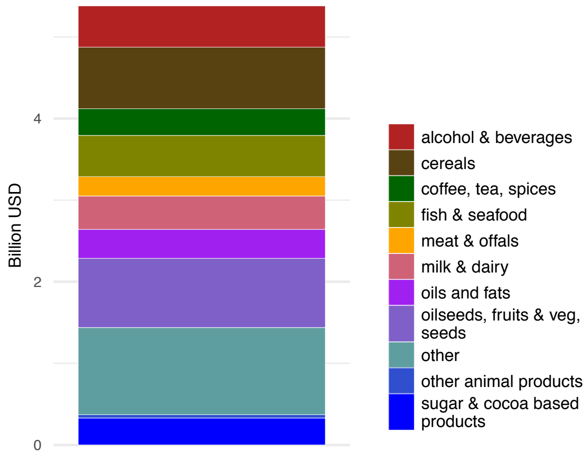
Trade

Fig. 4 | Main agricultural exports by value in 2015



Source: Official Statistics of Finland (2019)

Fig. 5 | Main agricultural imports by value in 2015



Source: Official Statistics of Finland (2019)

Deficit in agricultural trade in 2014: EUR 3.24 billion

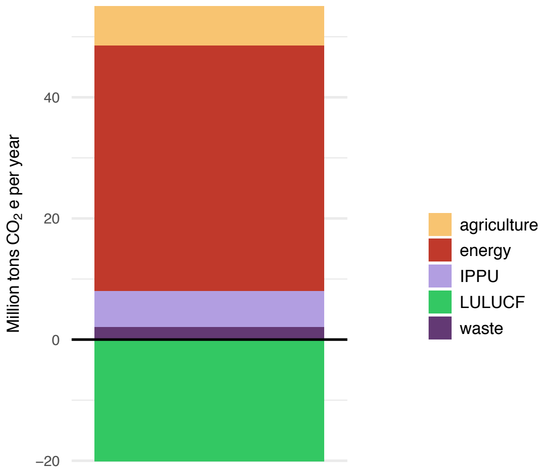
(Tullihallitus, 2019)

47th highest import value, and 43rd highest export value in the world in 2017

(Central Intelligence Agency, 2017)

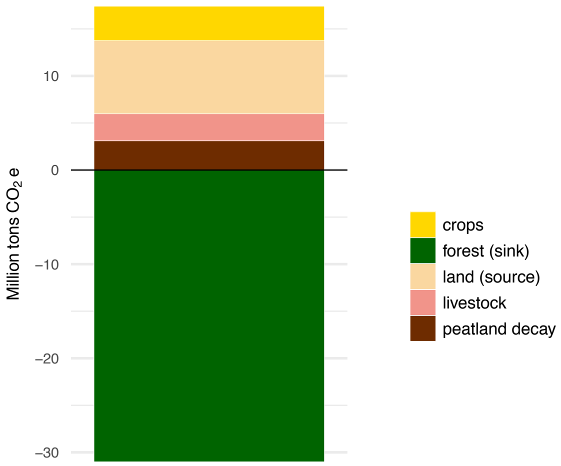
GHG Emissions

Fig. 6 | GHG emissions by sector in 2015



Source: Statistics Finland (2016)

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



Source: Statistics Finland (2016)

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 (large change)	Population (small change)
Scenario definition	GDP is expected to increase from USD 247 bln in 2015 to USD 462 bln in 2050, and GDP per capita from USD 45,057 to USD 78,428 (SSP2 scenario selected).	The population is expected to increase by 7.5% between 2015 and 2050 from 5.5 mln to 5.9 mln (SSP2 scenario selected).
Scenario justification	Annual GDP per capita is expected to increase by approximately 2.5% in 2018. GDP growth rate is expected to decrease to approximately 1% from 2020 onwards but will remain positive. The development of the GDP scenario is based on the 2018 Economic Survey of the Ministry of Finance of Finland (2018).	The development of the population scenario is based on estimations of Statistics Finland (2015).

TRADE

	Imports (small change)	Exports (large change)
Scenario definition	The share of total consumption which is imported increases: - from 47% to 71% for the share of rye imports, and - from 17% to 34% for the share of beef imports. The share of total consumption which is imported remains constant at 2010 levels for the other commodities.	Between 2010 and 2050, the exported quantity: - decreases from 370 kt to 185 kt for barley, - increases from 156 kt to 235 kt for milk, - decreases from 8 kt to 4 kt for pork, and - decreases from 335 kt to 168 kt for oats.
Scenario justification	Even if the imported share remains constant for most commodities, it can lead to large increase of imported quantities. For instance, imports of nuts and beans increase significantly up to 2050, from low levels of 2015 because of the dietary shift in our low carbon scenario on RuokaMinimi (Saarinen et al., 2019).	Based on long term estimations from DREMFIA sector model (H. Lehtonen, 2001; H. S. Lehtonen & Niemi, 2018).

Scenario signs no change, small change, large change

LAND

	Land conversion	Afforestation (small change)
Scenario definition	We assume that there will be no constraint on the expansion of the agricultural land outside beyond existing protected areas and under the total land boundary.	In our low carbon-scenario meat and milk consumption is assumed to decrease by 66%, and we assume 50% of freed grasslands to be reforested by 2050 leading to a reforestation target of 250 kha by 2050.
Scenario justification	Forest area has been very stable around 23 Mha for the past 50 years (Natural Resource Institute Finland, 2019). There is some conversion from forest land to human settlements (urbanization) and agricultural use. However, unutilized and marginal farmlands are afforested. Demand for farmland as a whole is not increasing despite a small population growth.	Reforestation of freed grasslands is based on expert estimations. 50% reforestation is ambitious, but by no means impossible.

BIODIVERSITY

	Protected areas (no change)
Scenario definition	The protected areas remain stable between 2000 and 2050.
Scenario justification	Based on data of Statistics Finland (2019b).

FOOD

	Diet (large change)	Food waste (no change)
Scenario definition	Between 2015 and 2050, the average daily calorie consumption per capita decreases slightly from 2,600 kcal to 2,500 kcal. Per capita consumption: - decreases by 66% for milk and meat, - increases for cereals, vegetables, pulses, and fish (cf. Discussion section). For the other food groups, there is no large shift in consumption.	Between 2015 and 2050, the share of final household consumption which is wasted remains stable at 10%.
Scenario justification	We base the diet in our low carbon scenario on “Ruokaminimi” project, to be soon reported. The main results are already available in the policy brief Saarinen et al. (2019).	There is scarce data on food waste at the household level.

Scenario signs no change small change large change

PRODUCTIVITY

	Crop productivity (small change)	Livestock productivity (small change)	Pasture stocking rate (no change)
Scenario definition	Between 2015 and 2050, crop productivity remains stable: - 3 t/ha for oats, - 3.2 t/ha for barley, and - 3.4 t/ha for wheat. And increases: - from 2.5 t/ha to 3.5 for rye, and - from 26 t/ha to 36 t/ha for potato.	Between 2015 and 2050, the productivity per head increases slightly for milk, chicken, eggs, and mutton, and a small decrease is expected for pork and beef: - chicken: from 1.4 to 1.5 kg/head, - milk: from 8.25 to 10.5 t/TLU, - eggs: from 19.6 to 25.6 kg/hen, - pork: from 80 to 85 kg/head, and - beef: from 330 to 350 kg/head.	The average livestock stocking density remains constant at 1.22 head/ha of pastureland between 2015 and 2050.
Scenario justification	Climate warming can be both beneficial and detrimental to crop production (Porter et al., 2014). While the growing season is expected to lengthen especially in the Boreal hemisphere (Ruosteenoja, Räisänen, Venäläinen, & Kämäräinen, 2016) climate change increases risks of e.g. floods and droughts (Schulz, 2009) and may also decrease productivity (Rötter et al., 2011). Successful adaptation to climate change through crop breeding and appropriate utilization of new cultivars may increase crop yields, in average, despite more frequent extreme weather events which decrease crop yields (Tao et al., 2017). Future crop yields depend on market prices of inputs and outputs and policy conditions. Overall, future crop yields are uncertain. Therefore, we assume that climate change has only minor effects on crop productivity, and thus crop productivity remains stable or might even increase for rye and potato.	Based on long term estimations from DREMFIA sector model (H. Lehtonen, 2001) based on recent applications (H. S. Lehtonen & Niemi, 2018).	Based on long term estimations from DREMFIA sector model (H. Lehtonen, 2001; H. S. Lehtonen & Niemi, 2018). In fact, pasturing is feasible only 4 months per year in southern Finland and less than 3 months per year in northern Finland, due to short growing period and cold winter when grass does not grow. Dairy cows also need other feed (e.g. cereals-based feeds and supplementary protein feed) during the growing period.

Scenario signs no change small change large change

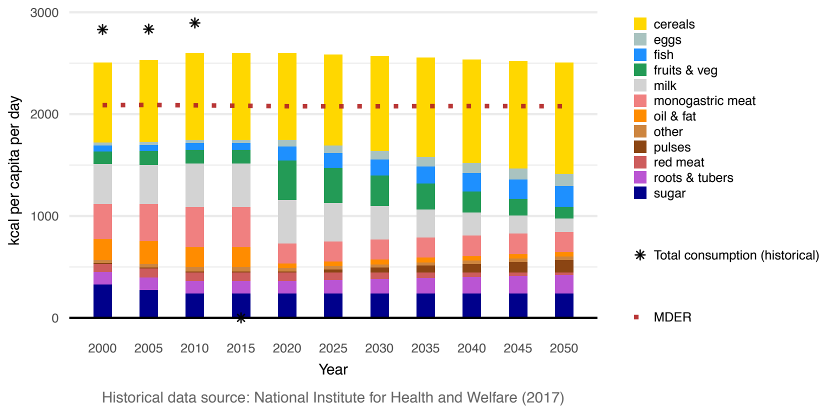
Results against the FABLE targets

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.

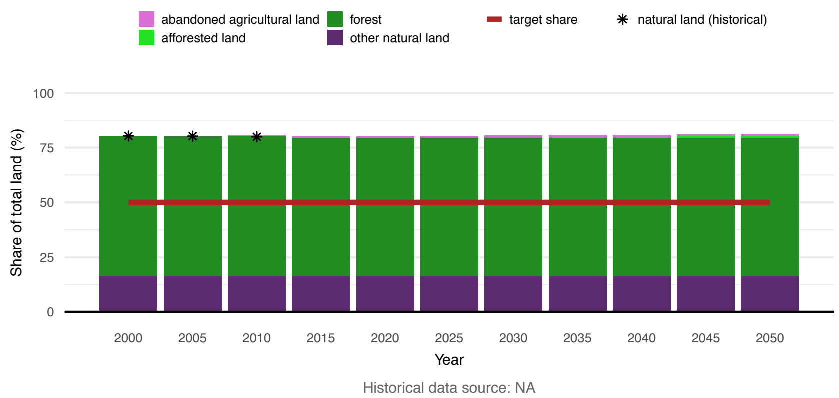


According to our results average daily energy intake per capita increases from 2,500 kcal/cap/day to 2,600 kcal/cap/day in 2000-2015. Calorie intake remains relatively stable, reaching 2,500 kcal/cap/day over the period 2020-2050. In this scenario we assume decreased meat and milk consumption, which is substituted by fruits and vegetables, pulses, and cereals.

The computed average calorie intake is 25% higher than the minimum requirement (MDER) at the national level in 2050. In 2021-2050 total protein intake decreases by 10%. Nevertheless, in 2050, the share of protein from total calorie consumption is still about 15%, which is in line with Finnish nutrition and food recommendations (Fogelholm et al., 2014).

Biodiversity

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

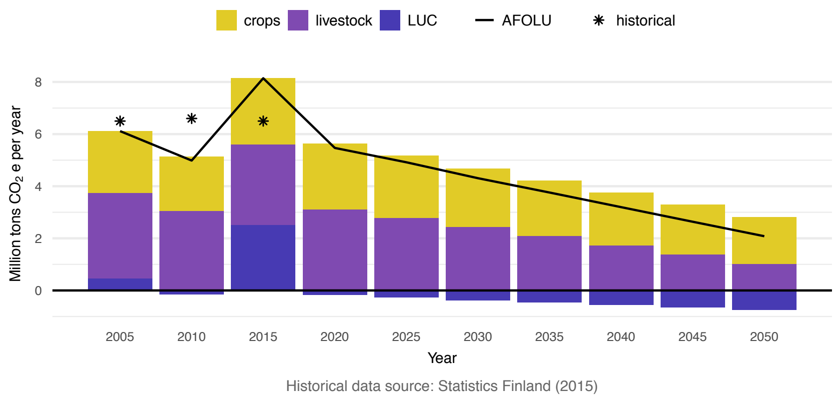


Our results show that the Share of Land which could support Biodiversity (SLB) remains stable between 2000-2015 at 92%. This number is in line with estimates based on the land cover statistics of Natural Resources Institute Finland. We project a slight increase of SLB from 92% to about 93% in this sustainable scenario due to reforestation of mainly old pastures.

Compared to the global target of having at least 50% SLB by 2050, our results are above the target.

GHG emissions

Fig. 10 | Computed GHG emissions from land and agriculture



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 and livestock.

Our results show annual GHG emissions between 5 and 6 Mt CO_2e/year (outlier is year 2015 with high emissions from land use change, due to atypical year for barley in 2010 and model assumptions in agriculture land expansion) over 2000-2015 which decrease over time. These are slightly lower than in Regina et al. (2014), which estimates 6 Mt CO_2e/ year over the same period with a stable trend. Peak AFOLU GHG emissions are computed for the period 2005 at 5,6 Mt CO_2e/year. This is mostly driven by GHG emissions from livestock. Net AFOLU GHG emissions reach 2,1 Mt CO_2e over the period 2046-2050: 2,8 Mt CO_2e from agriculture and -0,7 Mt CO_2e from Land Use, Land-Use Change, and Forestry (LULUC). Negative net emissions from LULUC by 2050 are mainly explained by afforestation. At this current stage of development, the FABLE Calculator does not account for existing forests' sequestration.

Currently agriculture is considered as one of the burden sharing sectors in the EU climate policy. 39% reduction target in GHG emissions during 2005-2030 has been set for the burden sharing sector in Finland. This target is well reached in agricultural sector in our results. Furthermore, reduced need for farmland makes afforestation possible and this increases carbon sink in the LULUCF sector. Even more afforestation could be possible than assumed in this scenario. Hence this agricultural and land use change also contributes to achieving challenging climate targets such as 1.5 degree target.

Forests

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

For the low carbon scenario, as milk and meat production decreases, we assume roughly half of freed grasslands are reforested, resulting in a positive 42 kha net forest change per each 5-year period after 2020. The large changes in 2010-2015 are due to atypical years in barley cultivation. In 2010, large areas of barley were left uncultivated, and by 2015 barley areas were taken back in cultivation. In the Calculator, we assume agricultural land expansion occurs at the expense of forests based on historical data from FAO, hence the large decreases in forest area.

Compared to the global target of having zero or positive net forest change after 2030, these results are above the target.

Other relevant results for national objectives

Table 1 | Other Results

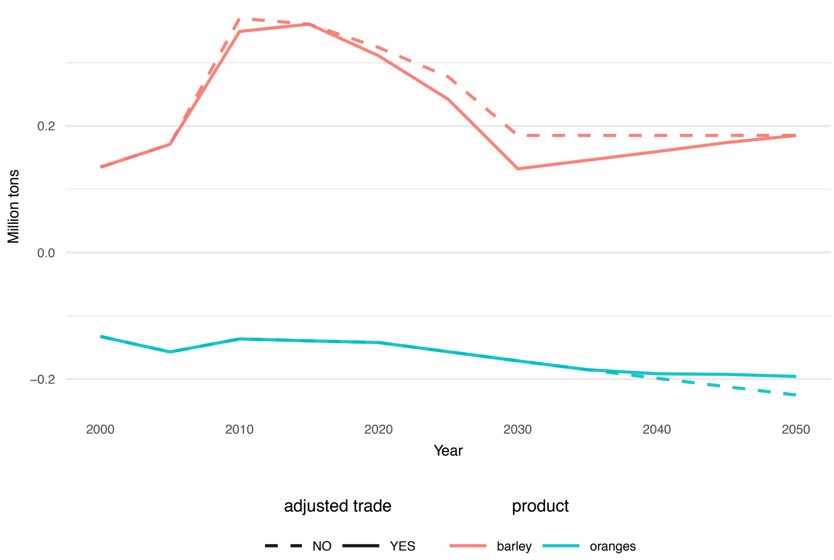
Variable	Unit	2000	2005	2010	2015	2020	2030	2040	2050
Barley									
Production	kt	1719	2035	1199	1677	1648	1301	1083	867
Exports	kt	135	171	370	361	324	185	185	185
Milk									
Production	kt	2417	2399	2302	2358	2412	1996	1532	1044
Exports	kt	395	347	156	166	176	196	215	235

Production of barley decreases by 50% by 2050. Exports decrease by 50% between 2010 and 2030 but remain stable for 2030 to 2050.

Production of milk remains stable until 2020, after which the consumption of milk begins to decrease, causing the production to decrease as well. Consumption decreases by 66% by 2050, and production follows this trend as well. Exports of dairy products, mainly milk powders, remain stable.

Impacts of trade adjustment to ensure global trade balance

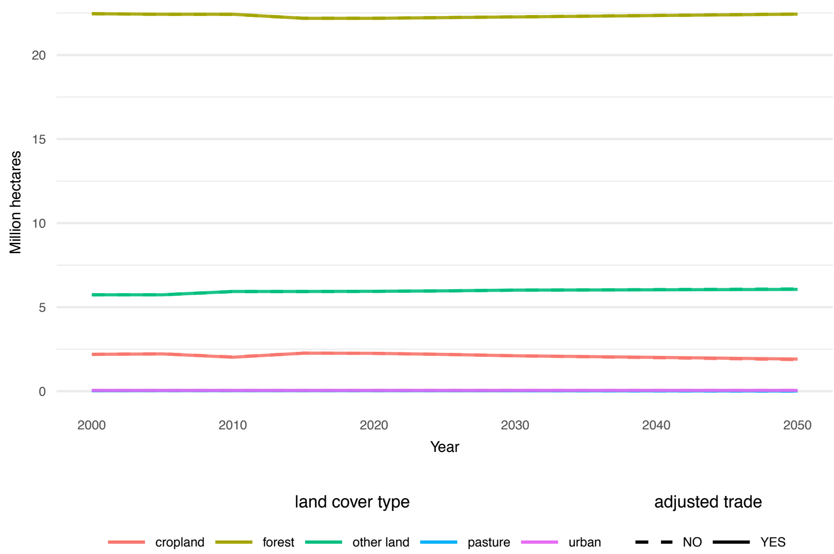
Fig. 12 | Impact of global trade harmonization on main exported/imported commodities over 2000-2050



Exports of barley decrease by about 10% on average when the trade is adjusted for global trade balance.

Imports of oranges remain the same until 2035, after which trade adjustment decreases the imports by up to 14%.

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



The trade adjustment for global trade balance has only minor effects on land use. All in all, the balancing has only a small effect on Finland's trade, thus the effect on FABLE's key targets is also small.

Discussion and next steps

Finland is committed to its Paris Agreement commitments and to the 1.5°C above pre-industrial levels target. The sector which shares the highest burden of greenhouse gas emissions has committed to 39% reduction by 2030, but agriculture – as a part of this burden sharing sector – has not been given explicit targets in greenhouse gas emissions abatement (Ministry of Environment, 2018). However, this 39% reduction target can be considered as one long-term goal. Our sustainable pathway results suggest that reaching this target is likely to require a significant shift in food consumption, agricultural production, and land use. New targets with more explicit commitments for agriculture can be expected in a few years. Agriculture is part of the Land Use, Land-Use Change, and Forestry (LULUCF) sector and specific measures on organic soils in agriculture could significantly contribute to decreasing greenhouse gas emissions from the LULUCF sector (Aakkula et al., 2019). Today, 10% of farmland is on organic soil, producing approximately 50% of CO_2 emissions from the overall farmland in Finland.

This sustainable pathway draws partly on the Low carbon agricultural scenario of Finland up to 2050 where very significant decreases in greenhouse gas emissions from agriculture are the priority. It has been relatively little discussed up to now, however Aakkula et al. (2019) and Saarinen et al. (2019) have recently analyzed some scenarios where significant reductions in agricultural greenhouse gas emissions will realize. But to the best of our knowledge, the analysis of the consequences of a strong dietary shift with the reduction of consumption of all meat and milk products by 67% is done here for the first time in the case of Finland or other Nordic countries. Protein intake of consumers from livestock production is replaced by increasing plant protein and fish consumption. Leguminous crops consumption, including peas, beans, and imported nuts, increases by a factor of 10. This is still feasible as the consumption levels in 2015 were very low. Expansion of the domestic food pea production is also relatively fast: the peas harvested area increases by a factor of 7.5, from 4 kha in 2010 up to 30 kha in 2050. Potato consumption increases gradually by 50% from 2015 level during 2021-2050. Potato, with low greenhouse gas emissions per ton produced, replaces a large part of imported durum wheat and rice. Consumption of fish (primarily Baltic herring with low GHG emissions) increases by 75 %. Human consumption of oats increases by 46% mainly due to increasing consumption of oat drinks. The use of other cereals for human consumption increases by 28%. While the diet changes significantly, daily calorie intake per capita remains stable during 2015-2050. With decreasing meat consumption, even though the consumption is substituted by pulses and fish, total protein intake decreases by 10% from 2015 levels, to about 84 g per capita per day, or about 15% of total calorie intake. This is still in line with Finnish nutrition and food recommendations (Fogelholm et al., 2014).

Much agricultural land is abandoned since areas of croplands used for feed production and grassland decrease to less than one third of the area in 2015. This is because domestic milk and meat production decreases by approximately 65%, following domestic consumption. We assume that exports are not competitive enough and do not increase due to higher production costs. However, there are some sustained exports and imports since there are quality and product type differences. Since the total agricultural production decreases significantly and shifts towards southern Finland, current agricultural support payments per hectare or per animal decrease significantly 2021-2050. Under the first pillar of the European Union's Common Agricultural Policy, payments (per hectare) and national payments coupled to livestock production (per animal) decrease by 30%.

However, under the second pillar of the Common Agricultural Policy, agri-environmental payments and payments for less favored areas are assumed to stay unchanged. These changes in agricultural support payments eliminate any risk of subsidy-driven production and subsidy-driven exports of agricultural products (even if this risk is rather low currently due to high production costs relative to the value of subsidies coupled to production). Hence domestic agricultural production closely follows domestic demand. Livestock production becomes more intensive in terms of land use. The remaining one third of livestock production is mostly produced in southern and middle parts of the country. This also implies that wheat is increasingly used as feed grain, thus, barley and oats are less used. Drinks made from oats become common but that has a small effect on total oats cultivation because oats have been an important feed grain. Decreasing livestock production drives down oats production despite increasing the use of oats for human consumption.

With regards to the FABLE Calculator, forestry sector is not included at the moment. As Finland's territory is predominantly covered by forests this sector is important when analyzing land-use allocation. In addition, the net trade specification in the Calculator hides some simultaneous exports and imports of the same commodity. Quality differences in e.g. wheat may imply that there are exports of feed quality wheat and imports of bread quality wheat. Hence the wheat production area would be larger and closer to the observed reality if both exports and imports of the same commodity would be accounted in the calculator.
In terms of implementing this sustainable pathway, the food consumption trend assumed in this study is the most important challenge. Regardless of the animated public debate on sustainable and climate friendly diets, the observed changes in the consumed quantities of meat, egg, and dairy products have been minor. However, new substitutes for meat and dairy products are coming to the market and they may trigger a large change in the next decade. Consumer behavior, however, is hard to predict or change, even by using policy instruments such as taxes. There are also other challenges, for example, there are still constraints on data availability for monitoring the evolution of land and food systems. Among policymakers, other priorities such as economic growth or employment, may reduce the focus on environmental issues. Law enforcement concerning the climate targets is still weak, and there are only few incentives for landowners to adopt effective GHG mitigation measures on organic soils.

To address these challenges the development of integrated policies would be key. As such, shifting agricultural policy to promote domestic plant-based alternatives to livestock products would increase the sustainability of crop farms. In addition, promoting sustainable fishing, and an increased use of Baltic herring for food instead of feed would be a positive change. Finally, creating incentives for cost effective GHG emission abatement on organic soils and carbon sequestration on mineral soils would also support this sustainable pathway for Finland. While reduced need of agricultural land for food production will release land area for afforestation and carbon sequestration, some relatively less productive farmlands, such as organic farming (Aakkula et al., 2019), could be afforested already now with little effect on agriculture and food security. Creating incentives for climate smart land use is as important as the agricultural change.

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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India

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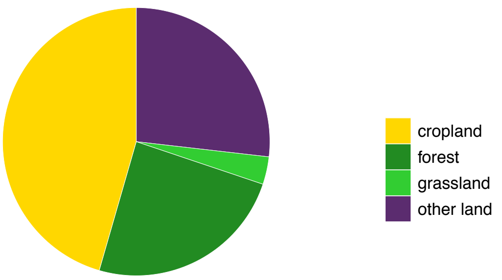
Land and food systems at a glance

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

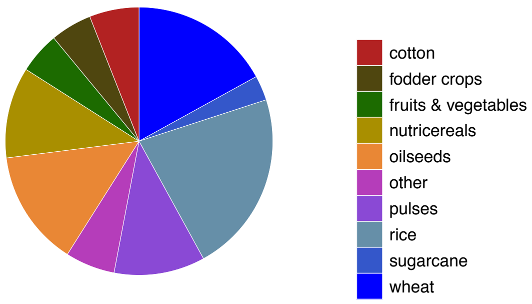
Land & Biodiversity

Fig. 1 | Area by land cover class in 2015



Source: Directorate of Economics & Statistics (2015)

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



Source: Directorate of Economics & Statistics (2015)

708,273 km² of forest area, of which 340,000 km² is degraded forestland

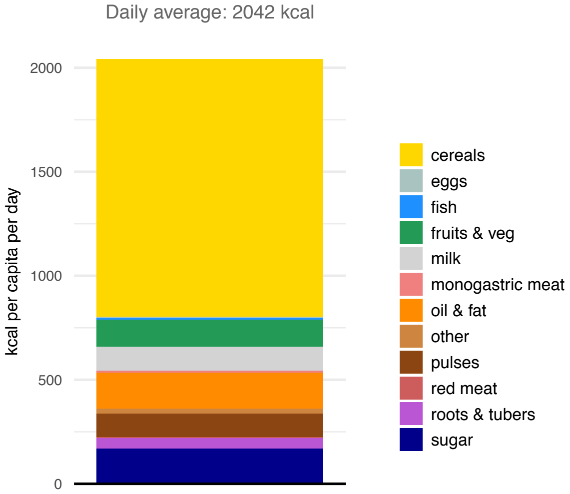
(TERI, 2018)

Endangered species: 172 species of plants

(IUCN Red List, 2019)

Food & Nutrition

Fig. 3 | Daily average intake per capita at the national level in 2011-2012



Source: NSS Report No. 558 (2011–12)

Share of undernourished in 2018: 14.8%

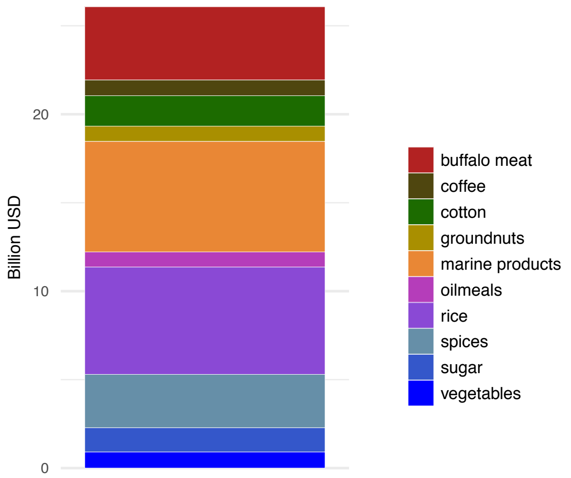
(FAO, IFAD, UNICEF, WFP and WHO, 2018)

Share of obese in 2016: 4.15%

(World Obesity Federation, 2017)

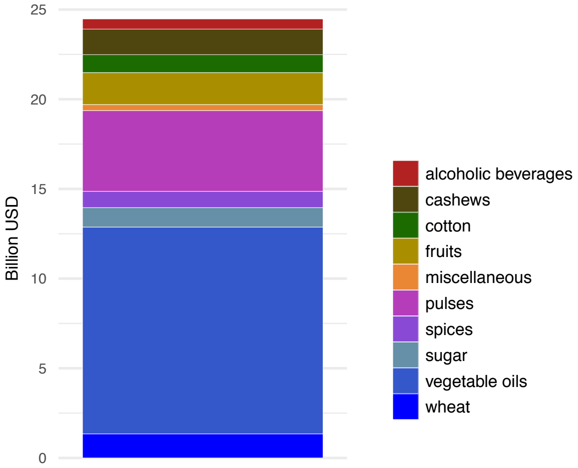
Trade

Fig. 4 | Main agricultural exports by value in 2017



Source: Ministry of Commerce & Industry (2018)

Fig. 5 | Main agricultural imports by value in 2017



Source: Ministry of Commerce & Industry (2018)

Surplus in agricultural trade balance in 2017: INR 619.25 bln

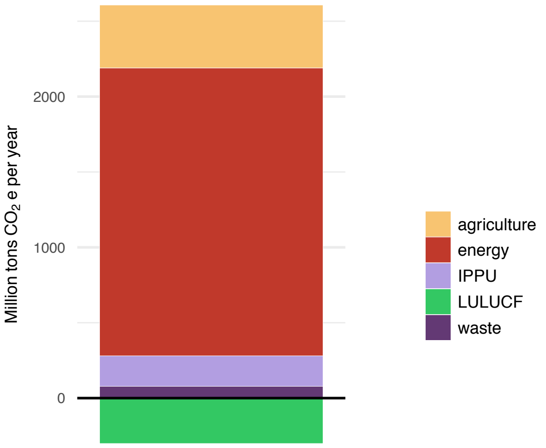
(Directorate of Economics and Statistics, 2018)

9th/7th most important exporter/ importer in the world in 2018

(World Trade Organisation, 2018)

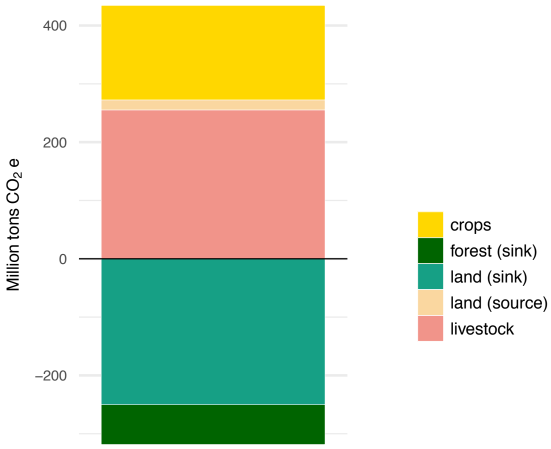
GHG Emissions

Fig. 6 | GHG emissions by sector in 2014



Source: Ministry of Environment, Forest & Climate Change (2018)

Fig. 7 | GHG emissions from agriculture and land use change in 2014



Source: Ministry of Environment, Forest & Climate Change (2018)

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 by 436% from USD 1,757 in 2015 to USD 7,712 in 2050 (SSP1 scenario selected).	The population is expected to increase by 31.57 % between 2015 and 2050 from 1.31 bln to 1.83 bln (UN constant fertility rate scenario selected).
Scenario justification	This strong growth in GDP per capita in India is also forecasted by other studies (Leimbach et al., 2017; PWC, 2017).	This is based on UN projections. Currently, India's population is 1.31 bln and it is expected to reach approximately 1.4 bln by 2022. The projection suggests that India's population will continue to grow for several decades up to 1.5 bln in 2030 and 1.8 bln in 2050 (United Nations, Department of Economic and Social Affairs, Population Division, 2015).

TRADE

	Imports	Exports
Scenario definition	The share of total consumption which is imported increases: - from 32% in 2015 to 63% in 2050 for soy oil. The share of total consumption which is imported remains constant at 2010 levels for the other commodities.	The exported quantity : - increases from 2.31 Mt in 2015 to 4.51 Mt in 2050 for rice, - increases from 2.6 Mt in 2015 to 4.7 Mt in 2050 for corn, - increases from 0.3 Mt in 2015 to 0.6 Mt in 2050 for milk, and - remains constant at 2010 levels for other products.
Scenario justification	India's agricultural imports, which accounted for 4.47% of India's total imports in 2014-15, registering a growth of nearly 17.8% between 2012 and 2015 (NCAER, 2015).	The pathway is based on the recent agricultural export policy of the Indian Government (Department of Commerce, 2018). The policy focuses on export-oriented production and better farm management to double farmers' income by 2022. It also aims to double agricultural exports from current USD 30 bln to USD 60 bln by 2022, and reach USD 100 bln in the next few years thereafter, relying on a stable trade policy regime. There is also an objective of diversifying our export basket, destinations, and boost high-value and value-added agricultural exports with a focus on perishables.

Scenario signs no change small change large change

LAND

	Land conversion	Afforestation (large change)
Scenario definition	We assume no expansion of agricultural land beyond 2015 agricultural area levels.	We assume total afforested/reforested area to reach 2.1 Mha 2050.
Scenario justification	Based on the Agricultural Statistics of India (2018), there has been very negligible change in agricultural land expansion since 2010. This can be explained by the fact that India is committed to its afforestation targets, and that cropping intensity has increased thus allowing for the necessary feeding of the growing population.	Based on India's Bonn Challenge Commitment (2014) and INDC (Government of India, 2015) which state that India's forest cover has increased, "from 23.4% in 2005 to 24% of the geographical area in 2013". The forest and tree cover of India is 24.39% of total land area or 80.20 Mha according to India's 2017 State of Forest Report (Forest Survey of India, 2017), India has pledged to restore 13 Mha of degraded and deforested land by 2020, and an additional 8 Mha by 2030.

BIODIVERSITY

	Protected areas (no change)
Scenario definition	The protected areas remain constant between 2015 to 2050.
Scenario justification	In India, the total area for conservation which is under protection ranges between 15 Mha in 2000 to 16.5 Mha in 2019 and has remained stable over the last 5 years. This area includes natural parks, wildlife sanctuary, community reserves, and conservation reserves (ENVIS Centre on Wildlife and Protected Areas, 2019).

OTHER

	Cropping Intensity (large change)
Scenario definition	We assume that the average crop harvesting intensity will increase from 1.1 in 2010 to 1.3 in 2030 and will remain constant at 2030 level for the rest of the period.
Scenario justification	The national statistics on land use show that cropping intensity is increasing in India (Department of Agriculture Cooperation and Farmers Welfare, 2018).

Scenario signs = no change → small change ↗ large change

FOOD

	Diet	Food waste
Scenario definition	Between 2015 and 2050, the average daily calorie consumption per capita increases from 2,116 kcal to 2,453 kcal. Per capita consumption: - decreases by 16% for cereals, - increases by 26% for milk, and - increases by 74% for the other food products.	Between 2015 and 2050, the share of household consumption which is wasted decreases from 10% to 5%.
Scenario justification	Studies suggest that as income will continue to rise, diets are projected to both diversify nutritionally and increase total energy intake, particularly from meat and dairy products (Ranganathan et al., 2016; Aleksandrowicz et al., 2019; Alexandratos and Bruinsma, 2012; NCAER, 2015; Indian Council of Agricultural Research, 2015).	Our assumption is based on several efforts made by the government and NGOs to reduce food waste in India by promoting awareness among large portions of the population over food wastage (Invest India, 2019).

PRODUCTIVITY

	Crop productivity	Livestock productivity	Pasture stocking rate
Scenario definition	Between 2015 and 2050, crop productivity increases: - from 2.2 t/ha to 3.7 t/ha for rice, - from 2.6 t/ha to 6.6 t/ha for corn, - from 0.05 t/ha to 0.44 t/ha for peas, and - from 70 t/ha to 75 t/ha for sugarcane.	Between 2015 and 2050, the productivity increases: - from 0.2 kg/head to 0.4 kg/head for chicken meat, - from 173 kg/TLU to 178 kg/head for pig meat, and - from 2.6 t/TLU to 4 t/TLU for cattle milk.	The average livestock stocking density remains constant at 12.38 TLU/ha of pastureland between 2015 and 2050.
Scenario justification	NCAER (2015) suggests that due to technological innovation and diffusion through institutional arrangements, growth in yield will be high in the coming decades. In addition, several subsidies will reduce the cost of technologies and increase economies of scale. The study suggests that the area expansion for several cereal crops including wheat is going to be weak and production, and growth will mostly be driven by yield increase.	Based on NCAER (2015), the increase in income levels, population, and urban space, as well as the increased use of feed will expand the production of livestock products in coming decades. Despite a major dependency on cereals, rising protein consumption will necessitate increasing livestock and dairy production. To meet the domestic protein demand, the Government of India is focusing on livestock intensification systems to improve yield (Planning Commission, 2012).	Initiatives were taken to improve livestock feeding systems because by 2025, India is likely to experience a fodder deficit of about 65% for green fodder and 25% for dry fodder (Indian Council of Agricultural Research, 2015; Planning Commission, 2012).

Scenario signs: Diet – large change; Food waste – large change; Crop productivity – large change; Livestock productivity – large change; Pasture stocking rate – no change.

Scenario signs = no change → small change ↗ large change

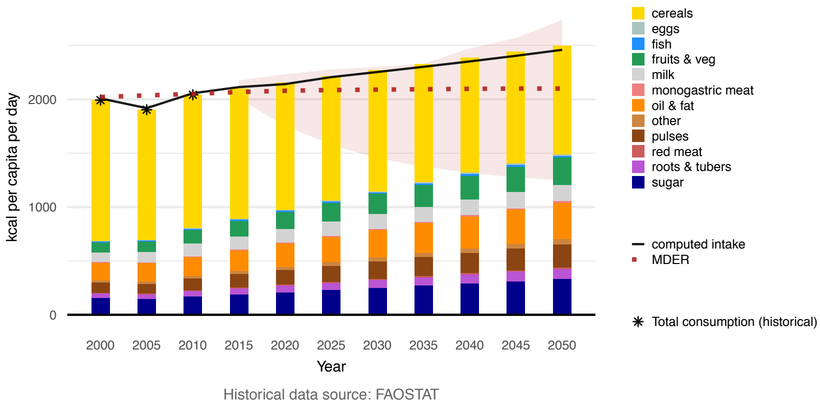
Results against the FABLE targets

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

Food security

Fig. 8 | Computed daily kilocalorie 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.

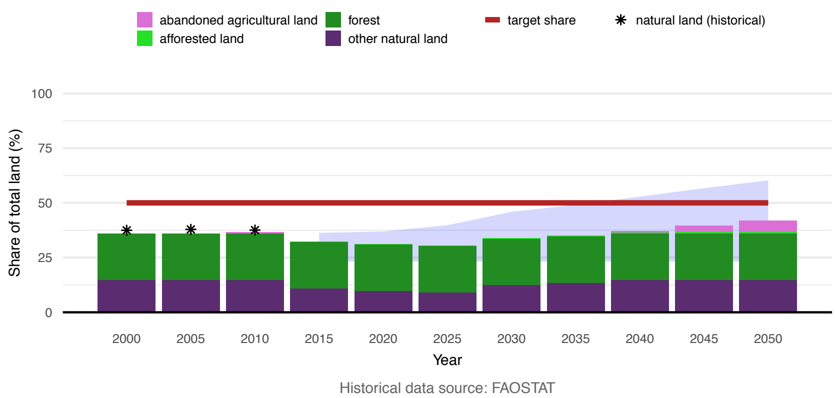


Our results show average daily energy intake per capita increases from 2000 kcal/cap/day in 2000 to 2260 kcal/cap/day in 2030 to 2,450 kcal/cap/day in 2050. This is 10% lower than the 68th round of India's National Sample Survey Office for the year 2012 due to some products not being taken into account into our calculations. Over the last decade, more than half of the food intake came from cereals (National Sample Survey Office, 2014).

In terms of recommended diet, our results show higher consumption of animal-based products and lower consumption of cereals. The computed average calorie intake is higher than the average minimum calorie requirement (MDER) at the national level from 2020 onwards.

Biodiversity

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

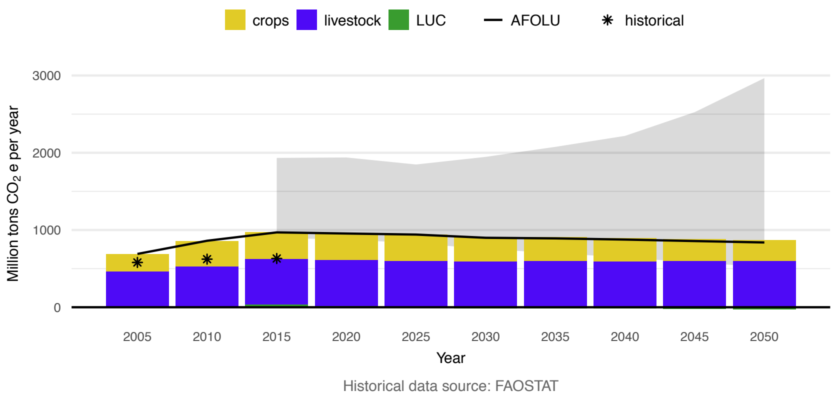


Our results show that the Share of the Land which could support Biodiversity conservation (SLB) remained stable between 2000-2015 at 36%. The lowest SLB is computed for the period 2020-2025 at 23% of total land. This is mostly driven by conversion of other natural land to cropland. SLB reaches its maximum value over the last period of simulation at 31%. This is mostly driven by abandonment of agricultural land and by a lower extent to afforestation.

Compared to the FABLE global target of having at least 50% SLB by 2050, our results are below the target, but our results are consistent with India's commitments under the Convention on Biological Diversity . For which India has recently submitted its sixth national report (Government of India, 2018). According to this report, "India has exceeded the terrestrial component of 17% of Aichi target 11, and 20% of corresponding National Biodiversity Targets relating to areas under biodiversity management".

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 and livestock.

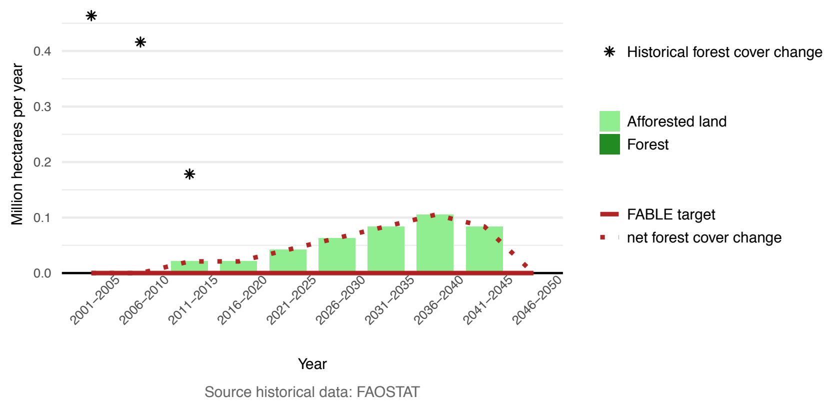
Our results show annual AFOLU GHG emissions between 642 and 969 Mt CO_2e/year over 2000-2015 which increase over time. This is 28% than FAO statistics in 2015 (FAOSTAT, 2019). For GHG emissions from agriculture only, our results are more than two times higher than reported emissions from the GHG platform India (GHG Platform India, 2017) and 36% higher than FAO. This is mostly due to an underestimation of Nitrous Oxide emissions from livestock on the GHG platform and from an overestimation of overall emissions from the livestock sector in our Calculator.

Peak AFOLU GHG emissions are computed for 2015 at 969 Mt CO_2e/year. This is mostly driven by GHG emissions from livestock. AFOLU GHG emissions reach 839 Mt CO2e over the period 2046-2050: 868 Mt from agriculture and -30 Mt from LULUCF. Negative net emissions from LULUCF by 2050 are mainly explained by agricultural land abandonment and afforestation.

Our results meet the FABLE target of having zero or negative emissions from land use change but emissions from the agricultural sector remain high over the whole period.

Forests

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



We do not project any deforestation over the whole period and afforestation varying between 21 kha/year and 105 kha/year between 2015-2045 with a peak over 2035-2040. According to FAO, the forest cover has increased by more than 400 kha/year over 2000-2010 and 170 kha/year over 2011-2015. Our results do not reflect well this past afforestation.

Compared to the FABLE global target of having zero or positive net forest change after 2030, our results meet the target. Our results also meet our national Bonn Challenge target by 2030.

Other relevant results for national objectives

Table 1 | Other Results

Variable	Unit	2000	2005	2010	2015	2020	2030	2040	2050
Crop Productivity									
Corn	t/ha	1.8	1.9	2.5	2.6	2.8	3.3	4.4	6.6
Peas	t/ha	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.4
Rice	t/ha	1.9	2.1	2.2	2.3	2.4	2.6	3.0	3.7
Sorghum	t/ha	0.8	0.8	0.9	0.9	0.9	1.0	1.1	1.3
Nuts	t/ha	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.4
Groundnut	t/ha	1.0	1.2	1.4	1.5	1.5	1.9	2.5	3.9
Pulses Other	t/ha	6.9	6.4	7.9	8.0	8.2	9.0	10.2	12.1
Sugarcane	t/ha	70.9	64.8	70.0	70.2	70.5	71.4	72.8	74.8
Land Cover Change									
Cropland (historical)	Mha	170.1	169.7	169.2					
Cropland (calculated)	Mha	170.1	169.7	167.1	173.9	173.8	159.8	150.3	136.4
Pasture (historical)	Mha	10.8	10.5	10.3					
Pasture (calculated)	Mha	15.2	15.3	15.4	17.0	17.0	17.0	17.0	16.9
Forest (historical)	Mha	65.4	67.7	68.4					
Forest (calculated)	Mha	65.4	65.4	65.4	65.4	65.4	65.4	65.4	65.4
Afforested land (calculated)	Mha	0.0	0.0	0.0	0.1	0.2	0.7	1.7	2.1
Other land (historical)	Mha	51.0	49.5	49.3					
Other land (calculated)	Mha	45.7	45.4	46.8	36.2	32.8	44.0	52.6	66.1
Urban (calculated)	Mha	0.9	1.6	2.7	4.7	8.1	10.4	10.4	10.4

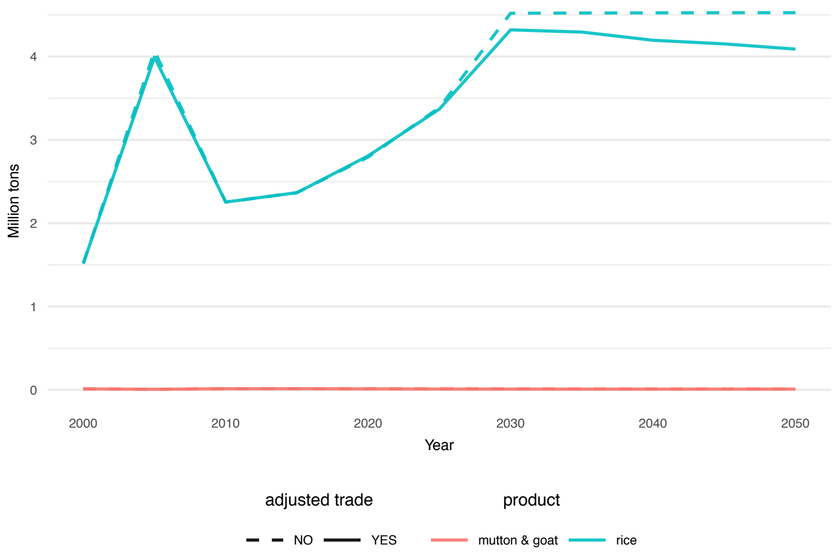
Source of historical data: FAOSTAT

Results shows that crop yield is going to increase in comparison to historical period. The New Biofuel Policy of India relies on achieving the ethanol blending target from surplus crop production. To achieve this target India needs a more intensified production system.

Our result shows a reduction of cropland area by 2050 while at the same time we have observed a deterioration of agricultural trade balance i.e., from a trade surplus at the beginning to a trade deficit by 2050. The increase of crop productivity allows increasing crop production even if the cropland area remains over 2015-2025 and even decreases after 2025.

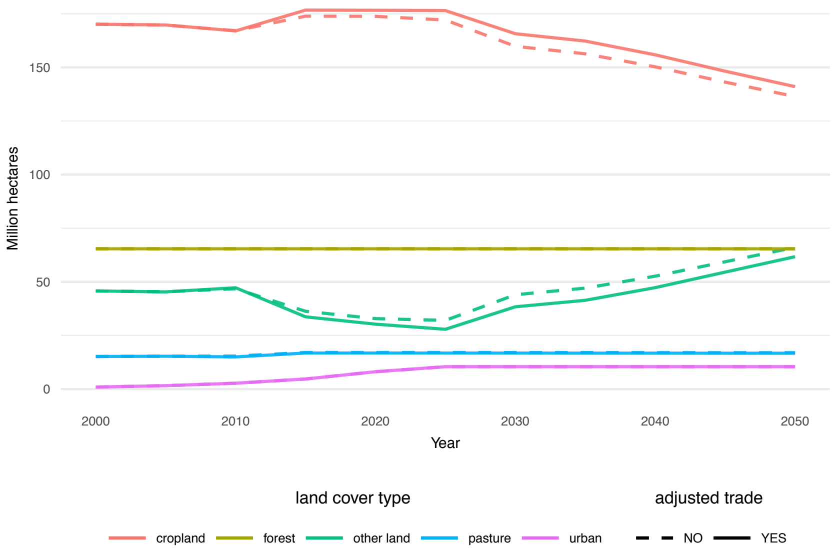
Impacts of trade adjustment to ensure global trade balance

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



Trade adjustment leads to a decline:
- in rice exports,
- in beef exports,
- in apple imports, and
- in sunflower imports.

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



Trade adjustment leads to a higher cropland area and lower other land area because the agricultural production has to increase to offset the reduction in imported quantities for several commodities.

Discussion and next steps

The sustainable pathway developed using this useful analytical tool, the FABLE Calculator, aims to achieve a sustainable food and land use future for India. The intention behind this pathway and results analysis is to enable policymakers and civil society to understand the present conditions and the future trends of sustainable indicators to support the setting of national targets and monitor their progress. The selected pathway is also developed to achieve several international commitments for climate mitigation and forest conservation such as the Paris Agreement, the Convention on Biological Diversity, the Sustainable Development Goals, and the Bonn Challenge. The results from the pathway show a seven-fold increase in GDP per capita during the period 2015 to 2050 which significantly impacts dietary change for the same period. The results show that the demand for livestock products increases over the same period which also results in a high increase in GHG emissions from the livestock sector. The increase in population between 2015 and 2050 leads to a growing demand for food and creates pressure on natural resources. However, we assume that there will be no expansion in the crop land area, but this is offset by significant crop productivity and crop harvesting intensity resulting in an overall increase in crop production. To conclude, the analysis presents interesting trade-offs in the course of India's development. The results show gains in India across many dimensions in the long term, while emphasizing that some key concerns remain. The forest cover increases, and so does the land that can support biodiversity. The energy intake in terms of calorific requirements increases significantly with time as people become richer. The country continues to gain in terms of production in agriculture, but overall carbon dioxide emissions from the agricultural sector remain high and are difficult to significantly reduce by 2050.

The FABLE Calculator covers many aspects of pathways for sustainable land use and food system, but it currently faces limitations. For example, it does not include different agricultural production systems and management which are geographically diversified in India. In addition, the soil nutrient management system needs to be included in the Calculator to support better results. Moreover, we have not disentangled the different drivers of future crop productivity. In terms of water and irrigation systems, the Calculator does not yet integrate this important factor in its analysis, and this should be included as a way to strengthen the development of sustainable pathways to achieve the SDGs. Finally, to provide more micro-level assessments of future pathways the Calculator would need to include country specific policy-based scenarios to unveil the integrated impact of a particular policy. Overall, the Calculator is a valuable tool to address a range of issues and trade-offs. The present analysis focuses on shedding the light on some important issues for the country, but also on additional issues that could be analyzed in the future.

- The present analysis does not delve deep into the challenge posed by the use of biofuels. Enhancing the use of biofuels for addressing climate change is bound to have an impact on land-use systems.
- International trade in agriculture has important implications for farmers' livelihoods as well as the domestic agricultural economy. It would be interesting to look into this aspect.
- India is a water-scarce country. Cropping patterns and agriculture are, in general, to a large extent driven by water availability. It would be useful to delve deeper into the issue of water and its relationship with agriculture and land-use.

- o Climate change will impact the productivity of crops across regions in India and will affect trade-offs between agriculture and land-use. This aspect is going to be critical and should be an important dimension to be explored in the future.
- o The representation of alternative yield improving technologies and irrigation systems is not included in the current analysis. To improve the real potential for productivity the Calculator would need to include this factor.

One of the main challenges of transforming the economy is to understand the incentives of different groups, and to assess the winners and losers in the transition towards a sustainable future. Our aim is to achieve a transition that is able to address multiple sustainable development objectives, ranging from enhanced nutrition and better agricultural practices, while ensuring low carbon dioxide emissions as well as allowing for a climate resilient economy. There will be interest groups and stakeholders that will be impacted by changes across all these different objectives. Therefore, it will be critical to understand their trade-offs, and devise ways to compensate the losers and incentivize the winners. The FABLE analysis can provide crucial evidence to better understand trade-offs and synergies while helping to translate these insights into on-the-ground transformation.

Integrated analysis is a critical step in this direction. FABLE seeks to integrate different, and often conflicting, objectives and dimensions within a unified framework. This is the strength and value added, and it complements many other sector-specific analyses undertaken in India. Through such integrated analysis, along with inputs from key stakeholders, we aim to inform policy and address the multiple development challenges faced by India's policy makers.

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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Indonesia

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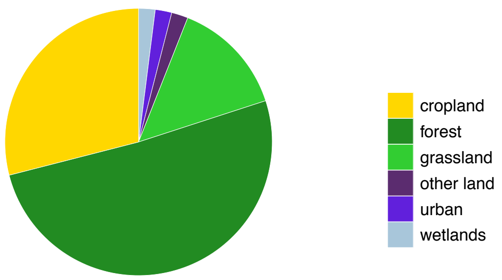
Land and food systems at a glance

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

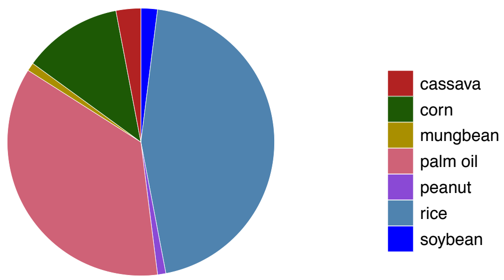
Land & Biodiversity

Fig. 1 | Area by land cover class in 2015



Source: Kementerian Lingkungan Hidup dan Kehutanan (2018)

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



Source: Kementerian Pertanian (2016)

Annual deforestation in 2015:
1 Mha

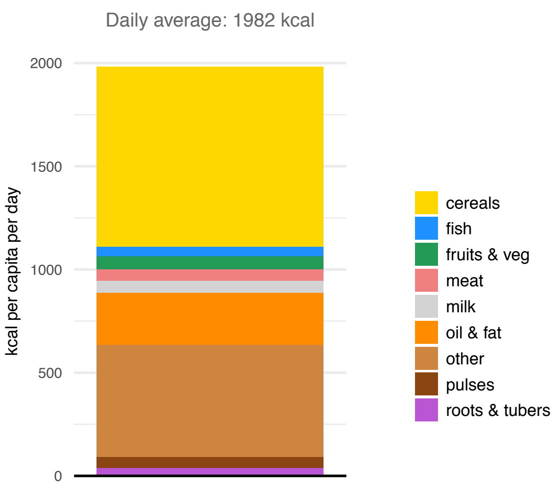
Source: Kementerian Lingkungan Hidup dan Kehutanan (2018)

Endangered species:
921 species in 2018

Source: Kementrian Lingkungan Hidup dan Kehutanan (2018)

Food & Nutrition

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



Source: Badan Pusat Statistik and Astuti (2015)

Share of undernourished in 2016:
8%

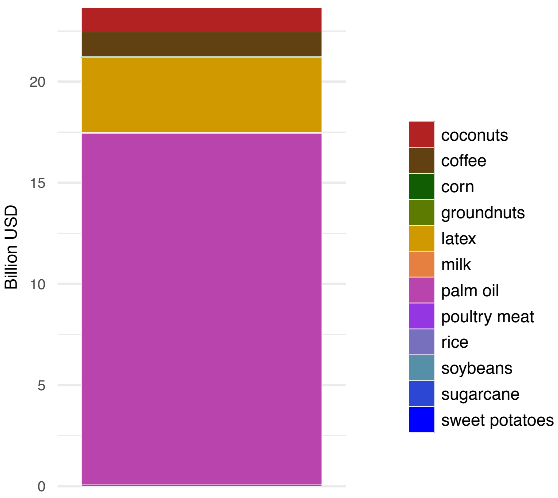
Source: FAOSTAT (2019)

Share of obesity in 2018:
23.1% of adults

Source: Harbuwono et al. (2018)

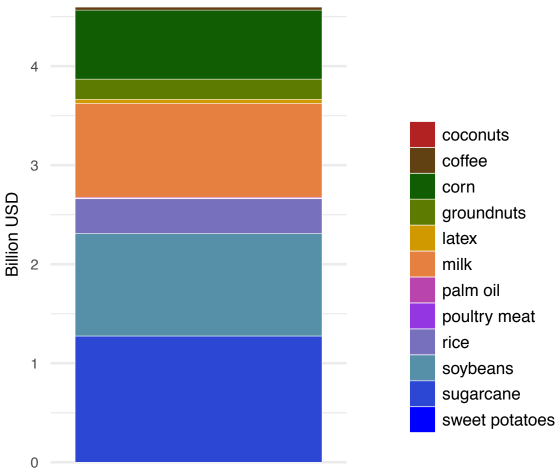
Trade

Fig. 4 | Main agricultural exports by value in 2015



Source: Kementerian Pertanian (2016)

Fig. 5 | Main agricultural imports by value in 2015



Source: Kementerian Pertanian (2016)

Surplus in agricultural trade balance in 2015:
USD 13.55 bln

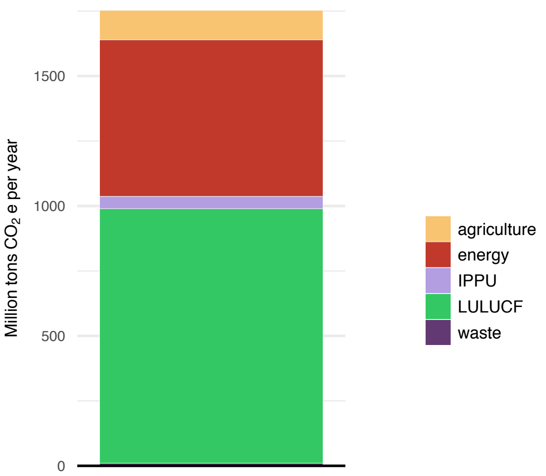
Source: Kementerian Pertanian (2016)

#1 palm oil, #2 rubber,
and #7 coffee exporter in 2017

Source: OEC MIT, (2019)

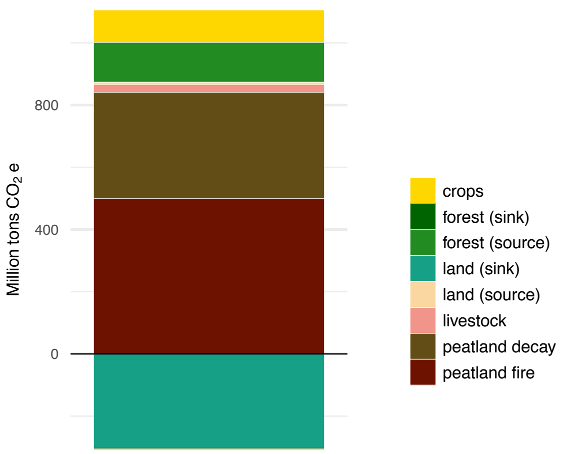
GHG Emissions

Fig. 6 | GHG emissions by sector in 2015



Source: Kementerian Pertanian (2016)

Fig. 7 | GHG emissions from agriculture and land use change in 2014



Source: MoEF, Republic of Indonesia (2017)

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 (large change)	Population (large change)
Scenario definition	GDP per capita is expected to increase from USD 3,827 in 2015 to USD 14,617 in 2050 (SSP1 scenario selected).	The population is expected to increase by 15% between 2015 and 2050 from 65.4 mln to 75.4 mln (UN Medium growth scenario selected).
Scenario justification	Based on Bappenas (2005; 2019) and Kementrian PPN/Bappenas (2019b).	Based on the Indonesian Central Bureau of Statistics' projections, in 2045 the Indonesian population will be 324 mln, which roughly matches our selected scenarios at 342 mln (Kementrian PPN/Bappenas, 2019a).

TRADE

	Imports (small change)	Exports (large change)
Scenario definition	The share of total consumption which is imported: - decreases from 2% in 2010 to 0% in 2050 for rice, - increases from 10% in 2010 to 19% in 2050 for corn, and - increases from 60% in 2010 to 100% in 2050 for milk. The share of domestic consumption which is imported remains at 2010 levels for the other commodities.	The exported quantity increases: - from 17.5 Mt in 2010 to 52.5 Mt in 2050 for Palm Oil (CPO or FFB), - from 2.3 Mt in 2010 to 7 Mt in 2050 for rubber, - from 0.5 Mt in 2010 to 1.5 Mt in 2050 for cocoa, The exported quantity remains constant at 2010 levels for all the other products.
Scenario justification	Increasing exports is also a main objective of the national development plan (Kementerian Pertanian, 2016).	Based on Arifin et al. (2018).

Scenario signs no change · small change · large change

LAND

	Land conversion	Afforestation (large change)
Scenario definition	We assume that there will be no constraint on the expansion of agricultural land beyond existing protected areas and under the total land boundary.	We assume total afforested/reforested areas will reach 2 Mha by 2050.
Scenario justification	2018, Indonesia regulates the suspension/moratorium of new permit or licenses in some types of forest area and peatland (President of the Republic of Indonesia, 2018).	Based on existing Bonn Challenge commitments of around 2 Mha, which come from private sector reforestation, and historical reforestation rate trends. In 2015, our National Restoration Targets in Bonn Challenge numbered around 30 Mha, but this number is yet to be considered in our scenario (President of the Republic of Indonesia, 2011; Ministry of Environment and Forestry, 2012).

BIODIVERSITY

	Protected areas (no change)
Scenario definition	Protected areas remain constant at 22 Mha over 2000-2050.
Scenario justification	Based on The State of Indonesia's Forest 2018 (Kementerian Lingkungan Hidup dan Kehutanan, 2018), Ministry of Environment and Forestry, Republic of Indonesia.

Scenario signs no change small change large change

FOOD

	Diet (large change)	Food waste (large change)
Scenario definition	Between 2015 and 2050, average daily calorie consumption per capita increases from 2,440 kcal to 2,960 kcal. Between 2015 and 2050, per capita kilocalorie consumption: - increases by 77% for fish, - increases by 9% for sugar, - increases by 9% for poultry meat, - increases by 51% for fruits and vegetables, - increases by 68% for other, which includes nuts, - decreases by 4% for oil and fat, and - decreases by 7% for red meat.11 For all other food groups, there is no large shift in consumption.	Between 2015 and 2050, the share of final household consumption which is wasted decreases from 10% to 5%.
Scenario justification	Based on Arifin et al. (2018).	Based on Arifin et al. (2018).

PRODUCTIVITY

	Crop productivity (large change)	Livestock productivity (small change)	Pasture stocking rate (no change)
Scenario definition	Between 2015 and 2050, crop productivity increases: - from 3.4 t/ha to 5 t/ha for rice, - from 4.6 t/ha to 16.3 t/ha for corn, - from 1.4 t/ha to 1.9 t/ha for soy, - from 61.8 t/ha to 87.8 t/ha for sugarcane, and - from 17.1 t/ha to 23.9 t/ha for oil palm fruit.	Between 2015 and 2050, the productivity per head increases: - from 29.1 kg/head to 30.2 kg/head for beef, - from 0.125 kg/head to 0.224 kg/head for chicken, and - from 2.3 t/head to 2.4 t/head for cow milk.	The average livestock stocking density remains constant at 1.9 TLU/ha of pasture between 2015 and 2050.
Scenario justification	According to the *6 Sasaran Strategis Kementerian Pertanian 2015 -2019*, Indonesia will aim to reach rice, corn, and soy self sufficiency and increase sugarcane and meat productivity. According to the Palm Oil Association Company and the Indonesian Government, by the end of 2030 palm oil production is expected to reach about 60 Mt CPO and 160 Mt by 2050 CPO (Kementrian PPN/Bappenas, 2014; Kementerian Pertanian, 2015).	Based on 6 Sasaran Strategis Kementerian Pertanian 2015 -2019, according to which Indonesia will aim to increase meat productivity (Kementerian Pertanian, 2015).	Based on 6 Sasaran Strategis Kementerian Pertanian 2015 -2019, the 4th aim of which is to better allocate resources on agriculture, bioindustry, and bioenergy (Kementerian Pertanian, 2015), however data is scarce on current and potential stocking rates in pastureland in Indonesia.

Scenario signs no change small change large change

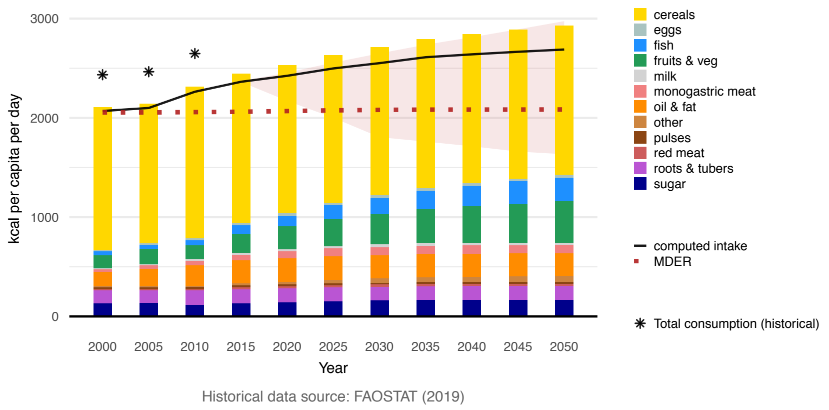
Results against the FABLE targets

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.

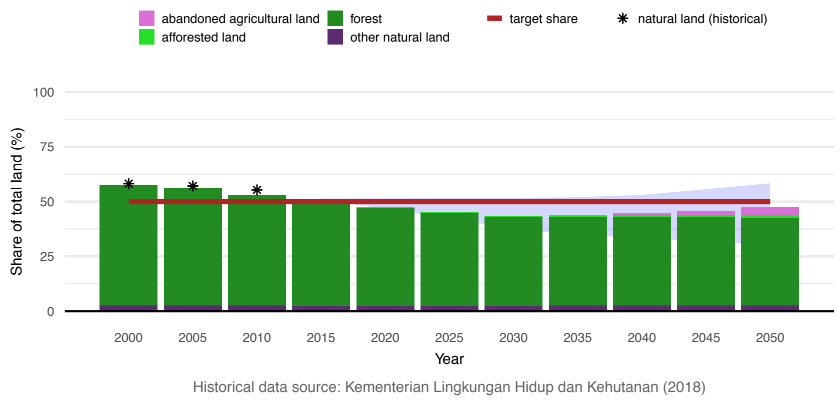


Our results show that average daily energy intake per capita increases between 2000 – 2015, from 2,089 kcal/cap/day and 2,367 kcal/cap/day. Over the last decade, food intake came mainly from cereals such as rice and maize. Calorie intake reaches 2,611 kcal/cap/day over the period 2031-2035 and 2,689 kcal/cap/day over the period 2046-2050. In terms of recommended diet, our results show stable consumption of cereals and higher consumption of fruits and vegetables, fish and sugar. The computed average calorie intake is 30 % higher than the Minimum Dietary Energy Requirement (MDER) at the national level in 2050.

Our results suggest that meeting national food security objectives in terms of reducing under-nourishment is attainable.

Biodiversity

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

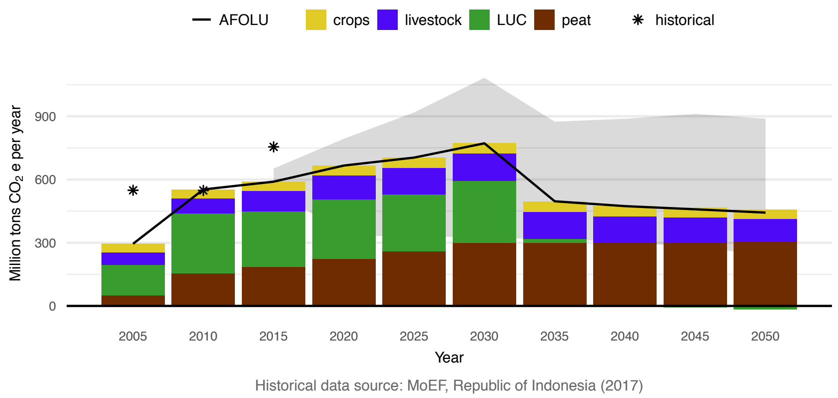


Our results show that the Share of Land which could support Biodiversity (SLB) decreased between 2000-2015 from 57% to 51%. The lowest SLB is computed for the period 2030 at 43% of total land. This is mostly driven by deforestation due to cropland expansion. SLB reaches 47% over the last period of simulation 2046-2050. The difference is explained by lower deforestation, afforestation, and abandonment of some cropland area where we assume some natural regrowth in vegetation.

Compared to the global target of having at least 50% SLB by 2050, our results are slightly below the target.

GHG emissions

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



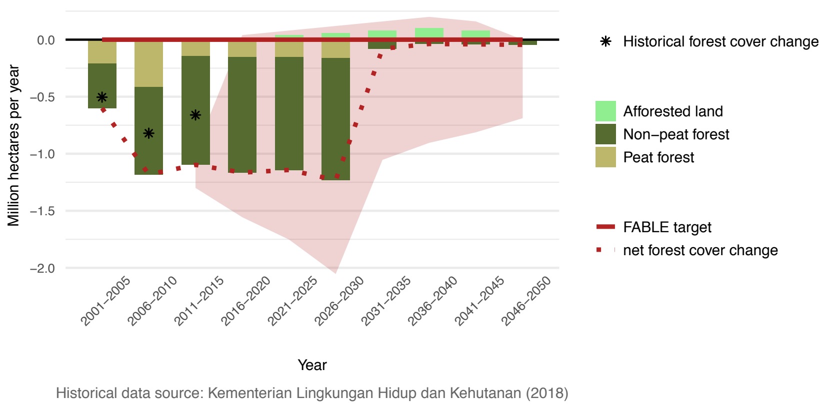
Note: AFOLU (Agriculture, Forestry and Other Land Use) is the sum of computed GHG emissions from crops, livestock and Land Use Change (LUC), emissions and sequestration from forestry are not included. Historical emissions include crops, livestock, peat decomposition, and land use change.

Our results show annual GHG emissions between 295 Mt CO_2e and 583 Mt CO_2e over 2000-2015. These are lower than Indonesia's 2nd Biennial Update Report (Republic of Indonesia, 2018), which estimates 423 Mt CO2e to 856 Mt CO2e from the AFOLU sectors over the same period and an increasing trend. Peak AFOLU GHG emissions are computed for the period 2026-2030 at 772 Mt CO_2e per year. AFOLU GHG emissions reach 443 Mt CO_2e over the period 2046-2050: 155 Mt CO_2e from agriculture, 303 from peatland decomposition and -15 from land use change. Positive net emissions from LULUCF by 2050 are mainly explained by peatland decomposition after drainage.

Compared to the global target of reducing emissions from agriculture, our results show only a slight reduction between 2035 and 2050 and do not meet the target of reaching zero or negative GHG emissions from LULUCF by 2050.

Forests

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



Our results show that annual deforestation ranged between 0.6 Mha and 1.1 Mha from 2005-2015 and tended to decrease over time. This is higher than the net deforestation estimates from the Ministry of Environment and Forestry which show 0.82 Mha in 2006-2010 to 0.66 Mha in 2011-2016.

The deforestation peak is computed for 2030 at 1.2 Mha/year and declines thereafter. This is mostly driven by the expansion of the area under rice, oil palm, cocoa, coconut, and vegetable cultivation. Afforestation is computed from 2015-2050 and leads to a zero or slightly positive net forest cover change over 2035-2045.

Compared to the global target of having zero or positive net forest change after 2030, our results almost reach the target with a net afforestation over 2030-2045 and a slightly negative forest change in 2050 (-45 kha/year).

Other relevant results for national objectives

Table 1 | Other Results

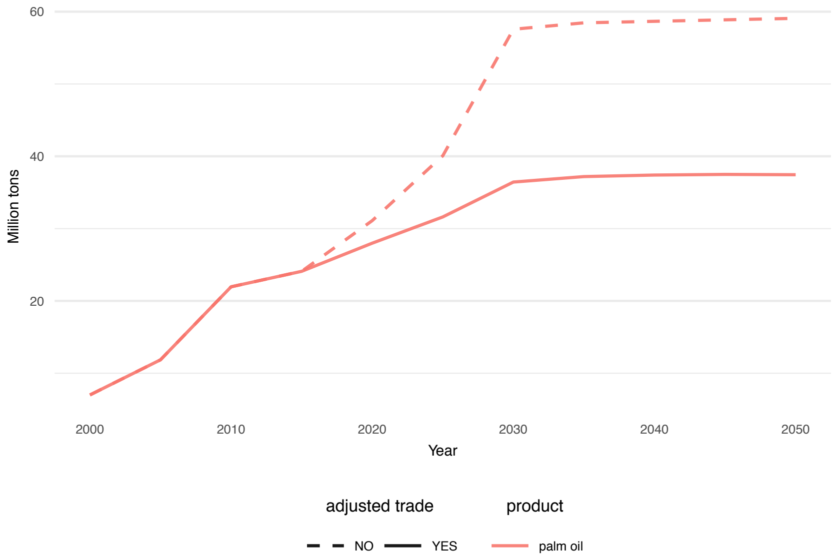
Variable	Unit	2000	2005	2010	2015	2020	2030	2040	2050
Palm oil									
Production (historical)	Mt	7.0	11.9	22.0					
Production (calculated)	Mt	7.0	11.9	21.9	24.1	31.1	57.6	58.7	59.1
Exports (calculated)	Mt	4.7	11.2	17.5	19.2	26.0	51.9	52.5	52.5

Source of historical data: FAOSTAT

Palm Oil production is projected to continue increasing until 2050. However, production begins to stabilize from 2030 onwards, reaching a level of 59 Mt in 2050. Historically, Indonesian exports amounted to approximately 32 Mt in 2015 (Kementerian Pertanian, 2016), which is higher than the calculated export quantities of 17.5 Mt. The projected exported quantities increase almost threefold until 2030, reaching 51.9 Mt compared to the calculated value for 2015. From 2035 to 2050, the exported quantities remain stable at 52.5 Mt.

Impacts of trade adjustment to ensure global trade balance

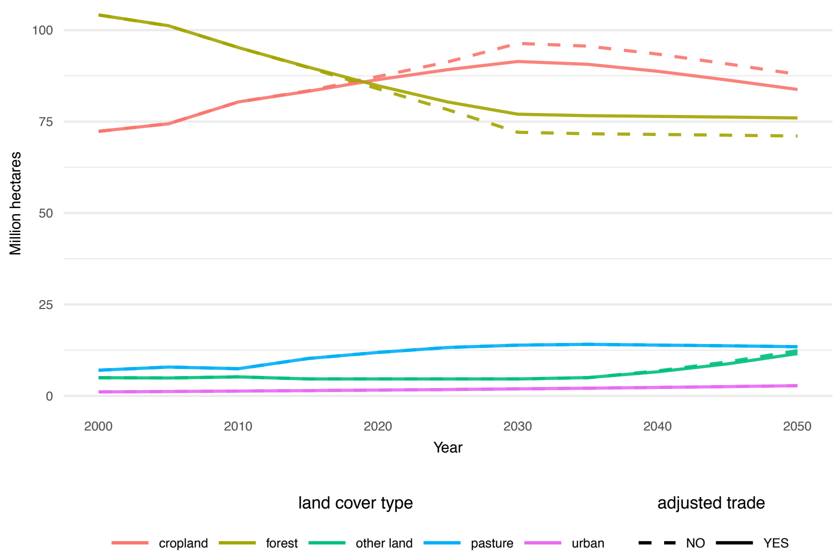
Fig. 12 | Impact of global trade harmonization on main exported/imported commodities over 2000-2050



Changes between the results with and without trade adjustment appear first in 2020 and become more pronounced from 2030 onwards, peaking in 2050 with a 41% reduction in palm oil exports compared to the results without trade adjustment. Historically, Indonesia's oil palm export amounted to 28 Mt in 2015, therefore our results tend to underestimate past growth in palm oil exports.

No change is observed between the results for imported commodities with and without trade adjustments.

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



The trade adjustment affects results concerning cropland and forested area starting in 2020. The cropland area declines by 4.7% and forest area increases by 7% by 2050 compared to no trade adjustment. This mostly results from the adjustment in palm oil exports after trade adjustment.

Discussion and next steps

In the context of the FABLE Scenathon, the Indonesian team has applied a set of assumptions to support pathways that help realize collective goals. The assumptions and some of the associated challenges and limitations of these initial results are discussed below.

Reflecting Indonesia's strong economic ambitions, per capita GDP increases by 19% in 2050, following the SSP1 scenario for GDP and the UN constant fertility scenario for population growth. The sustainable pathway scenario targets 2 Mha for ecosystem restoration by 2050. A moderate increase of crop and livestock productivity is set toward 2050 to maintain stable import volumes for all products with the exception corn and milk which increase and rice which decreases. The exported quantities of the main exported commodities strongly increase throughout the period. Food waste is set to decrease while the per capita consumption of cereals increases which leads to an increase in total calorie consumption per capita.

One of the main challenges faced in the process of refining the FABLE Calculator was setting limitations on certain values that can be achieved in a given time step. For example, in our scenario, we selected high productivity for corn. This resulted in the yield increasing from 4.6 to 16.3 tons per hectare. These numbers are currently unrealistic compared to the literature on maximum corn yields, which show a maximum of around 10 tons per hectare. There are also opportunities to refine the results concerning greenhouse gas emissions. These include, for example, capturing the various sources for peat emissions from the AFOLU sector in greater detail e.g. peat decomposition dynamics and the representation of peat fires.

Some of the strategic national policies should be better reflected in the Calculator. The Calculator places a strong emphasis on food production to meet a certain level of demand with limited consideration of land availability. In Indonesia, many farmers still practice slash and burn (shifting cultivation) in forest area that is characterized by low cropping intensity and low productivity compared to permanent agriculture. Increasing crop productivity and cropping intensity are the main targets for the agricultural sector to reduce demand for land. TORA (Tanah Objek Reforma Agraria) and Social Forestry (SF) are among the national policies which are designed to provide legal access to communities for owning and managing forest area. Under the TORA program, a community is provided legal certainty over land ownership within the forest area. With the legal ownership over the land, farmers will have access to government subsidies, credit, and extension services for supporting their farming activity on the land. Under the SF program, a community can be granted permits to manage the forest area for agroforestry or timber plantations (Community Timber Plantation-HTR, Community Forestry and Village Forest). The government has allocated approximately 4.9 million hectares and 12 million hectares of forest area for TORA and SF, respectively. These programs will contribute to the increase of crop production.

Our reforestation numbers come from the Indonesian private sector pledges made to the Bonn Challenge in 2015 and the historical reforestation rate trends in Indonesia. However, according to the Indonesian National Restoration plan, afforestation/reforestation should reach around 30 Mha (International Union for Conservation of Nature, 2015), mainly focusing on conservation areas. In the Indonesian context, reforestation means reforesting non-forested land in forest areas, while afforestation aims to reforest non-forested land in non-forest areas (APL).

In addition, the biodiversity aspects in the Indonesian FABLE Calculator also need more work in the future. In particular, the Calculator should be aligned with the different conservation statuses in Indonesia and our classification systems on protected areas, which are good methods for achieving unbiased results. Protected forest in Indonesia is classified into two functions: conservation forest (i.e. Nature Conservation Area) and protection forest (Hutan Lindung). In the draft Medium-Term Development Plan for Forestry, the conservation forest will be about 22.1 Mha and Protection Forest about 29.6 Mha (KLHK, 2018).

Finally, the one map policy is still in progress and will likely affect data availability and resolve some data inconsistencies among ministries. Collaboration among ministries working on low-carbon development needs to be improved and policies relating to future land demands across sectors need to be synchronized. Bringing together institutions and governmental and non-governmental organizations will help stakeholders understand the pathways needed for Indonesia to achieve sustainable food and land-use systems and guide their implementation.

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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Malaysia

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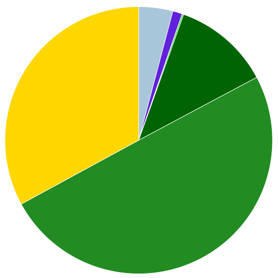
Land and food systems at a glance

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

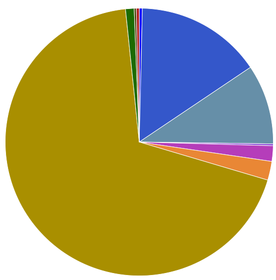
Land & Biodiversity

Fig. 1 | Area by land cover class in 2015



Source: Global Forest Watch

Fig. 2 | Share of harvested area by crop in 2012



Source: FAOSTAT

Annual deforestation in 2015:
70kha = 0.38% of total forest area

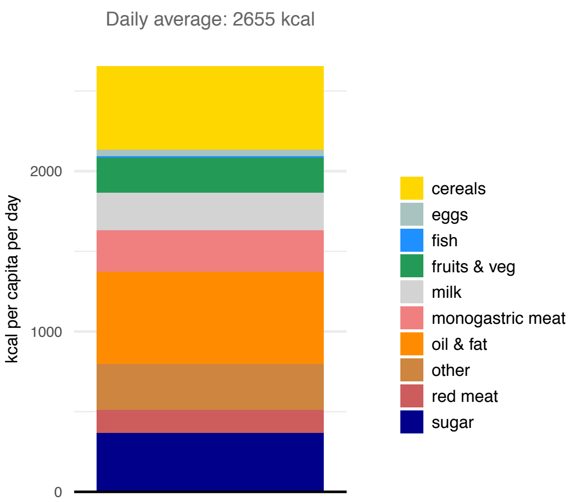
(UNFCCC and Ministry of Science, Technology, Environment and Climate Change, 2018)

Endangered species: 536

(IUCN Red List, 2019)

Food & Nutrition

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



Source: Zainuddin (2015)

Share of undernourished in 2015:
2.9%

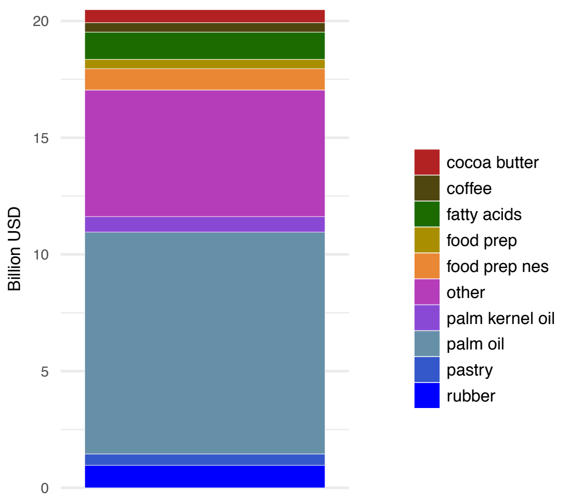
(World Bank, 2019)

Share of obese in 2016:
12.9%

(FAO, IFAD, UNICEF, WFP and WHO, 2018)

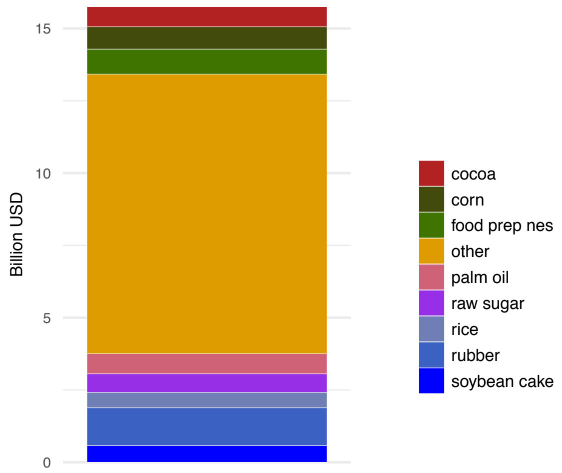
Trade

Fig. 4 | Main agricultural exports by value in 2015



Source: FAOSTAT

Fig. 5 | Main agricultural imports by value in 2015



Source: FAOSTAT

Deficit in agricultural trade balance in 2015: USD 4.7 billion

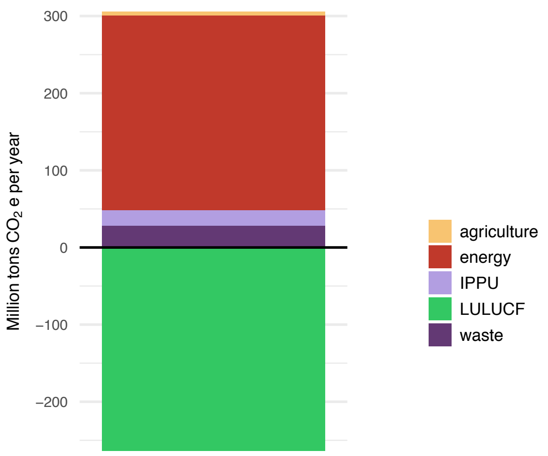
(FAOSTAT, 2019)

2nd most important palm oil exporter in the world in 2015

(FAOSTAT, 2019)

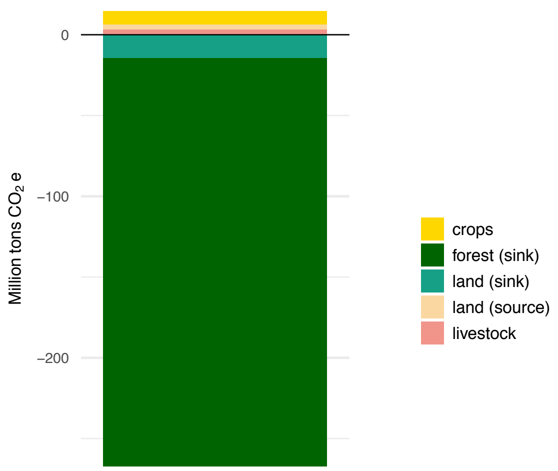
GHG Emissions

Fig. 6 | GHG emissions by sector in 2015



Source: 3rd NC and 2d BUR to the UNFCCC (2018)

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



Source: FAOSTAT

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 by 92.8% from USD 10,741 in 2015 to USD 20,713 in 2050 (SSP2 scenario selected).	Population is expected to increase by 43.9% between 2015 and 2050 from 30.7 mln to 44.2 mln (SSP2 scenario selected).
Scenario justification	Based on the International Monetary Fund – World Economic Outlook (2018), which forecasted a steady increase in Malaysia's nominal GDP per capita: USD 11,385 in December 2019 and USD 15,455 in December 2024.	Based on Department of Statistics Malaysia (2016), which projects that Malaysia's population will reach 41.5 mln by 2040.

TRADE

	Imports	Exports
Scenario definition	The share of total consumption which is imported is assumed to remain constant at 2010 levels for all commodities: - 100% for corn, - 97% for sugar, - 100% for wheat, - 100% for soybean, - 40% for rice, - 93% for milk, - 80% for beef, and - 20% for vegetables.	The exported quantity increases: - from 17.8 Mt in 2010 to 35.7 Mt in 2050 for palm oil, and - from 2.2 Mt in 2010 to 4.4 Mt in 2050 for palm kernel cake. The exported quantity remains constant at 2010 level for other products.
Scenario justification	Based on the Department of Statistics, Malaysia and the Ministry of Agriculture and Agro-based Industry (Department of Statistics Malaysia Official Portal, 2018).	Based on the Department of Statistics, Malaysia and the Ministry of Agriculture and Agro-based Industry (Department of Statistics Malaysia Official Portal, 2018).

Scenario signs no change small change large change

LAND

	Land conversion	Afforestation (large change)
Scenario definition	We assume that there will be no constraint on the expansion of agricultural land beyond existing protected areas and under the total land boundary.	We assume total afforested area will reach 2 Mha by 2045.
Scenario justification	Based on a projected 2.2% decline in land capable growing agrifood crops, from 870 kha in 2010 to 825kha in 2020. Forest areas also declined from about 6.1 Mha/year in 2010 to some 5.9 Mha in 2015 due to conversion of forests to other land uses. The rate of deforestation in the period was 0.66% yr-1 (Hamdan et al., 2016; Dardak, 2019).	Based on a positive historical reforestation trend from 33 kha/year in 2005 to 135 kha/year in 2010 (Hamdan et al., 2016; Raihan et al., 2017). Malaysia has not made a commitment to the Bonn Challenge, but it does target to retain 50% of its forest cover and is a signatory to international commitments such as CBD Aichi Target 15, UNFCCC REDD+ goal and the Rio+20 land degradation neutrality goal.

BIODIVERSITY

	Protected areas (no change)
Scenario definition	Protected areas remain constant over 2000-2050.
Scenario justification	There is a well-established trajectory in relation to forest biodiversity conservation through the establishment of Permanent Reserved Forest (PRF)/Permanent Forest Estates (PFE), which currently cover 14.5 Mha in Malaysia, collectively (Ministry of Natural Resources and Environment, 2014a). There is a clearly defined target in Malaysia's National Policy on Biological Diversity 2016-2025 (Ministry of Natural Resources and Environment, 2014b), under Goal 3, Target 6, which states "By 2025, at least 20% of terrestrial areas and inland waters, and 10% of coastal and marine areas, are conserved through a representative system of protected areas and other effective area-based conservation measures".

Scenario signs no change small change large change

FOOD

	Diet	Food waste
Scenario definition	Between 2015 and 2050, the average daily calorie consumption per capita remains quite stable from 2,600 kcal to 2,629 kcal. Per capita consumption: - decreases by 16.9% for cereals, - increases by 53.9% for monogastric animal meat, - increases by 142.2% for milk, - increases by 14.7% for oilseeds and oil, - increases by 23.7% for eggs, - increases by 0.4% for pulses, - increases by 72.9% for ruminant animal meat, - decreases by 11.3% for roots, and - decreases by 27.6% for sugar. For the other food groups, there is no large shift in consumption.	Between 2015 and 2050, the share of final household consumption which is wasted remains stable.
Scenario justification	Based on Zainuddin (2015) who found that the intake of energy among Malaysian adults falls short on recommended intake. Most of the studies in Malaysia on nutrient intake focuses on gender differences, instead of timeline comparison and projections. However, Lee and Muda (2019) specifically highlighted that fruit and vegetable intake was below recommended levels, while sugar and fat intake was substantially higher. This may lead to overweight and obesity.	Based on estimates that food waste is projected to increase from 4.4 Mt in 2005 to 6.5 Mt in 2020 (Abdul Hamid et al., 2012).

PRODUCTIVITY

	Crop productivity	Livestock productivity	Pasture stocking rate
Scenario definition	Between 2015 and 2050, crop productivity increases: - from 2.5 t/ha to 3.53 t/ha for rice, - from 61.9 t/ha to 67.6 t/ha for oil palm fruit, and - from 0.9 t/ha to 1.2 t/ha for rubber.	Between 2015 and 2050, productivity per head increases: - from 1t/TLU to 2.4 t/TLU for cattle milk, - from 0.5 kg/head to 0.55 kg/head for poultry meat, and - doubles for beef meat.	The average ruminant stocking density remains constant at 2.1 TLU/ha per pastureland.
Scenario justification	Based on data from Selected Agricultural Indicators from the Department of Statistics of Malaysia (2018). The sources contained in the DOSM data include Booklet of Crop Statistics (Food Crops Sub-sector) – Department of Agriculture Malaysia (2012), Malaysian Palm Oil Board, Malaysian Cocoa Board, Malaysian Pepper Board and National Kenaf and Tobacco Board) and the USDA (2019).	Based on efforts to ensure adequate supply of poultry and eggs for the domestic market and to capitalize on export markets, as well as to develop Malaysia's potential as an international halal food hub (Prime Minister's Office, 2019). Livestock productivity increases based on projected agro-food production (Bakar et al., 2012).	

Scenario signs (=) no change (→) small change (↗) large change

Diet: small change; Food waste: no change; Crop productivity: large change; Livestock productivity: large change; Pasture stocking rate: no change.

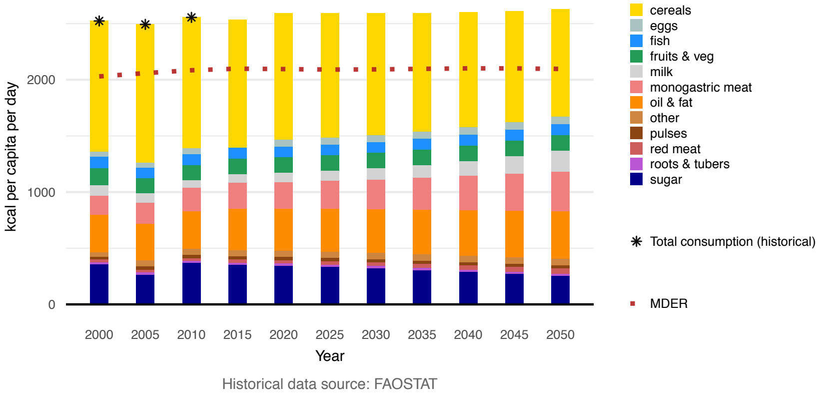
Results against the FABLE targets

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 kilocalorie 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.



Our results show average daily energy intake per capita increases between 2,438 and 2,510 kcal/cap/day from 2000-2015. This is 5% lower than FAO due to some products not being taken into account into our calculation. Calorie intake reaches 2,512 over the period 2031-2035 and 2,550 kcal/cap/day over the period 2046-2050. In terms of recommended diet, our results show lower consumption of cereals.

The computed average calorie intake is higher than the Minimum Dietary Energy Requirement (MDER) at the national level in 2030 and in 2050.The recommended average daily dietary energy consumption per capita for energy requirements for a moderately active adult in Malaysia ranges from 1,840 to 2,240 kcal/cap/day (according to gender and body weight), based on Malaysia's Ministry of Health report.

Biodiversity

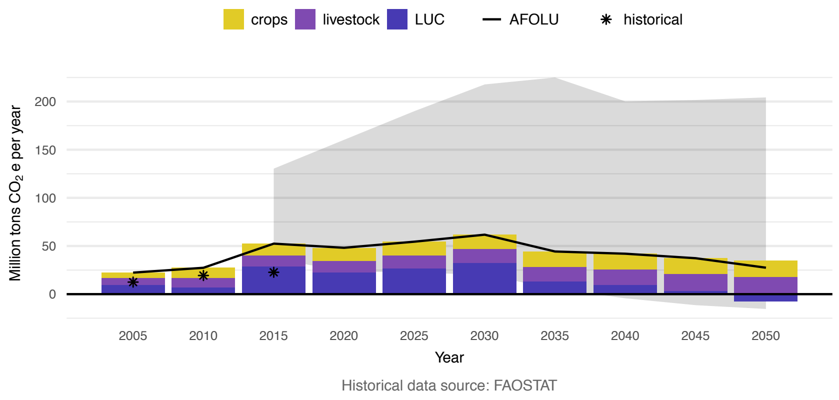
Fig. 9 | Computed share of the total land which could support biodiversity over 2000-2050

Our results show that the Share of Land which could support Biodiversity (SLB) decreased between 2000-2015 from 78% to 77%. The lowest SLB is computed for the period 2046-2050 at 73% of total land. This is mostly driven by forest conversion to cropland. SLB reaches 73% over the last period of simulation, 2046-2050. This decline is due to the reduction in forest cover which is only partly offset by higher afforested area.

Compared to the global target of having at least 50% SLB by 2050, our results are above the target. Other supporting national plans to help increase biodiversity conservation in Malaysia include the National Tiger Conservation Action Plan for Malaysia 2008-2020 and the Malaysian National Elephant Conversation Action Plan 2013-2022 (Economic Planning Unit, 2017).

GHG emissions

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



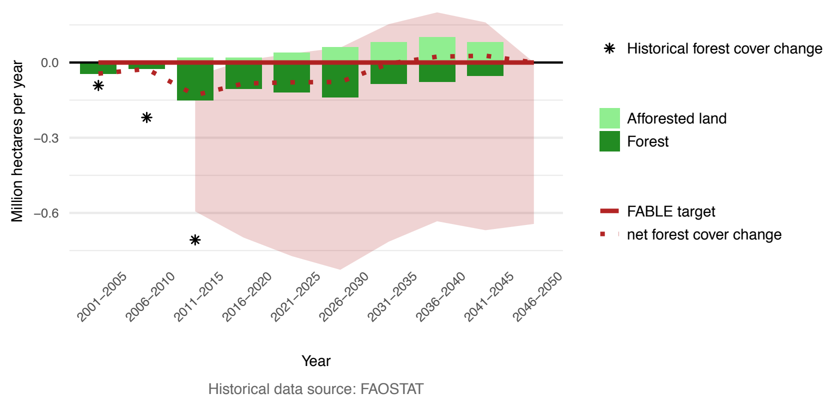
Note: AFOLU (Agriculture, Forestry and Other Land Use) is the sum of computed GHG emissions from crops, livestock and Land Use Change (LUC), emissions and sequestration from forestry are not included. Historical emissions include crops and livestock.

Our results show annual GHG emissions between 10 and 52 MT CO_2e from 2000-2015, which increase over time. These are higher than stated in the Malaysia Third National Communication and Second Biennial Update Report to the UNFCCC which estimates a net carbon sink of 0.9 Mt CO_2e/year over the same period and an increasing trend. Our results on GHG emissions from agriculture are also above FAO statistics (+20% in 2000, +65% in 2015). Peak AFOLU GHG emissions are computed for the period 2026-2030 at 62 Mt CO_2e/year. This is mostly driven by GHG emissions from LULUCF. AFOLU GHG emissions reach 27 Mt CO_2e over the period 2046-2050: 17 Mt CO_2e from crops, 18 Mt CO_2e from livestock and -7 Mt CO_2 from LUC. Zero net emissions from LULUCF by 2050 are mainly explained by afforestation.

Compared to the global target of reaching zero or negative GHG emissions from LULUCF by 2050, our results meet the target. Our results show that there needs to be a decrease in deforestation in order to achieve zero or negative GHG emissions from LULUCF by 2050.

Forests

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



Our results show annual deforestation between 25 kha/year and 125 kha/year over 2000-2015 and which increases over time. This is lower than the deforestation estimates from Global Forest Watch (between 287 and 454 kha/year) but higher than the net forest cover change reported by FAO (140 kha of deforestation over 2000-2005 but with net forest gain over 2005-2015). Peak deforestation is computed for the period 2010-2015 at 150 kha/year. This is mostly driven by cropland expansion. Afforestation is computed for 2016-2045 at 100 kha/year maximum over 2035-2040.

Compared to the global target of having zero or positive net forest change after 2030, our results are below the target, but this target is met from 2040 onwards. With 60% of the total area covered by forest in 2050, our results meet a national pledge of having 50% of land area retained as forest cover (Convention on Biological Diversity, 2019).

Other relevant results for national objectives

Table 1 | Other Results

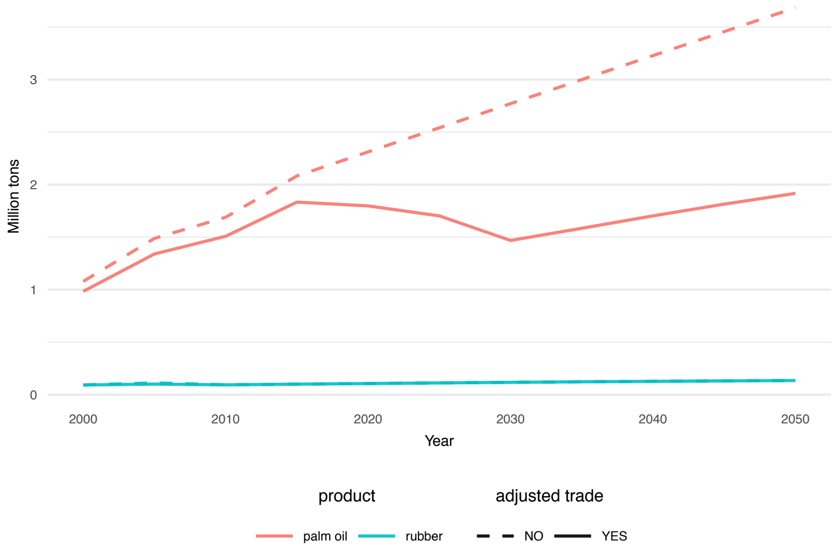
Variable	Unit	2000	2005	2010	2015	2020	2030	2040	2050
Area by land cover									
Cropland (historical)	Mha	6.7	6.9	7.2					
Cropland (calculated)	Mha	6.7	6.9	6.9	7.4	7.6	8.0	8.2	8.3
Pasture (historical	Mha	0.3	0.3	0.3					
Pasture (calculated)	Mha	0.3	0.4	0.3	0.4	0.5	0.5	0.5	0.5
Forest (historical)	Mha	21.6	20.9	20.5					
Forest (calculated)	Mha	21.6	21.4	21.2	20.5	20.0	18.7	17.9	17.6
Afforested land (calculated)	Mha	0.0	0.0	0.0	0.1	0.2	0.7	1.6	2.0
Otherland (historical)	Mha	4.2	4.8	4.9					
OtherLand (calculated)	Mha	4.0	4.0	4.1	4.0	4.0	3.8	3.5	3.4
Urban (calculated)	Mha	0.2	0.2	0.3	0.4	0.6	1.1	1.1	1.1

Source of historical data: FAOSTAT

Our results align well with observed historical trends. In addition to the current pledge of retaining 50% of land as forest cover, additional national level afforestation targets need to be set to further maintain the amount of forest cover and limit the amount of conversion due to future expansion of crop and urban land.

Impacts of trade adjustment to ensure global trade balance

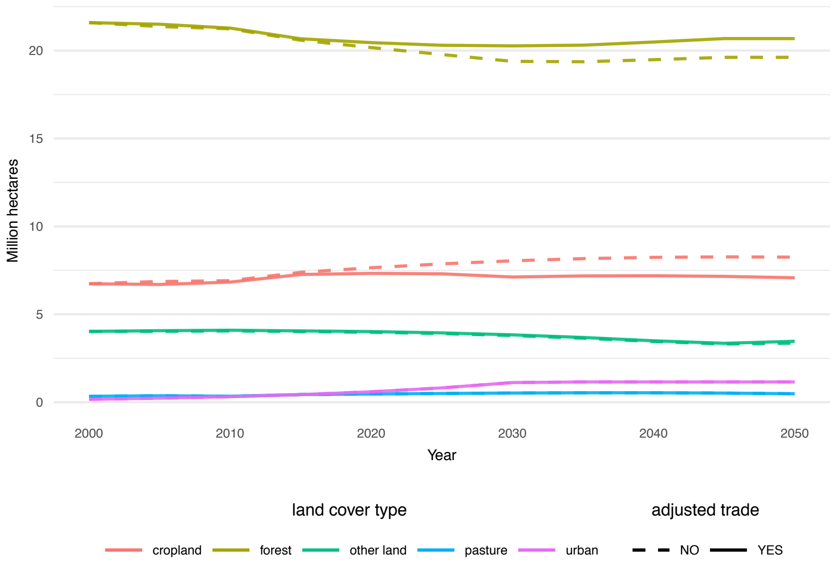
Fig. 12 | Impact of global trade harmonization on main exported/imported commodities over 2000-2050



Only oil palm was chosen, as it is Malaysia's main export commodity. The change in exports compared to no trade is evident beginning in 2000, when it increases and is continuously increasing at a high rate. When trade is not adjusted, exports reach up to more than 35 mln tons in 2050.

Trade adjustments made no change to imports of corn, milk, soycake, and wheat.

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



There is a clearly observed difference in cropland area when trade is adjusted, which is likely due to continuing expansion in oil palm plantations.

Discussion and next steps

Malaysia is a tropical developing country that covers an area of approximately 33.2 Mha, consisting of Peninsular Malaysia, the states of Sabah and Sarawak in the eastern region and the Federal Territory of Labuan in the northwestern coastal area of Borneo Island. The two regions of Eastern and Peninsular Malaysia are separated by about 540 km of the South China Sea. Malaysia is among the 12 mega-diverse countries in the world and is globally recognized via its significant representation of several G200 Ecoregions in East and West Malaysia, including tropical lowlands, mangroves, peat and montane forests, as well as its marine ecoregions. Historically, large scale plantations were introduced by the British for crops such as rubber, palm oil, and cocoa, which have been maintained until today. Agriculture makes up 12% of Malaysia's GDP.

The assumptions and scenarios in this chapter outline our initial findings for a sustainable food and land-use pathway for Malaysia. According to this pathway, GDP and population will grow following the "Middle of the Road" scenario. Productive land under the total land boundary could continue to expand while at the same time retaining 50% of forest cover (as per Malaysia's pledge to the Rio Earth Summit 1992). In terms of productivity, we assume the same productivity growth as per 2000-2010, which would lead to an increase of main crops such as rice, oil palm, and rubber. This is similar for the case of livestock productivity, which we expect to increase for cattle milk, poultry meat, and eggs. Imports are expected to increase proportionally with demand and palm oil exports are also expected to increase. The consumption of meat, a staple of the Malaysian diet, is expected to further increase.

In the future, there are several limitations that we would like to address in the FABLE Calculator. Firstly, the Calculator calculates values based on global databases, which do not necessarily reflect local contexts. Secondly, in Malaysia, reported forest data comes from three different national sources, and is divided into Peninsular Malaysia, Sabah, and Sarawak. Forest definitions should be adapted to better reflect these geographic divisions.

While Malaysia does not have a set of afforestation targets as per the Bonn Challenge, it is committed to retaining 50% of forest cover, and is a signatory to international commitments such as United Nations Convention on Biological Diversity (CBD) Aichi Target 15, United Nations Framework Convention on Climate Change (UNFCCC) Reducing emissions from deforestation and forest degradation (REDD+) goal, and the Rio +20 land degradation neutrality goal. The Calculator only offers two scenarios for afforestation, which are "no afforestation target" and "Bonn Challenge". This is a third limitation as Malaysia's target to retain forest cover does not fall into either category and choosing one over another leads to discrepancies. Therefore, while we opted to select the more ambitious target it does not reflect the Malaysian context as well as we would like.

Fourth, in Malaysia, biodiversity conservation is pursued through the establishment of Permanent Reserved Forest (PRF) and via a network of Protected Areas (PAs) (both terrestrial and marine), which includes Wildlife Sanctuaries, National and State Parks, Nature Reserves and Protection Forests within the PRFs. The PAs are governed by different laws with varying degrees of protection status, as well as gazettal and de-gazettal procedures. In the future, we will seek to make the Calculator's definitions of "Protected Areas" and land conversion more specific so they can better support policy-oriented outcomes.

Finally, the dietary scenario does not take into account the status of malnutrition in the country.

In Malaysia, the recommended daily intake of energy is broken down by age group, gender, and level of activity of the individual, as reported by the Ministry of Health. This is the ideal case scenario, which we hope to incorporate in the Calculator in the future. We also hope to look at issues related to malnutrition, such as stunting and obesity.

Some of the core challenges for the realization of this sustainable food and land-use pathway in Malaysia include: poor accessibility of national documents; a lack of government monitoring infrastructure; a lack of data availability; a dearth of existing research on FABLE systems; limited consideration for environmental issues in policymaking; and weak enforcement mechanisms and legal precedence in environmental laws. Broadly, there is no constitutional protection for the right to a clean and low carbon environment.

In conclusion, Malaysia needs to be more ambitious in setting targets for a better environment. Malaysia is on the right economic-growth trajectory but falls short on socio-environmental equity. Projections developed as part of FABLE are crucial tools to raise greater awareness among Malaysians, in particular regarding what is to come by 2050. Therefore, we need to take the output data for mitigation and adaptation measures seriously. A deep decarbonization pathway needs to be pursued for a low carbon future. We also need to aspire to conserve forest and biodiversity the best we can via setting afforestation targets and increasing protected areas. Viable technological advancements and solutions should be taken into consideration in order to achieve such targets. More studies need to be undertaken in various sectors, including food, production, agricultural trade, biodiversity conservation, land use management, and greenhouse gas emissions. Strong political will be needed to achieve all this and push forward socio-environmentally just agendas for a sustainable future.

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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Mexico

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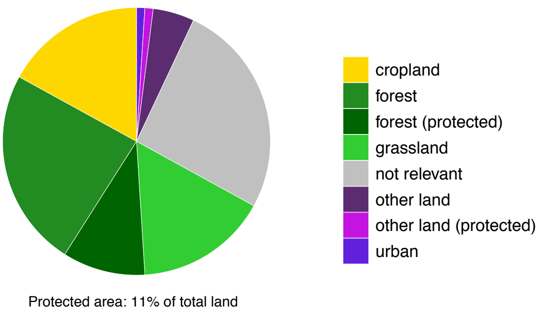
Land and food systems at a glance

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

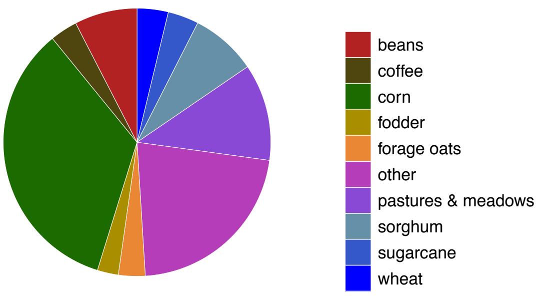
Land & Biodiversity

Fig. 1 | Area by land cover class in 2015



Source: INEGI (2015)

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



Source: SIAP (2017)

Annual deforestation in the period 2011-2014: 251.2kha per year^{-1} = 0.3% of total forest area

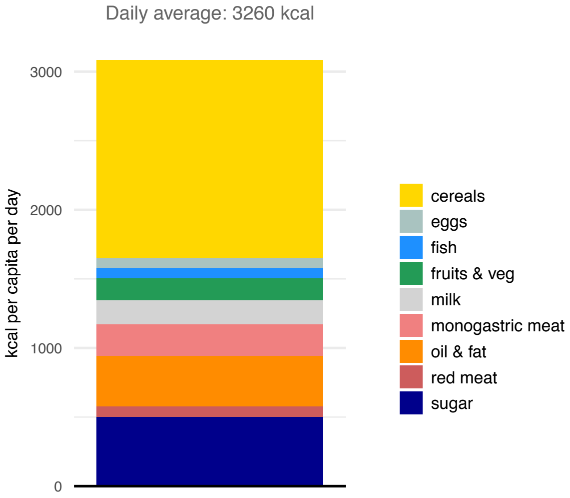
(INECC, 2018)

Endangered species in 2016: 2,606

(CONABIO, 2019)

Food & Nutrition

Fig. 3 | Daily average intake per capita at the national level in 2012



Source: SADER (2012)

Share of undernourished in 2015: 4%

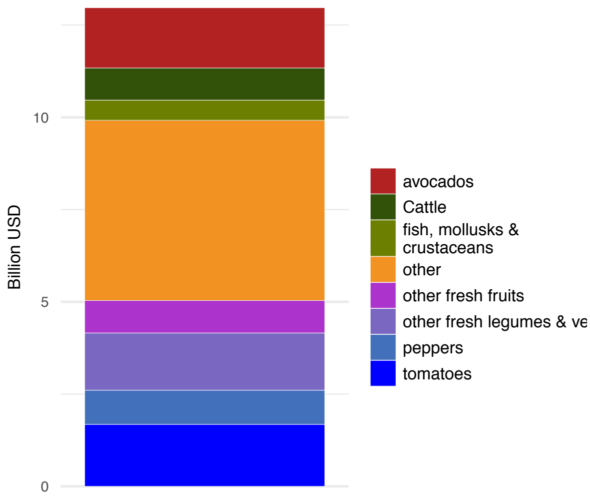
(World Bank, 2019)

Share of obese in 2015: 32.4%

(OECD, 2017)

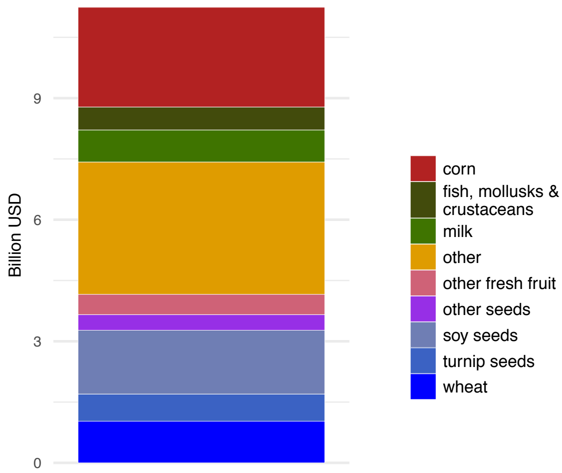
Trade

Fig. 4 | Main agricultural exports by value in 2015



Source: Bank of Mexico (2015)

Fig. 5 | Main agricultural imports by value in 2015



Source: Bank of Mexico (2015)

Surplus in agricultural trade balance in 2015: USD 1.7 bln

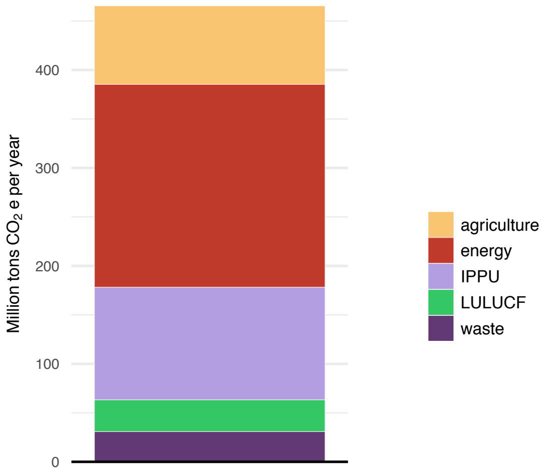
(Bank of Mexico, 2015)

11th most important exporter and 13th most important importer in the world in 2015

(Central Intelligence Agency, 2017)

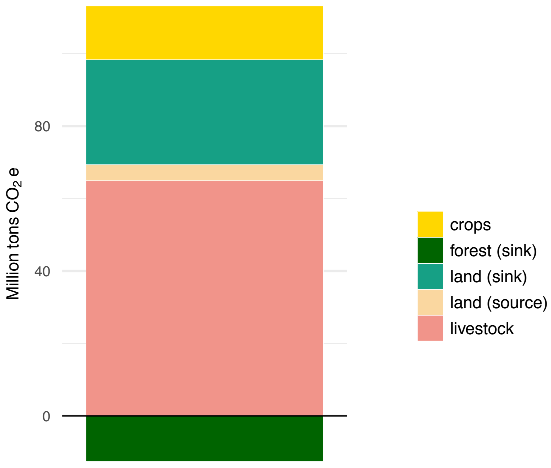
GHG Emissions

Fig. 6 | GHG emissions by sector in 2015



Source: INECC (2015)

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



Source: INECC (2015)

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 by 21.6% from USD 9,611 in 2015 to USD 23,044 in 2050 (SSP2 scenario selected).	The population is expected to increase by 4% annually between 2015-2050, from 125 mln in 2015 to 145 mln in 2050 (UN low growth scenario selected).
Scenario justification	Based on Mexico GDP growth forecast 2018 – 2020 and up to 2060. According to IMF estimates, Mexican GDP will reach USD 3.2 tln by 2050 or USD 21,567 per capita using our population projections. The SSP2 scenario most closely reflects these estimates (OECD, 2018).	According to projections of the National Population Council (CONAPO, 2018), the population will grow at a decreasing rate, with low mortality and fertility. The CONAPO projects that by 2050 the population will reach 148 mln, which roughly matches the chosen scenario.

TRADE

	Imports	Exports
Scenario definition	The share of total consumption which is imported increases: - from 20% in 2010 to 40% in 2050 for milk, - from 9% in 2010 to 18% in 2050 for beef, and - from 26% in 2010 to 53% in 2050 for corn. The share of total consumption which is imported is fixed at 2010 levels for all other products.	The export quantity increases from 2010 to 2050: - from 1.4 Mt to 2.1 Mt for tomatoes, - from 5 kt to 7 kt for peppers, and - from 1 Mt to 1.5 Mt for fruits. The exported quantity remains constant at 2010 levels for the other commodities.
Scenario justification	Mexican imports have been increasing since 1994, hence we chose a scenario that reflects this trend. We selected imports that require more agricultural expansion (milk, beef, and corn for animal feed) (OEC, 2018a).	Mexican exports have been increasing since 2000, hence we chose a scenario that reflects this trend. We selected pepper, tomatoes, and fruits since their export has increased since 2000 (OEC, 2018b).

Scenario signs no change small change large change

LAND

	Land conversion	Afforestation
Scenario definition	We assume no expansion of agricultural land beyond 2015 agricultural area levels.	We assume total afforested area will reach 8.47 Mha by 2050.
Scenario justification	Based on the Agricultural National Plan 2017-2030 (SAGARPA, 2017), which states that Mexico will not expand its agricultural area beyond the 2016 extent. This assumption is also supported by (Armenteras et al., 2017; García-Barrios et al., 2009; Ibarrola-Rivas and Granados-Ramírez, 2017; Mas et al., 2004). Under the Nationally Determined Contributions (NDCs) Mexico has also committed to reach zero deforestation by 2030 (INECC, 2018).	Based on Mexico's 2014 commitment to reforest 8.47 Mha by 2020 as part of the Bonn Challenge (Bonn Challenge, 2014; INECC, 2018). While there is no reforestation target beyond 2020, afforestation would occur in some of the most deforested states in Mexico, paying particular attention to tropical and subtropical moist forest and tropical dry and temperate forests.

FOOD

	Diet	Food waste
Scenario definition	Between 2015 and 2050, the average daily calorie consumption per capita increases from 2,512 kcal to 2,717 kcal. Per capita consumption: - increases by 27% for ruminant meat, - increases by 25% for vegetable oils, - increases by 34% for sugar, - increases by 9% for fruits and vegetables, - increases by 10% for pulses, - increases by 90% for other, including nuts, and - remains constant for cereals and milk.	Between 2010 and 2050, the share of final household consumption which is wasted decreases from 10% to 5%.
Scenario justification	Dietary changes across populations are difficult to achieve, Mexican health authorities have been advancing on addressing the unhealthy food habits that had caused a nutritional epidemic. The Mexican Health Department recommends a more active lifestyle and reduced consumption of processed foods and sugars. It also recommends lower consumption of animal protein among middle and high urban income homes; increased consumption is recommended for low urban and rural homes where animal protein intake is below the dietary recommendations. The recommendations of middle-of-the-range physical activity levels has a strong focus on whole grains and cereals (Barquera et al., 2013; Bonvecchio-Arenas et al., 2013; Ibarrola-Rivas and Granados-Ramírez, 2017; Rivera et al., 2004; Stevens et al., 2008). Dietary changes across populations are difficult to achieve, Mexican health authorities have been advancing on addressing the unhealthy food habits that had caused a nutritional epidemic. The diet that we have created should be accomplished with a minimum amount of processed foods. Despite these recommendations there are not specific measures to implement these recommendations.	While we were unable to identify research or data on food waste in Mexico to justify this scenario, preliminary data suggest that food waste in Mexico might be higher than 10%. We aimed for large reductions as it is beneficial in our view to pursue maximum efforts to reduce food waste.

Scenario signs no change small change large change

BIODIVERSITY

	Protected areas (no change)
Scenario definition	Protected areas remain constant between 2015 and 2050.
Scenario justification	In 2018, Mexico had 16% of its total area to conservation under protection (Protected Areas) which includes natural parks, biosphere reserves and, more recently, private lands voluntarily set aside for conservation. Other instruments of protection, where we do not know the full amount of area covered, include payment for environmental services, units for environmental management and sustainable forest management (CONANP-SEMARNAT, 2017; Pisanty et al., 2016). These other instruments of protection work by increasing the selected area's conservation value by protecting and maintaining its biodiversity and ecological functions. We assume that instead of creating additional protected areas, Mexico will work to sustainably manage and promote activities that increase the conservation value of its land.

PRODUCTIVITY

	Crop productivity (large change)	Livestock productivity (large change)	Pasture stocking rate (large change)
Scenario definition	Crop productivity increases: - from 2.5 t/ha in 2000 to 7.4 t/ha in 2050 for corn, and - from 0.6 t/ha in 2000 to 1.2 t/ha in 2050 for beans.	Between 2015 and 2050, the productivity per head increases: - from 55 kg/head to 86 kg/head for beef, - from 1 kg/head to 1.2 kg/head for chicken, - from 1.6 kg/head to 1.9 kg/head for eggs, - from 5.4 t/head to 8.44 t/head for cow milk, and - from 75 kg/head to 126 kg/head for pork meat.	The average livestock stocking density increases from 0.32 TLU/ha to 0.46 TLU/ha between 2015 and 2050.
Scenario justification	Based on the Agricultural National Plan 2017-2030 (SAGARPA, 2017), one of the main goals of which is to increase corn and bean productivity without increasing the production area. Compared to 2015, corn production could potentially increase by between 2.3% and 4% by 2030 depending on the type of corn. Combined, it could reach a national average of 6.2 t/ha. In the case of beans, yields could potentially double by 2050 from 0.7 t/ha to 1.4 t/ha.	Based on the Agricultural National Plan 2017-2030 (SAGARPA, 2017), one of the main goals of which is to increase livestock productivity without increasing the area of productive land (Monterroso Rivas and Gomez Diaz, 2003; SAGARPA and FAO, 2012).	In Mexico, one of the objectives regarding livestock has been to increase production by promoting feed lots for beef production. While there is very little information on the pasture stocking rate for Mexico, cattle ranching has risen due to beef demand so we assume that the density of cattle per hectare has also grown as result of government incentives to improve productivity (Monterroso Rivas and Gomez Diaz, 2003; SAGARPA and FAO, 2012).

Scenario signs = no change → small change ↗ large change

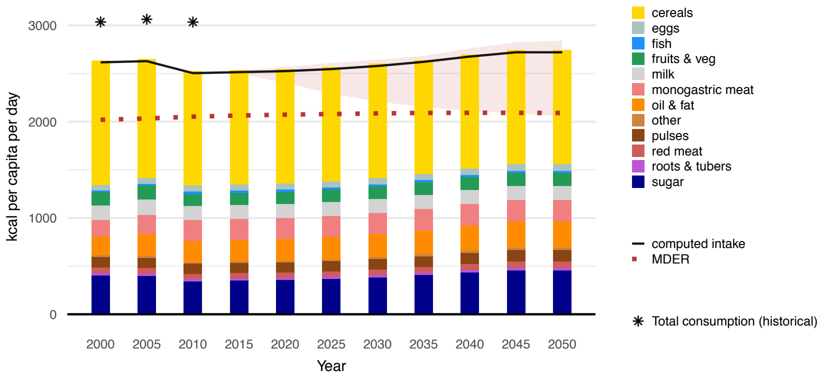
Results against the FABLE targets

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.



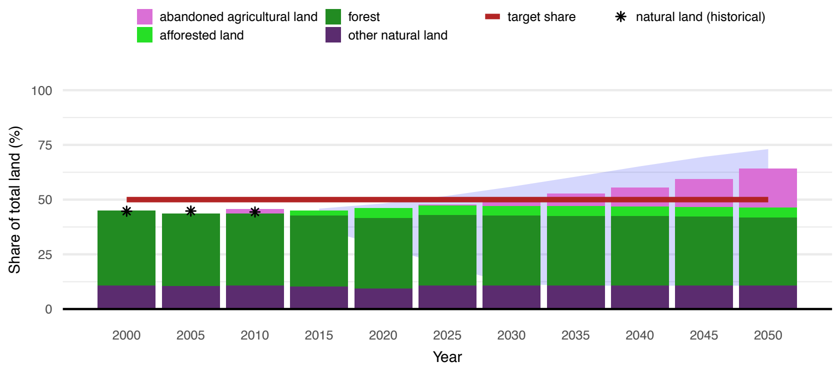
Historical data source: FAOSTAT

Our results show an increase in average daily energy intake per capita from 2,536 in 2015 to 2,777 kcal/cap/day in 2050. The computed average calorie intake is 35% higher than the Minimum Dietary Energy Requirement (MDER) at the national level in 2050 and is a direct result of the middle physical activity lifestyle selected.

In terms of recommended diet, our results suggest that continuing current trends might lead to a significant deviation compared to the national food security objective of reducing obesity thanks to an increase in physical activity, a reduction in sugars, oils, and dairy (Behrens et al., 2017) (Barquera et al., 2013). However, recommendations should not be made across all population equally. Rural and urban low income populations do not consume enough animal protein while middle to high income urban populations exceed the healthy recommendation (Rivera et al. 2014).

Biodiversity

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



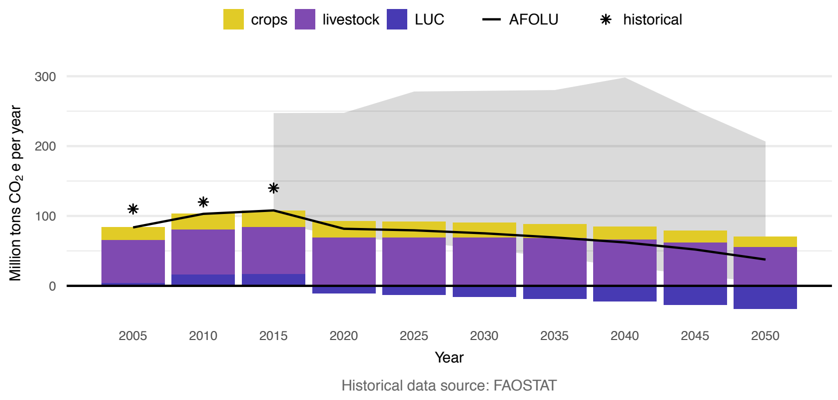
Historical data source: FAOSTAT

The Share of terrestrial Land that could support Biodiversity (SLB) remains constant over 2010-2015 at 45%. This is slightly below Gonzalez-Abraham et al. (2015), who estimate that 56% of the terrestrial area with vegetation cover is in a reasonably good environmental condition. The SLB increases after 2020 due to afforestation and abandonment of agricultural land.

Compared to the global target of having at least 50% of SLB by 2050, our results are above the target. Specifically, Mexico would reach the target in 2035 and reach 65% SLB in 2050.

GHG emissions

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



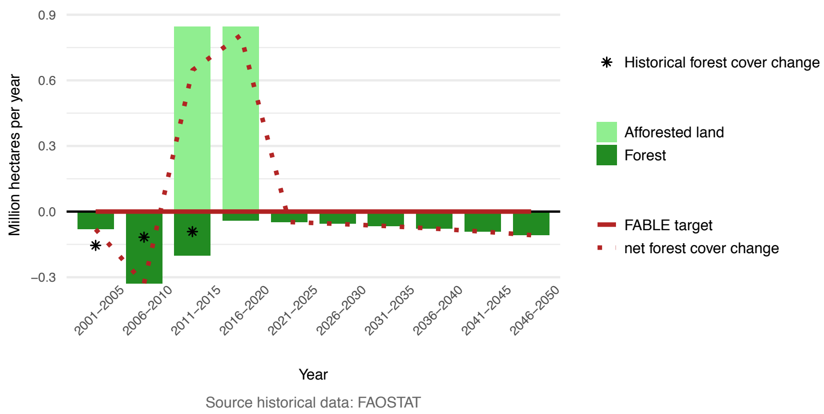
Note: AFOLU (Agriculture, Forestry and Other Land Use) is the sum of computed GHG emissions from crops, livestock and Land Use Change (LUC), emissions and sequestration from forestry are not included. Historical emissions include crops and livestock.

GHG emissions from land-use change first increase until 2015 and then go from being a net source to a net sink of CO_2. Total GHG emissions increase until 2015, when they reach 110 Mt CO_2e per year. This peak concurs with national data. Our results for total AFOLU emissions in 2015 are 110 Mt CO_2e, whereas the national assessment shows 102 Mt CO_2e (INECC, 2018).

Our results show that crop and livestock emissions increase slightly after 2005, peak in 2025 at 90 Mt CO_2e before slowly decreasing until 2050. The most important source of GHG emissions is livestock production, which, despite a decreasing trend starting in 2035, remains a major emitter until 2050. Our projections are fairly consistent with national assessments (INECC, 2018).

Forests

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



The results show a peak in deforestation for the period 2006-2010 with a loss of 0.3 Mha/year. The growth of afforested land due to the Bonn Challenge commitment leads to a positive net forest cover change in 2010-2015 and in 2015-2020. This leads to a net forest cover change between 2000-2015 of 1.2 Mha loss compared to 1.8 Mha according to FAO. National studies show that during the period 2010-2015, deforestation decreased and reached the historically low level of 0.458 Mha (INECC, 2018). We assume no afforestation after 2020, which is in line with Mexico's current commitment.

In Mexico the expansion of agricultural land and cattle ranching are the main drivers of forest loss (Mas et al., 2004; García-Barrios et al., 2009; Armenteras et al., 2017; SEMARNAT, 2015). However, our results show that despite no expansion of productive land, there is still some deforestation in the period 2021-2025 due to urban expansion.

Other relevant results for national objectives

Table 1 | Other Results

Variable	Unit	2000	2005	2010	2015	2020	2030	2040	2050
Trade									
Trade balance	Bln USD	-1.86	-2.32	-0.65	0.14	-0.06	0.38	-0.56	-1.22
Production quantities of selected commodities									
Corn (historical)	Mt	17.56	19.34	23.30					
Corn (calculated)	Mt	17.38	17.29	18.94	20.36	20.55	20.04	18.73	16.81
Beans (historical)	Mt	0.89	0.83	1.16					
Beans (calculated)	Mt	0.88	0.81	1.14	1.33	1.40	1.51	1.59	1.60
Beef (historical)	Mt	1.41	1.56	1.74					
Beef (calculated)	Mt	1.40	1.54	1.72	1.84	1.94	2.13	2.36	2.38
Mutton Goat (historical)	Mt	0.07	0.09	0.10					
Mutton Goat (calculated)	Mt	0.07	0.09	0.09	0.10	0.11	0.12	0.14	0.14
Pork (historical)	Mt	1.03	1.10	1.17					
Pork (calculated)	Mt	1.02	1.09	1.16	1.25	1.31	1.39	1.41	1.40
Chicken (historical)	Mt	1.87	2.48	2.72					
Chicken (calculated)	Mt	1.85	2.46	2.70	2.89	3.04	3.21	3.27	3.25

Source historical data: FAOSTAT

Compared to the Mexican National Institute of Statistics and Geography (INEGI, 2019b), our results do not diverge from recent historical trends in the Mexican trade balance, where a trade deficit in agricultural products is the norm. However, since 2015 this trend has reversed, reaching USD 1.7 bln (INEGI, 2019b). Our results show fluctuations from USD -0.67 bln to a maximum surplus of USD 0.57 bln in 2030. After 2035, our results show a growing deficit until 2050. Mexico does not have a national objective for trade besides the commercial treaties already in place or in negotiation.

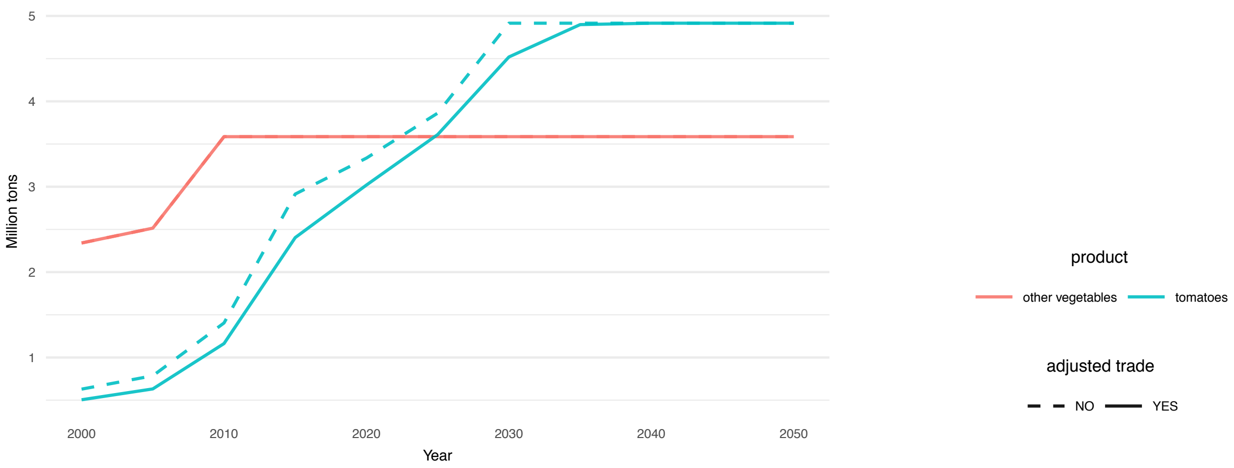
Our results show that corn production increases until 2020 and decreases from 2020-2050. This is based on the assumption that a higher share of internal consumption will be met by imports. The combination of higher imports and higher productivity results in a decline in corn harvested area from 6 Mha in 2015 to 2.3 Mha in 2050. Our results are inconsistent with national projections which show a general reduction in yields due to higher instabilities in production due to climate change (SAGARPA and FAO, 2012).

Our results show that bean production (second most important crop) increases from 2015 until 2050. The assumption of higher productivity results in a decline of harvested area from 1.9 Mha in 2020 to 1.3 Mha in 2050 without compromising its production. Our results are inconsistent with national projections that show production instability and lower yields due to climate change (SAGARPA & FAO, 2012).

Livestock production increases, stabilizes, then falls very slightly for all meat products, including beef, goat, lamb, pork, and chicken. This trend is the result of an increase in animal protein consumption assumed in the selected diet (Rivera et al., 2004). Mexico does not have livestock production projections.

Impacts of trade adjustment to ensure global trade balance

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

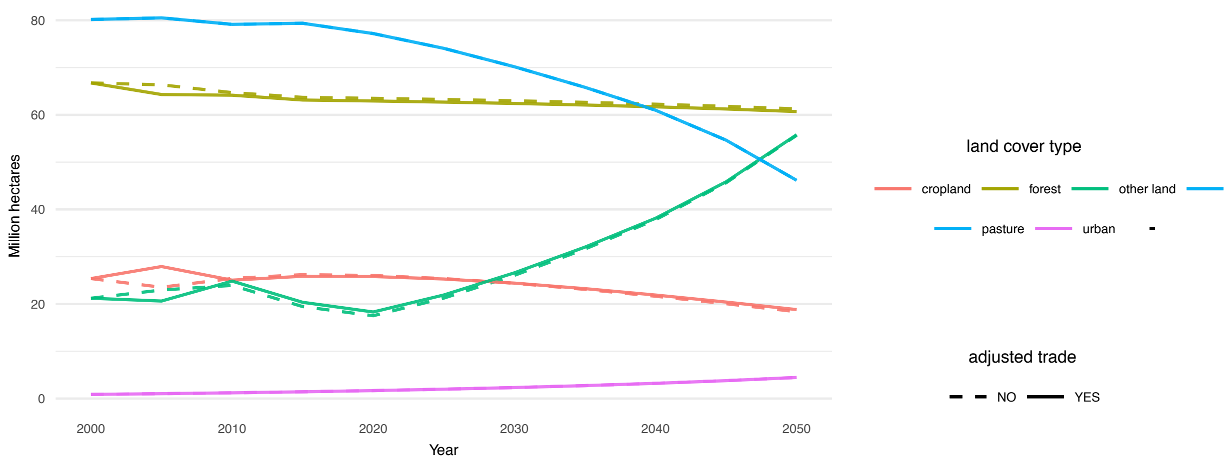


The evolution in exports compared to no trade adjustment for tomatoes and fruits is very slight. With trade adjustment, production decreases by less than 20% between 2015 and 2030. Beginning in 2035, there is no difference between the two scenarios.

Between 2010 and 2030, the evolution of exports compared to no trade adjustment for other vegetables is 72% lower by 2030.

There is no significant change in the imports of key commodities when the trade adjustment is applied.

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



Land-Use Change trends are mostly unaffected by the trade adjustment. Cropland area continues to decline and forests, pasture, and urban areas all remain unchanged. Trade adjustment increases the amount of cropland reduction beginning in 2015. Other land is positively affected and increases its area, thus mirroring cropland loss.

Discussion and next steps

Our results are driven to a large extent by the livestock sector and the evolution of cattle and pasture productivity. Livestock is expected to be the main source of greenhouse gas emissions in the Agriculture, Forestry, and Other Land Use sector, while at the same time abandoned pastures, thanks to pasture productivity, increasingly play an important role in carbon sequestration. However, it is difficult to assess the realism of our results as there are large data gaps on the carrying-capacity, density, and spatial distribution of cattle and, even more importantly, on the ecological effects of free-range cattle ranching.

There are several key limitations to the FABLE Calculator that are important to highlight. The Calculator does not currently consider ecosystem degradation and invasive species, which may affect the productive and regenerative capacity of land and food systems in the future. Moreover, climate shocks and climate change are also not considered. Estimates from (Murray-Tortarolo et al., 2018) show that climate change might lead to a 10-30% reduction of the rainfed corn yield by 2050. Future model development should focus on these aspects to avoid overly optimistic results.

It is also important to differentiate corn production for human consumption and corn production for animal feed. The yield difference between the two is significant so in the future it will be important for us to model public policies that affect these two types of corn production.

Finally, Mexico has created a large network of Protected Areas that cover 16% of its terrestrial area. This effort is not reflected in the current Calculator, so we intend to improve it and to also include all other conservation mechanisms that Mexico has under its current Environmental Law (Pisanty et al., 2016).

There are several technologies that could help increase the level of ambition of our pathway. These include: the use of improved seeds to improve yields for our main crops, as well as the inclusion of traits for drought resistance which are important for climate change adaptation of rainfed systems; the adoption of sustainable agricultural practices adapted to the diversity of agroecological regions in Mexico; and an increase in the development and adoption of sustainable forest management.

There are two important challenges that hinder the adoption of these practices and the implementation of this pathway. The first relates to data. Even though the National Institute of Statistics and Geography (INEGI) generates and compiles data with the same criteria for the entire country, it is challenging to maintain the same indicators and monitoring programs for more than one political term (6 years). This generates temporal and spatial data gaps and makes it difficult to assess the success of programs that have been implemented.

There are also important data constraints on free-range livestock (population size and spatial distribution) and food waste. This lack of data generates a gap in any analysis on productivity and the ecological effects of food waste and free-range livestock.

The second relates to the policy-making process. Designing and implementing national-level policies requires the use of monitoring frameworks that use a systems approach to effectively exploit data generated at sub-national scales. Therefore, multiple sectors and types of collaborators (e.g. scientific and policy-making communities) should be jointly involved in the design of more comprehensive scenarios for land and food systems in order to mitigate against climate change. Attention to the environment should cut across all government agencies so that resources and programs coordinate with each other and transcend a change of government.

We see several other areas that would allow Mexico to develop integrated policies to address these challenges. First, public policy development should come from evidence-based research. Second, efforts should be made to improve capacity building within different government agencies in order to promote greater understanding of environmental issues, including the costs of not addressing them. Third, INEGI should improve monitoring instruments to measure the evolution of land and food systems. At the same time, government agencies need to implement independent evaluation systems for the policies they are implementing. Finally, more funding should be made available for research focusing on land and food studies. For example, increased investment in breeding for main crops, including maize (open-pollinated varieties and hybrids) for traits like drought resistance that are important for climate change adaptation.

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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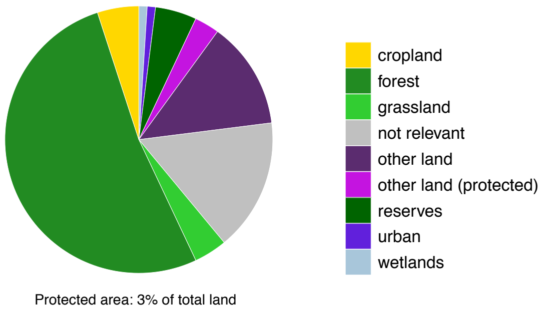
Land and food systems at a glance

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

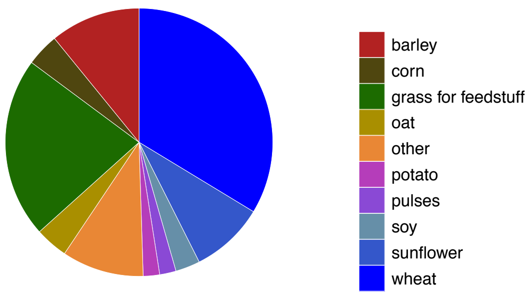
Land & Biodiversity

Fig. 1 | Area by land cover class in 2015



Source: Rosreestr (2015)

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



Source: Rosstat (2015)

Annual deforestation in 2015:
1,382 kha = 0.15% of total forest area

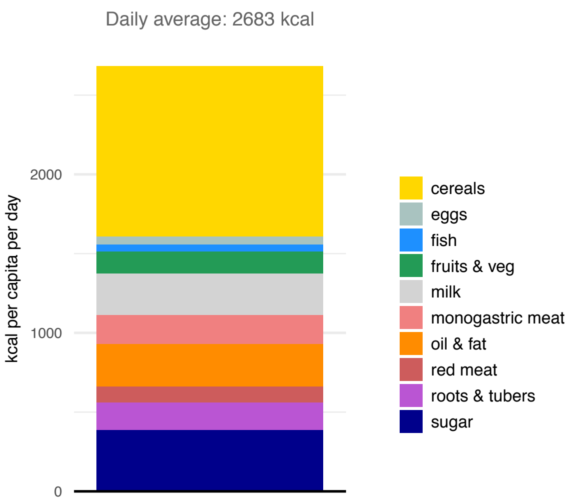
(National greenhouse inventories, 2019)

Endangered species: 872
in Russian Red Data Book

(Popov et al., 2017)

Food & Nutrition

Fig. 3 | Daily average intake per capita at the national level in 2010



Source: FAOSTAT

Share of
undernourished
in 2015:
2.5%

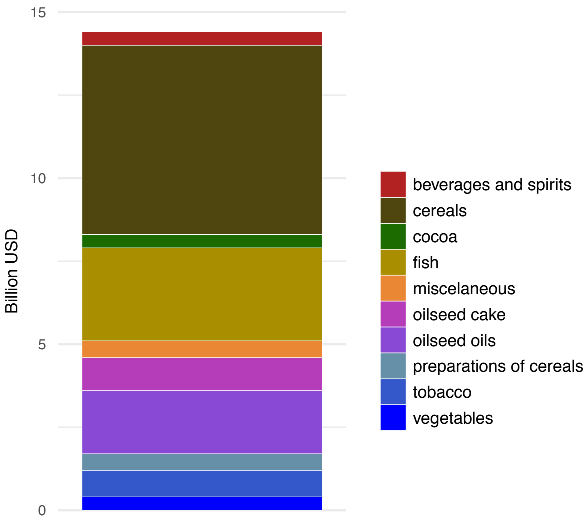
(World Bank, 2019)

Share of obese
in 2016:
1.2%

(Russian Health Ministry, 2019)

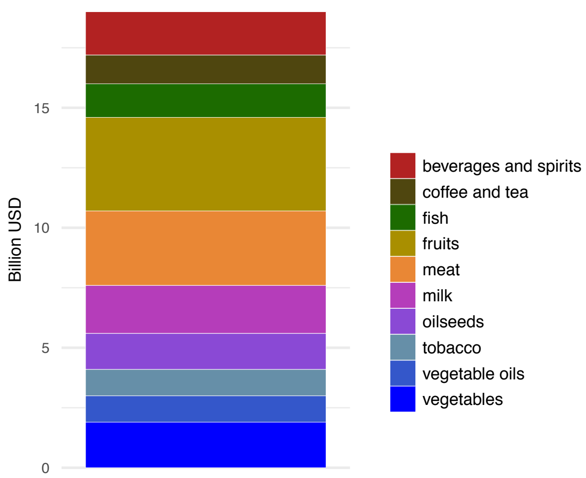
Trade

Fig. 4 | Main agricultural exports by value in 2015



Source: International Trade Center

Fig. 5 | Main agricultural imports by value in 2015



Source: International Trade Center

Deficit in agricultural trade balance in 2015: USD 10.2 bln (0.75% of GDP)

(Intracen, 2019)

8th most important importer of milk products in 2015, 9th in fruit

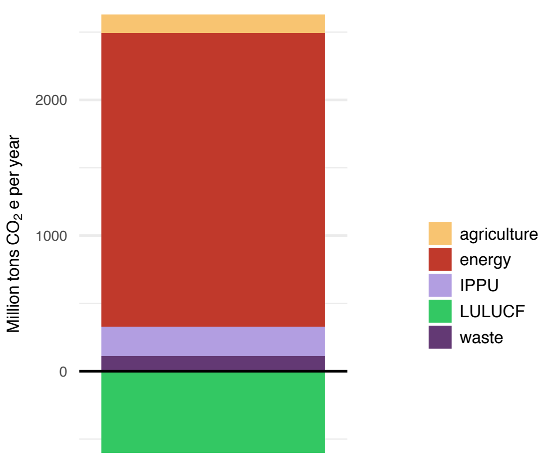
(Intracen, 2019)

10th most important fish exporter in 2015, 8th in cereals, and 11th in vegetable oils

(Intracen, 2019)

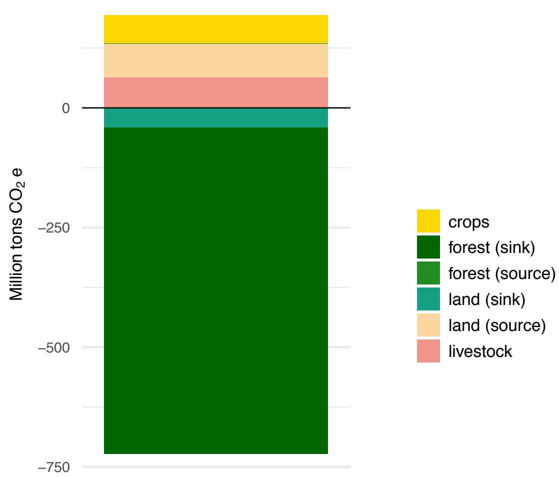
GHG Emissions

Fig. 6 | GHG emissions by sector in 2015



Source: National greenhouse gas inventories (2015)

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



Source: National greenhouse gas inventories (2015)

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 (large change)	Population (no change)
Scenario definition	GDP is expected to increase by 165% from USD 1,660 bln in 2015 to USD 2,745 bln in 2050 (SSP2 scenario selected).	Population is expected to decrease by 1.2% between 2015 and 2050 from 143.9 mln to 142.2 mln (UN Instant Replacement scenario selected).
Scenario justification	This is a conservative assumption compared to projections from the Ministry of Economy of Russia which assumes a 164% increase in real GDP by 2036 relative to 2020 (Ministry of Economy of Russia, 2018).	This is in line with findings of most other population projection trends for Russia. The official projections by Rosstat (Federal statistical agency of Russia) show a 1.8% decrease in population by 2036 relative to 2020 in the median scenario (Rosstat, 2019).

TRADE

	Imports (large change)	Exports (large change)
Scenario definition	The share of total consumption which is imported decreases: - from 6% in 2010 to 3% in 2050 for milk, - from 34% in 2010 to 17% in 2050 for sugar, - from 20% in 2010 to 4% in 2050 for chicken meat, and - from 27% in 2010 to 5% in 2050 for pork. The share of total consumption which is imported remains constant at 2010 levels for the other commodities.	The exported quantity increases: - from 13.7 Mt in 2015 to 59.2 Mt in 2050 for wheat, - from 0.3 Mt in 2015 to 4.2 Mt in 2050 for corn, - from 5.8 Mt in 2015 to 32.1 Mt in 2050 for barley, - from 0.5 Mt in 2015 to 5.4 Mt in 2050 for sunflower oil, and - from 0.2 Mt in 2015 to 1.5 Mt in 2050 for soy oil. The exported quantity remains constant at 2010 levels for the other commodities.
Scenario justification	Declining imports for some products reflects the development of a domestic Federal agricultural program which in recent years has had a positive influence on the growth in milk and meat (Ministry of Agriculture, 2019). This is not applied to: 1) beef, as it is expensive to produce domestically and incomes are declining; 2) fruits, since the climate does not support the production of certain fruits; and 3) tomatoes, since they are cheaper to produce elsewhere.	Based on historical trends and the current government's programs focused on doubling the value of agricultural exports by 2024 (Government of Russia, 2016).

Scenario signs no change small change large change

LAND

	Land conversion	Afforestation (no change)
Scenario definition	We assume that there will be no constraint on the expansion of agricultural land beyond existing protected areas and under the total land boundary.	We do not assume active afforestation.
Scenario justification	There is no evidence of clearing forests for cropland or pasture in the last 20 years or signs that this will change in the near future (National greenhouse inventories, 2019): we assume that Russia will continue to be a major exporter of timber and that there will be some supporting programs for protecting forests and reforestation (National greenhouse inventories, 2019) and that the cattle and sheep stock will remain constant. This last assumption is supported by the declining historical trends of the cattle herd, and the limited sheep herd that is mostly located in the Caucasus region where there is extensive pasture production system.	Some argue that the area of the forests in Russia is actually increasing on its own (mostly in remote, undeveloped areas). According to FAO ((2012), page 18) Russian forest area may increase from 5 to 8 Mha by 2030 from compared to 2015 levels.

BIODIVERSITY

	Protected areas (no change)
Scenario definition	Protected areas remain constant between 2015- 2050.
Scenario justification	The model numbers show that the potential area for biodiversity protection would be approximately 44% to 50% of the Russian territory but official numbers in 2015, report that protected areas only represent 3% of the total territory (Rosreestr, 2019).

Scenario signs = no change → small change ↗ large change

FOOD

	Diet (no change)	Food waste (large change)
Scenario definition	Between 2015 and 2050, the average daily calorie consumption per capita remains constant at around 2,500 kcal.	Between 2015 and 2050, the share of final household consumption which is wasted decreases from 10% to 5%.
Scenario justification	According to the Russian National Strategy for healthy life 2025 (Ministry of Health, 2016), consumption should be reduced by 2025: by 10-15% for alcohol, tobacco, salt; by 30% for saturated fatty acid; and by 10% for products with added sugar. However, since there is no clear strategy to trigger this change, we have not implemented these recommendations.	Since we lack official projections for food waste, we only consider this to be one possible assumption.

PRODUCTIVITY

	Crop productivity (large change)	Livestock productivity (large change)	Pasture stocking rate (no change)
Scenario definition	Between 2015 and 2050, crop productivity increases: - from 2.4 t/ha to 6.7 t/ha for wheat, - from 2.3 t/ha to 5.5 t/ha for barley, - from 1.2 t/ha 1.5 t/ha for rapeseed, and - from 10 t/ha 13 t/ha for potato.	Between 2015 and 2050, the livestock productivity increases: - from 141 kg/TLU to 275 kg/head for beef, - from 600 kg/head to 2 t/head for pork, and - from 5.3 t/head to 9.8 t/head for cow milk.	The average livestock stocking density remains constant at 0.23 TLU/ha pastureland between 2015 and 2050.
Scenario justification	We assume that Russia will continue to improve cropland productivity based on historical crop yield trends. There are, however, currently no sources, either official or in the literature, to prove this.	While we could not identify any source, either official or in the literature to confirm this assumption, we think that Russia will continue to experience high productivity growth in the future driven by technological development to improve its competitiveness on international markets.	While we lack official numbers for this variable, trends over the last few years show a relatively small decrease in the cattle herd and an increase in the sheep herd and a stable pasture area (Rosstat, 2019).

Scenario signs no change small change large change

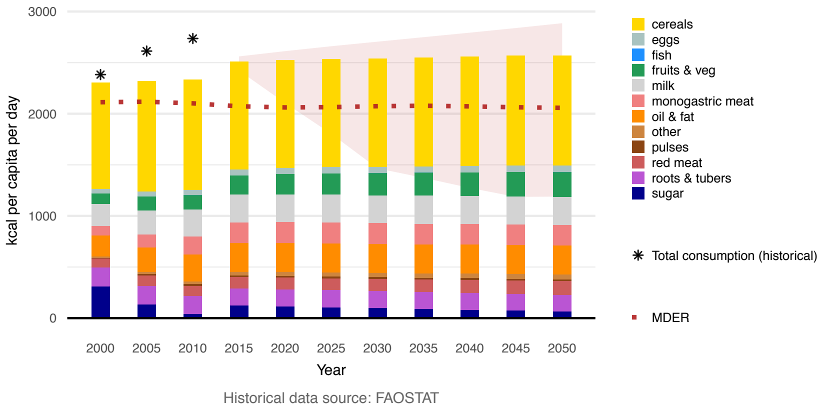
Results against the FABLE targets

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

Food security

Fig. 8 | Computed daily kilocalorie 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.

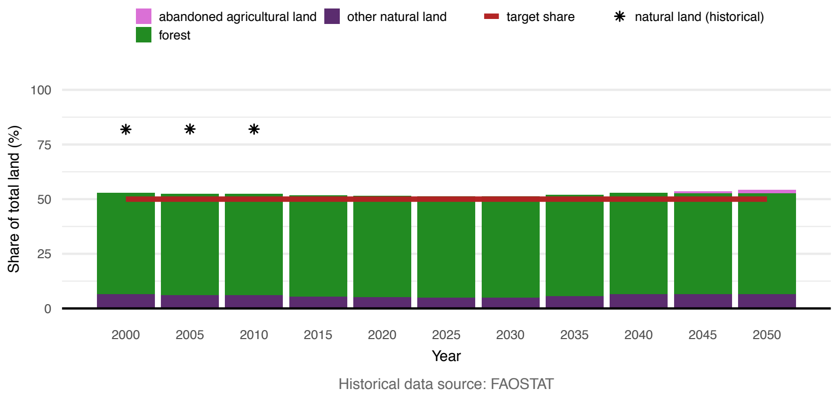


Our results show that average daily energy intake per capita increased between 2000-2015 period. After 2020, calorie intake reaches 2,550 kcal/cap/day and stabilizes over time. The computed diet does not meet the Russian National Strategy for healthy life 2025 recommendations for reducing fat and sugar consumption.

The computed average calorie intake in 2050 is almost 20% higher than the Minimum Dietary Energy Requirement (MDER) at the national level in 2050.

Biodiversity

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

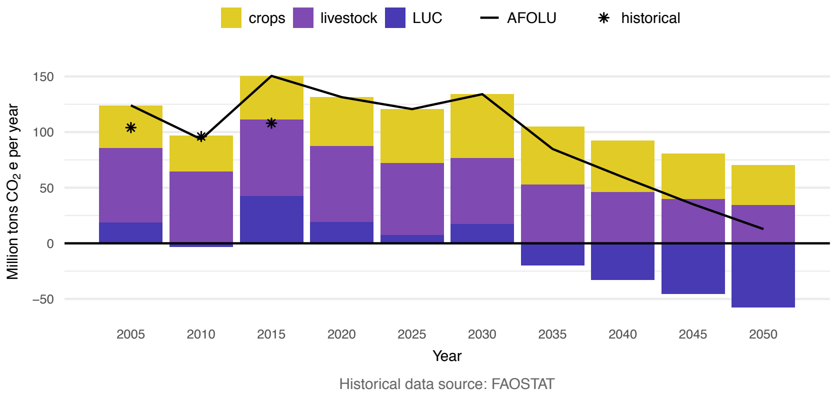


Our results show that the Share of Land which could support Biodiversity conservation (SLB) over the observed period is above 50%. This is made possible by the large forest and tundra areas that cover more than 50% of Russian territory. The majority of forests and tundra land are uninhabited as they are located in Northern or Far Northern regions that are relatively separated from most economic activities.

Compared to the global target of having at least 50% SLB by 2050, our results are above the target.

GHG emissions

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



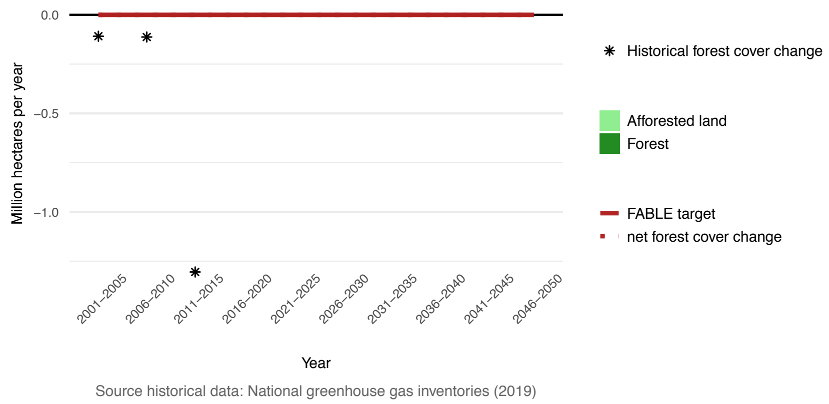
Note: AFOLU (Agriculture, Forestry and Other Land Use) is the sum of computed GHG emissions from crops, livestock and Land Use Change (LUC), emissions and sequestration from forestry are not included. Historical emissions include crops and livestock.

Our results show annual GHG emissions from AFOLU between 92 and 150 Mt CO2eq/year from 2005-2015, then a decreasing trend for the remainder of the projected period. For the historical period, our results match official data on agricultural emissions which fluctuate between 96 and 120 Mt CO2eq/year from 2000-2015. AFOLU GHG emissions are projected decrease over the period 2015-2030 from 160 to 98 Mt CO2e/year. This is mostly driven by GHG emissions from livestock and carbon sequestration on abandoned pastures and cropland.

Our results meet the target of reducing emissions from agriculture and reaching zero or negative GHG emissions from LULUCF by 2050 at the national level.

Forests

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



The FABLE Calculator shows no forest cover change for Russia: there is no deforestation and no afforestation target was implemented. The forest area remains constant at 800 mln ha for the whole period of simulation. The National greenhouse gas inventories (2019) show historical deforestation of about 100 kha/year over 2000-2010 and a peak of deforestation of 1 Mha/year over 2011-2015. However, this deforestation might be caused by factors which are not yet covered in the FABLE Calculator such as forest fires, mining, and logging.

Compared to the global target of having zero or positive net forest change after 2030, our results show zero net forest cover change over the whole period.

Other relevant results for national objectives

Table 1 | Other Results

Variable	Unit	2000	2005	2010	2015	2020	2030	2040	2050
Cropland (historical)*	Mha	52.9	52.1	53.7	57.7				
Cropland (calculated)*	Mha	43.0	45.5	44.7	54.5	61.4	78.8	60.3	42.4

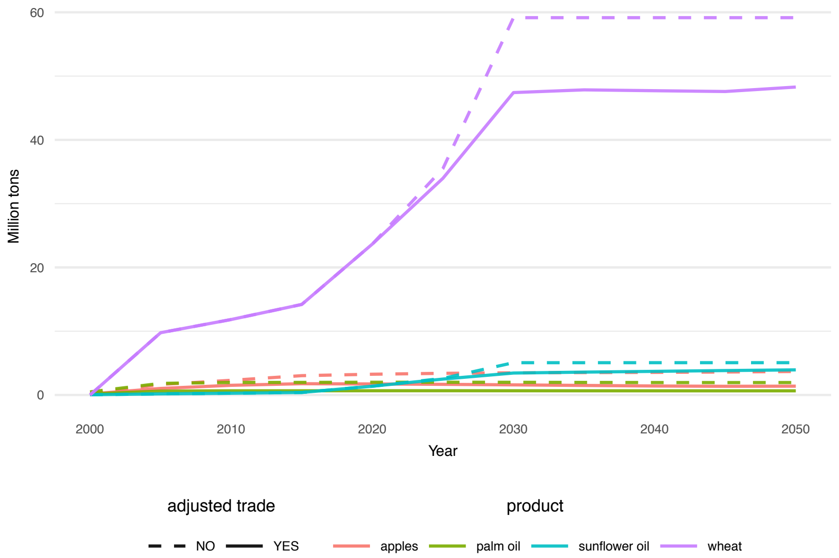
*selected commodities are: corn, peas, rice, oats, rye, barley, millet, sorghum, wheat, onion, potato, tomato, vegetable other, sunflower, soy, and rapeseed
Source historical data: Rosstat, 2019

In this table we group selected crops and compare aggregated area with the model projections and official historical data of Russia. The crops are: corn, peas, rice, oats, rye, barley, millet, sorghum, wheat, onion, potato, tomato, vegetable other, sunflower, soy, and rapeseed. For many crops, our estimates for the historical period are lower than the cropland area reported by Rosstat. The official data is about 20% higher than the model results in 2000-2010 period and only 6% higher in 2015.

According to the Russian program on the development of rural territories up to 2030, Russia would like to increase its cropland without specifying the amount. Some media report that the grain area will increase by a maximum of 3-4 Mha over the next 5 years. Our own assumption is that Russia could also increase its oil crops acreage as it is currently the most profitable sector in Russian agriculture. Between 2010-2030, the model projects a strong expansion of cropland area but after 2030 the model projects a drop in cropland area due to high yield development. We have not seen such projections in any official Russian documents.

Impacts of trade adjustment to ensure global trade balance

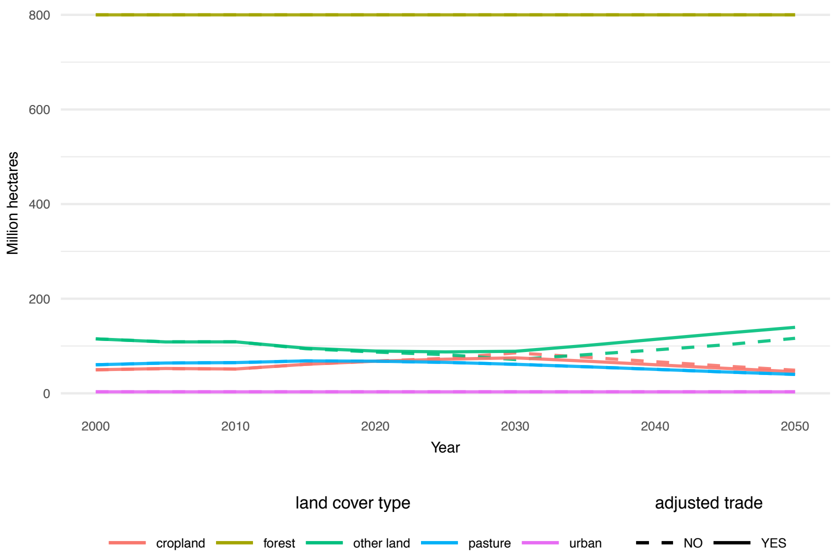
Fig. 12 | Impact of global trade harmonization on main exported/imported commodities over 2000-2050



Trade adjustment leads to lower exports of wheat and sunflower oil. By 2030, exports for wheat are reduced by 25% and sunflower oil by almost 50%. The historical trend is much more ambitious with 21 Mt of Russian wheat exports in 2015 and 43 Mt of wheat exports in 2018 (in the Calculator it is 14 Mt in 2015 and 23 Mt in 2020) and 1.4 Mt of sunflower oil exports in 2015 and 2.1 Mt in 2018 (in the Calculator it is 0.4 Mt in 2015 and 1.3 Mt in 2020).

Trade adjustment also reduces imports for palm oil and apples. Starting in 2005, imports for palm oil with no trade adjustment are 3 times higher than with the trade adjustment. Beginning in 2025, apple imports without trade adjustment are more than two times higher than with the trade adjustment.

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



After trade adjustment, cropland area declines by about 10-15% and other land increases. This is explained by higher crop exports without trade adjustment.

Discussion and next steps

The main assumptions in this analysis are consistent with current development trends in Russian agriculture and future government programs, including development of agricultural markets (up to 2030), the program of rural territorial development (up to 2030), and improvement of export capacity to meet expected increases in pork, poultry, grain, and oil crop production and greater trade with large markets such as China. We implemented these growth assumptions in the FABLE Calculator to evaluate how land use, GHG emissions, trade, and diets will change. The estimates show a flat trend in the emissions from agricultural activities until 2030 and a reduction afterwards. There is a possibility to decrease cropland in Russia after 2030 if accompanied with parallel improvements in productivity growth, reduced GHG emissions from agriculture, and avoided emissions from land-use change.

The main advantage for Russia in the land-use change sector is that its development pathway for agriculture is disconnected from that of the forestry sector. This is the result of geographic separation: most agriculture is in the south and southwest (the Black Sea and Caspian Sea basins) and the west (near the border and the Volga river basin), while most intensive forestry extraction comes from the northwest and the far east. Therefore, we do not expect cropland expansion in areas where forests are located. However, cropland expansion is still possible in areas where cropland was abandoned after the fall of Soviet period but where climatic and soil conditions are favorable and there is good infrastructure.

One limitation of this analysis is that currently we do not take into account 700 Mha of land in the FABLE Calculator because it is mostly composed of territory that is not related to agricultural and food systems and is not well covered by statistical data. It may be important for carbon sequestration and biodiversity; therefore, it will be reconsidered in the next phase of the project. Russia has a large access to natural marine resources and is one of the leading global producers and exporters of fish, which is also an important component of Russian diets. It would be also good to include the fish sector in the FABLE Calculator.

Soil organic carbon is also not included in this analysis. The problem is that Russia has a large area of unused cropland that is included in the estimates from soil emissions on cropland. This is because Rosreestr (Land registration palace of Russia) shows cropland area at around 100-110 Mha and Rosstat (Federal statistical agency) shows cropland (sawn) area at 80 Mha as well as around 10 Mha of fallow land (also according to Rosstat). Therefore, when the report (National greenhouse inventories, 2019) shows emissions from soils at approximately 60 mln CO2eq per year we do not know if these come only from the ploughed (sawn) land or if they also include land that is not sawn but included in the registration books of Rosreestr. This needs to be clarified in order to have proper emissions estimates from ploughed land and emissions (or probable sequestration) of carbon in abandoned (or unused) cropland and pastures. When this has been carried out at the federal level, Russia should proceed in developing a database for regional emissions (sequestration) on agricultural land.

According to official Russian reports on GHG emissions from agriculture, land-use change and other sources (National greenhouse inventories, 2019) the main methodological problem is a large deviation between estimates of GHG emissions de facto (field experiments) from models. In the report, Russia has some items which have relatively close estimates, such as those of enteric fermentation emissions, which have a deviation of 1-2% between experiments and model. However, some items have an almost 100% deviation, such as emissions from peatland used in agriculture. This last case is also relevant for large areas of Russian forests and pastures. Therefore, more research is needed (beyond FABLE) including case studies of different aspects of emissions from abandoned and remote areas in Russia. This is essential not only for Russia's balance of GHG emissions, but for other countries as well.

The current assumption of the model used in the FABLE Calculator is that with further land intensification in agriculture the emissions from agriculture and land-use change are likely to decrease in the long term. We view this as a topic of ongoing debate, meaning that for different cases it might not work. The current FAO data shows that, for Brazil and China, cropland area, crop yields, fertilizers, and manure applied to cultivated soils or pastures increased at the same time, bringing higher emissions from agriculture. In Russia, the cropland area increased by almost 10% and chemical fertilizer use increased by 70% from 2007-2017 but did not cause high GHG emissions. This is because Russia still uses two to three times less fertilizer per hectare compared to China and Brazil and because cropland expanded to former agricultural land that had been abandoned for several years. That means that in temperate zones the additional land increase for agriculture might be more environmentally friendly that in tropical agriculture. That would be interesting for a whole-world analysis to test for some policies based on the carbon footprint of imported agricultural raw materials and food. An important topic of discussion among Russian authorities and researchers is the possibility of becoming a net exporter of pork and chicken. According to some Russian news sources (Dyatlovskaya, 2019), in 2019 Russia will export around 20-30 kt of chicken meat to China, with a possible growth up to 150 kt in the near future.

The main challenge for Russia in developing a pathway for low agricultural carbon emissions are: 1) optimizing fertilizer consumption by using seeds which consume a larger share of fertilizer for plant growth (currently it is around 50-60%); 2) improving manure management and storage systems in regions with intensive pig and poultry production; 3) switching from intensive feedlots to more grassland grazing for cattle, which will reduce environmental impact in terms of enteric fermentation emissions.

Russia is one of the few countries that has the option to develop a rather intensive form of agriculture or remain with the current relatively extensive one. In fact, there is a large difference among Russian regions (oblast and republics – first administrative level) in their agricultural development and regional policies. Currently there is no official pathway or a document which integrates the development of agriculture and healthy diets together with sustainable land-use systems, emissions from agriculture and land-use change. To start working in this direction we would suggest organizing a working group to see how to integrate different work streams of specific ministries and researchers to reveal the necessity of such integrative programs of development. One of the first decisions for such a program (pathway) would be the collection of data such as emissions from farms, the implementation of sustainable agricultural practices like growing legumes, returning crop residues to the soil at harvest, growing draught resistant crops, breeding cattle on pasture areas, or processing manure for energy. Russia could think of implementing advertisements to promote such practices and for guaranteeing a number of marketplaces (or retail stores) for products from farms that are using one of these mentioned sustainable practices. This would help to more accurately estimate emissions from different types of farms, and technologies they use, and create an environment where farmers and consumers know that the government is creating the correct market signals for a sustainable development and healthy-food-consumption pathway.

Regarding current instruments or measures of Russian agricultural policy, we see two main measures which should be improved or even eliminated. First, the Russian government provides large subsidies for companies (farms) with intensive cattle feeding which creates additional methane emissions. There are, however, other farms where cattle are put to pasture, which produce much lower emissions. In our view, it is unnecessary to support farms that create additional emissions when there are other more economical practices that are also more environmentally friendly. Secondly, the Russian government uses a system of penalties for farms with uncultivated cropland. In our view, the government should not interfere with the economic decisions of farmers. Rather, farmers should be allowed to decide what to do with their own lands. Instead, the government could develop certain monitoring methods to observe what is happing on abandoned and unused fields or pastures in order to create and support the environment for improved biodiversity protection. Another step forward would be for Russia to create a cap and trade carbon system where abandoned land could serve as a major carbon sink in the Eurasian region.

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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Rwanda

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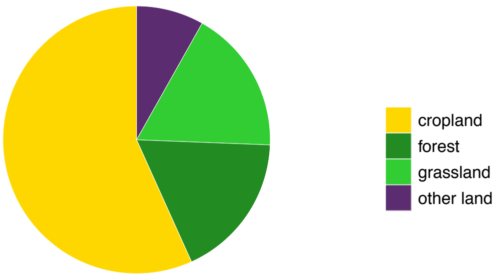
Land and food systems at a glance

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

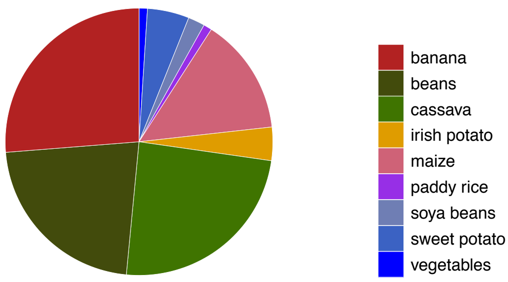
Land & Biodiversity

Fig. 1 | Area by land cover class in 2015



Source: FAOSTAT

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



Source: NISR (2016)

Annual afforestation in 2015:
23 ha = 0.012% of total forest area

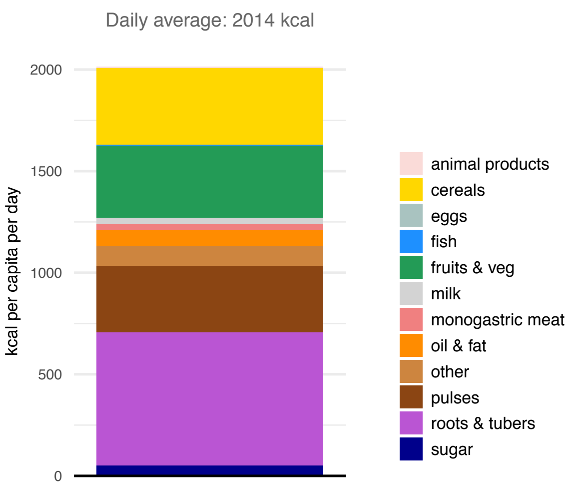
(National Institute of Statistics of Rwanda & Ministry of Environment and Ministry of Lands and Forestry, 2018)

Endangered species: 3 vascular plants, 9 mammals, and 9 breeding birds

(WRI, 2003)

Food & Nutrition

Fig. 3 | Daily average intake per capita at the national level in 2013



Source: Comprehensive Africa Agriculture Development Programme (2013)

Share of undernourished in 2015:
34%

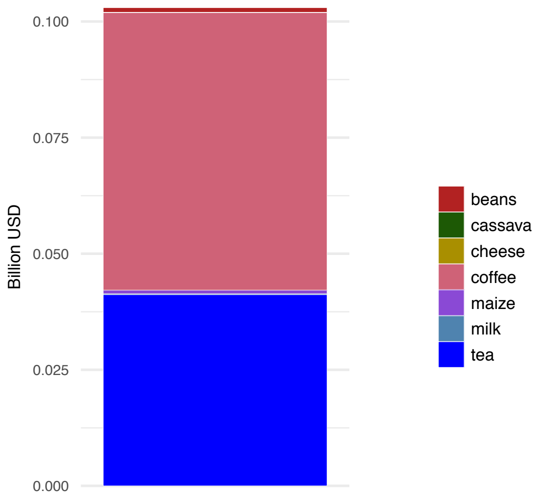
(World Bank, 2019)

Share of obese in 2016:
5.8%

(NISR, 2015)

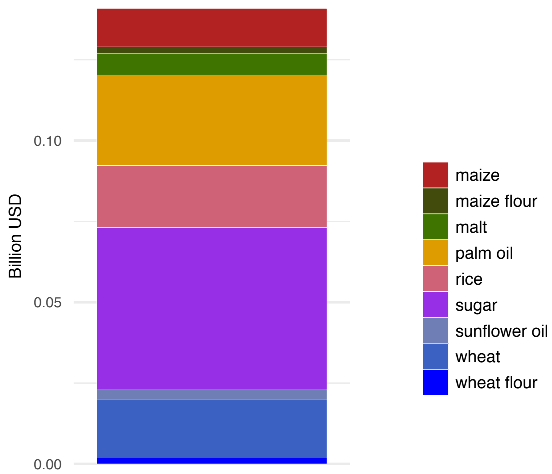
Trade

Fig. 4 | Main agricultural exports by value in 2015



Source: FAOSTAT

Fig. 5 | Main agricultural imports by value in 2015



Source: US Department of Commerce

Deficit in agricultural trade balance in 2015: USD 85.5 mln

(Commerce, 2019)

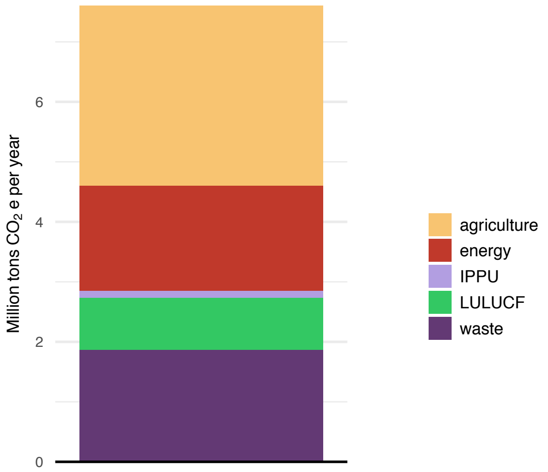
167th most important importer in the world in 2015
(OEC, 2019)

156th most important exporter in the world in 2017

(Central Intelligence Agency, 2017)

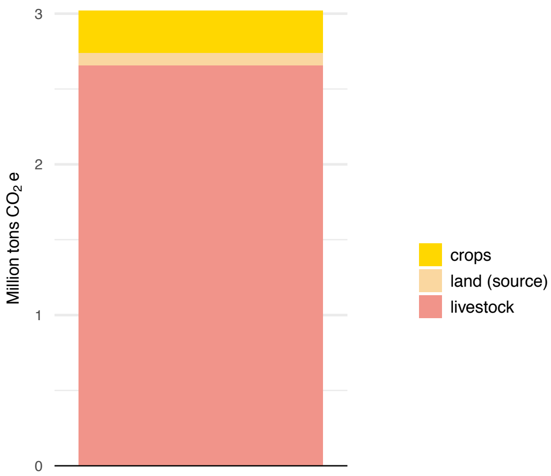
GHG Emissions

Fig. 6 | GHG emissions by sector in 2014



Source: ClimateLinks

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



Source: FAOSTAT

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 by 73.38% from USD 714 in 2015 to USD 1,238 in 2050 (SSP2 scenario selected).	Population is expected to increase by 92.2% between 2015 and 2050 from 11.6 mln to 22.3 mln (SSP2 scenario selected).
Scenario justification	Based on World Bank (2018), the future drivers of growth in Rwanda (which are innovation, integration, agglomeration, and competition) could help sustain GDP growth. Rwanda's average GDP growth was around 7% from 2007-2017.	Our assumption is equivalent to a future average annual growth rate of 1.9%, which is lower than the annual population growth rate of 2.6% observed in the past decade (Ministry of Finance and Economic Planning, 2000; National Institute of Statistics of Rwanda, 2012).

TRADE

	Imports	Exports
Scenario definition	The share of total consumption which is imported increases: - from 48% in 2015 to 92% in 2050 for wheat. The share of total consumption which is imported remains stable at 2010 level for the other commodities.	The exported quantity increases: - from 23 kt in 2015 to 33 kt in 2050 for tea, - from 18 kt in 2015 to 26 kt in 2050 for coffee. Exported quantities remain stable at 2010 level for the other commodities.
Scenario justification	Based on IndexMundi (2019), which shows that Rwanda experienced higher imports for corn, wheat, and sorghum in the past.	The forecasted increase in coffee and tea exports is based on data from the Government of Rwanda (Ministry of Agriculture and Animal Husbandry, 2008; Ministry of Agriculture and Animal Resources, 2008), which focuses on the progress made in the coffee and tea sectors by increasing the quantity and quality of tea and fully and semi-washed coffee. The Rwanda national export strategy of 2012 also emphasizes the increase in coffee and tea exports (Ministry of Trade and Industry, 2012).

Scenario signs no change small change large change

LAND

	Land conversion	Afforestation (no change)
Scenario definition	Forests cannot be converted to agricultural land. There is no constraint on other natural land conversion beyond protected areas.	We did not take afforestation into account in this pathway.
Scenario justification	Based on Government of Rwanda (2018), the change in forestry land was very small (0.1%) from 2014 to 2015 and the Government of Rwanda wants to increase the forest area (Ministry of Lands and Forestry, 2017).	The national forestry policy aims to increase the forestry area from 18.7% to 30% of Rwanda's total land area through afforestation and reforestation by 2030 (Ministry of Lands and Forestry, 2018). However, we preferred to exclude this afforestation target. Since afforested land cannot be used for production in the Calculator, this would have created too much tension on the food markets.

BIODIVERSITY

	Protected areas (no change)
Scenario definition	The protected areas remain stable at 82 kha between 2015 and 2050.
Scenario justification	Our assumption is below the Government of Rwanda's (2000) target of protecting 10.3% of Rwanda's land mass to maintain biodiversity, which is equivalent to 260 kha of land under protection.

FOOD

	Diet (large change)	Food waste (large change)
Scenario definition	Between 2015 and 2050, the average daily calorie consumption per capita increases from 1,931 kcal to 2,219 kcal. Per capita consumption: - increases by 55% for cereals, - decreases by 8% for pulses, - increases by 25% for vegetable oil, - increases by 7% for pulses, - increases by 51% for sugar, - increases by 52% for milk, - increases by 264% for chicken and pork, - increases by 150% for eggs, - increases by 100% for fish, - remains stable for fruits and vegetables and beef.	Between 2015 and 2050, the share of final household consumption which is wasted decreases from 9% to 5%.
Scenario justification		There is very little research on food waste in Rwanda, so there is no data to compare this value with.

Scenario signs = no change → small change ↗ large change

PRODUCTIVITY

	Crop productivity (large change)	Livestock productivity (large change)	Pasture stocking rate (no change)
Scenario definition	Between 2015 and 2050, crop productivity increases: - from 15.8 t/ha to 24.9 t/ha for cassava, - from 15.5 t/ha to 28.3 t/ha for Irish potato, - from 10.8 t/ha to 19.4 t/ha for plantain, - from 3.1 t/ha to 11.1 t/ha for corn.	Between 2015 and 2050, the productivity per head increases: - from 26 kg/ head to 36 kg/ head for beef, - from 0.07 kg/head to 0.8 kg/head for chicken, - from 0.7 t/ head to 1.1 t/ head for milk.	The ruminant density stays constant at 2.35 TLU/ha over 2015-2050.
Scenario justification	Based on Niyitanga et al. (2015), there is room to further increase potato yield to 40 t/ha to help close the 76.4% yield gap for potato. This includes the adoption of improved agricultural practices by farmers to help increase crop productivity. The results are also in line with the national targets of increasing crop productivity through an intensification program (Ministry of Agriculture and Animal Resources, 2012).	Based on the International Livestock Research Institute (2017). These results are in accordance with national targets for increasing productivity and total production in livestock value chains for cow dairy, red meat-milk, poultry, and pork on the basis of using better genetics, feed, and the adoption of health services, among others. For example, the projected increase in national cow milk production will result from an increase in crossbred and pure exotic cows, including through artificial insemination and synchronization, combined with improved feed and health interventions.	No data on national average livestock stocking densities to compare this value with.

OTHER

	Harvest Intensity (no change)
Scenario definition	The average crop harvesting intensity remains constant at 1.29 over 2015-2050.
Scenario justification	

Scenario signs = no change → small change ↗ large change

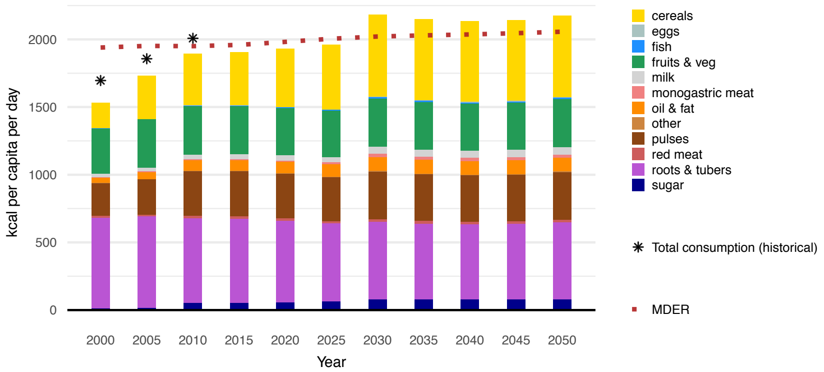
Results against the FABLE targets

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.



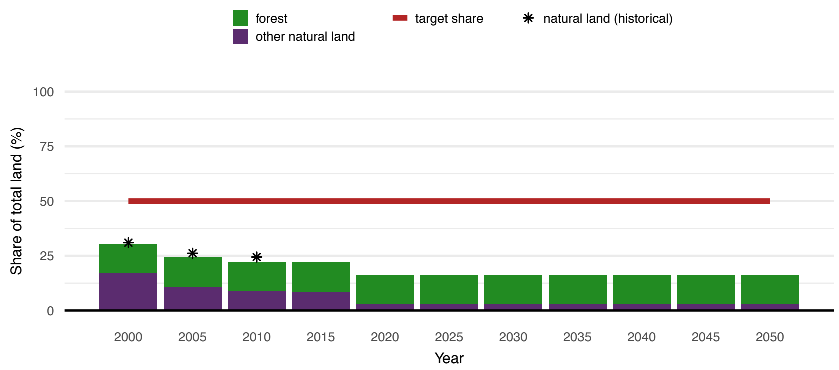
Historical data source: FAOSTAT

Our results show increasing average daily energy intake per capita from 1,903 kcal/cap/day in 2015 to 2,165 kcal/cap/day in 2050. This daily energy intake is above the MDER and the 2,100 kcal/dap/day requirement of the Comprehensive Africa Agriculture Development Programme (2013) from 2025 onwards.

Compared to the healthy diet, our results show higher consumption of roots and tubers, pulses and fruits and vegetables and lower consumption of cereals, animal products, and oil and fat.

Biodiversity

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



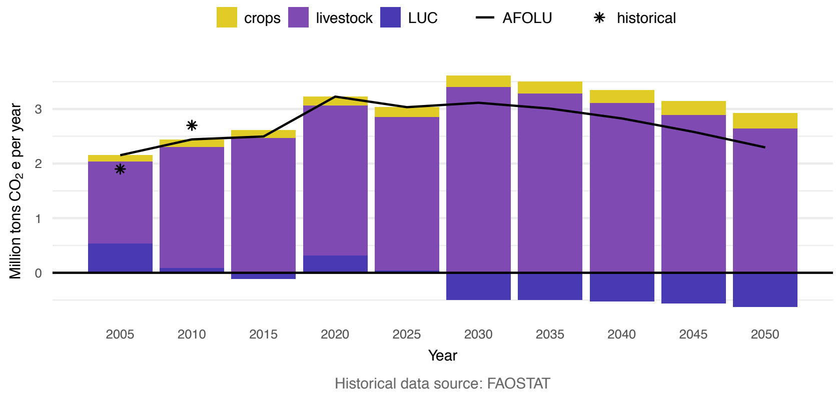
Historical data source: FAOSTAT

Our results show that the Share of Land which can support Biodiversity (SLB) decreased between 2000-2015 from 32.31% to 25.79%. This is slightly below FAO's data, which estimates forest area increase in 2005 and 2010 compared to 2000 (Republic of Rwanda, 2014). The lowest SLB is computed from 2020 onwards at 17% of total land. This is mostly driven by other non-managed land conversion to cropland/pasture. There is no more available other natural land outside protected areas after 2020 and based on historical data, we assume that agricultural land cannot expand on forest land. This is the reason why the SLB remains stable at 17% until the last period of simulation, 2046-2050.

Compared to the global target of having at least 50% SLB by 2050, our results are below the target. But this number could be compatible with the national target of having at least 10.3% of land area protected to maintain biodiversity by 2020 (Republic of Rwanda, 2014).

GHG emissions

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



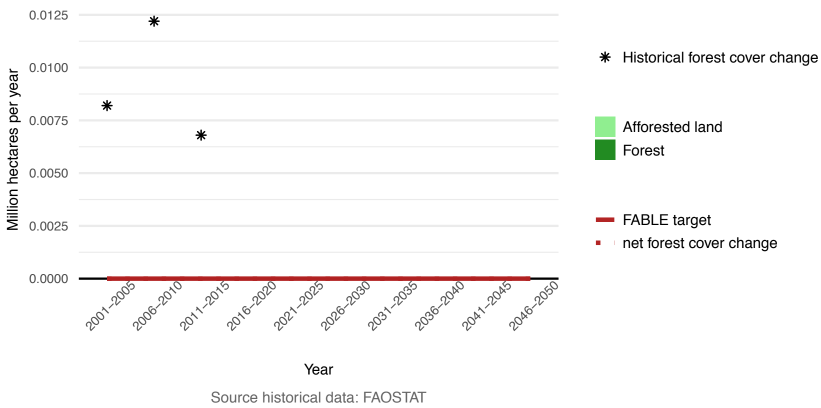
Note: AFOLU (Agriculture, Forestry and Other Land Use) is the sum of computed GHG emissions from crops, livestock and Land Use Change (LUC), emissions and sequestration from forestry are not included. Historical emissions include crops and livestock.

Our results show historical annual GHG emissions from agriculture at 1.2 $MtCO_2e$/year in 2000 and 2.4 $MtCO_2e$/year in 2010. This is 15% below FAO estimates in 2010 due to the underestimation of GHG emissions from the livestock sector. Peak AFOLU GHG emissions are computed for the period 2025-2030 at 3.2 Mt CO_2e/year. AFOLU GHG emissions decline, reaching 2.3 $MtCO_2e$/year in 2050: 2.9 from agriculture and -0.6 from LULUCF. Negative-net emissions from LULUCF by 2050 are mainly explained by pasture abandonment.

Compared to the global target of reaching zero or negative GHG emissions from LULUCF by 2050, our results are above the target. Our results show that AFOLU could contribute to as much as 95% of Rwanda's total GHG emissions reduction objective.

Forests

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

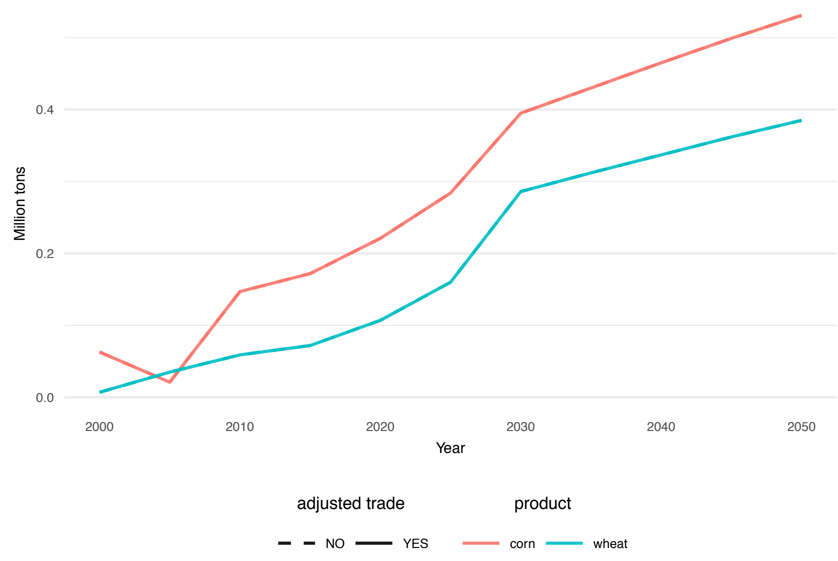


Our results show no deforestation between 2000 and 2050. This is consistent with FAO data. However, our results do not represent past afforestation efforts well.

Compared to the global target of having zero or positive net forest change after 2030, our results are at the target. Our results do not meet the national objectives of having forest covering 30% of national land by 2020 (Ministry of Lands and Forestry, 2018). Ambitious afforestation targets were removed from our simulations after they led to large negative impacts on food security. The fact that afforested area cannot be used for agricultural production in the Calculator could explain this contradiction between our results and past observations.

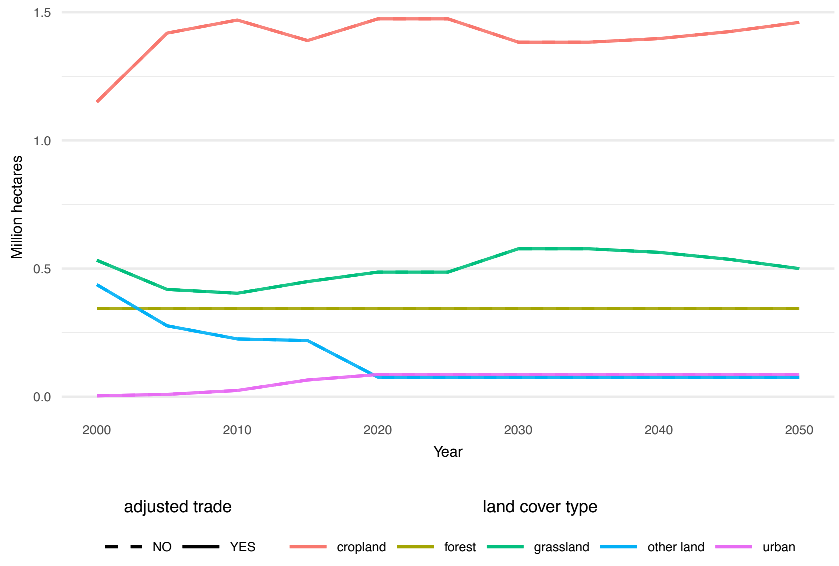
Impacts of trade adjustment to ensure global trade balance

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



Trade adjustment does not impact exported or imported traded volumes for Rwanda.

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



Trade adjustment does not have any impact on overall land use in Rwanda.

Discussion and next steps

Under this pathway, Rwanda's GDP and population would continue to increase, as would crop and livestock productivity, imports and exports of key commodities, and the average daily food intake. Food waste would decline while protected land would remain stable.

We did not consider afforestation in this pathway as the FABLE Calculator does not allow afforested land to be used for agriculture, so an afforestation target would have led to tension on the food market. Agroforestry is a common agricultural practice in Rwanda which was not included as part of this analysis. These are limitations to the results and will need to be addressed going forward.

Rwanda's agriculture systems will likely shift from subsistence to professional agriculture and we see the opportunity for ambitious yield increases. Niyitanga et al. (2015) show that improved agricultural practices could go a long way towards closing the yield gap.

Additional technologies could enable Rwanda to raise the level of ambition of its objectives for sustainable land-use and food systems: settlement building technologies (housing stocks), technologies for improved water and fertilizer use, organic farming and conservation agriculture, food processing and storage, as well as policies to encourage the reduction of fertility rate.

Many policies are already in place that would support these suggested measures. The government has established free education up to 12 years of age and this has already yielded many positive impacts. Once a critical mass of people become better educated, good policies that are already in place will be further improved and implemented and will positively impact food security and environmental protection.

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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United Kingdom

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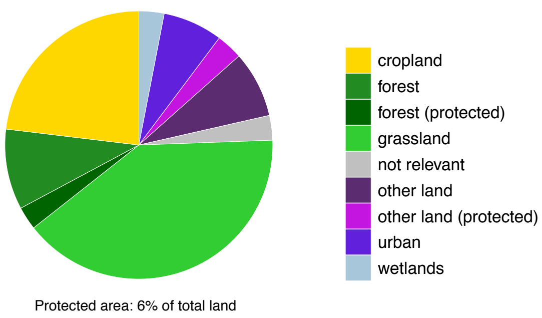
Land and food systems at a glance

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

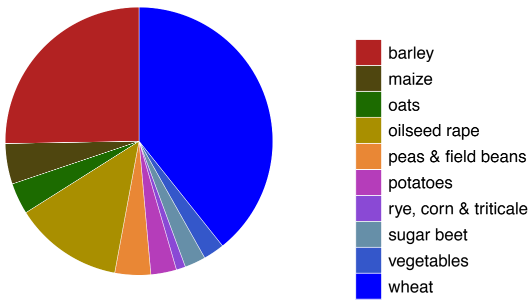
Land & Biodiversity

Fig. 1 | Area by land cover class in 2015



Source: Rowland et al. (2017)

Fig. 2 | Share of harvested area by crop in 2018



Source: Dept. for Environment, Food & Rural Affairs (2018)

No annual deforestation in 2015

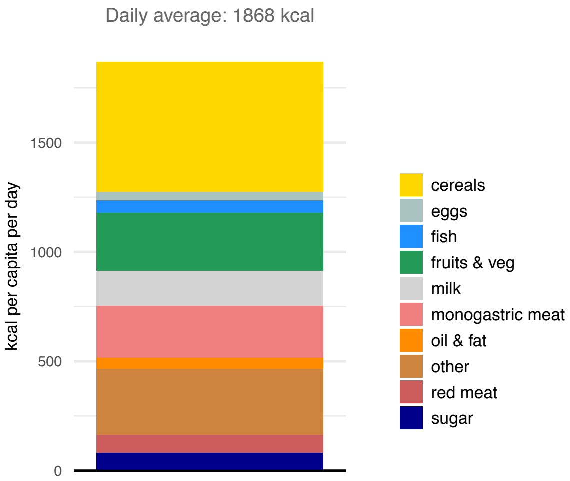
(FAO, 2014)

Endangered species:
108 vulnerable or higher

(IUCN Red List, 2019)

Food & Nutrition

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



Source: Food Standards Agency and Public Health England (2018)

Share of undernourished in 2015: 2.5%

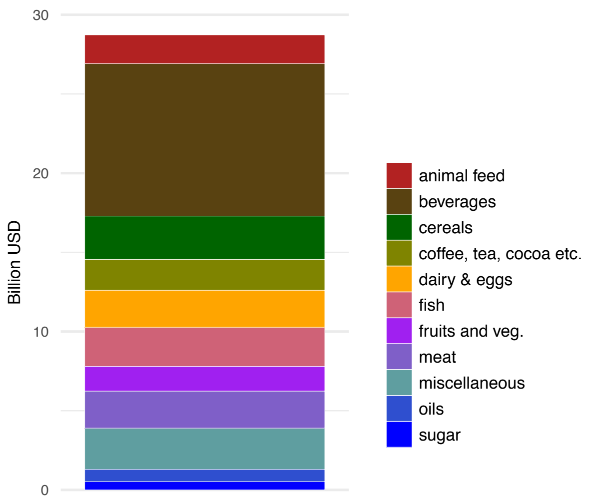
(World Bank, 2019)

Share of obese in 2017: 29%

(NHS, 2019)

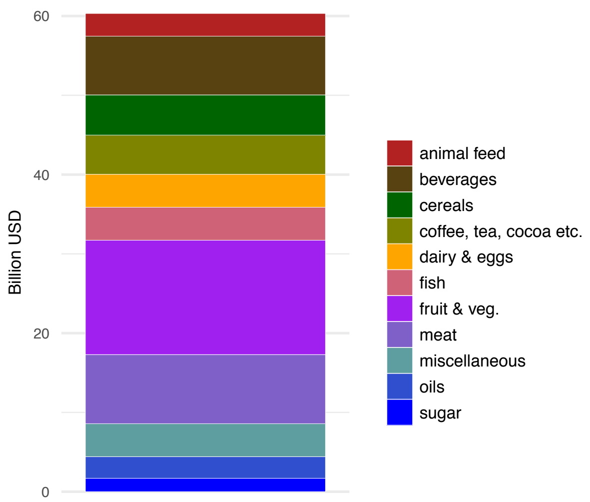
Trade

Fig. 4 | Main agricultural exports by value in 2017



Source: HMRC (2017)

Fig. 5 | Main agricultural imports by value in 2015



Source: HMRC (2017)

Deficit in agricultural trade balance in 2017: USD 18.5 bln

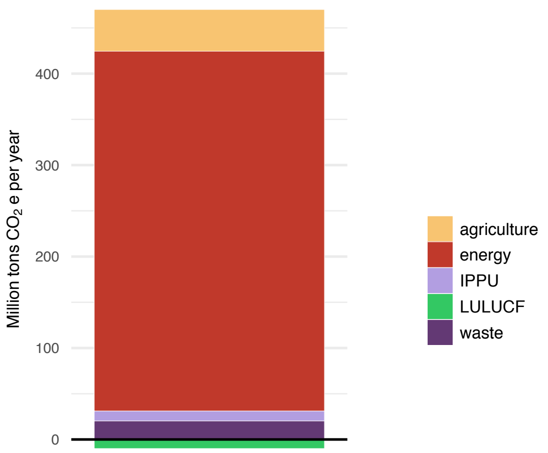
(DEFRA, 2017)

5th most important importer in the world in 2015

(FAOSTAT, 2019)

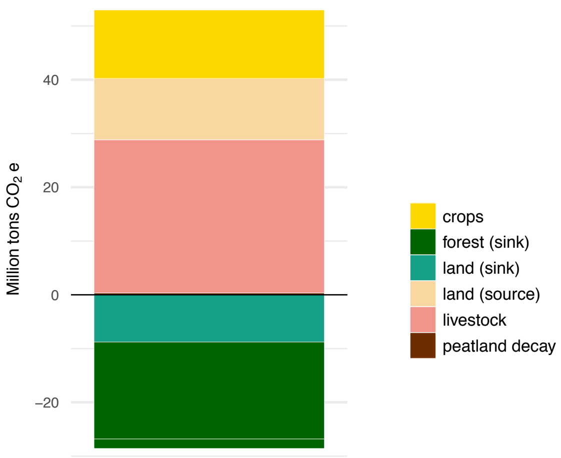
GHG Emissions

Fig. 6 | GHG emissions by sector in 2017



Source: Dept. for Business, Energy & Industrial Strategy (2019)

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



Source: Dept. for Business, Energy & Industrial Strategy (2019)

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 (large change)	Population (small change)
Scenario definition	GDP per capita is expected to increase by 135% from USD 41,440 in 2015 to USD 97,530 in 2050 (SSP2 scenario selected).	The population is expected to increase by 15% between 2015 and 2050 from 65.4 mln to 75.4 mln (UN Medium growth scenario selected).
Scenario justification	This is based on an annual 2.5% growth rate in GDP, similar to the predictions made by PwC in their report (PWC, 2017).	This is similar to the predictions on UK population from the UN and Office of National Statistics (Office for National Statistics, 2017; UNDESA, 2017).

TRADE

	Imports (small change)	Exports (no change)
Scenario definition	The share of total consumption which is imported: - decreases by 50% for milk and orange between 2010 and 2050 (e.g. from 17% to 9% for milk), - remains constant for the other products.	The exported quantity remains constant.
Scenario justification	Based on the Government's Agriculture policy statement that there is opportunity for the UK to import less food (House of Lords, 2018).	Imports are reduced by increasing production rather than by reducing export quantities.

Scenario signs no change small change large change

LAND

	Land conversion	Afforestation (large change)
Scenario definition	We assume that there will be no constraint on the expansion of the agricultural land beyond existing protected areas and under the total land boundary.	We assume a high level of afforestation with a total targeted afforested area of 1.7 Mha by 2050.
Scenario justification	Currently, there is no effort that we are aware of aiming to limit agricultural land expansion. This will critically depend on the replacement of the EU Common Agricultural Policy following the UK's exit from the EU. However, the Committee on Climate Change's (CCC) Land Use Report proposes that land needs to be released from agricultural production to reduce GHG emissions. It should be noted that the other driver assumptions mean that this assumption plays no role in the final results (as productive land declines) (Committee on Climate Change, 2018).	Based on CCC Land Use Report, which assumes a high ambition scenario with an annual forest planting rate of 50kha/year, which "exceeds historic afforestation levels, but is not far off the levels achieved in 1971" (Committee on Climate Change, 2018).

BIODIVERSITY

	Protected areas (no change)
Scenario definition	The protected areas remain constant at 1.5 Mha between 2015 and 2050.
Scenario justification	Based on recent trends of terrestrial protected areas (DEFRA, 2018c).

Scenario signs no change small change large change

FOOD

	Diet (large change)	Food waste (large change)
Scenario definition	Between 2015 and 2050, the average daily calorie consumption per capita decreases from 2,704 kcal to 2,590 kcal. Per capita consumption: - increases by 5% for pig and poultry meat, - decreases by 46% for milk, - increases by 33% for eggs, - increases by 622% for pulses, - decreases by 48% for ruminant meat, - increases by 18% for cereals, - increases by 10% for fruits and vegetables, - decreases by 28% for oilseeds, - increases by 26% for roots, - decreases by 68% for sugar.	Between 2015 and 2050, the share of household consumption which is wasted decreases from 10% to 5%.
Scenario justification	Based on the Eatwell guide (2016), which defines the government's recommendations on eating healthily and achieving a balanced diet. This is the dietary assumption behind the CCC Land Use Report (Committee on Climate Change, 2018).	Based on the CCC Land Use Report's high ambition scenario (Committee on Climate Change, 2018).

PRODUCTIVITY

	Crop productivity (large change)	Livestock productivity (small change)	Pasture stocking rate (large change)
Scenario definition	Between 2015 and 2050, crop productivity increases: - from 7.9 t/ha to 15.4 t/ha for wheat, - from 45 t/ha to 88 t/ha for potato.	Between 2015 and 2050, the productivity per head increases: - from 111.7 kg/head to 126.4 kg/head for cattle meat, - from 1.37 kg/head to 1.44 kg/head for chicken meat, - from 8.8 t/head to 10 t/head for cattle milk.	The average livestock stocking density increases from 1.31 TLU/ha to 1.66 TLU/ha pasture between 2015 and 2050.
Scenario justification	Based on the CCC Land Use Report's high ambition scenario for GHG emissions reduction, due to advances in technology, improvements in farming efficiency and plant breeding. This is less ambitious in timescale than the very high ambition target of Rothamsted Research's 20:20 Wheat Programme (Rothamsted Research, 2017), which aims to double the UK's wheat yields by 2032 (Committee on Climate Change, 2018).	Based on the qualitative assessment of the text regarding improvements in productivity of agriculture in the CCC Land Use Report, through better health of animals, as well as breeding and grazing practices (Committee on Climate Change, 2018).	Based on the CCC Land Use Report's high ambition scenario, in which livestock density increases by 50% (Committee on Climate Change, 2018).

Scenario signs no change · small change · large change

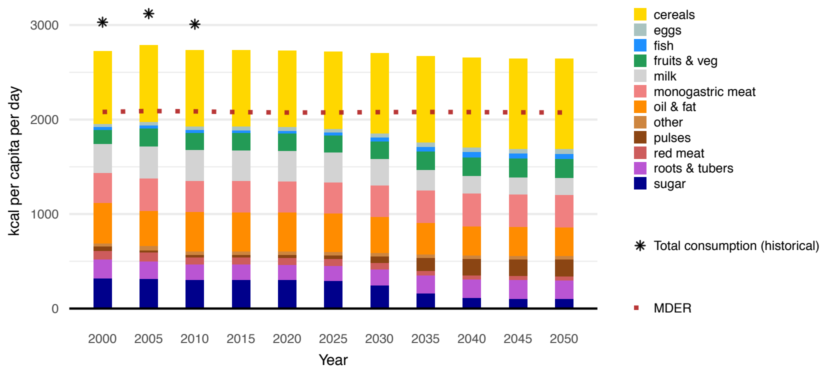
Results against the FABLE targets

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.



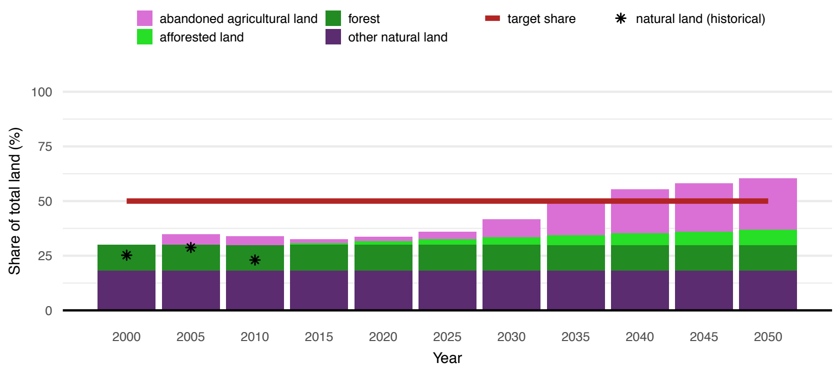
Historical data source: FAOSTAT (2019)

Our results show that average daily energy intake per capita increases between 2,696 and 2,704 kcal/cap/day from 2000-2015. This is 11% lower than FAOSTAT due to some products not being taken into account in our calculation. Over the last decade, 29% of the food intake came from cereals. Calorie intake reaches 2,625 over the period 2031-2035 and 2,590 kcal/cap/day over the period 2046-2050.

In terms of recommended diet, our results show higher consumption of pulses and cereals and lower consumption of ruminant meat and sugar. The computed average calorie intake is 20% higher than the Minimum Dietary Energy Requirement (MDER) at the national level in 2050.

Biodiversity

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



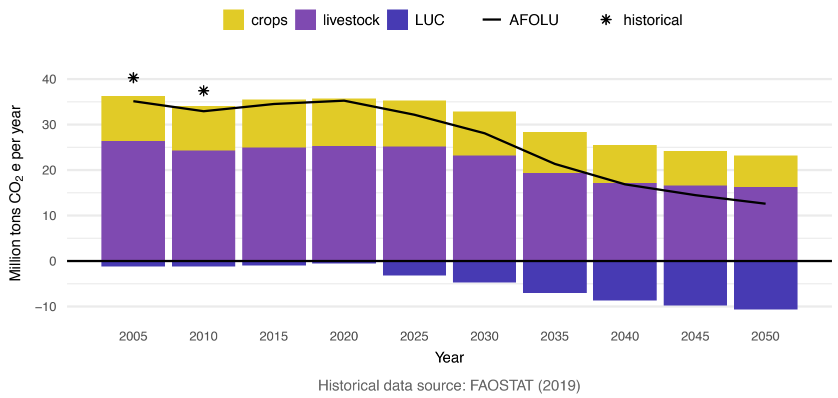
Historical data source: FAOSTAT (2019)

Our results show that the Share of Land which can support Biodiversity (SLB) decreased between 2000-2015 from 36% to 34%. This number is higher than estimates based on CEH Land Cover Map statistics (Rowland et al., 2017). The lowest SLB is computed for the period 2011-2015 at 34% of total land. SLB reaches 62% over the last period of simulation, 2046-2050. The difference is explained by higher afforestation and conversion to the other land class.

Compared to the global target of having at least 50% SLB by 2050, our results are above the target. Our results are consistent with national biodiversity objectives of halving the rate of loss of natural habitats by 2020, or where possible, reducing the loss to zero.

GHG emissions

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



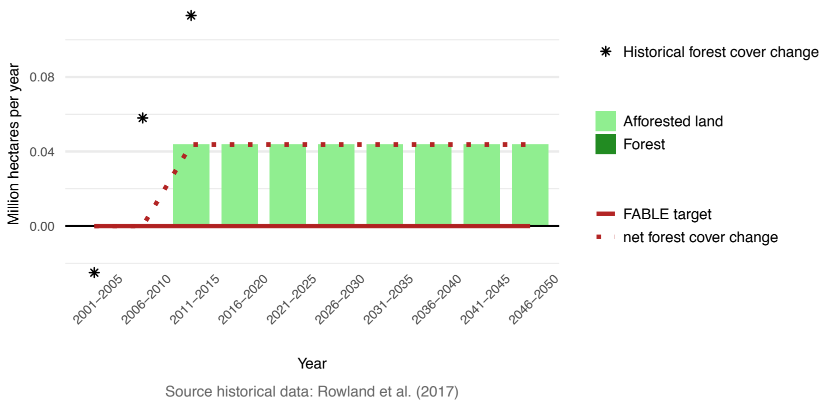
Note: AFOLU (Agriculture, Forestry and Other Land Use) is the sum of computed GHG emissions from crops, livestock and Land Use Change (LUC), emissions and sequestration from forestry are not included. Historical emissions include crops and livestock.

Our results show annual GHG emissions between 42 and 33 Mt CO_2e/year over 2000-2015 which decrease over time. These are similar to FAO, which estimates a maximum of 44 Mt CO_2e/year over the same period with a decreasing trend. Peak AFOLU GHG emissions are computed in 2000 at 42 Mt CO_2e/year. This is mostly driven by GHG emissions from livestock. AFOLU GHG emissions reach 13 Mt CO_2e over the period 2046-2050: 17 Mt from agriculture and -4 Mt from LULUCF. Negative net emissions from LULUCF by 2050 are mainly explained by afforestation.

Compared to the global target of reducing emissions from agriculture and reaching zero or negative GHG emissions from LULUCF by 2050, our results are above the target. Our results show that AFOLU could contribute to as much as 30% of the total GHG emissions reduction objective of the UK.

Forests

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



There is no deforestation computed in our results from 2000-2015. This is consistent with the FAO Global Forest Resources Assessment. Afforestation is computed from 2015-2050 and leads to a positive net forest cover change over 1.7 Mha.

Compared to the global target of having zero or positive net forest change after 2030, our results are above the target. Our results meet national objectives of having increased net forest cover change by 2060 at 5 kha/year (House of Commons, 2017).

Other relevant results for national objectives

Table 1 | Other Results

Variable	Unit	2000	2005	2010	2015	2020	2030	2040	2050
Wheat									
Production (historical)	Mt	16.7	14.9	14.9					
Production (calculated)	Mt	16.6	13.9	14.7	16.4	16.8	17.6	18.5	19.0
Beef									
Production (historical)	kt	705	762	908					
Production (calculated)	kt	698	742	845	870	887	801	541	518
Land cover									
Cropland (historical)	Mha	5.8	6.1	6.1	5.7				
Cropland (calculated)	Mha	5.8	5.4	5.5	5.8	5.7	5.4	4.8	4.1
Pasture (historical)	Mha	10.0	9.7	9.6	9.8				
Pasture (calculated)	Mha	9.8	9.0	9.1	9.0	8.8	7.2	4.4	3.7
Urban (historical)	Mha	1.7	1.5	1.6	1.8				
Urban (calculated)	Mha	1.7	1.7	1.7	1.7	1.7	1.8	1.8	1.8
Forest (historical)	Mha	2.9	2.9	2.9	3.1				
Forest (calculated)	Mha	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9
Afforestated land (calculated)	Mha	0.0	0.0	0.0	0.2	0.4	0.9	1.3	1.8
Other land (historical)	Mha	4.3	4.5	4.4	4.2				
Other land (calculated)	Mha	4.5	5.7	5.5	5.0	5.1	6.5	9.5	10.3

Source of historical data: FAOSTAT for production, CEH LCM for land cover

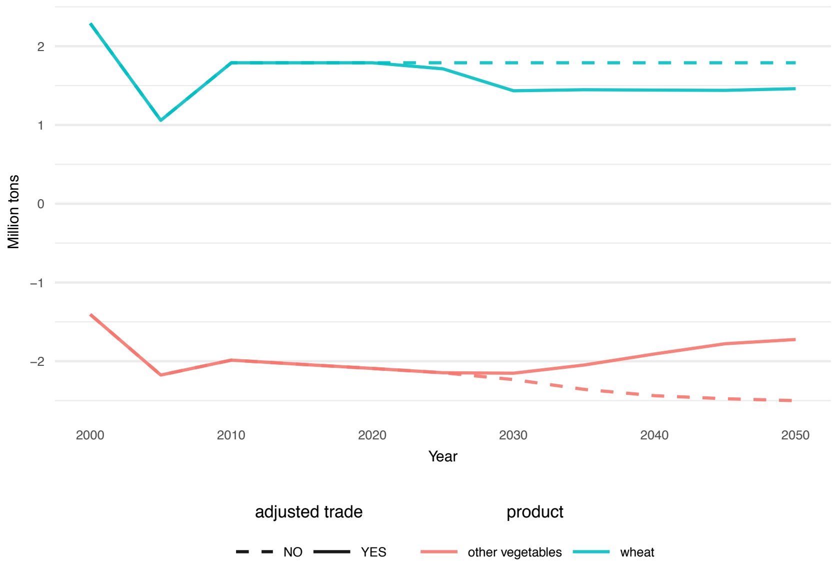
Historical wheat production has fluctuated about a mean quantity of around 15 Mt, which is matched well by the Calculator. Our results suggest that wheat production will increase overall given the scenario assumptions made. This is due to a balance between a reduction in cropland and an increase in yield over the model integration.

The Calculator matches historical beef production data well, as both FAOSTAT (2019) and the Office for National Statistics (2019) indicate a growth from around 700 kt to 900 kt between 2000 and 2015. Beef production decreases over the next 35 years, driven by the shift away from a meat-based to a plant-based diet. The reduction in production is not as severe as the change in pasture land cover would imply due to an increase in both livestock productivity and stocking density.

The Calculator generally matches the historical trends well. We see large changes away from productive land to "other land" and new forest. This is consistent with the high ambition scenario of the CCC Land Use Report (Committee on Climate Change, 2018).

Impacts of trade adjustment to ensure global trade balance

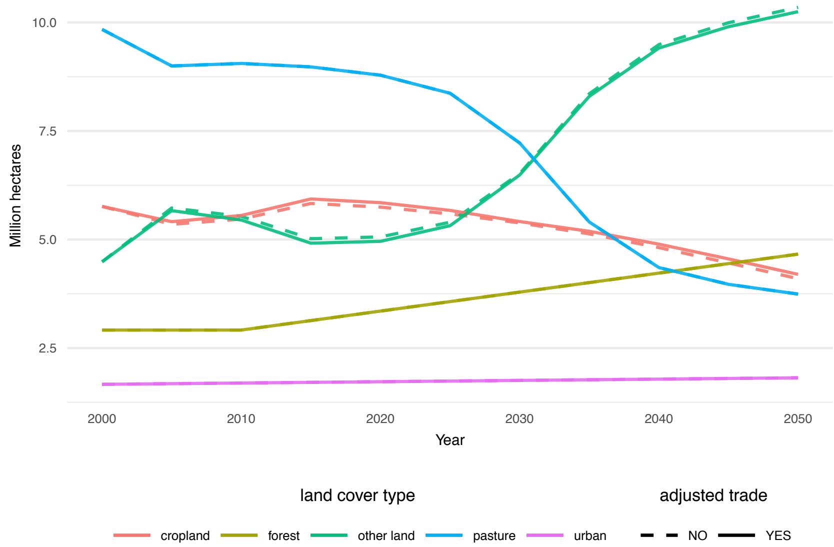
Fig. 12 | Impact of global trade harmonization on main exported/imported commodities over 2000-2050



The impact of the trade adjustment on wheat exports is to reduce them to a lower, but still stable, value (around 350 kt lower). Barley exports show no changes at the start or end of the pathway but dip in the middle, rather than staying stable, when the trade adjustment is applied.

Other vegetable imports increase in the future to 2.5 Mt in 2050 if trade adjustments are not included and are reduced to around 1.7 Mt if they are.

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



There is very little difference between the changes in land cover with and without adjusting trade.

Discussion and next steps

The UK government recognizes that the current approach to land use is not sustainable and that there is now an opportunity to define a better land strategy that responds fully to the challenge of climate change and delivers environmental quality and a full range of ecosystem services. The Government's 25-year Environment Plan, Agriculture Bill and proposed Environment Bill (DEFRA, 2018a, 2019; House of Commons, 2018) will set the future direction of policy for the use of land. The Department of Environment, Food and Rural Affairs has also commissioned a review to frame a UK Food Strategy. Meeting the target in the UK Climate Change Act (UK Government, 2008) to reduce emissions by at least 80% of 1990 levels by 2050 will require existing progress in the land use sector to be supplemented by more ambitious measures (Committee on Climate Change, 2015). The existing policy framework involves an industry-led voluntary approach to emissions reduction in agriculture, combined with an afforestation target to plant 27,000 hectares per annum across the UK by 2030. This approach is insufficient to meet the ambition set out in the Committee on Climate Change's trajectory to meet the fifth carbon budget (Committee on Climate Change, 2018). Given the recent announcement by the UK Prime Minister to further enhance this target to net zero greenhouse gas emissions by 2050 (Committee on Climate Change, 2019), it is essential that the key objectives of the Climate Change Act (2008) (achieving deep emissions reduction and adapting to the impact of a changing climate) are at the heart of the land use reforms.

More ambitious measures are described in recent reports by the Royal Society (Royal Society & Royal Academy of Engineering, 2018) and the Committee on Climate Change (2018). The pathway simulated using the FABLE Calculator is largely based on assumptions from the Committee on Climate Change report. These include measures such as improving agricultural productivity, shifting of diets towards healthier eating guidelines, food waste reduction, and afforestation. Projected outcomes from simulating this pathway using the FABLE Calculator show that net zero emissions are still not reached by 2050 but are reduced from 42 to 13 Mt CO2e/year. This is largely due to major shifts away from livestock-based foods, leading to reductions in pastureland, as well as an increasing area of new forests.

The Committee on Climate Change report focuses on measures that release land from current uses to provide for settlement growth and to maintain current per capita food production (with an increasing population) combined with measures to reduce greenhouse gas emissions from land. Some measures included in the report cannot currently be represented explicitly within the FABLE Calculator. These include moving horticulture indoors, low-carbon farming practices, forestry management, agro-forestry and hedgerows, bioenergy crops, sequestration of soil carbon (e.g. with biochar and/or mineral carbon) and peatland restoration. Low carbon farming practices, such as nitrogen use efficiency, livestock measures (e.g. improving the feed digestibility of cattle and sheep, improving animal health and fertility, and improving the feed conversion ratio through the use of genetics) and manure management, can be partly included through assumptions related to productivity in the calculator. Including peatland restoration and management in the FABLE Calculator would be highly desirable in future Scenathons as it represents a key component of UK ambitions for reducing emissions, covering 12% of the land area with three quarters of peatlands being in various states of degradation.

It would also be useful to include bioenergy crops within future versions of the FABLE Calculator, as although current planting of such crops is very low, there is an ambition to increase this level to consider the emissions savings from displacing fossil fuels alongside any net carbon benefits that are derived while growing these crops (Committee on Climate Change, 2018). Furthermore, some food sectors are not included in the Calculator, in particular fish supply is not modelled, which has a bearing on the results due to the assumption of dietary shifts towards increased fish consumption. Freshwater aquaculture may compete for scarce water resources with irrigated agriculture.

Other cross-sectoral interactions that it would be useful to represent in the FABLE Calculator include better inclusion of biodiversity and habitat indicators (as the UK has a range of goals regarding biodiversity, but these are difficult to match to the current metric in the calculator); effects on water resources (i.e. is sufficient water available to irrigate crops in the future?) and water quality (as diffuse pollution from arable land and pastures are now the main source of freshwater pollution and dairying is projected to become more intensive and concentrated on lowland pastures in the pathway).

Technological innovation (alongside behavioral change) is seen as key to enabling the UK to meet its land use objectives. UK agricultural productivity growth has lagged behind other developed countries in the last decade and further investment in innovation and technology will be crucial for delivering a range of options that can: (i) increase agricultural productivity sustainably, including the use of breeding to boost crops yields; (ii) reduce on-farm non-CO_2 emissions through the development of low-carbon fertilizers, and the use of genetic selection of livestock for inherently low enteric emissions; and (iii) reduce production costs to deliver at scale a range of novel protein sources that are produced without the requirement for land (e.g. synthetic meat and dairy products) (Committee on Climate Change, 2018).

There is significant political interest in implementing sustainable land use pathways in the UK. Specifically, the UK's exit from the EU presents a mix of increased uncertainty and a potential unprecedented opportunity for land use change through the design and implementation of new environmental land management policies that support a move towards alternative land uses and reward land-owners for public goods that deliver climate mitigation and adaptation objectives where wider environmental benefits are also achieved (Committee on Climate Change, 2018). However, there are key barriers to transitioning to different patterns of land use and management, including inertia in moving away from the status quo; mismatched financial incentives and other non-financial barriers (e.g. 30-40% of UK farms are estimated to be tenanted with the average tenancy being only 3.7 years, although in terms of area many of these farms are small); and a lack of information and support for land managers and consumers.

In order to develop the integrated policies to address these challenges there needs to be buy-in across government departments and from national to local scales to the increased ambitions. In particular, there needs to be a process to gain public support and to reconcile differences between the preferences of individuals and communities with societal needs. Spatially-explicit modelling tools are needed to support such awareness raising and detailed planning at fine resolutions that are relevant to farmers, land owners/managers and local communities.

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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USA

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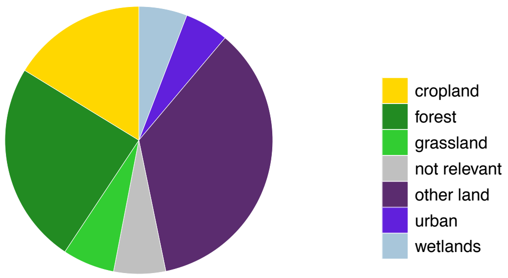
Land and food systems at a glance

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

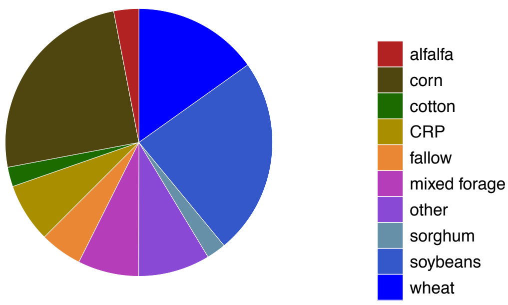
Land & Biodiversity

Fig. 1 | Area by land cover class in 2016



Source: Multi–Resolution Land Characteristics (MRLC) Consortium (2019)

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



Source: US Department of Agriculture (2016)

No annual deforestation in 2015

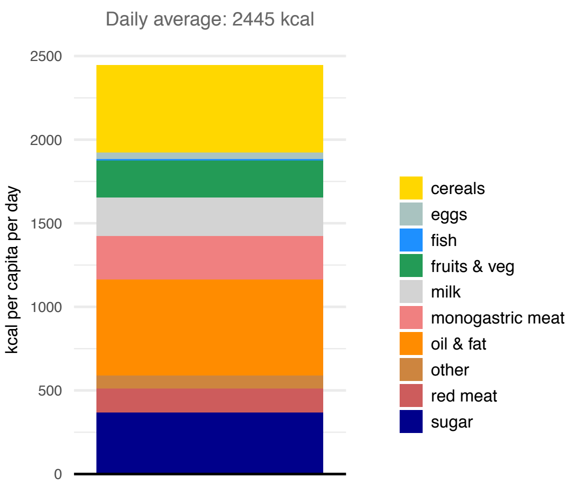
(FAOSTAT, 2019)

Endangered or threatened species: 2,275

(U.S. Fish and Wildlife Service, 2019)

Food & Nutrition

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



Source: US Department of Agriculture (2018)

Share of undernourished in 2015: 3 - 4.5%

(World Bank, 2019; U.S. Department of Agriculture, 2019a)

Share of obese in 2015: 39.6% of adults and 18.5% of children

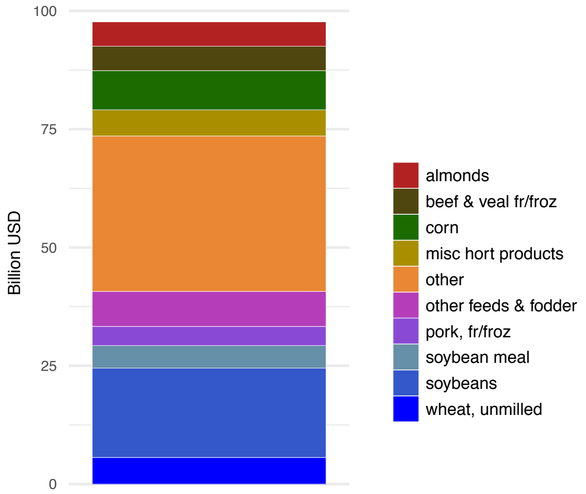
(Hales et al., 2017)

or 24.4% overall

(Ng et al., 2014)

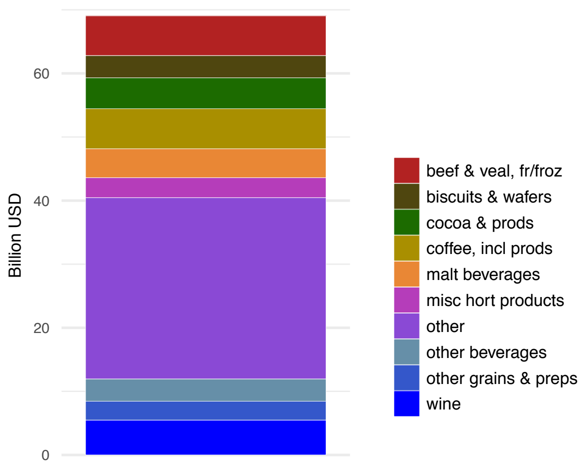
Trade

Fig. 4 | Main agricultural exports by value in 2015



Source: US Department of Agriculture (2019)

Fig. 5 | Main agricultural imports by value in 2015



Source: US Department of Agriculture (2019)

Surplus in agricultural trade: More than USD 10 billion, but declining since 2015

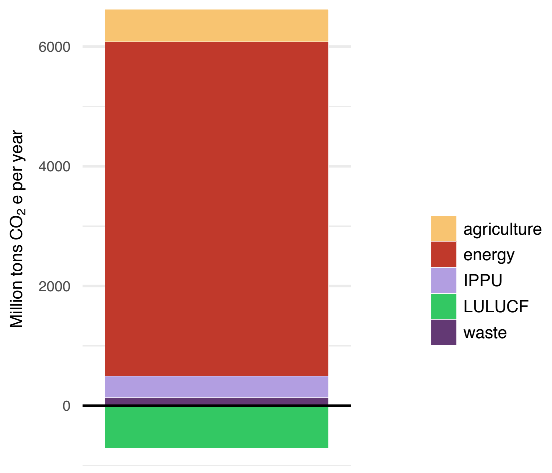
(U.S. Department of Agriculture, 2018)

Top exporter in the world in 2016

(World Bank, 2016)

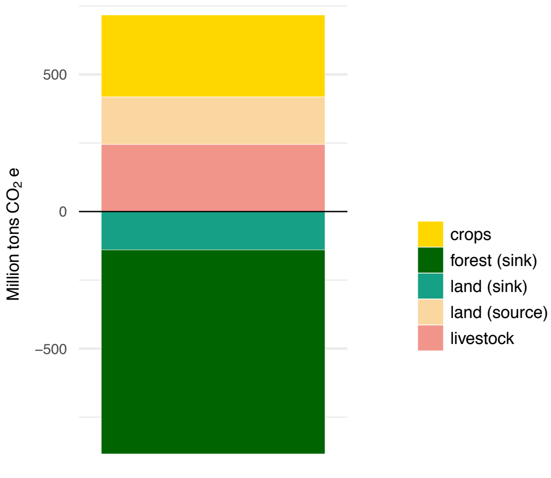
GHG Emissions

Fig. 6 | GHG emissions by sector in 2015



Source: US Environmental Protection Agency (2017a)

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



Source: US Environmental Protection Agency (2017a)

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 (large change)	Population (large change)
Scenario definition	GDP per capita is expected to increase from USD 16.6 tln, or USD 51,886 per capita, in 2015 to USD 31.8 tln, or USD 79,817 per capita, in 2050 (SSP2 selected)	The population is expected to increase by 0.6% per year between 2015 and 2050 from 319 mln to 398 mln (SSP2 selected)
Scenario justification	This is based on combined long-term projections from U.S. Congressional Budget Office, U.S. Department of Agriculture, The World Bank, IMF, United Nations, OECD, European Commission, and The Economist Intelligence Unit, which were aggregated by Knoema (2019).	Based on The US Census Bureau's report, "Projections of the Size and Composition of the US Population: 2014 to 2060" (Colby and Ortman, 2015).

TRADE

	Imports (large change)	Exports (large change)
Scenario definition	The share of the US consumption which is imported evolves: - from 38% in 2010 to 75% in 2050 for fish, - from 4% in 2010 to 8% in 2050 for tomatoes, - from 10% in 2010 to 21% for oranges, - from 15% in 2010 to 29% in 2050 for vegetables, and - from 14% in 2019 to 27% in 2050 for fruits. - Remains constant at 2010 share for other products	The exported quantity in 1000 t changes: - from 44% in 2010 to 54% in 2050 for wheat, - from 97% in 2010 to 92% in 2050 for soybean, - from 14.4% in 2010 to 23.3% in 2050 for corn, - from 9.2% in 2010 to 30% in 2050 for beef (from 1.1 mln tons to 3.3 mln tons), - from 18% in 2010 to 40% for chicken, and - from 12.2% in 2020 to 30% for pork. - Remains constant at 2010 quantity for other products
Scenario justification	The import assumptions reflect changes in dietary assumptions in the sustainable pathway scenario i.e. more fish, fruits, and vegetable consumption.	The assumption that US exports will increase is based on the expectation that global demand for grains and oilseeds will grow. Beef, chicken, and pork exports increase in alignment with reduced domestic demand for meat due to healthy dietary shifts and an anticipated increase in absolute beef demand globally due to the growing middle class in China and in an attempt to offset additional deforestation due to increased beef production Brazil.

Scenario signs no change · small change · large change

LAND

	Land conversion	Afforestation (large change)
Scenario definition	We assume that there will be no constraint on the expansion of agricultural land beyond existing protected areas and under the total land boundary.	We assume a high level of afforestation with a total targeted afforested area of 40 Mha by 2050.
Scenario justification	The US has no land use policy prohibiting land conversion at the national level.	This is double the target set in the US Mid-Century Strategy Report for Deep Decarbonization in the Benchmark scenario, or roughly consistent with reforestation targets assuming no CO2 removal technologies are employed (The White House Council on Environmental Quality, 2016), a US government report published in November 2016, which lays out a long-term strategy to decarbonize the US economy by 2050. Though high, this level of afforestation is technically feasible based on recent analysis (Fargione et al., 2018).

BIODIVERSITY

	Protected areas (large change)
Scenario definition	The protected areas increase from 11% of total land in 2015 to 50% in 2050. However, this target does not assume that all land categorized to meet this target will meet the strict management standards of other state or federally protected areas.
Scenario justification	Otherland (grass and shrubland) and forest land cover types together made up almost 50% of land in the conterminous US in 2015. If at least 50% of all land in 2050 were capable of supporting biodiversity, that would effectively mean ensuring no conversion of existing otherland or forestland for human uses.

Scenario signs no change small change large change

FOOD

	Diet (large change)	Food waste (no change)
Scenario definition	Between 2015 and 2050, the average daily calorie consumption per capita decreases from 2,700 kcal to 2,500 kcal. Per capita consumption: - decreases by 50% for beef, - decreases by 50% for other meats, - increases by 5% for milk, - decreases by 47% for oils, - increases by 50% for other, including nuts, - decreases by 50% in eggs, - increases by 40% for pulses, - increases by 38% for roots, - decreases by 3% for sugar, - increases by 76% for fruit and vegetables, and - increases by 200% for fish.	By 2050, the share of final household consumption which is wasted remains stable at 10%.
Scenario justification	Based on the USDA "US Healthy Style Diet" (U.S. Department of Health and Human Services and U.S. Department of Agriculture, 2015). Adjustments to the current average US diet were made to achieve the "US Healthy Style Diet" by 2050, which was converted from volumetric or weight specifications to calories using representative food types per category (e.g., apples, bananas, carrots, and spinach for "fruit and vegetables").	This is a more optimistic assumption than the official estimates: USDA Economic Research Service estimates that 31% of food produced in 2010 was wasted at the consumer or retail levels (Buzby et al., 2014). But in 2015, the US EPA and USDA announced a goal of reducing food waste by 50% by 2030, relative to 2010 levels, which would mean about 15% of all food produced would be wasted in 2030 (U.S. Department of Agriculture, 2016b).

Scenario signs no change · small change · large change

PRODUCTIVITY

	Crop productivity	Livestock productivity	Pasture stocking rate
Scenario definition	Between 2015 and 2050, crop productivity increases: - from 9.7 t/ha to 13.7 t/ha for corn, - from 3.1 t/ha to 7.8 t/ha for wheat, and - from 3 t/ ha to 4.4 t/ha for soybean.	Between 2015 and 2050, the productivity per head increases: - from 128 kg/head to 166 kg/head for beef, - from 1 kg/head to 1.6 kg/head for chicken, and - from 8.8 t/head in 2015 to 10.8 t/head in 2050 for cow's milk.	The average ruminant livestock stocking density remains constant at 0.42 TLU/ha of pastureland between 2015 and 2050.
Scenario justification	Based on US Department of Agriculture (USDA) Agricultural Projections to 2028 report (U.S. Department of Agriculture, 2019b). The following are the actual projections from the report: - Corn increases from 11.08 t/ha in 2017/18 to 12.2 t/ha in 2028 (assuming the same productivity improvement rate, then it is 14.7 in 2050). - Wheat increases from 3.1 t/ha in 2010 to 3.4 t/ha in 2028 (assuming the same productivity improvement rate, then it is 4.2 in 2050). - Soybean increases from 3.3 t/ha in 2010 to 3.6 t/ha in 2028 (assuming the same productivity improvement rate, then it is 4.9 t/ha in 2050).	Based on USDA Agricultural Projections to 2028 report (U.S. Department of Agriculture, 2019b). The following are the actual projections from the report: - USDA does not report productivity per head; instead, national production of 26,187 mln pounds of beef and 93,702,000 cattle in inventory in 2017 were used to calculate the following productivity values. As a result of this calculation, these values may not be directly comparable with those used in the Calculator. - Beef productivity increases from 127 kg/head in 2017 to 148 kg/head in 2028 (assuming the same productivity improvement rate, then it is 201 kg/head in 2050). - The U.S. team was unable to find equivalent stats by head for chicken. - Milk productivity increases from 10.4 t/head in 2017 to 12 t/head in 2028 (assuming the same productivity improvement rate, then it is 16 t/head in 2050)	No data on US national average livestock stocking densities to compare this value with.

Scenario signs no change small change large change

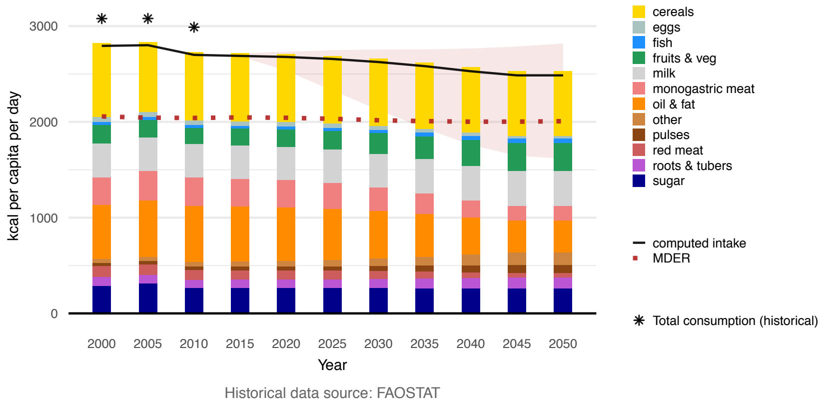
Results against the FABLE targets

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

Food security

Fig. 8 | Computed daily kilocalorie 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. The pink envelope shows the range of the evolution of the daily kilocalorie intake per capita across a large number of combination of scenarios in the US FABLE calculator.

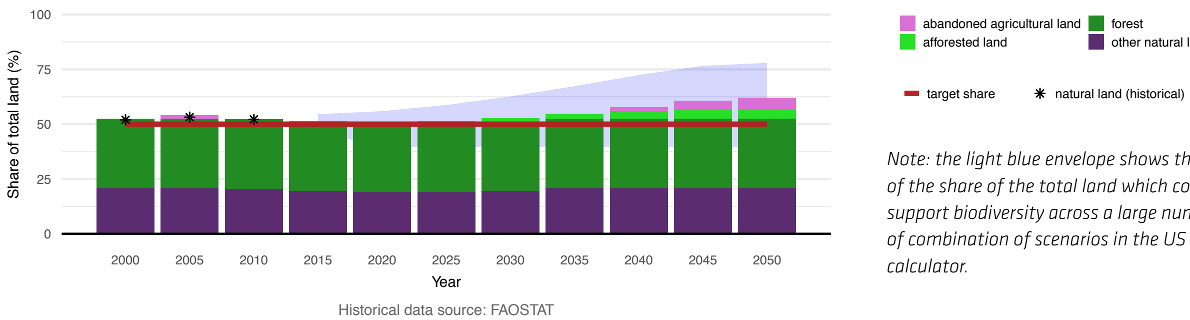


Our results show average daily energy intake per capita decreases from 2,650 to 2,500 kcal/cap/day from 2000-2050. Historical values are 30% lower than FAO's report due to some products not being accounted for in our calculation. Over the last decade, 30% of the food intake came from cereals.

In terms of recommended diet, our results show lower consumption of meats, eggs, oils and higher consumption of fish, fruits and vegetables, roots, and pulses. The computed surplus of average calorie intake compared to the MDER at the national level reduces over time and reaches 20% in 2050. This should not threaten the food security objective as there is a high prevalence of obesity in the US (~40%). However, this shift will be extremely challenging to achieve given that recent USDA projections show increasing per capita meat and egg intake.

Biodiversity

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



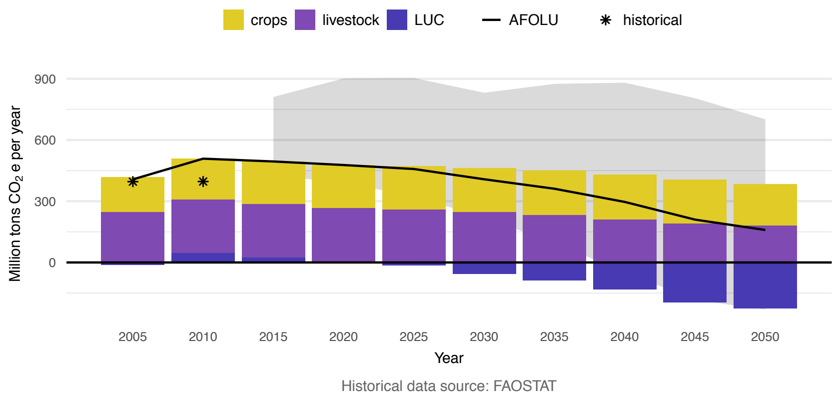
Note: the light blue envelope shows the range of the share of the total land which could support biodiversity across a large number of combination of scenarios in the US FABLE calculator.

Our results show that the Share of Land which can support Biodiversity (SLB) remained fairly constant between 2000-2015 at around 54%. The lowest SLB is computed for the period 2015 to 2030 at 52.4% of total land. This is mostly driven by otherland conversion to cropland. SLB reaches 60% over the last period of simulation 2046-2050. This difference is explained by reaching the afforestation target of 40 Mha and increasing otherland after agricultural land abandonment due to diet shifts.

Compared to the global target of having at least 50% SLB by 2050, our results are above the target. There are no national policy commitments to which the US could calibrate assumptions.

GHG emissions

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



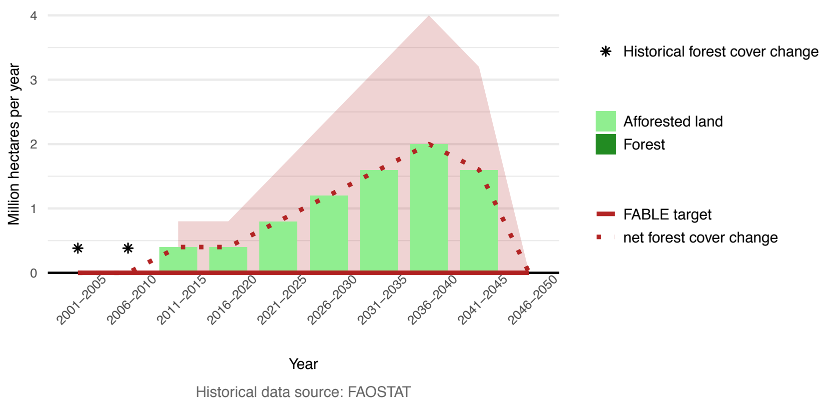
Note: AFOLU (Agriculture, Forestry and Other Land Use) is the sum of computed GHG emissions from crops, livestock and Land Use Change (LUC), emissions and sequestration from forestry are not included. Historical emissions include crops, livestock, land use change and carbon sequestration in grasslands and forests. The grey envelope shows the range of the evolution of the total net AFOLU emissions across a large number of combination of scenarios in the US FABLE calculator.

Our results show annual gross GHG emissions between 320 and 500 Mt CO_2eq from 2000-2050, which decrease over time. Agriculture sector emissions align reasonably with the US GHG Inventory (Environmental Protection Agency, 2017a), but LUC and forest sector emissions diverge substantially. From 2025 onward, LUC emissions are negative (indicating a positive net sink), driven by high levels of reforestation due to the reforestation target and pastureland abandonment. The historic carbon emissions from land use and LUC differ from observed inventory estimates (which indicate a net carbon sink from US LULUCF) and recent projections of forest carbon fluxes that show a declining (e.g., Wear and Coulston, 2015; Latta et al., 2018) or a slightly increasing sink (Tian et al., 2018). These publications, along with the US GHG Inventory, show a significant annual forest carbon flux attributed to aboveground carbon storage on existing forests. This flux source is not represented in the FABLE Calculator, hence we are under-representing the projected LULUCF flux and net abatement potential that the land-use sectors could provide.

Compared to the global target of reducing emissions from agriculture and reaching zero or negative GHG emissions from LULUCF by 2050, our results exceed the target.

Forests

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



Our results show no annual deforestation, which is consistent with recent US trends as reported by the FAO (2016). Afforestation results over 2010-2020 are similar compared to other sources that model forest area increase of 5 Mha and historical rate of forest increase of about 705 kha per year between 2007 and 2012 (Wear and Coulston, 2015; Tian et al., 2018). We assume afforestation of 40 Mha from 2015 to 2045: 10% from cropland, 10% from pastureland, and 80% from otherland. While this is significantly higher than current policies and programs in place for incentivizing reforestation (e.g., Conservation Reserve Program target of 9.7 Mha, Hellerstein, 2017), it is consistent with technical feasibility studies (Fargione et al., 2018). The ratio of projected afforestation between cropland and pasture is consistent with findings in Cai et al. (2018).

Compared to the global target of having zero or positive net forest change after 2030, our results are above the target.

Other relevant results for national objectives

Table 1 | Other Results

Variable	Unit	2000	2005	2010	2015	2020	2030	2040	2050
Beef Production. Imports and Exports									
Production (historical)	Mt	12.3	11.2	12.0					
Production (calculated)	Mt	12.1	11.1	11.9	12.2	12.5	12.5	11.4	10.9
Imports (calculated)	Mt	0.2	1.4	0.0	0.0	0.0	0.0	0.0	0.0
Exports (calculated)	Mt	0.0	0.0	0.0	0.2	0.3	1.2	2.6	3.3
Land-Use Change									
Cropland (historical)	Mha	178	168	159					
Cropland (calculated)	Mha	178	168	159	161	161	161	156	143
Pasture (historical)	Mha	236	244	250					
Pasture (calculated)	Mha	232	227	251	255	257	247	213	188
Forest (historical)	Mha	300	302	304					
Forest (calculated)	Mha	300	300	300	300	300	300	300	300
Afforested land (calculated)	Mha	0	0	0	2	4	14	32	40
Other land (historical)	Mha	202	202	202					
Other land (calculated)	Mha	197	210	194	184	176	172	184	213
Urban (calculated)	Mha	9	11	12	14	17	23	31	32

Source historical data: FAOSTAT

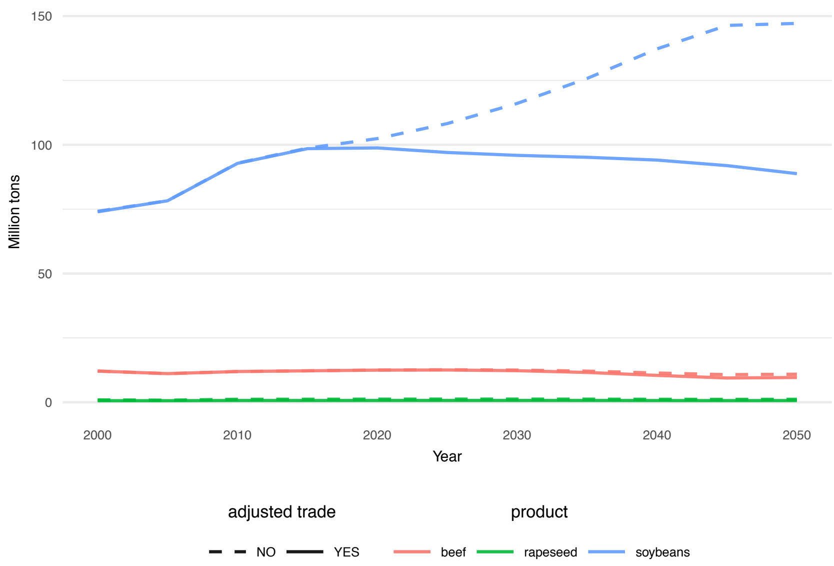
Domestic beef production has historically been high, with imports and exports comprising much smaller fractions of the beef market. Between 2015 and 2050, beef production would peak in 2025 and decline to below 2005 levels by 2050. This trend is due to healthy dietary shifts that reduce beef consumption per capita by 50% by 2050, which allows for the surplus in domestic production to be exported.

Soybean production under a sustainable land-use pathway is expected to continue increasing, primarily to meet export demand. Vegetable production declined between 2000 and 2010, but due to healthy dietary shifts, vegetable production and imports are expected to increase significantly.

The FABLE Calculator is generally able to back-cast historic land-cover trends (with pasture in 2005 being a minor exception).
The sustainable land-use pathway designed here results in slightly increasing cropland extent from 2015 until around 2035, after which cropland area begins a slow and steady decline through 2050. Pastureland extent also increases slightly between 2015 and 2025, after which it declines rapidly through 2050. Otherland decreases between 2015 and 2025 due to the combined expansion of cropland, pastureland, and urban areas, but starts to make a steady recovery to 2005 levels by 2050 due to cropland and pastureland contraction.

Impacts of trade adjustment to ensure global trade balance

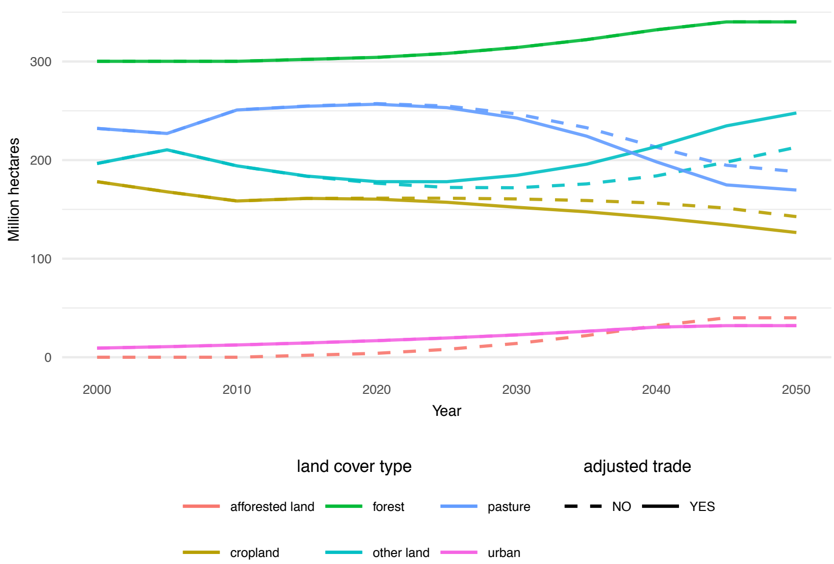
Fig. 12 | Impact of global trade harmonization on main exported/imported commodities over 2000-2050



US exports of soybean, rapeseed, and to lesser extents, wheat and beef were reduced compared to the values presented in the preceding table.

Coffee imports decrease after trade adjustments. In light of reduced imports, and to meet per capita growth projections, US coffee production must increase from 13kt in 2050 to 1.4Mt. This seems unlikely unless Hawaii and Puerto Rico significantly expand production.

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



The most significant impacts of trade adjustment were on beef and soy exports. As a result, domestic production of these two commodities decreased, causing more cropland to otherland and pasture to otherland conversion. In total, otherland increased about 30 Mha.

Discussion and next steps

In the absence of federal policy targets or results for many of the Sustainable Development Goals explored in this report, the sustainable land-use pathway presented here is based on the US modeling team's assumptions, commitments in the federal government's Mid-Century Strategy report (The White House Council on Environmental Quality, 2016), and the most recent available literature. As a general principle, we strove to meet the four FABLE targets at the national level and participated in the Scenathon with the intention of minimizing international supply chain related land-use impacts.

While nutritional health is not a target, we chose to examine co-benefits of healthy diets on achieving sustainable land use domestically and, through the Scenathon, globally. Of all the assumption modifications made in the Calculator (population, imports, exports, food waste, productivity of crops and livestock, and diets), we find that land-use and land-cover trajectories, as well as greenhouse gas emissions from the agricultural sector, are highly sensitive to diet and productivity assumptions - and it is the combination of the two, rather than one alone, that lead to a sustainable land-use trajectory. If we assumed no crop or livestock productivity changes and current diet composition, there would be an increase in cropland production of 12 Mha by 2050 compared to 2010, but an increase in pastureland of 62 Mha over the same period. However, if we assumed high crop and livestock productivity, there would actually be a decrease in cropland of 12 Mha and an increase in pastureland of 34 Mha (halving the amount of pastureland growth, compared to the BAU productivity and diet scenario). If we assumed only a shift from today's diet to the "Healthy US-style diet" recommended by the USDA, there would be an increase in cropland of 18 Mha, but a decrease in pastureland of 33 Mha. It was the combination of the healthy diet shift and high productivity assumptions that would lead to stable or declining area of cropland and pastureland by 2050 - with about 15 Mha reduction in cropland and 80 Mha reduction in pastureland. Recognizing the drastic reduction in pastureland and the potential for the US to offset deforestation resulting from the potential rising demand for beef globally, we decided to triple the quantity of beef exports from the US by 2050. However, many other countries also adopted sustainable diets in their pathways, and thus, trade adjustments addressed the surplus of beef on the global market by reducing the amount of exports from the US to be just twice the historic quantity (2,200 Mt in 2050 vs. 1,100 Mt in 2010).

These productivity and diet assumptions enable ambitious natural climate solution implementation in ways that do not compete for productive uses of land. Of the 95 Mha of crop and pastureland that could be taken out of productive use by 2050, 40 Mha could be reforested as one of many activities making up a suite of mitigation and sequestration targets necessary to achieve 80% economy-wide greenhouse gas reductions below 2005 levels by 2050, as outlined in the US Mid-Century Strategy report (The White House Council on Environmental Quality, 2016). The 40 Mha target is approximately consistent with meeting the reforestation target needed if no other CO2 removal technologies were deployed by 2050 (e.g., Bioenergy with Carbon Capture and Sequestration or Direct Air Capture) (The White House Council on Environmental Quality, 2016).

We have identified six key limitations of the US FABLE Calculator that warrant additional consideration in future iterations.

First, we do not explicitly include bioenergy, including first- and second-generation biofuels expected under the US federal Renewable Fuels Standard requirements, which, if met, would require a large allocation of US land resources (Environmental Protection Agency, 2015). Furthermore, several longer-term climate stabilization pathways (The White House Council on Environmental Quality, 2016) and Intergovernmental Panel on Climate Change (2018) rely heavily on large-scale investments in technologies like bioenergy with carbon capture and sequestration (BECCS) to produce negative emissions sources. Understanding the impacts on other land uses are a critical component of trade-offs between these very different climate mitigation pathways. We currently do not account for the land resource requirements of BECCS expansion in the US to hit climate stabilization targets; instead, we focus on land use activities that increase carbon sequestration on the landscape (e.g., re/afforestation).

Second, we do not account for the land use requirements of other conventional (natural gas) or renewable (wind and solar) energy technologies, which could have significant land requirements by mid-century. Trainor et al. (2016) anticipate that the total land use requirements, which account for spacing between wind turbines and natural gas wells, would be equivalent to the land area of the state of Texas, and direct land requirements would be equivalent to the land area of the state of South Dakota.

Third, we do not consider the role of forest management on land-use and carbon outcomes. Management interventions in forestry can increase carbon uptake (Tian et al., 2018), but can also raise important biodiversity concerns when switching from naturally regenerated stands to monoculture plantations (Paillet et al., 2010). Future iterations of this Calculator and land-sector projections should attempt to differentiate between naturally regenerated (non-managed) and planted (intensively managed) forest systems.

Also, in developing the US sustainable land-use pathway the US FABLE team identified several data inconsistencies between FAO sources that provide the basis of the FABLE Calculator and more detailed US sources. While US statistics are the primary source for FAO reported US data, information is aggregated in a way that makes calibration difficult for the US Calculator. One example is the FAO land use categorization system that is used in the Calculator - this system differs from land-use categories defined in widely utilized land-use/land-cover statistics in the US, including the USDA Major Land Use Database, the Natural Resources Inventory, and National Land Cover Database. US land-use/land-cover datasets are often used to calibrate land resource availability in US-focused models (Jones et al., 2019). Moving from a more detailed land categorization system to the FAO aggregates presents challenges in reconciling differences in key land categories such as cropland (e.g., the FAO does not distinguish between "cropland," which is used for direct crop production, and "cropland pasture," which is not actively cultivated for crop production but is part of the permanent crop rotation in the US). Future efforts will identify key underlying data differences in coordination with other members of the FABLE Consortium, as well as approaches to better reconcile global and national data inconsistencies.

Fourth, while we account for potential land resource constraints on pursuing different biodiversity, climate, and healthy diet policy aspirations, we do not explicitly address other resource constraints. For instance, water availability and quality can limit growth in agricultural production (and forestry), and could pose local constraints for future investments in specialty crop production to hit healthy diet targets, though these dietary pathways can be water-saving globally relative to business as usual (Willett et al., 2019). Furthermore, agricultural water requirements could increase substantially with bioenergy or BECCS expansion for longer-term climate mitigation goals (Beringer et al., 2011). Climate change could exacerbate this concern in some regions of the US as higher temperatures and shifting precipitation patterns increase the demand for irrigation water (Environmental Protection Agency, 2017b; Baker et al., 2018). Future integrated assessment modeling efforts that explicitly recognize regional water constraints could inform future versions of this Calculator, resulting in more robust trade-off analysis of alternative land-sector pathways.

Fifth, average diet assumptions are overly simplistic, and given that the Calculator is a demand-driven model, more accurately or realistically representing the demand for specific food types will be important for improving the model. Additionally, assuming an average "US-Style Healthy Diet" for the entire population does not lend itself well to understanding the impacts of ongoing trends in dietary preferences (e.g., vegetarian, flexitarian diets, plant-based meat substitutes). Thus, constructing average diets using a "bottom-up" approach based on percentage of population adopting different diets could help in understanding the sensitivity of emerging or novel dietary choices and products on land-use pathways.

Finally, productivity values for crops and livestock are based on linear extrapolations of historic trends. Future versions of the Calculator or partial equilibrium land-use models should account for the counteracting effects of climate change on productivity.

There are no specific policy targets in the US currently that would increase the level of ambition in the sustainable land-use pathway as a whole. However, several policy proposals that have recently been put forward for debate have the potential to interact with the specific land-use sector targets outlined in this narrative. First, a national clean energy standard (NCES) announced in May 2019 is currently being debated (Morehouse, 2019). A US NCES would create additional competition in the land-use sectors for renewable energy development, which would potentially conflict with food production and healthy diet goals but could reduce greenhouse gas emissions from the energy and industrial sectors substantially. Ambitious policy frameworks such as the Green New Deal could have similar implications. Emerging proposals to increase fossil energy extraction on public lands in the US should also be addressed in future iterations of this Calculator. Likewise, various state-level proposals to increase management or timber removals on public forestland to reduce wildfire risk could have land carbon and biomass supply implications.

Nearly half of the states have joined the US Climate Alliance, which commits member states to reduce greenhouse gas emissions 26-28% below 2005 levels by 2025. Several Climate Alliance states have passed legislation to achieve far more ambitious mid-century targets, including 80-85% GHG reductions below 1990s levels by 2050 (California and New York) and 100% clean and renewable energy targets by 2040-2050 (Hawaii, California, New Mexico, Washington, and New York). Even without an NCES, these regional or state-level commitments could result in a sizable demand for land use to support low-carbon electricity as well as natural and working land climate solutions (e.g., reforestation, increase soil carbon sequestration).

While technologically advanced, the US would benefit from increased investments in agricultural research related to specialty crops (e.g., fruits, vegetables and nuts) that would comprise a higher share of total caloric intake and agricultural area under a healthy diet future. Current agronomic knowledge of these systems in the US context lags scientific knowledge of primary grains and oilseeds produced in the US. If dietary shifts are driven by policy, preference changes, or environmental conditions, new scientific research on non-traditional crops (e.g., pulses) is needed to enhance the resilience of the US food supply system.

One of the key levers for achieving sustainable land use in this pathway is shifting dietary preferences to a healthy US style diet - which effectively requires reversing recent historical trends of increasing red meat, poultry, and dairy consumption per capita. Under current 2015 diet assumptions for the US and "Middle of the Road" GDP and population growth assumptions, the amount of otherland (primarily grass and shrubland) converted to pasture land must increase from 249 Mha to 293 Mha in 2040 and 283 Mha in 2050. With the exception of importing more meat products or feed, no other combination of reasonable pathway levers (e.g., crop productivity, food waste) can achieve a stable or declining trajectory for land under agricultural use. Healthier dietary choices can be encouraged and incentivized through stronger educational campaigns and removing direct and indirect subsidies for the dairy and meat industries so that commodity prices most closely reflect the true cost of production.

Another primary challenge in implementing a sustainable land-use pathway in the US is resistance to regulation on the part of landowners and managers and the political feasibility of ambitious land-use sector policies. It is important to note that while the assumptions developed for this US sustainable land-use pathway are based on information in publicly available reports, databases, and peer reviewed literature, this pathway does not represent current policies or programs being implemented at the US federal level, and are thus hypothetical policy targets. However, the Calculator and its sustainable land-use scenario provide key information on potential trade-offs associated with ambitious land sector policy goals. In the absence of strong policy incentives, private sector leadership and philanthropic contributions can also help advance sustainable land-use goals, so the FABLE Consortium and country-level sustainable land-use pathways can help inform investment strategies for these non-governmental entities.

The analysis for land use policy design should be based on a unified and consistent set of assumptions. For example, consistent definitions of land cover type (pastureland, grassland, forest) across various federal agencies could avoid mis-interpretation of model assumptions on land-cover conversion. Future approaches should also be detailed enough - spatially and in terms of sector representation - to support land use decisions at state or regional levels given that land conservation and natural resource management requires highly spatially explicit planning.

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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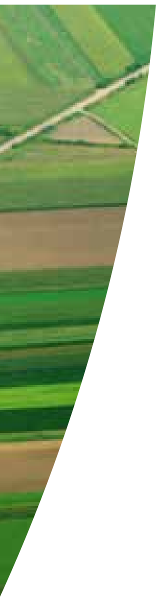

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