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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.

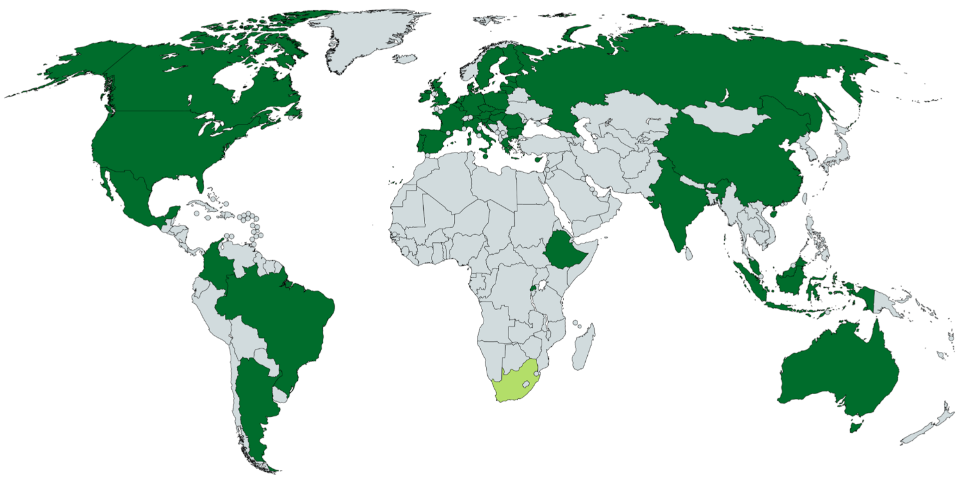
We welcome comments and suggestions for improving the work presented in this first report. And we invite research teams and other partners to join this consortium.

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.



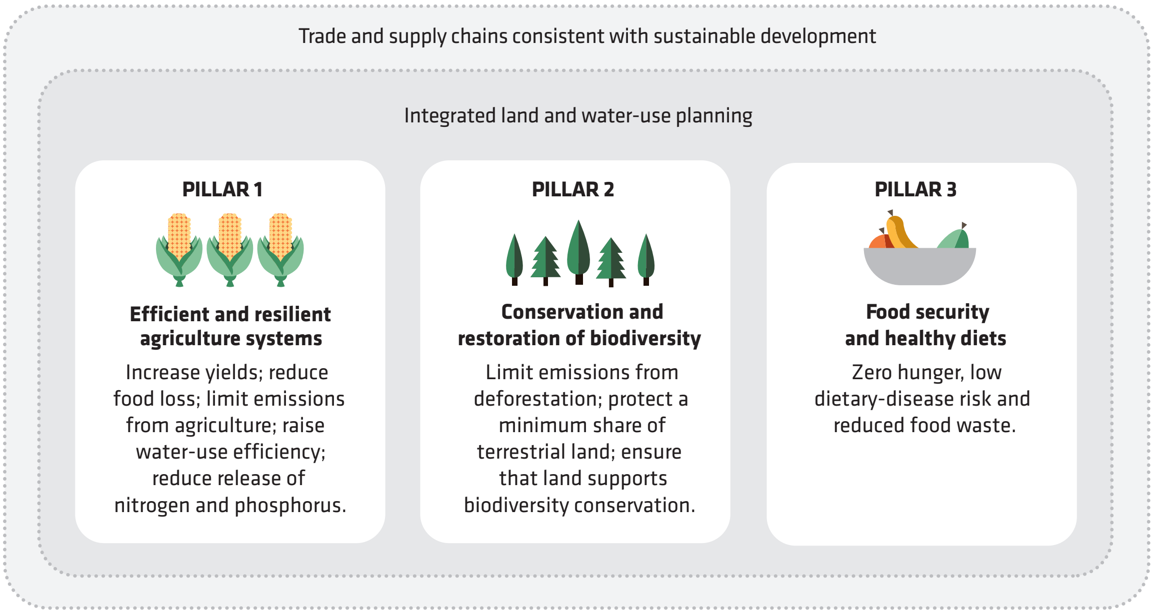
been considered. The report does not discuss policy options for transforming these systems, their implementation, or associated costs and economic benefits. These critical issues will be addressed in the global report by the Food and Land-Use Coalition, which will be published in September 2019 ahead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

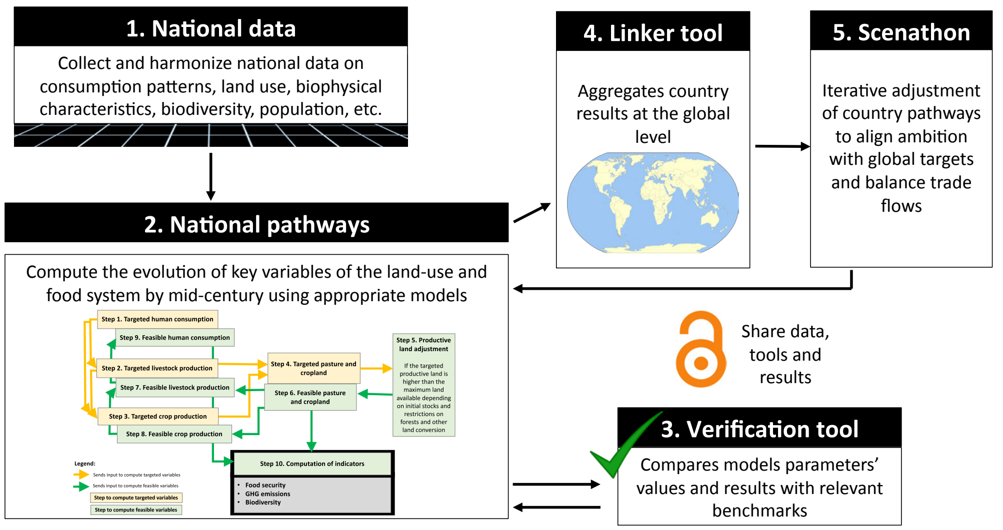
3. **Analysis of national policy options and support to national and international policy processes** will be undertaken over the coming year.

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.

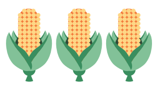
The feasibility of rapid progress towards the FABLE objectives is driven largely by six factors: (1) large gains in agricultural productivity; (2) shifts in diets towards less meat consumption, with reductions in food overconsumption; (3) a

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

Trade consistent with sustainable development

Integrated land use planning

PILLAR 1



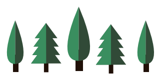
Efficient and resilient agriculture systems

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

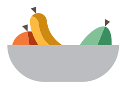
Net global forest cover change:
+1.6 Mha/year in 2050

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%

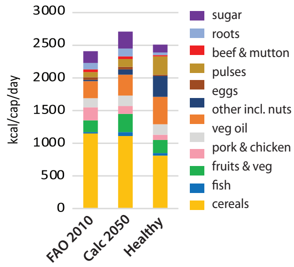
PILLAR 3



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).

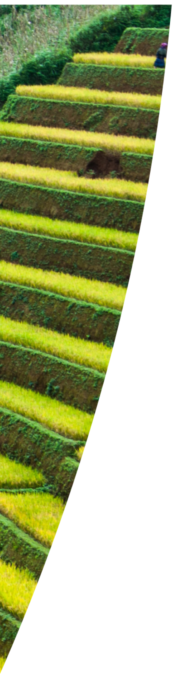
1.5. How FABLE is addressing each crisis

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

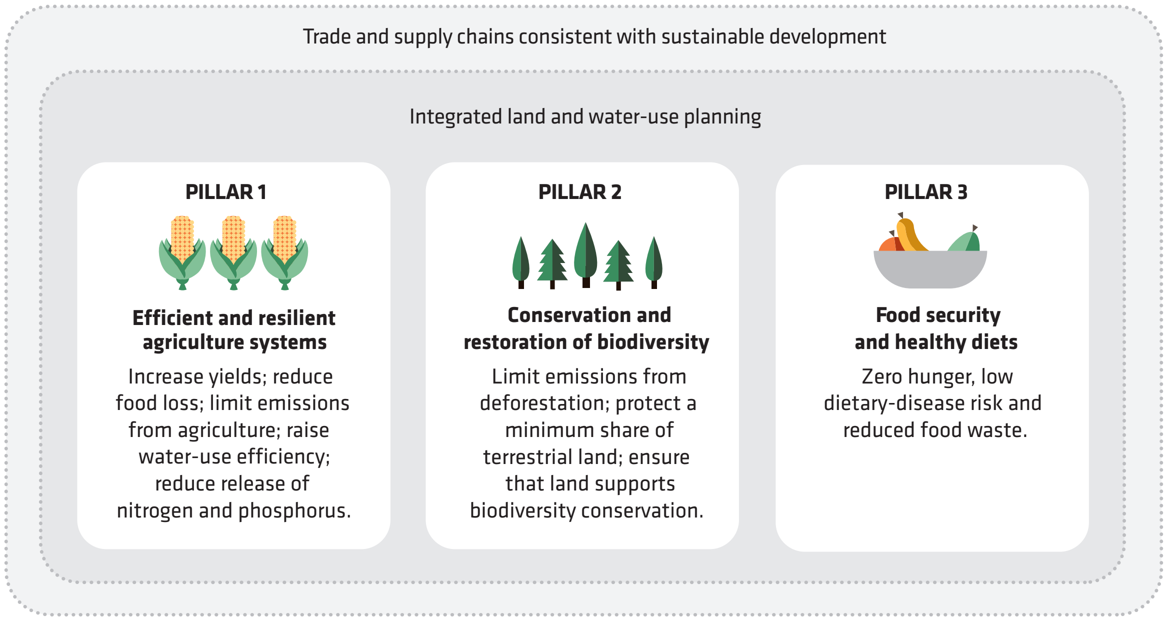
The good news is that solutions exist to address the four interconnected crises of land-use and food systems, which include non-food crops, such as fibers and animal feed. Success will require integrated strategies that are mindful of trade-offs, as they may occur between, for example, increasing agricultural 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.

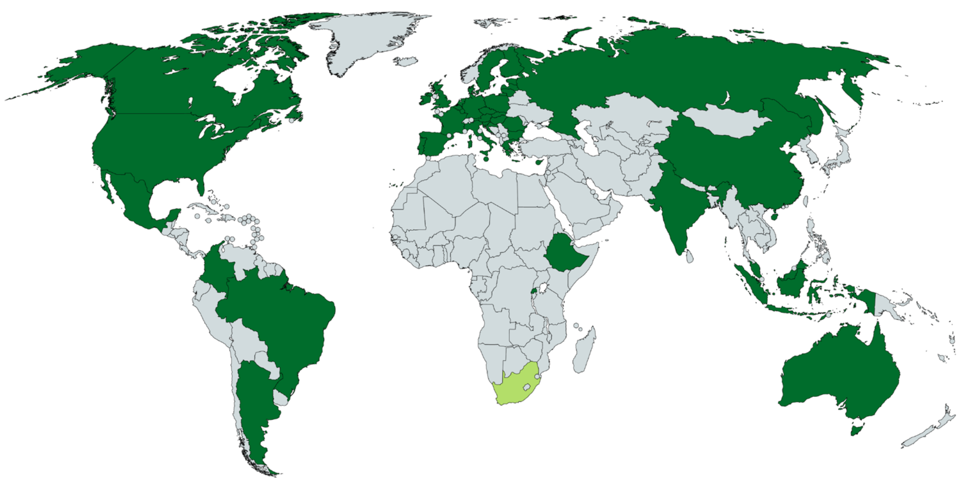
FABLE is inspired by experiences from land-use policy impact assessments carried out in a range of countries, including the European Union, USA, and Australia. In particular, FABLE draws on Brazil's experience in implementing the GLOBIOM land-use model, which is now used to formulate and implement ambitious 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.

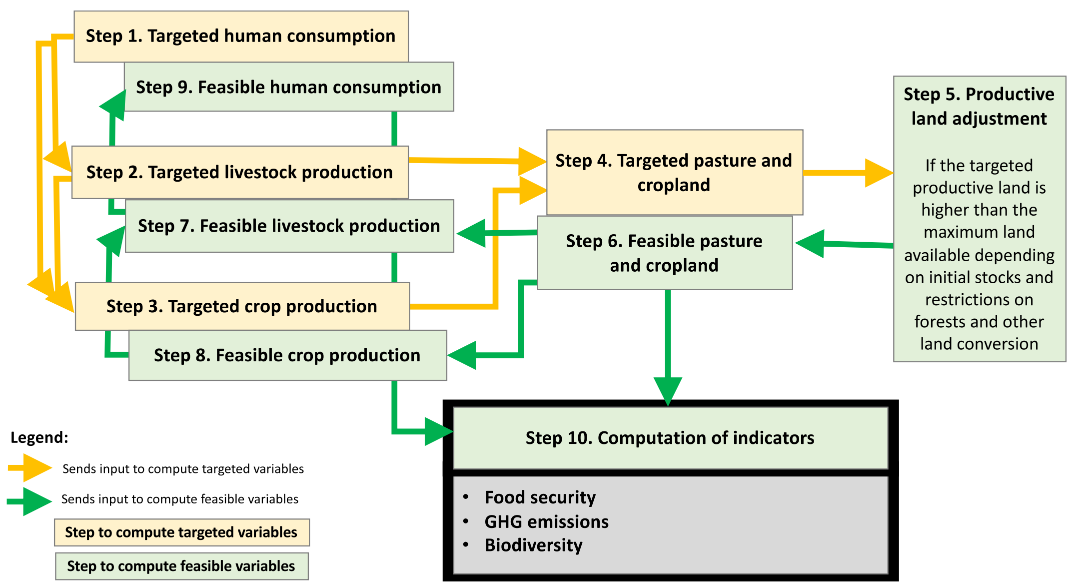
The FABLE Calculator can quickly generate pathways towards sustainable land-use and food systems using national-level data. It can also operate at sub-national levels. While the Calculator does not allow for geospatial disaggregation or for dynamic optimization, it ensures maximum transparency. Users 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".

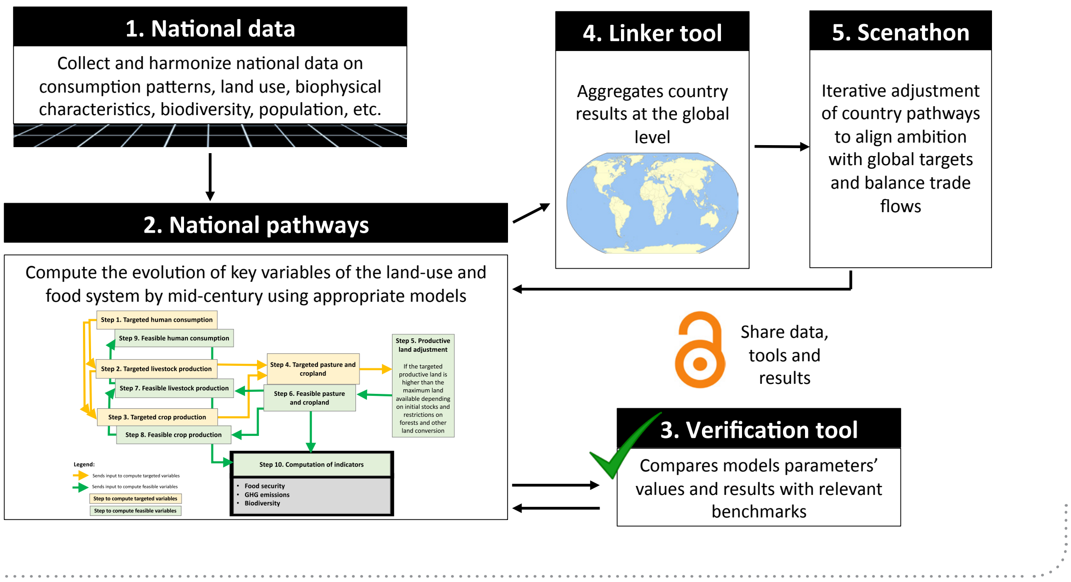
3.3.1. Preparation of national data

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.

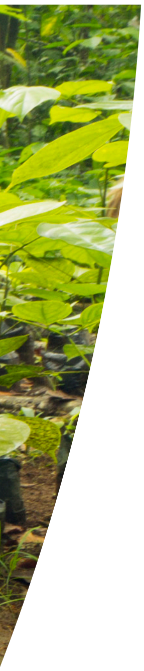
3.4. Technology and policy roundtables

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

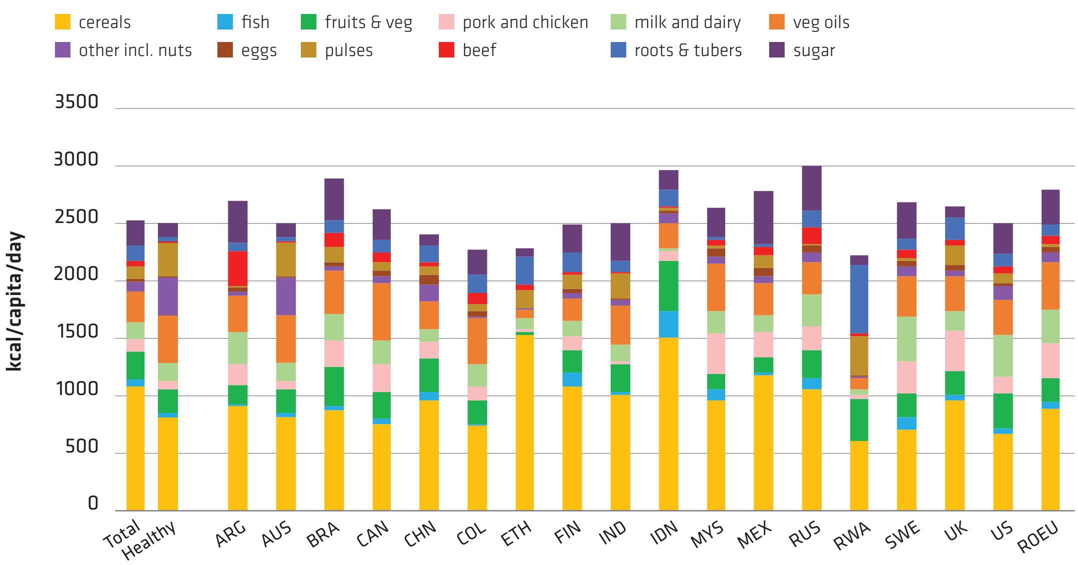
UN medium-variant, mainly because of different assumptions on female education attainment and different levels of education-specific fertility in Africa (KC and Lutz, 2017). Based on our assumptions, some 44 percent of this increase occurs in Asia, 37 percent in Africa, and 7 percent in the Middle East.

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.*

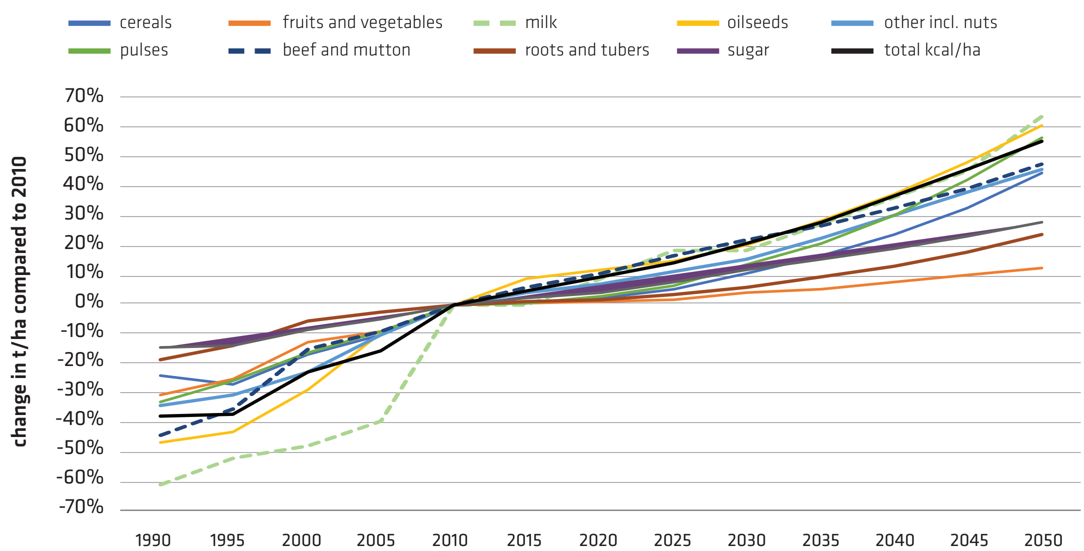


Table 2 *Summary of the main assumptions of FABLE pathways.*

		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).

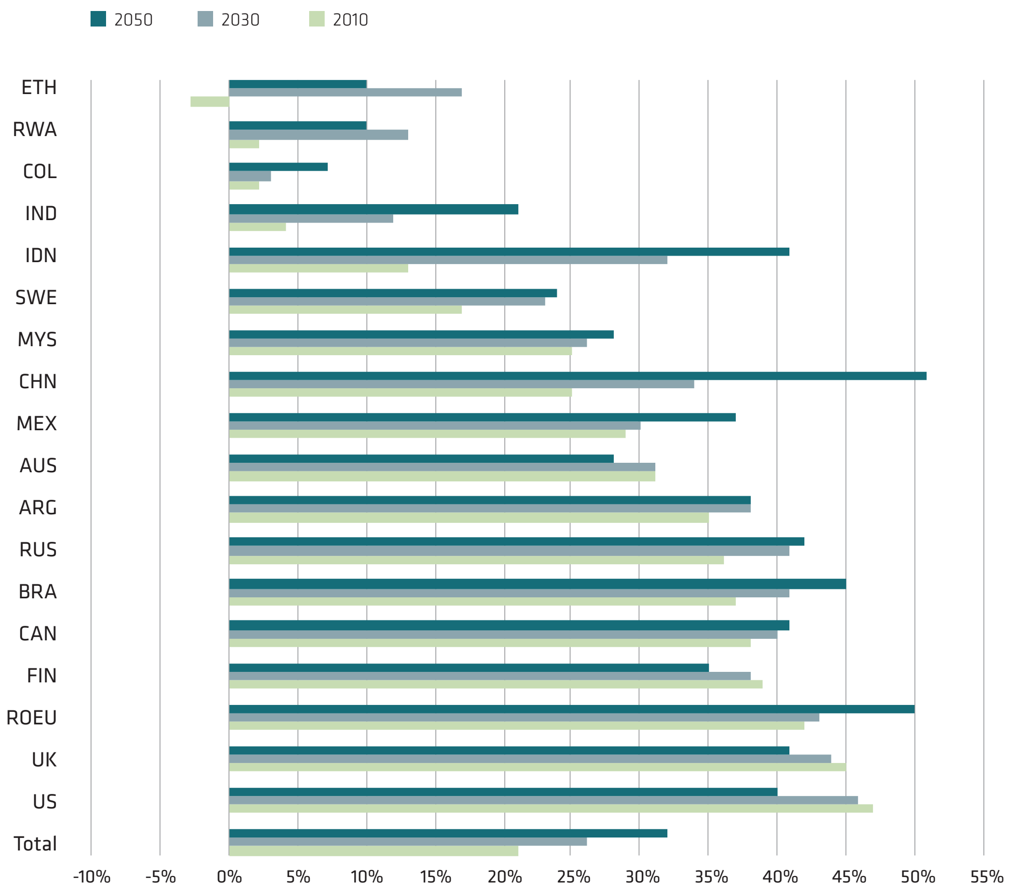
4.2.1. Food security

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).*

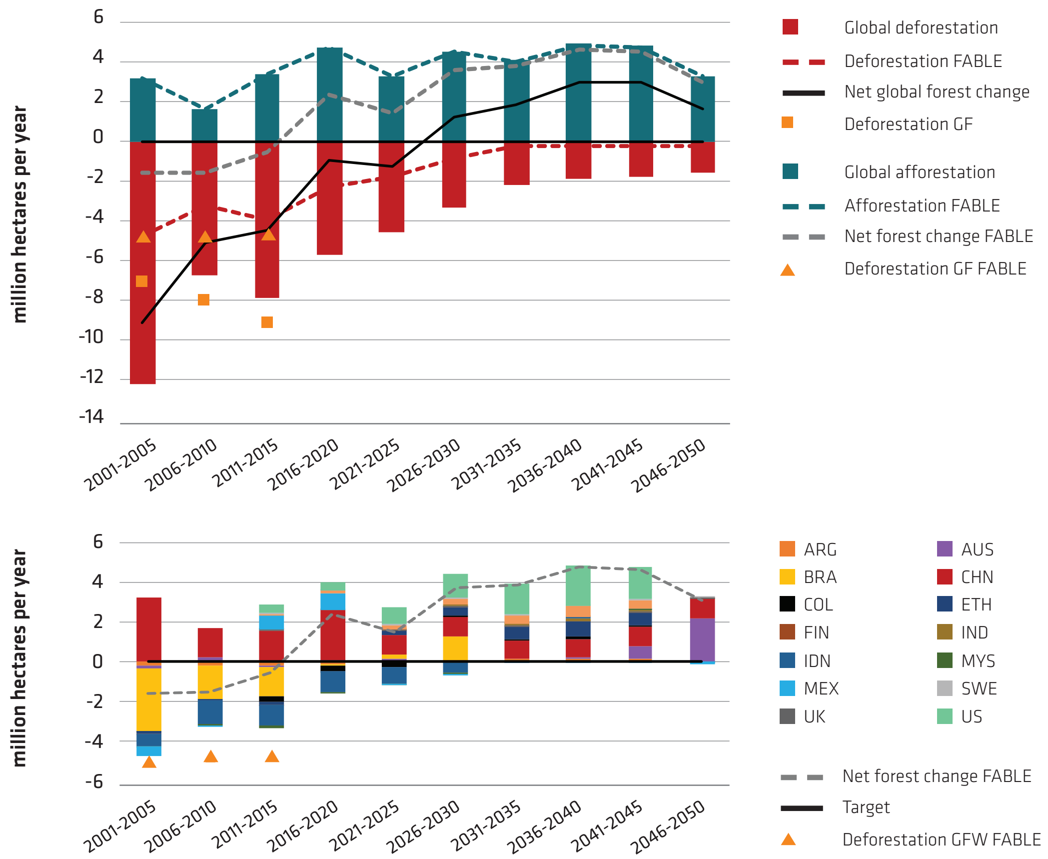


Note: Energy intake also includes the 2010 consumption level of animal fat and alcohol reported by FAO, as these are not computed in the calculator in 2050. These two items represent 6 percent of average calorie intake in FABLE countries. A surplus indicates that the computed energy intake is higher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

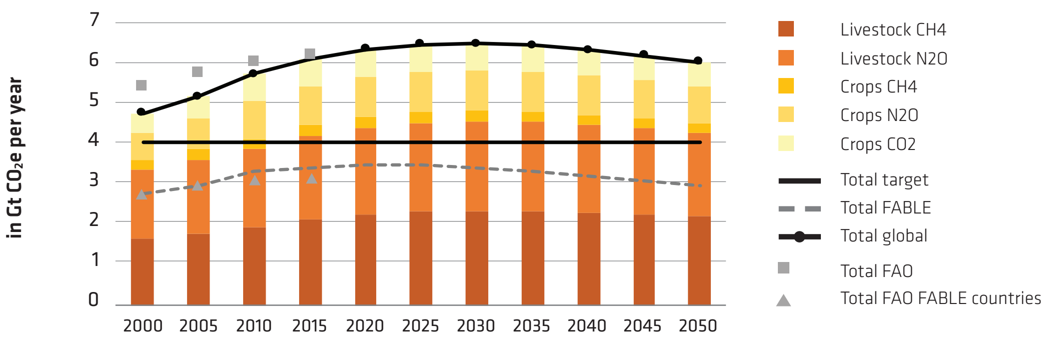
FABLE countries account for a large share of historical deforestation. This share reduces after 2015, and FABLE countries reach zero deforestation after 2030. As each country team defines and implements its afforestation target over different time scales, the total afforested area fluctuates over the 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.

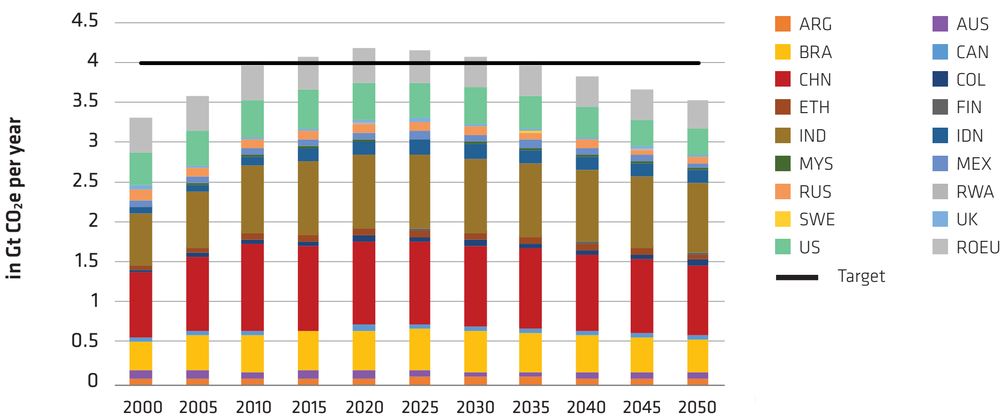
4.2.3. Greenhouse gas emissions reduction

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.

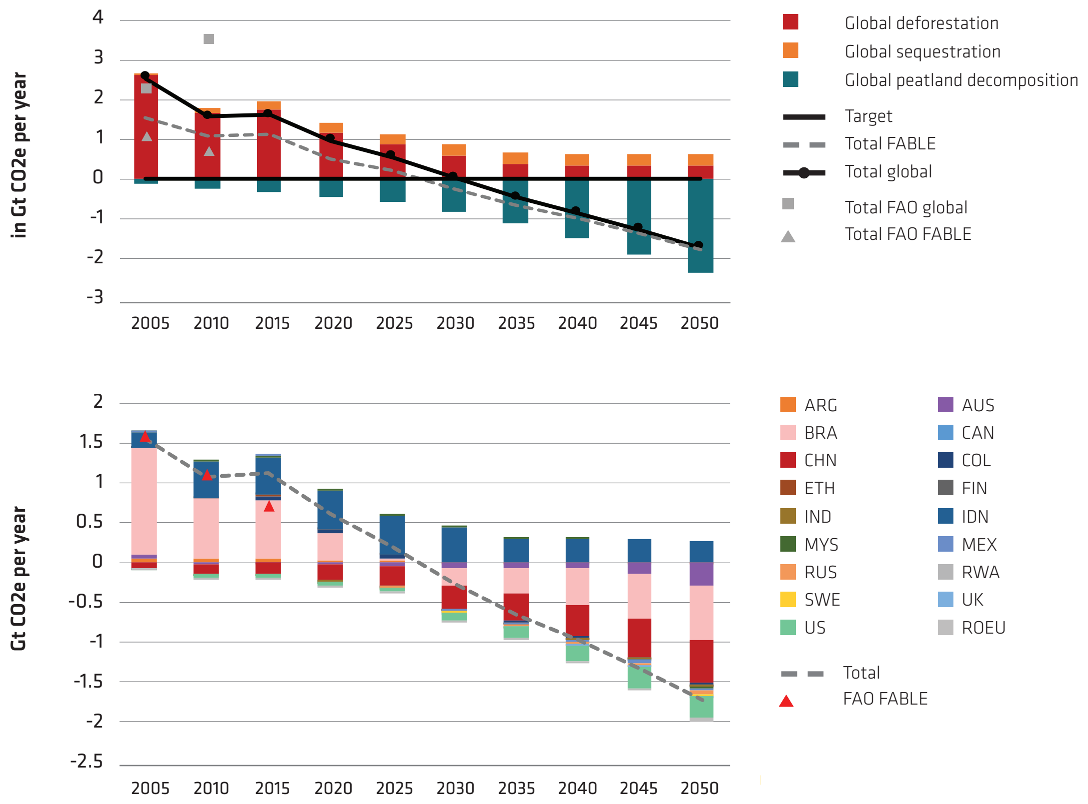
percent above the target (Figure 10, top). This is mostly driven by increases in emissions from the livestock sector. Projected emissions from agriculture only start to decline after 2035, and at a pace which remains too slow to reach the target.

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

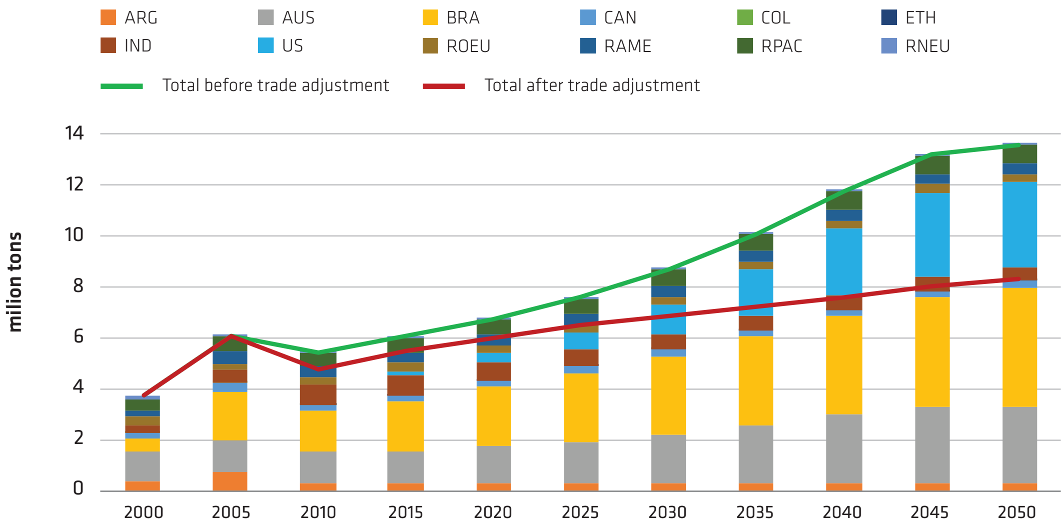
Based on projections by the FABLE country teams, total beef exports exceed imports before the trade adjustment by a substantial margin. The Rest of the World regions represent more than half of total imports, followed by Russia, UK, China, Mexico, Malaysia, and Indonesia. Total beef imports are projected 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.*



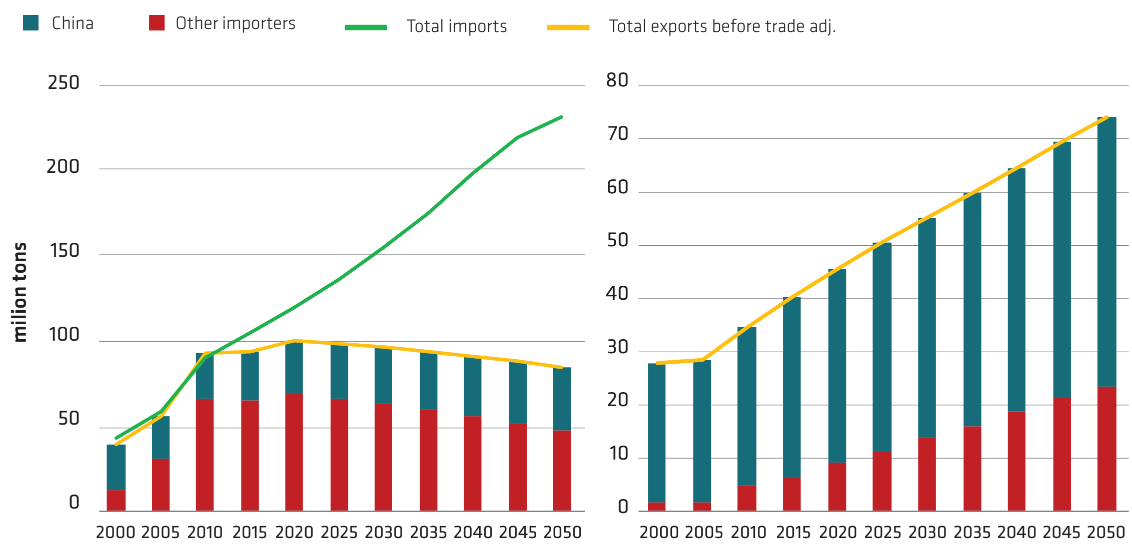
ROEU: Rest of European Union; RAME: Rest of America; RPAC: Rest of Pacific Islands; RNEU: Rest of Europe (Non-EU)

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.

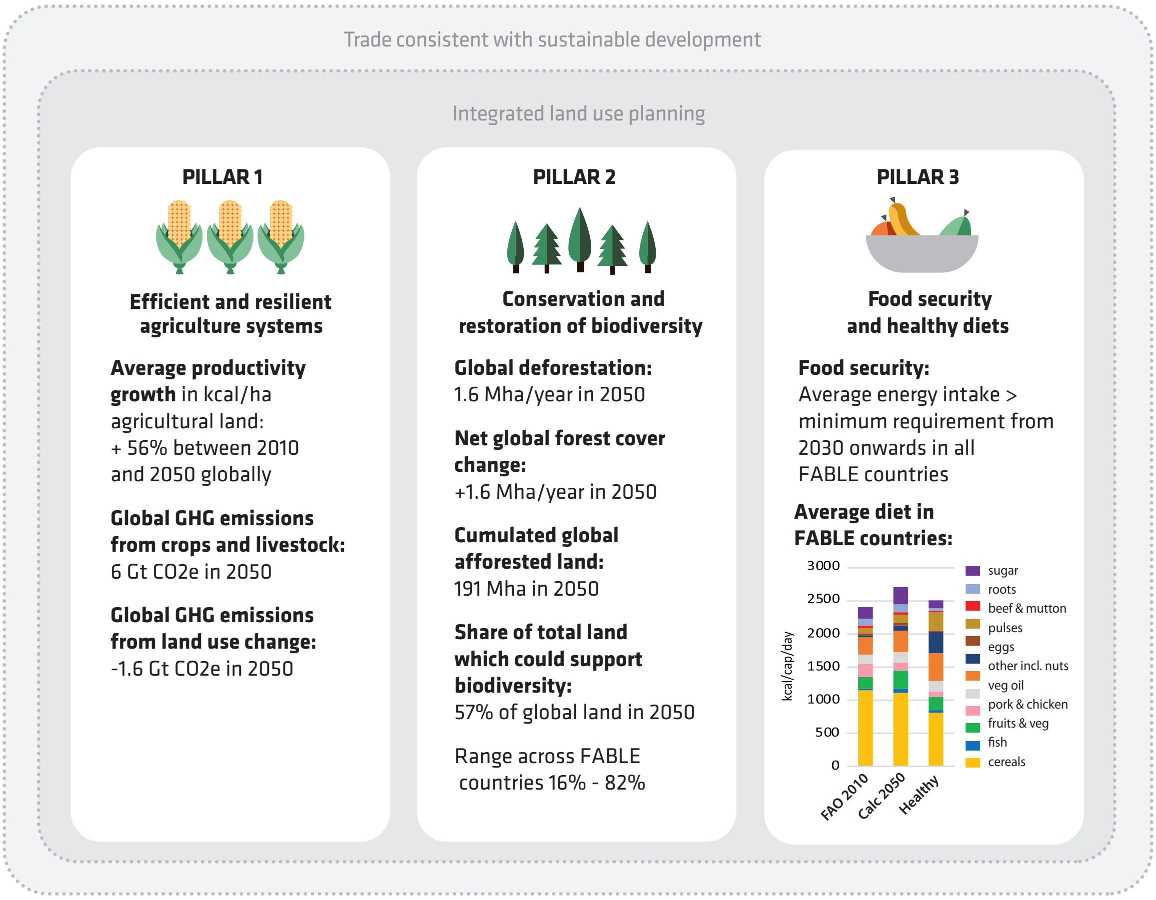
Our preliminary results show that action on one pillar is not sufficient to achieve the transformation unless backed by action on all other pillars. Since food systems and land-use change account for just under one third of countries' greenhouse gas emissions (Poore and Nemecek, 2018), governments that 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.*



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.

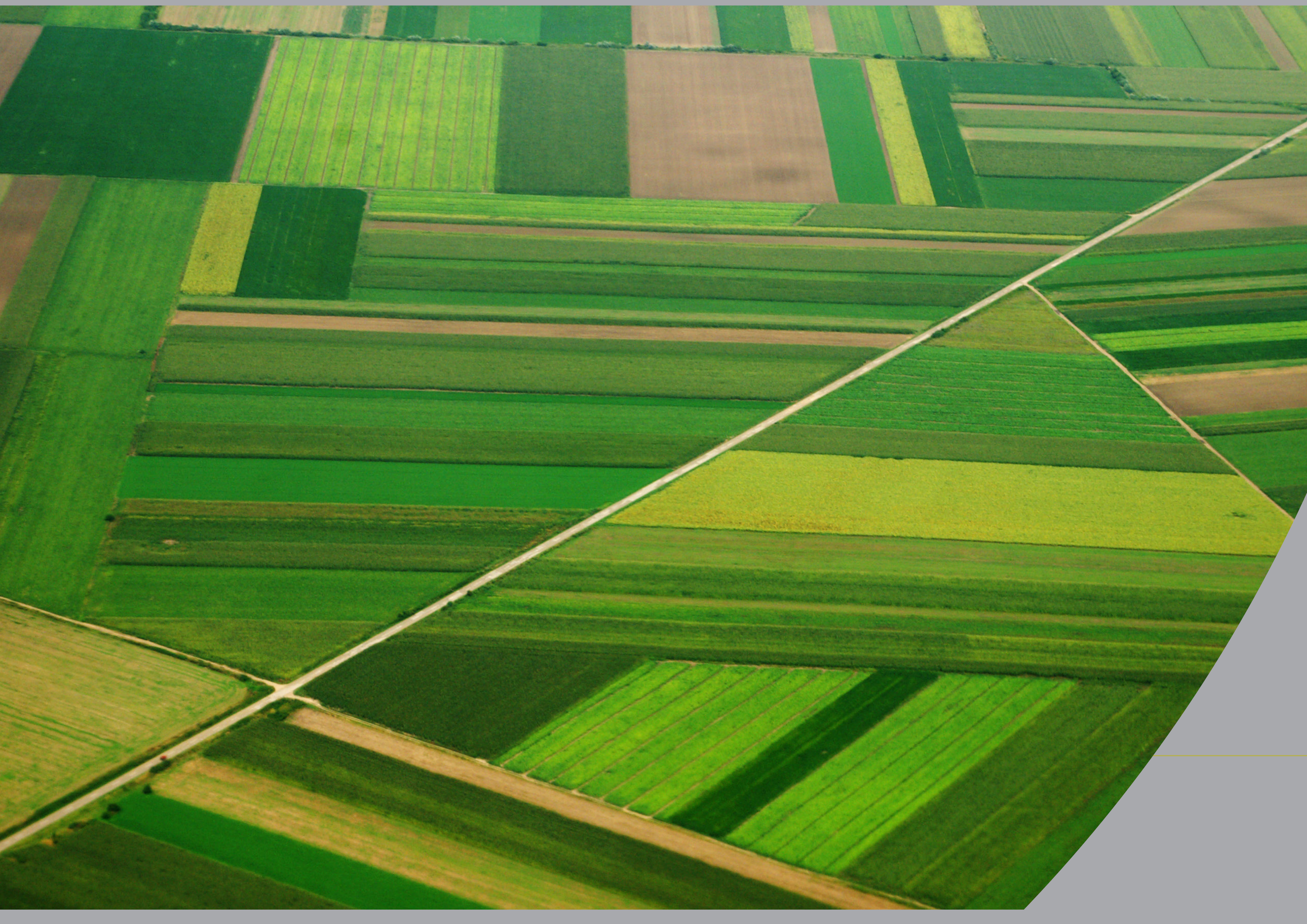
Fourth, we will improve the scope and methodology of the FABLE Scenathon to (1) cover a greater number of targets, including for water management and fertilizer run-off (nitrogen and phosphorous); (2) enhance the way in which trade is covered in the Scenathon; (3) include spatial aspects of land-use 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. References



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