Part 4

Transforming Food and Land systems to achieve the SDGs

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Authors

FABLE Secretariat: Clara Douzal (SDSN), Charlotte Chemarin (Alliance Bioversity International – CIAT), Aline Mosnier (SDSN), Davide Cozza (SDSN), Maria Diaz (SDSN), Sarah Jones (Alliance Bioversity International – CIAT), Fernando Orduña-Cabrera (IIASA), Alejandro Rios-Ochoa (IIASA), Lucie Adenäuer (SDSN), Yiorgos Vittis (IIASA), Andrea Sanchez (Alliance Bioversity International – CIAT), Valeria Javalera-Rincon (IIASA), Marcial Sandoval G. (IIASA), Michael Obersteiner (IIASA, Oxford University), Fabrice DeClerck (Alliance Bioversity International – CIAT, EAT), Carolina Navarrete Frias (Alliance Bioversity International – CIAT).

FABLE Country Teams: Argentina: Federico Frank (National Agricultural Technology Institute), Adrian Monjeau (Fundación Bariloche), Camila Bertranou (Fundación Bariloche), **Australia**: Javier Navarro- Garcia (CSIRO), Raymundo Marcos-Martinez (CSIRO), **Brazil**: Wanderson Costa (INPE), Fernando Ramos (INPE), **Canada**: René Reyes (UBC, Instituto Forestal de Chile), Hisham Zerrifi (UBC), Gregory Paradis (University of British Columbia), Avery Maloney (University of British Columbia), **Colombia**: John Chavarro (Javeriana University, CENIGAA), Andres Peña (Javeriana University), Ricardo Arguello (Independent), Jorge Escobar (Javeriana University), Wilfredo Marimon Bolivar (CENIGAA), **Denmark**: Simone Højte (CONCITO), Regitze Skou Fertin (CONCITO), Emil Fraas (CONCITO), Tavs Nyord (CONCITO), **Ethiopia**: Yonas Getaneh (Alliance of BI-CIAT), Yirgalem Nigussie (PSI), Mekonnen Bekele (PSI), Kalkidan Mulatu (Alliance of BI-CIAT), Wuletawu Abera (Alliance of BI-CIAT), Yodit Balcha (Alliance of BI-CIAT), Desalegn Anshiso (PSI), Tadesse Kuma (PSI), Degefie Tibebe (Alliance of BI-CIAT), Desalegn Begna (PSI), Jemal Mohammed (PSI), Beneberu Assefa (PSI), Kaleab Kebede (PSI), Meron Eshete (Alliance of BI-CIAT), Tagay Hamza (MoWE), Getachew Tesfaye (Alliance of BI-CIAT), Lulseged Tamene (Alliance of BI-CIAT), **Finland**: Heikki Lehtonen (Natural Resources Institute Finland), Janne Rämö (Natural Resources Institute Finland), **Germany**: Livia Rasche (Universität Hohenheim), Uwe Schneider (University of Hamburg), Jan Steinhauser (International Institute for Applied Systems Analysis), **Greece**: Conrad Landis (AE4RIA), Konstantinos Dellis (AE4RIA), Alexandra Ioannou (AE4RIA), Maria Angeliki Chatzigiannakou (Uppsala University), Chrysi Laspidou (AE4RIA), Phoebe Koundouri (AE4RIA), **India**: Ankit Saha (IIMA), Vartika Singh (IIMA), Prantika Das (IIMA), Aditi Joshi (IIMA), Chandan Kumar Jha (IIMA), and Ranjan Kumar Ghosh (IIMA), Hermann Lotze-Campen (Humboldt-Universität zu Berlin, Department of Agricultural Economics, PIK), Miodrag Stevanović (PIK), **Indonesia**: Habiburrachman A.H. Fuad (Research Center for Climate Change, University of Indonesia), **Mexico**: Charlotte Gonzalez-Abraham (Independent), Marcela Olguín (SilvaCarbon- Latin America, the Caribbean and Canada), Sonia Rodriguez Ramirez (National Institute of Public Health of Mexico), Gordon McCord (UCSD), Juan Manuel Torres Rojo (Centro de Investigación y Docencia Económicas), Arturo Flores Martinez (Instituto Politécnico Nacional), Oscar G. Cardenas Hernandez (Universidad de Guadalajara), Daniel Avila Ortega (Stockholm University), **Nepal**: Shyam Basnet (Southasia Institute of Advanced Studies (SIAS)), Prajal Pradhan (University of Gottingen), Sushant Acharya (Southasia Institute of Advanced Studies (SIAS), Rajendra Uprety (AgriGreen Nepal), Pashupati Pokhrel (Ministry of Industry, Agriculture and Cooperative, Koshi provincial government, Nepal), Dil Khatri (Southasia Institute of Advanced Studies (SIAS); Swedish University of Agricultural Sciences), Ram Basnet (Freelance Consultant), **Norway**: Bob Van Oort (CICERO), Anne-Sophie Daloz (CICERO), **Russian Federation**: Anton Strokov (RANEPA), **Rwanda**: Dative Imanirareba (Rwanda Fertilizer Company), **Sweden**: Marianne Hall (Lund University), Ingo Fetzer (Planetary Boundary Research Network and the Baltic Sea group, Stockholm Resilience Centre Stockholm University), **Türkiye**: Zeynep Tacer Caba (BAU SÜGAM (Bahçeşehir University, Sustainable Food Systems Research Centre)), Müge Kesici (BAU SÜGAM), Pınar Özuyar (BAU SÜGAM), **United Kingdom**: Alison Smith (University of Oxford), John Lynch (University of Oxford), Paula Harrison (UKCEH), Sarah Jones (UKCEH/University of Lancaster), and Freya Whittaker (UKCEH), **United States**: Grace C. Wu (UCSB), Justin Baker (NCSU), Gordon McCord (UCSD), Christopher Wade (RTI International).

Part 4

Transforming Food and Land systems to achieve the SDGs

SDG 2 (Zero Hunger) is one of the five SDGs that the international community will review in depth at the High-Level Political Forum on Sustainable Development in July 2024. SDG 2 faces numerous challenges and shows concerning trends in global progress: 600 million people still suffer from hunger,[1] and the prevalence of undernourishment increased to 10% of the global population in 2021 after years of decline.[1,2] Despite a drop in the number of countries experiencing high food prices, falling from 48.1% in 2020 to 21.5% in 2021,[3] accompanied by a steady increase in cereal yield from 3.4 tonnes per hectare in 2000 to 4.4 tonnes per hectare in 2021,[4] the prevalence of stunting and wasting among children under the age of five remains high (20% and 7%, respectively, in 2021 according to SDR 2024). Many countries now face the dual challenge of undernourishment and overweight. The global prevalence of obesity has increased from 9% in 2005 to 16% in 2022, indicating an alarming upward trend. According to the SDG Index, none of the 193 UN member states has achieved SDG 2 (see Part 2).

Among the six Transformations[13] required to ensure the achievement of all SDGs, the fourth focuses on food, land, and water. This Transformation underpins the achievement of SDG 2, SDG 6 (Clean Water and Sanitation), SDG 12 (Responsible Consumption and Production), SDG 13 (Climate Action), SDG 14 (Life Below Water), and SDG 15 (Life on Land), and contributes to the achievement of all of the SDGs. Our food and land-use systems play a pivotal role in the stability of our planetary boundaries and the Earth's system resilience.[11] Agriculture accounts for more than half the Earth's land surface[6] and 70% of freshwater use,[7] yet it is profoundly affected by the worsening climate-change crisis and increasing water scarcity.[8] Food systems already contribute to one-third of global human-induced greenhouse gas emissions[9] and are the main driver of biodiversity loss.[10]

A holistic approach is needed to leverage potential synergies and trade-offs associated with the transformation of food and land systems[13] and to account for environmental and social spillovers embodied in the trade of agrifood products.[12] The Food, Agriculture, Biodiversity, Land, and Energy (FABLE) Consortium, a global network established in 2017, aims to support this integrated approach by facilitating the development of ambitious, locally tailored strategies for food and land-use systems. FABLE brings together researchers from universities and national research centres worldwide, fostering collaboration among interdisciplinary teams and dialogues with stakeholders to develop national quantitative pathways. FABLE members support the alignment of national objectives with planetary boundaries and sustainability targets.

Here we present results of the 2023 'Scenathon', in which researchers from 22 countries across all continents, together with the FABLE Secretariat, explored three alternative futures for national and regional food and land-use systems. *Scenathon* stands for 'a marathon of scenarios' and refers to an iterative process used by FABLE to compare and align national pathways with the SDGs and planetary boundaries. This is the third Scenathon coordinated across FABLE country teams, following the first in 2019[14] and the second in 2020.[15] Using an open-access modelling tool, the FABLE Calculator and the FABLE decentralized modelling infrastructure, we compare our results with global sustainability goals across four main areas: **1)** food security and nutrition [SDGs 2 and 3]; **2)** GHG emissions reduction [SDG 13]; **3)** forest and biodiversity conservation [SDG 15]; and **4)** sustainable water, nitrogen, and phosphorous use [SDGs 6, 12 and 14]. We highlight change levers to guide sustainable development policies to 2030 and to 2050, together with risks of trade-offs and opportunities for synergies.

4.1 The FABLE Scenathon 2023 approach

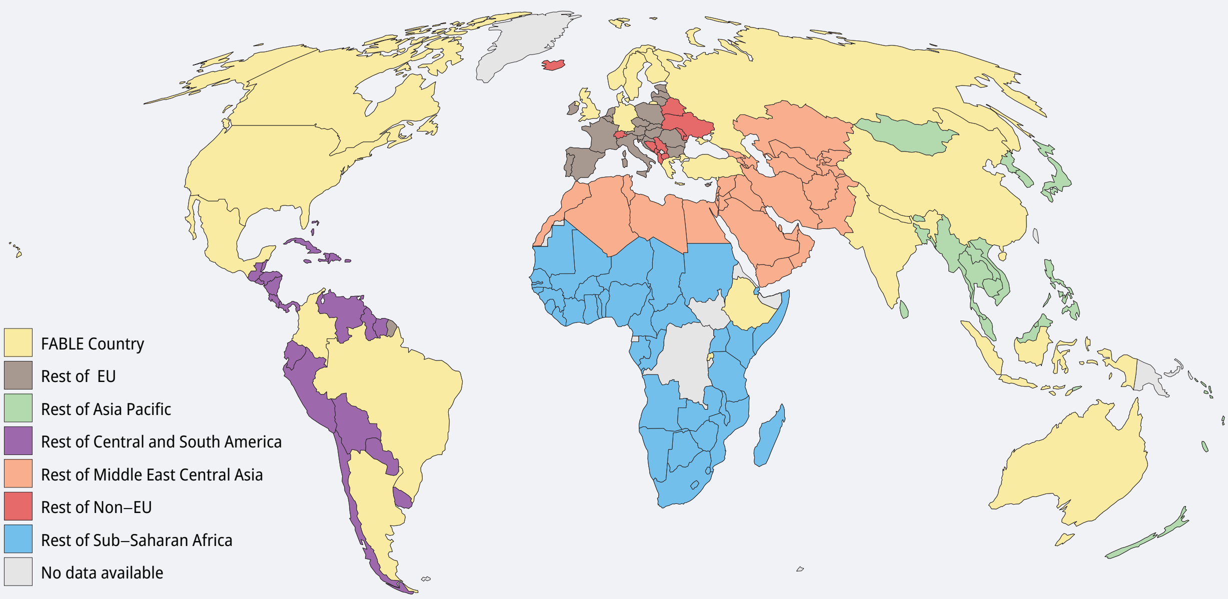
We use the FABLE Calculator,[16] an Excel-based tool that computes land use, land cover, animal stocks, and agricultural input use for each 5 year-time period until 2050.* Countries represented individually in the Scenathon 2023 were Argentina, Australia, Brazil, Canada, China, Colombia, Denmark, Ethiopia, Finland, Germany, Greece, India, Indonesia, Mexico, Norway, Nepal, Russia, Rwanda, Sweden, Türkiye, the UK, and the United States. These 22 countries account for 60% of global terrestrial land and are home to 4.5 billion people. To ensure global coverage, all remaining countries were grouped into six 'rest of' world regions (Figure 4.1). Country models were uploaded to the Scenathon web platform, with their exports adjusted to achieve equilibrium between global exports and global imports. Standardised reporting tables allowed aggregation of national and regional results to the global level.[19]

In the Scenathon 2023, participants agreed on a set of targets to be achieved collectively and simultaneously. Those 16 targets encompass four domains (Figure 4.2), related to the following SDGs:

SDG 2 – Target 2.1 is to end hunger by 2030, while target 2.2 aims to eliminate all forms of malnutrition, including both insufficient and excessive kilocalorie intake in comparison to what is needed for a healthy life. For target 2.1, we compute the prevalence of undernourishment by country and region.[20] For target 2.2, we compare the average per capita kilocalorie intake of each country and region with the minimum dietary energy requirement (MDER), setting a range of 10% to 50% above the MDER as our food security objective.

* Other models, such as the global partial equilibrium models MAgPIE[17] and GLOBIOM,[18] have provided complementary results for some countries, allowing useful benchmarking of results across pathways.

Figure 4.1
Countries and regions included in the Scenathon 2023



Source: Authors
Disclaimer: The boundaries, colors, denominations, and other information shown on any map in this work do not imply any judgment on the part of the SDSN and co-authors of this chapter concerning the legal status of any territory or the endorsement or acceptance of such boundaries.

SDG 13 – The climate-change mitigation targets are based on the Paris Climate Agreement[21] goal of limiting warming to 1.5 degrees Celsius by the end of the century, along with estimates of corresponding GHG emissions threshold from agriculture and land-use change in the latest IPCC assessment report[8] and related literature.[22, 23] To meet these goals, GHG emissions from on-farm agricultural production must be below 4 Gt CO_2e per year by 2050 and the agriculture, forestry and other land use sector should have become a net sink (-1.3 Gt CO_2 per year in 2050). In accordance with the 2021 methane pledge[24] and UNEP's estimates of methane reduction potential, targets aim to decrease global agricultural methane emissions by 20 Mt CH_4 and 28 Mt CH_4 by 2030 and 2050 respectively compared to 2020 levels.

SDG 15 – The land and biodiversity targets are based on the Kunming-Montreal Global Biodiversity Framework (KMGBF).[25] Target 1 of the KMGBF, which aims at halting the loss of land important to biodiversity by 2030, is captured by our targets of reaching zero deforestation and zero loss of current 'land where natural processes predominate' (LNPP)[26,27] as well as a target to increase the area of LNPP by 15% between 2020 and 2050. In Target 3 of the KMGBF, countries have also committed to ensuring that, by 2030, at least 30% of global ice-free terrestrial land is effectively conserved and managed through systems of protected areas and other effective conservation measures. Target 10 of the KMGBF addresses the need to increase the coverage of biodiversity-friendly agricultural practices, which is reflected in a global target of achieving 50% of cropland under agroecological practices.

Figure 4.2
Sustainability targets that need to be met collectively in the Scenathon 2023

SDG	Indicator	Target 2030	Target 2050
2 ZERO HUNGER	Kilocalories per capita per day	At least 10% > MDER(i) Lower than 50% > MDER(i)	
	Prevalence of undernourishment	< 5%	
15 LIFE ON LAND	Protected areas	30% of total land	
	Agroecological practices	50% of cropland	
	Deforestation	No loss	
	Land where Natural Processes Predominate	No loss in mature LNPP	15% gain in total LNPP compared to 2020
13 CLIMATE ACTION	CO_2e from agriculture(ii)		< 4 Gt CO_2e
	CH_4 from agriculture	-20 Mt compared to 2020	-28 Mt compared to 2020
	CO_2 from AFOLU(iii)		< -1.3 Gt in 2050
	Cumulative CO_2 from AFOLU(iii)		< 40 Gt between 2020 and 2050
14 LIFE BELOW WATER	Nitrogen application		< 68 Tg (or Mt)
	Phosphorous application		< 16 Tg (or Mt)
	Consumptive blue water use for irrigation		< 2,453 km^3 yr-1

Notes:
(i) MDER = Minimum Dietary Energy Requirement
(ii) This target includes on-farm CO_2, CH_4, and N_2O emissions from crops and livestock production, with CO_2e computed using AR6 GWP.
(iii) AFOLU = agriculture, forestry and other land use. This target includes CO_2 emissions from crops and livestock production, CO_2 emissions from land conversion, CO_2 sequestration from afforestation and abandonment of agricultural land, and CO_2 savings due to the substitution of fossil fuels by biofuels.
Source: Authors

SDG 6 and SDG 14 – Nitrogen and phosphorus have allowed for a dramatic increase in agricultural land productivity in recent decades, but in many places, nitrogen from chemical fertilizers and organic manure applied to soil exceeds crop growth requirements, with the remainder leaching into waterways and polluting the air, causing negative impacts on terrestrial biodiversity, aquatic biodiversity, and human health. The global targets for water, phosphorous and nitrogen use draw from the scientific literature on planetary boundaries.[28, 29–31]

FABLE evaluated three different pathways (combinations of scenarios at the national level) for achieving these targets: the Current Trends pathway, the National Commitments pathway, and the Global Sustainability pathway. The **Current Trends pathway (CT)** represents a low-ambition trajectory primarily shaped by existing policies, offering a glimpse into a future heavily reliant on current practices and policies. In contrast, the **National Commitments pathway (NC)** attempts to predict how food and land systems will evolve if national strategies, pledges, and targets concerning climate, biodiversity, and food systems are met. Finally, the **Global Sustainability pathway (GS)** identifies how feasible additional actions could potentially be taken to help align national and regional pathways with global sustainability targets.

For each of these pathways, researchers established a number of assumptions for each country and region regarding the evolution of various parameters of the model related to population growth, dietary patterns, food waste, food import and export levels, crop and livestock productivity, agricultural expansion, afforestation, livestock density, protected areas expansion, post-harvest losses, biofuel demand, urban expansion, agricultural practice coverage, and irrigation area expansion. Assumptions on the extent to which these levers will drive changes in food and land systems from 2020 to 2050 vary across countries and regions (Figure 4.8). To validate and even co-design some of these assumptions, teams in Colombia, Denmark, Ethiopia, Greece, India, Mexico, Norway, and the UK held in-country consultations with local stakeholders. In addition, for the first time, the Secretariat invited third parties to provide feedback on the pathways' assumptions online via the FABLE Consortium website.

4.2 Can we achieve the SDGs related to food and land systems?

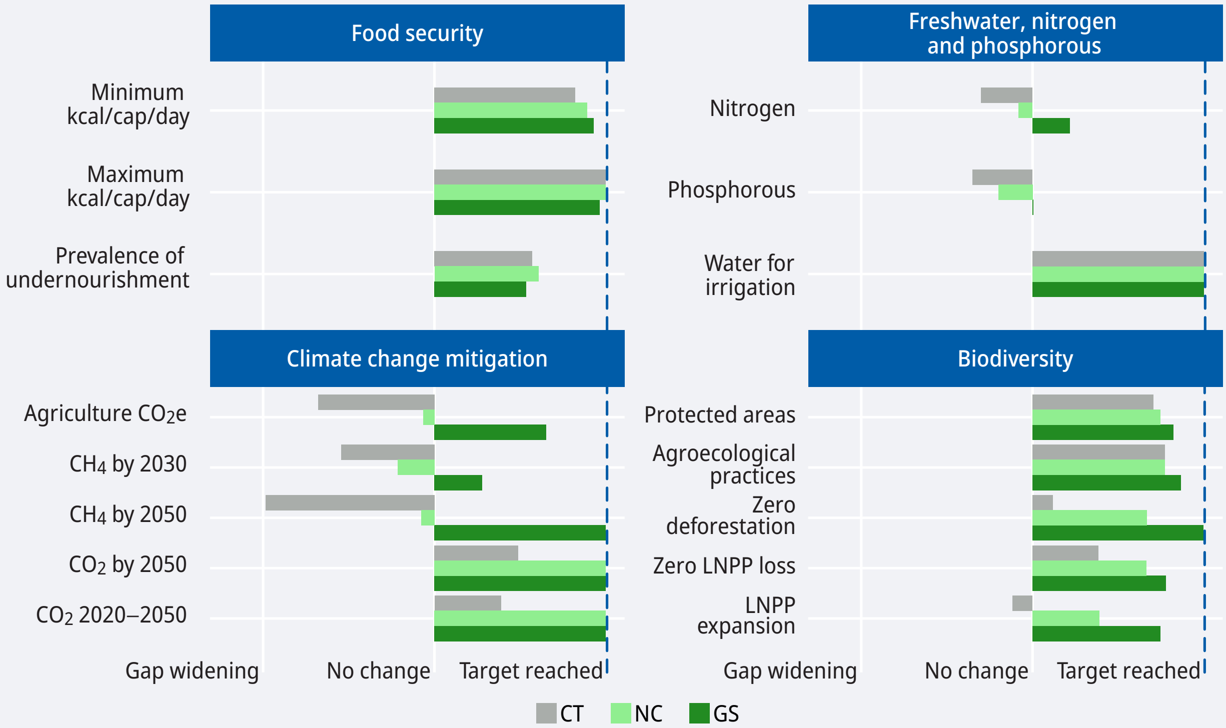
Of the 16 targets used to assess progress towards sustainable food systems, only two are met in CT, while climate mitigation, nitrogen, phosphorous and LNPP goals trend in the reverse direction and the gap to meet these targets widens. In NC, we achieve four targets, yet this comes at the cost of higher phosphorous and nitrogen use and increased GHG emissions. In the most ambitious pathway (GS), five targets are reached, and we are making progress towards all targets except the prevalence of undernourishment (Figure 4.3; Part 4 Annex).

Many of these results are driven by interactions between the evolution of demand and land productivity. Demand takes into account food, feed and other non-food uses (including biofuels) as well as food loss and waste. In 2020, almost half of the demand in terms of calories was for food, 16% for feed, 14% for food loss and waste, and 23% for other non-food uses. Between 2000 and 2020, overall demand and land productivity***** both grew at a rate of 2.4% per year, resulting in a stable global agricultural land area during this period. However, trends were uneven across world regions, with agricultural land expanding in the global South and reducing in the global North, due to demand growing faster than productivity in the Global South and vice versa in the North.

Our results showed that land productivity and demand continue to grow at the same pace globally in CT, although at a slower rate from 2020 to 2050 than that of 2000 to 2020 (reduced to around 0.7% per year). In NC and GS, however, land productivity increases at a greater speed than demand (+0.4 and +0.8 percentage points per year between 2020 and 2050 in NC and GS respectively), leading to an 11% reduction of total agricultural land in NC and a 22% reduction in GS, with the largest absolute reductions observed in Australia, the United States, and China.

* Total demand growth is expressed as the average annual growth rate of total kilocalories demanded, land productivity growth is expressed as the average annual growth rate of the total kilocalories produced divided by the sum of cropland and pastureland area, using FAOSTAT data.

Figure 4.3
Gap between global results in each pathway and the global sustainability targets



Notes: Targets have been standardized to allow for comparison. "No-change" indicates a level equivalent to that of 2020. The left area indicates a deterioration compared to 2000–2020, while the right area indicates an improvement towards achieving the targets. The gap for undernourishment target is measured by the proportion of countries and regions where the prevalence of undernourishment is below 5% between 2030 and 2050. The gaps for the dietary intake targets are measured by the proportion of countries and regions within the Minimum Dietary Energy Requirement (MDER) range during the same period. For targets on protected areas, agroecological practices, and LNPP expansion, the gaps are measured as their positions within a range from 0% to their respective FABLE targets. The gaps for the remaining targets are assessed by comparing their levels or trends in the target year with those of 2020. Detailed results are given in Figure 4.9.
Source: Authors

The evolution of demand

In our projections, by 2050, total consumption will increase from 2020 in CT, increase but more slowly in NC, and decrease in GS. At the global level, average per capita kilocalorie intake remains nearly constant between 2020 and 2050, although dietary composition changes over time and varies across pathways. In all three pathways, and to a greater extent in NC and GS, scenarios with shifts towards national dietary recommendations or the Planetary Healthy Diet proposed by the EAT–*Lancet* Commission result in a reduction of per capita kilocalorie intake in countries with currently high levels of consumption, with the largest reductions seen in the consumption of animal products, oils, and sugar. Countries with a lower per capita consumption in 2020 increase their intake per capita over time in all three pathways, although to a lesser extent in NC and GS due to lower target consumption, with increased intakes of oils, meat, pulses, and sugar in CT and oils, nuts, fruits and vegetables in NC and GS. The consumption of cereals decreases (from 53% of total intake in 2020 to 47%, 45% and 41% in 2050 in CT, NC, and GS respectively), however, cereals continue to be the dominant food group at the global level in all pathways. Nuts and pulses see the largest relative consumption increases in all three pathways, accompanied with increased trade volume for those products globally.

Fewer countries meet targets on avoiding overconsumption compared to the targets on achieving minimum average calorie consumption levels. Our findings indicate trade-offs between limiting overconsumption and reducing hunger, as measured by the prevalence of undernourishment, but the latter is dependent on mechanisms not represented in our model, such as the evolution of inequalities, the level of support for the poorest, the impacts on food prices of measures introduced to promote these dietary shifts and, more particularly, the cost of healthy foods (see Part 4 Annex).

While global consumption of animal-based products increases over time in CT and NC, so does demand for feed (+29% between 2020 and 2050 in CT, +4% in NC), particularly for corn, wheat, and barley in CT and for corn, rice, and sorghum in NC. The worldwide trade volume for these products increases correspondingly. Reducing global consumption of animal-based products in GS reduces feed demand by 13% between 2020 and 2050, primarily for corn, wheat, and barley. In parallel, post-harvest losses and food waste are assumed to decrease in several countries and regions in NC and GS, with an average reduction of 1.1% and 1.8% per year between 2020 and 2050 in NC and GS respectively. These reductions help to close the gap towards achieving SDG 12.3 and SDG 2, although they rely on a reduction of food loss and waste across the whole food chain.

The evolution of productivity

Total land productivity is a combination of cropland productivity (here measured as plant-based kilocalories per hectare of cropland) and pastureland productivity (kilocalories from the production of ruminants per hectare of pastureland). Both cropland and pastureland productivity* increase over time in all pathways, with the GS pathway showing the greatest gains (+18% for cropland and +35% for pasture) by 2050 compared to 2020.

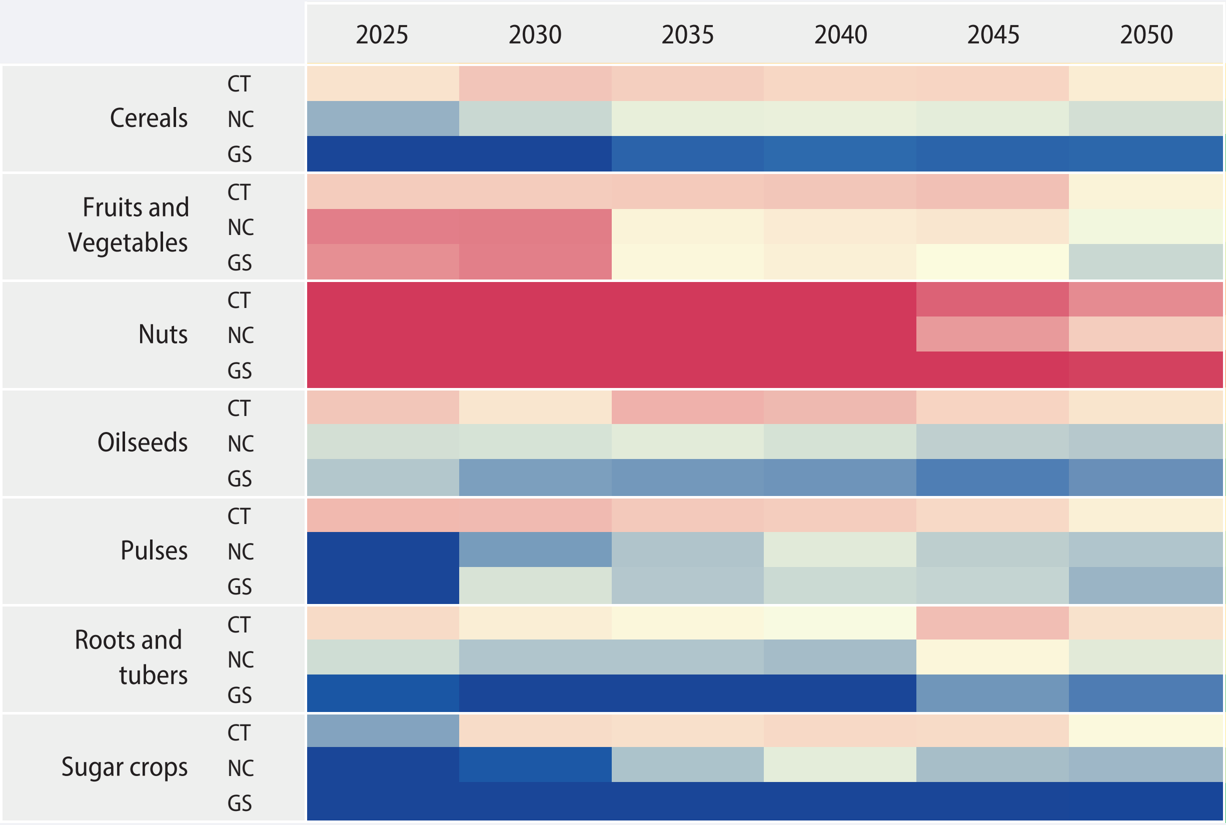
* In our model, the evolution of crop yield depends on technological change, fertilizer use, the number of harvests per hectare per year, and the adoption of irrigation and agroecological practices, while pastureland productivity depends on the number of ruminants per hectare of pasture (stocking rate) and the use of complementary non-grass feed.

When we compare the evolution of crop productivity and demand for different types of crops we observe that: 1) in CT, the average productivity increase is lower than demand growth for almost all crop types, but this situation tends to switch in GS, 2) the rate of increased productivity of nuts, fruits and vegetables consistently lags behind the rate of demand growth, and 3) the most challenging decade is ahead of us, with demand growing faster than productivity for more crops up to 2030 (Figure 4.4).

Higher agricultural productivity saves land, but depending on how it is achieved, can lead to trade-offs with other SDGs. In many places, nitrogen from chemical fertilizers and organic manure applied to soil exceeds crop growth requirements and leaches into waterways, with negative impacts on aquatic biodiversity (SDG 14) and human health through the pollution of drinking water (SDG 6). Through dietary shifts and the increasing use of organic fertilizer instead of synthetic fertilizer in organic farming systems, the global peak volume of nitrogen applied to soils and left on pasture is reached by 2040 in NC and 2020 in GS. However, even with ambitious sustainability efforts, we fail to stay within the nitrogen and phosphorus planetary boundaries. The per hectare application of nitrogen and phosphorus on agricultural land continues to increase in India in all pathways, even though the critical surplus has already been exceeded.[31] The share of harvested area under irrigation remains stable across time for all pathways, at around 20%, which explains how all three remain largely below the water planetary boundary. These results likely underestimate increases in irrigation water demand over the coming decades, as two-fifths of the world's population already live in areas that suffer high water stress and this proportion will increase with climate change.[32] This highlights the need for a deeper analysis of results concerning input use – at the river basin level, for example.

Agroecological practices can alleviate the tradeoffs between SDG 2 (Zero Hunger) and the other SDGs by relying more on enhancing natural ecosystem processes rather than external inputs. These practices can help restore biodiversity and build production resilience to climate change. In our model, we include organic farming, reduced tillage, cover crops, cultivar mixtures, embedded natural systems, and a mix of

Figure 4.4
Growth in annual productivity vs. growth in demand for various crop types, 2025–2050



Notes: CT: Current Trends pathway, NC: National Commitments pathway, GS: Global Sustainability pathway.
Shades of pink indicate that the productivity growth rate is lower than the demand growth rate, with darker pink indicating a larger negative value. Shades of blue indicate that the productivity growth rate is higher or equal to the demand growth rate, with darker blue indicating a larger positive value. Other crop types represented in the FABLE Calculator but not displayed here are 'Beverage crops, cocoa, and spices' and 'Fiber crops'.
Source: Authors

diversified farming systems that all impact productivity, climate and biodiversity outcomes[33] (and in the case of organic farming, lead to the substitution of manure for synthetic fertilizers). Under GS, an increased adoption of agroecological practices, particularly in the six regions and in China, Russia, and Argentina, narrows the gap but still falls short of the 50% target. An ambitious expansion of organic farming that coincides with a reduction of livestock herds due to dietary shifts under NC and GS also raises the possibility of manure shortages in some European countries.

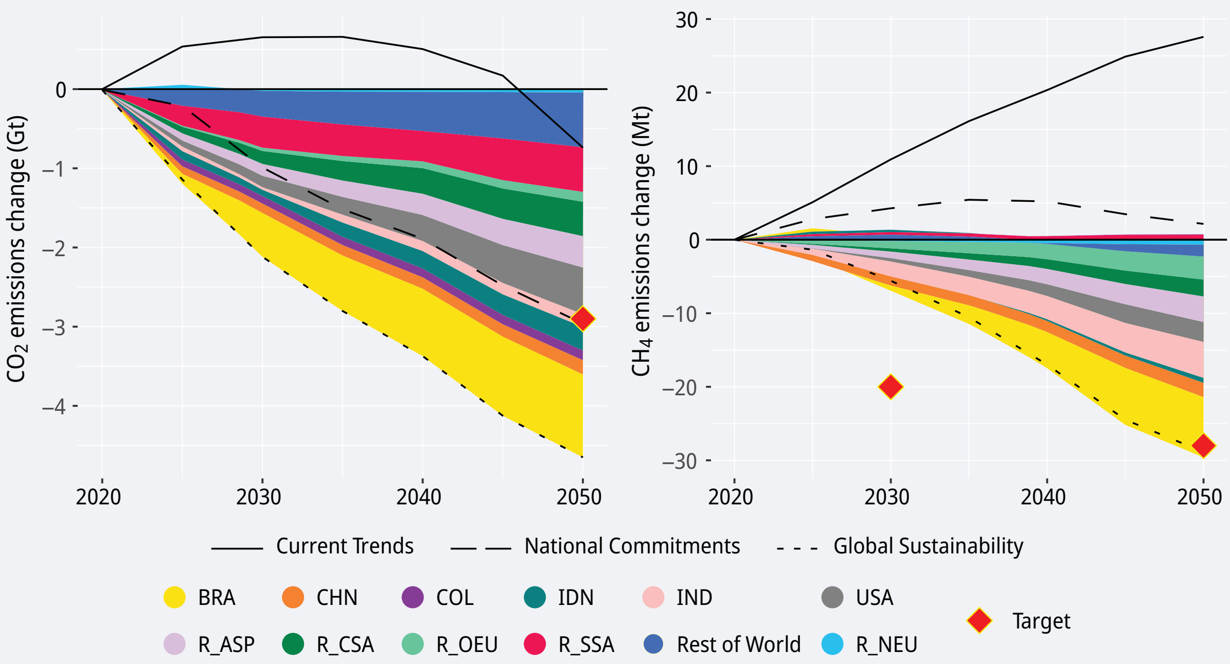
The evolution of agricultural land

Agricultural land expansion or reduction is a key driver of our results regarding SDG 15 (Life on Land). The area of existing mature LNPP (land where natural processes predominate) decreases substantially between 2020 and 2030 in all pathways due to conversion into productive lands or newly afforested areas. In NC, 44 million hectares of loss of LNPP is avoided compared to CT, but large losses continue in Brazil, Mexico, Sub-Saharan Africa, the United States, and the 'rest of Non-EU countries' region. The GS pathway is effective in ending deforestation* (and, consequently, the target of no loss of LNPP in forests) through the success of zero-deforestation policies (for example, in Brazil and Indonesia) combined with dietary shifts and productivity increases. However, 30 million hectares of grasslands, shrublands, wetlands and other non-forested LNPP are lost, with the result that the world significantly overshoots the zero-loss target of the Kunming-Montreal Global Biodiversity Framework. Despite the continued losses in biodiversity-rich areas, a large decrease in productive lands in NC and GS allows for net gains in LNPP between 2020 and 2050 (+6% in NC, +11% in GS), but this still falls short of our target (+15%). Any future expansion of areas where natural processes predominate is dependent on the potential for these to become established on newly afforested land and abandoned agricultural land.

In parallel, we observe that the share of protected areas – including 'other effective area-based conservation measures' (OECMs) – increases in all pathways. The target is almost achieved in GS (25% protected by 2030) thanks to ambitious expansions of protected areas in Ethiopia, Canada, Finland, Mexico, and Sweden.

* A small, deforested area remains in GS due to some urban expansion.

Figure 4.5
GHG emission changes in the GS pathway including the breakdown by FABLE countries and regions in addition to total changes in CT, GS and NC pathways compared with 2020 levels



Notes: Targets and emissions reductions are expressed in absolute reduction levels compared to 2020. The decomposition is done for GS only. BRA- Brazil, CHN- China, IDN- Indonesia, COL- Colombia, IND- India, R_ASP- Rest of Asia and Pacific, R_CSA- Rest of Central and South America, R_OEU- Rest of European Union, R_NEU- Rest of Europe non-EU, R_SSA- Rest of Sub-Saharan Africa.
Source: Authors

The evolution of GHG emissions

Methane (CH_4) remains in the atmosphere for a much shorter time than CO_2, but it also absorbs much more energy, leading to a large potential to curb GHG emissions in the short term. Both in CT and NC, we fall significantly short of our CH_4 targets in 2030, with emissions continuing to increase after 2020 (Figure 4.5). In GS, the CH_4 emissions reduction target is achieved by 2050 (-29 Mt). However, even if CH4 emissions have started declining by 2030, it will not be enough to meet the short-term target. This reduction is made possible by increased livestock productivity (especially in Brazil, Central and South America, the Middle East, and Sub-Saharan Africa), combined with a dietary shift towards a reduced consumption of red meat (especially in the USA, Brazil and rest of EU).

To stay below 1.5°C of global warming, we need to achieve CO_2 neutrality by 2050 along with net negative CO_2 emissions from AFOLU ('agriculture, forestry and other land use'). We meet our 2050 target in both NC and GS (Figure 4.5). Our results show net removals of 2.3 Gt CO_2 and 3.6 Gt CO_2 by 2050, which are equally attributed to sequestration on abandoned productive land, prevented deforestation, and afforestation efforts. However, while our findings highlight the significant progress that can be realised towards reducing GHG emissions from agriculture and through land use change, the FABLE target of agricultural emissions being less than 4 Gt CO_2e per year by 2050 is not achieved. Agricultural emissions are reduced by 1.1 Gt and 1.4 Gt annually in NC and GS compared to CT. Although to meet the target, N_2O emissions need to be cut by 56% compared to 2020, in GS we lower them by 34%, due to a reduced number of ruminants, lower crop residues and a reduction in synthetic fertilizers associated with a lower production of major crops such as corn, rice, barley, and sugarcane.

4.3 Discussion and recommendations

What are the main levers to achieve the SDGs related to food and land systems from our results?

The higher the future demand for agricultural commodities, the greater the need to increase productivity to prevent land expansion, which could compromise SDG 13 (Climate Action) and 15 (Life on Land). Currently, 38% of total cropland[34] and 30% of water for agriculture[35] is used for animal feed, so limiting protein consumption to recommended levels and increasing the share of proteins derived from plants saves resources. Many countries have taken the opportunity of renewing their Dietary Guidelines to promote healthy and sustainable diets, including Brazil,[36] Germany, and Sweden. This effort must be pursued in other countries and accompanied by strong economic incentives for the food industry and consumers.

Yield gaps are particularly large for rainfed cereals in Africa.[37] The application of more nutrients will be required to close this gap, but this will depend on improving access to quality inputs, especially for smallholders, to reach SDG target 2.3. Practices need to be carefully tailored to the local context, soils, and climate to avoid worsening pollution and compromising SDGs 6, 14, and 15. Our findings particularly highlight the importance of investing in nuts, fruits and vegetables: while shifts towards healthier diets increase demand for these products, our projections of productivity growth for these products lags behind. This could lead to a sharp increase in prices, reducing the affordability of healthy diets in the future.

Regulations and incentives to prevent the conversion of forest and other biodiversity-rich areas to agricultural land are critical to achieving SDG 15 (Life on Land) and also significantly contribute to SDG 13 (Climate Action). In GS, 19 of the 22 participating countries as well as all regions assume effective deforestation control mechanisms will have been implemented by 2030. While FAO reports that deforestation has slowed in recent years, increases have been observed in Brazil and Indonesia. Countries urgently need to invest in robust, transparent and inclusive deforestation monitoring systems to ensure that their commitments will be translated into action.

What other levers are needed to meet the targets that are not represented in this study?

Our results show a significant number of countries are failing to reduce the prevalence of undernourishment to below 5%. This result is driven by the assumption that inequalities will remain constant over time, meaning that unless inequalities are sufficiently addressed, SDG 2 cannot be met without wasting resources and generating large surpluses for the wealthier, compromising the achievement of SDGs 3, 6, 13, 14, and 15.

The challenge of staying within the planetary boundary for nitrogen and phosphorous has also been highlighted by other studies,[38] but significant gaps remain in our analysis. The fertilizer reductions from certain agroecological practices that improve soil health, notably using leguminous crops for nitrogen fixation, are not yet captured in the model, meaning our results may underestimate the pollution and cost reductions from expanding agroecological practices. These could help to close gaps towards meeting our targets.[39,40] More generally, technologies for precision agriculture or the introduction of new cultivars, feed additives, vaccines, inhibitors, or alternate wetting and drying to reduce water use in rice irrigation[41] could enable additional reductions of CH_4 and N_2O emissions. However, the deployment of mitigation measures in agriculture remains slow, due to a lack of institutional support.[8] Effective policy interventions and investment plans are urgently needed.

The 2011 Aichi Target pledge for countries to protect 17% of land and marine areas by 2020 was almost achieved,[42] however the quality of protected areas varies across regions, often excluding zones of particular importance for biodiversity.[43,44] This highlights the importance of monitoring 'land where natural processes predominate' separately from the coverage of protected areas. Better targeting of protected area expansion and other effective area-based conservation measures to incorporate zones that play key roles in biodiversity, such as linking up habitat areas, as well as the provision of financial support and inclusive governance approaches to ensure effective protection and buy-in from the local population could help achieve SDG 15 (Life on Land) and the Kunming- Montreal Global Biodiversity Framework targets.

Which SDGs related to food and land systems are not represented here and what measures are needed to avoid trade-offs?

Achieving SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action) requires close collaboration between the energy sector and the agricultural and forestry sectors. Several studies have highlighted, for example, risks associated with the large-scale deployment of biofuels.[45] New opportunities to develop clean energy, such as through agrivoltaics, woody energy crops, or bioenergy with carbon capture and storage (BECCS), need to be carefully assessed in the context of limited resources and the prioritisation of SDG 2 (Zero Hunger).

Around one-quarter of the world's labour force works in agriculture,[46] with many living below the poverty line.[47] Quality Education (SDG 4) in rural areas and Gender Equality (SDG 5) are critical levers to help farmers adopt new practices and rise out of poverty. Our results find that in GS, total agricultural work, measured in full-time equivalent workers, would decrease by 19% by 2050 compared to 2020. Support will be needed to help these workers diversify their income sources and receive a larger share of the value added of the agrifood system. Finally, SDG 16 (Peace, Justice, and Strong Institutions) represents the enabling condition to achieving all of the other SDGs. More concertation and coordination are needed at the local, national, and international levels (see Parts 1 and 3) to monitor trade-offs between all SDGs and ensure a more equitable distribution of costs and benefits across and within countries in order to avoid conflicts.

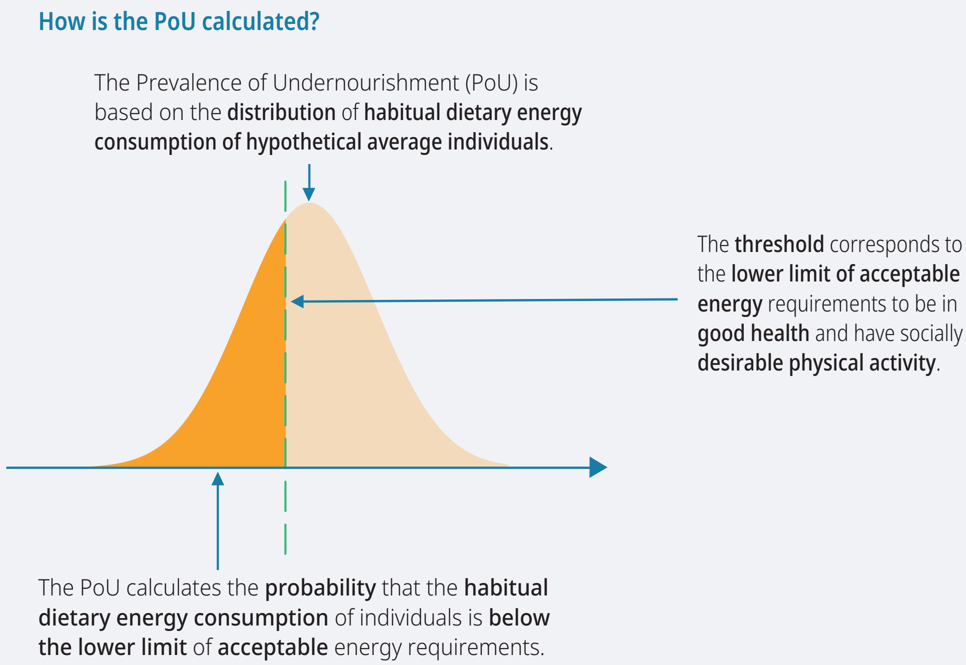
Part 4 Annex: Levers for change

Computation of the prevalence of undernourishment

In the actual computations, the distribution is assumed to be lognormal and thus fully characterized by three parameters: mean dietary energy consumption (DEC), its coefficient of variation (CV), and the minimum dietary energy requirement (MDER) per capita. The CV is affected by differences in energy requirements across a country's population (i.e., normal diversity in the population) as well as by differences in household socio-economic characteristics (i.e., inequalities in the ability of households to match consumption to requirements). The CV is taken from the FAO and kept constant at 2020 levels from 2020 onward.

To project the future prevalence of undernourishment (PoU), we need to project these three variables. The Average kilocalorie intake per capita and the minimum dietary energy requirement (MDER) are taken from the FABLE Calculator, but the coefficient of variation is currently kept constant. Since the MDER varies only very slightly across pathways, our findings indicate that the evolution of PoU is driven only by the evolution of average kilocalorie intake: if it increases, PoU decreases; if it decreases, PoU increases.

Figure 4.6
Computation of the prevalence of undernourishment



Source: FAO

Figure 4.7
Projected and FAO historical values of prevalence of undernourishment

		CV	Prevalence of Undernourishment			
		FAO		FABLE projections		
		2020	2020	2020	2030	2050
ARG	CT	0.28	3.3	3.1	3.5	3.7
	NC				3.5	3.7
	GS				6.5	3.6
BRA	CT	0.27	3.7	3.5	2.1	0.7
	NC				2.4	1.1
	GS				4.5	9.9
COL	CT	0.31	6.3	7.3	6.4	4.7
	NC				6.8	6.8
	GS				7.9	8.9
ETH	CT	0.37	22.3	21.4	22.5	25
	NC				22.5	25
	GS				22.5	25
IDN	CT	0.28	6.1	9.6	10	13.6
	NC				6.1	6.3
	GS				7.4	37
IND	CT	0.29	15.9	15.2	14.9	13.6
	NC				15.3	16.6
	GS				15.3	16.5
NPL	CT	0.28	5.2	4.2	5.1	6.2
	NC				5.2	6.2
	GS				6	16.4
RWA	CT	0.36	32.4	29.1	12.5	17.2
	NC				12.4	12
	GS				12.7	12.9
ASP	CT	0.24	7.7	3.5	3.2	1.6
	NC				2.7	1.6
	GS				5.7	13.4
CSA	CT	0.27	14.2	8.7	7.5	4.6
	NC				7.5	4.6
	GS				9.2	8.7
NEU	CT	0.22	4.1	2.7	3	2.9
	NC				3.5	4.5
	GS				3.2	4
NMC	CT	0.3	13.2	8.4	6.8	3.9
	NC				7.7	5.8
	GS				9.8	12.1
SSA	CT	0.32	19.7	23	20.8	18.1
	NC				20.8	18
	GS				22.1	20.5

Note: Australia, Canada, China, Germany, Denmark, Finland, the UK, Greece, Mexico, Norway, Russia, Sweden, The US, and the rest of EU region are not listed here because they have a prevalence of undernourishment below 2.5% in 2020 and below 5% from 2030 on.
Source: FAO and authors

Figure 4.8
Levers for change

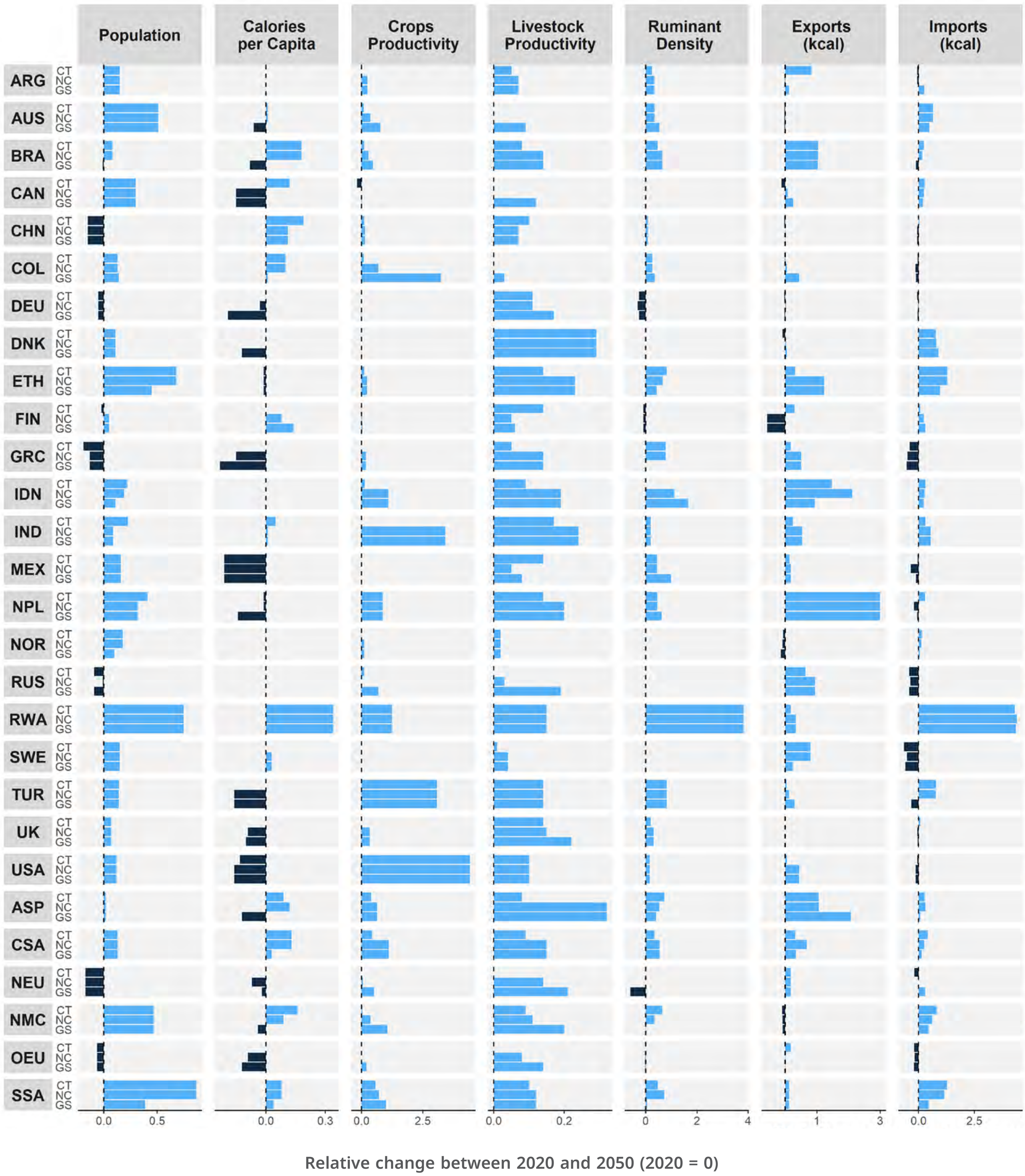
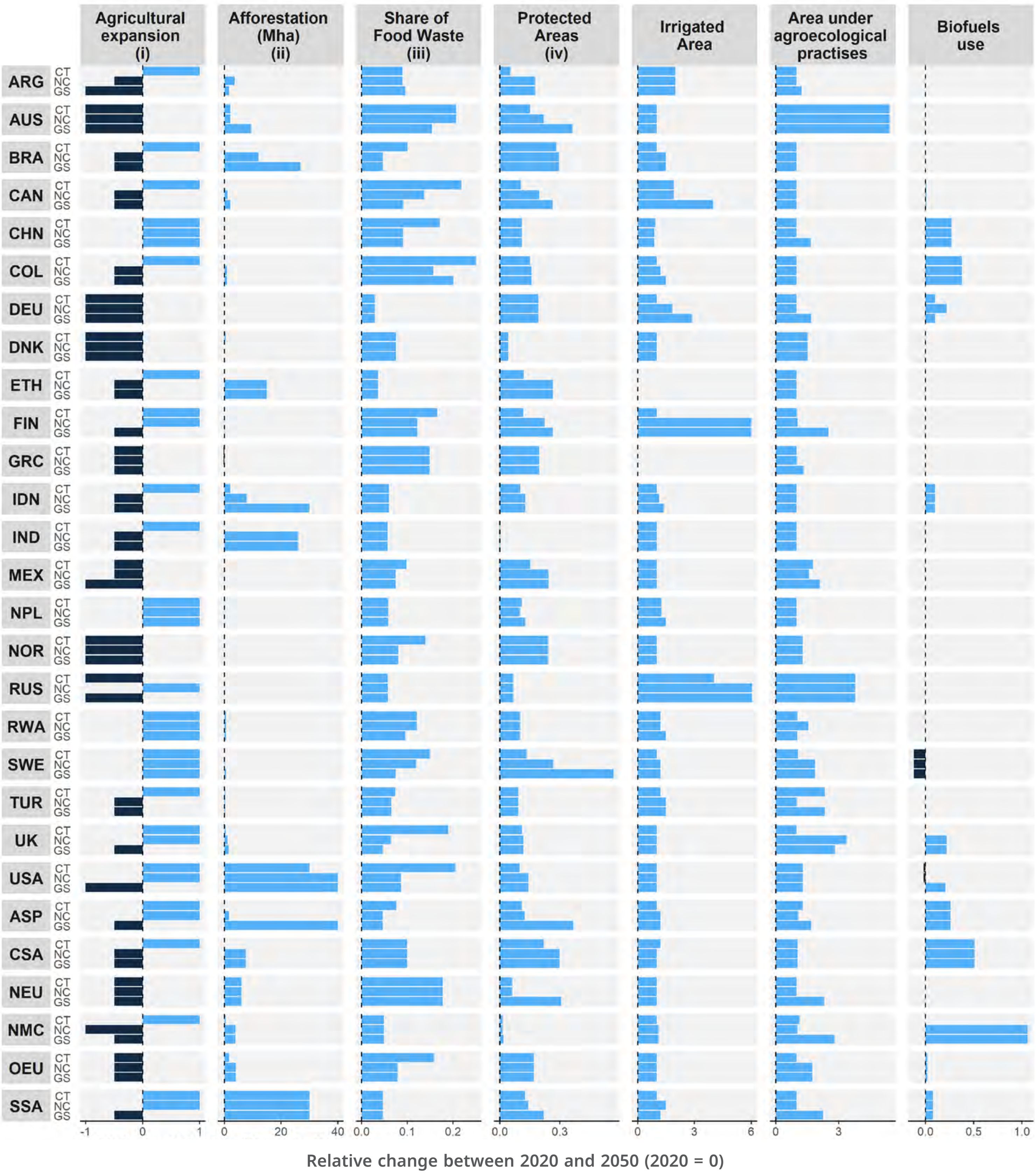


Figure 4.8
(continued)



Notes: Relative changes can be derived from both the country team's scenario assumptions and the combined effect of multiple changes in the calculator.
(i) Results are expressed in code, taking the value 1 for the 'Free expansion scenario', -0.5 for 'No deforestation' and -1 for 'No Agricultural expansion'. (ii) Results are expressed in net increase rather than relative change. (iii) Results are expressed % of consumption which is wasted. (iv) Results are expressed in % of total land in 2050.
Source: Authors

Results by target

Figure 4.9
Detailed results by target and pathway

Domain	Target	Current Trends	National Commitments	Global Sustainability
Food security	Kcal/cap/day at least 10% >MDER from 2030 on in each country	Yes	Yes	No (IDN)
	Kcal/cap/day lower than 50% >MDER from 2030 on in each country	No (ARG, BRA, CAN, CHN, TUR)	NO (BRA, RUS, TUR)	No (ARG, RUS)
	<5% of prevalence of undernourishment from 2030 on in each country	No (6 countries, 3 regions)	No (6 countries, 3 regions)	No (8 countries, 5 regions)
Biodiversity	Protected areas on 30% of total land in 2030	21.10%	22.40%	24.60%
	50% of cropland under agroecological practices in 2030	38.60%	38.60%	43.30%
	No loss of mature forest from 2030	- 100 Mha	- 38 Mha	- 0.32 Mha
	No loss of mature land where natural processes predominate from 2030	- 97 Mha	- 53 Mha	- 35 Mha
	15% gain in land where natural processes predominate between 2020 and 2050	-1.60%	6.00%	11.20%
Climate change mitigation	< 4 Gt CO_2e from agriculture in 2050	7.2 Gt	6.1 Gt	4.7 Gt
	-20 Mt CH_4 from agriculture in 2030 compared to 2020	+ 10.9 Mt	+ 4.2 Mt	- 5.6 Mt
	-28 Mt CH_4 from agriculture in 2050 compared to 2020	+ 27.6 Mt	+ 2.2 Mt	- 28.8 Mt
	< -1.3 Gt CO_2 from AFOLU in 2050	+ 0.01 Gt	- 2.3 Gt	- 3.6 Gt
	< 40 Gt CO_2 from AFOLU cumulated between 2020 and 2050	57.6 Gt	- 1.7 Gt	- 42.4 Gt
Freshwater, Nitrogen and Phosphorus	< 68 Tg of nitrogen use in 2050	283 Tg	247 Tg	198 Tg
	< 16 Tg of phosphorous use in 2050	34.1 Tg	32.1 Tg	29.3 Tg
	< 2,453 km^3 of blue water used for irrigation in 2050	1323 km^3	1094 km^3	912 km^3

Notes: MDER = Minimum Dietary Energy Requirement, AFOLU = agriculture, forestry and other land use
IDN– Indonesia, ARG–Argentina, BRA- Brazil, CAN- Canada, CHN- China, RUS- Russian Federation, TUR- Türkiye.
Source: Authors

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