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The future of food and agriculture

Alternative pathways to 2050

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Foreword

The last century has seen great socio-economic progress and significant welfare improvements worldwide. However, a world of "freedom from fear and want", as envisioned by the founders of the United Nations, has yet to be achieved.

Much also remains to be done to fulfil FAO's vision of creating "a world free from hunger and malnutrition, where food and agriculture contribute to improving the living standards of all, especially the poorest, in an economically, socially and environmentally sustainable manner".

Progress towards eliminating hunger and malnutrition is still insufficient to meet the goals of the 2030 Agenda for Sustainable Development

Addressing the challenges of hunger, food insecurity and malnutrition in all its forms features prominently in the targets of the second Sustainable Development Goal (SDG) of the 2030 Agenda for Sustainable Development. However, despite great progress towards increasing income and wealth globally, billions of people still face pervasive poverty, hunger and malnutrition, and various dimensions of inequality, joblessness, disease and deprivation from vital goods and services. FAO's most recent estimates indicate that 821 million people, approximately one out of every nine people in the world, were undernourished in 2017. Worse still, after a prolonged decline, both the absolute number of undernourished people and the prevalence of undernourishment (PoU) have started increasing again, signalling a possible reversal of trends. At the same time, food insecurity is contributing to undernutrition, as well as overweight and obesity, and high rates of these forms of malnutrition coexist in many countries.

Agriculture, including fisheries and forestry, is far from being sustainable

Much of humanity's progress has come at a considerable cost to the environment. To produce more food and other non-food agricultural goods, a combination of intensified agricultural production processes and the clearing of forests has led to the degradation of natural resources and is contributing to climate change.

Should we continue to address these challenges with a "business as usual" approach, the future will not look promising. Sustainable food and agriculture systems cannot be achieved without significant additional efforts.

Still, options to face these challenges are available

Options to face these challenges exist, but they need to be considered carefully. Food and agriculture systems may follow alternative pathways, depending on the evolution of a variety of factors such as population growth, dietary choices, technological progress, income distribution, the state and use of natural resources, climatic changes and efforts to prevent and resolve conflicts. These pathways can and will be impacted by strategic choices and policy decisions. Swift and purposeful actions are needed to ensure the sustainability of food and agriculture systems in the long run. The future is uncertain, but to act now, we need a good sense of what the world may look like under potentially different pathways.

This report explores different future pathways for food and agriculture systems through three distinct scenarios characterized by the way the key challenges to food security, nutrition and sustainability are dealt with: boldly, partially or not at all. It improves our ex ante understanding of alternative future long-term trends, both globally and at the regional level, of key variables and indicators affecting the future of food and agriculture. On the basis of these findings, the report highlights possible strategic options to guide food and agricultural systems along a more socially, environmentally and economically sustainable path.

This report shows convincingly, on the basis of quantitative evidence, that we can achieve more with less, and produce safe and nutritious food for all, while containing the expansion of agricultural sectors and hence limit the use of natural resources.

The purpose of this publication is to bridge a knowledge gap regarding the future of food and agriculture at a time when countries, international organizations, civil society and academia are increasingly requesting an authoritative foresight exercise in this domain. This work catalyses a wealth of multidisciplinary expertise and draws on many different data sources, from both inside and outside FAO. In rigorous but accessible language, the report sheds light on our responsibilities in shaping our common future.

Decision makers, the international community, academia and civil society are invited to give this report due consideration, not as the end point of an analytical endeavor, but rather as the starting point for a dialogue on strategic policy choices and processes aimed at shaping sustainable development patterns at country, regional and global levels.

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Abbreviations

AfDB	African Development Bank
AR5	Fifth Assessment Report of the IPCC
BAU	Business as usual scenario
CES	Constant elasticity of substitution
CFS	Committee on World Food Security
CO_2	Carbon dioxide
CO_2eq	Carbon dioxide equivalent
COP21	Twenty-first Conference of the Parties of the United Nations Framework Convention on Climate Change (Paris, 2015)
CV	Coefficient of variation
DEC	Daily energy consumption
DES	Daily energy supply
EAP	East Asia and the Pacific
ECA	Europe and Central Asia
EEZ	Exclusive Economic Zones
ENVISAGE	Environmental Impact and Sustainability Applied General Equilibrium model
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FDI	Foreign direct investment
FLW	Food loss and waste
FSN	Food security and nutrition
GAEZ	Global Agro-Ecological Zones (FAO-IIASA)
GAPS	Global Agriculture Perspectives System (FAO)
GCM	General circulation model
GDP	Gross domestic product
GHG	Greenhouse gas
GLC	Global land cover
GLEAM	Global Livestock Environmental Assessment Model (FAO)
GTAP	Global Trade Analysis Project
GtCO_2eq	Gigatonnes carbon dioxide equivalent
GWP	Global warming potential
HIC	High-income countries
IFAD	International Fund for Agricultural Development
IFPRI	International Food Policy Research Institute
IIASA	International Institute for Applied Systems Analysis
IMPACT	International Model for Policy Analysis of Agricultural Commodities and Trade
INDC	Intended Nationally Determined Contribution
IPCC	Intergovernmental Panel on Climate Change
IRWR	Internal renewable water resources

ISIC	UN International Standard Industrial Classification of All Economic Activities
ISI-MIP	Inter-Sectoral Impact Model Intercomparison Project
IUCN	International Union for Conservation of Nature
Kcal	Kilocalories
LAC	Latin America and the Caribbean
LGP	Length of growing period
LIC	Low-income countries
LMIC	Low- and middle-income countries
LSU	Livestock units
MDER	Minimum daily energy requirements
MDG	Millennium Development Goals
NDC	Nationally Determined Contribution
NNA	Near East and North Africa
OCHA	United Nations Office for the Coordination of Humanitarian Affairs
ODA	Official development assistance
OECD	Organisation for Economic Co-operation and Development
PoU	Prevalence of Undernourishment
R&D	Research and development
RCP	Representative Concentration Pathway
REDD	Reducing Emissions from Deforestation and Forest Degradation (UN Programme)
REDD+	Nationally-led processes for REDD
SAS	South Asia
SDGs	Sustainable Development Goals
SNA	System of National Accounts of the United Nations
SSA	Sub-Saharan Africa
SSP	Shared Socio-economic Pathways
SSS	Stratified societies scenario
TFP	Total factor productivity
TSS	Towards sustainability scenario
TWR	Total renewable water resources
UN	United Nations
UNCCD	United Nations Convention to Combat Desertification
UNCTAD	United Nations Conference on Trade and Development
UNECA	United Nations Economic Commission for Africa
UNICEF	United Nations Children's Fund
USD	United States dollar
USDA ERS	Economic Research Service of the United States Department of Agriculture
WDPD	World Database on Protected Areas
WFP	World Food Programme
WHO	World Health Organization

Executive summary

The future of food and agriculture: the overarching concern and key messages

The future of food and agriculture[1] faces uncertainties that give rise to serious questions and concerns regarding its performances and sustainability. Uncertainties revolve around different factors, including population growth, dietary choices, technological progress, income distribution, the state of natural resources, climate change, the sustainability of peace, etc. Nobody knows with precision how these factors will evolve over time; however, they are certain to shape the future. For this reason, countries, international organizations, civil society and academia are increasingly requesting an authoritative foresight exercise that outlines alternative scenarios and highlights potential pathways for food and agricultural systems.

This publication bridges the knowledge gap regarding the future of food and agriculture. It does not provide a detailed list of specific policy measures to achieve an ideal future, which is beyond the scope of a global long-term foresight exercise. Rather, this report highlights global challenges for the future of food and agricultural systems, and discusses how tackling these challenges – or leaving them unaddressed – will affect the sustainability of food and agricultural systems. The analysis is quantitative in nature, given the need to substantiate the possible scenarios with quantitative long-term projections of food and agriculture. At the same time, the interpretation of the quantitative findings relies on extensive qualitative analysis.

The analysis of the alternative scenarios detailed in this report addresses fundamental questions regarding the future of food and agriculture; it supports the identification of strategic orientations that nurture national, regional and global dialogues and policymaking processes, and helps shape key messages to guide food and agricultural systems along sustainable pathways.

[1] In this report, "agriculture" comprises all agricultural sectors, including crops, livestock, fisheries and forestry.

WILL GLOBAL FOOD AND AGRICULTURAL SYSTEMS BE ABLE TO FEED HUMANITY SUSTAINABLY AND SATISFACTORILY IN THE FUTURE, WHILE ALSO ACCOMMODATING ADDITIONAL NON-FOOD AGRICULTURAL DEMAND?

KEY MESSAGES

Food and agricultural systems are affected by trends that may jeopardize their future sustainability.

Population and income growth drive the demand for food and bring about changes in people's dietary preferences. Persistent poverty, inequality and unemployment constrain access to food and hamper the achievement of food security and nutrition goals. Agricultural production is limited by the increasing scarcity and diminishing quality of land and water resources, as well as by insufficient investment in sustainable agriculture. Climate change is increasingly affecting yields and rural livelihoods, while agriculture continues to emit greenhouse gases (GHGs).

Changing course is critical – "business as usual" is no longer an option.

If food and agricultural systems remain on their current path, the evidence points to a future characterized by persistent food insecurity and unsustainable economic growth. Many countries and regions are already committed to increasing the sustainability of their food and agriculture systems. However, fully meeting Sustainable Development Goals (SDGs) targets, as envisaged by the 2030 Agenda for Sustainable Development, will require additional efforts to address growing inequalities and gender imbalances, sustain peace, reduce GHG emissions, avoid resource depleting farming systems, manage the demand for resource-intensive animal food products, and reduce food loss and waste, among other challenges.

A more sustainable future is attainable, but getting there will not be easy.

To move away from "business as usual", all societies will be required to renew the assets used to produce goods and services, or capital stock, develop new solutions, and implement innovative technologies. In the spirit of solidarity enshrined in the SDGs, countries and social groups that can reasonably shoulder the costs involved in the necessary transformations have to provide support to those already affected by the negative effects of unsustainable development, and help them prepare a better future for the next generations.

All countries must commit to responsibility-sharing in implementing fundamental changes.

The global transformative process required to improve the sustainability of food and agriculture transcends the divide between "developed" and "developing" countries. All countries will be affected in this process, as "fundamental changes in the way societies consume and produce are indispensable for achieving global sustainable development" (Rio+20. *The future we want* [UN, 2012]).

Raising consumer awareness will help contain the need to unnecessarily expand food production and reduce the "triple burden" of malnutrition …

Agricultural production is expected to rise worldwide in response to population growth, dietary changes and increased incomes. Raising consumer awareness about environmentally sustainable and healthier diets, reducing food waste, pricing food to reflect the negative externalities of its production, and limiting the use of grains for biofuel production will all be critical to curb the demand for agricultural products. These actions will also be critical to reduce the "triple burden" of malnutrition that is, undernourishment, micronutrient deficiencies, and overweight and obesity, that often exist within a single country or even community.

… but producing more will be unavoidable, and the way forward is doing so with less.

Those working in food and agriculture must learn how to satisfy a growing demand under more significant resource constraints by improving land and water use, reducing GHG emissions, increasing efficiency in energy production and consumption, and restoring soils and forests. These are just some of the variety of strategic options to consider in search of sustainability.

While moving towards sustainability, food prices might increase significantly …

If the entire range of production and consumption costs is taken into account, including resource degradation and GHG emissions, evidence indicates that food prices are likely to increase significantly. Such increases could lead to a more careful use of both natural resources and of food itself.

… yet environmental sustainability and food security can yet go hand in hand.

While moving food and agricultural systems towards sustainability may drive up food prices and restrain global agricultural output, the per capita food availability and access to food in low- and middle-income countries can improve substantially if a more equitable distribution of income within and across countries is pursued.

A more equitable income distribution is a must …

Ensuring a more equitable distribution of income within and across countries is indispensable in the quest for food security, better nutrition and environmental sustainability of food systems. Among the strategic options to achieve this goal are: promoting sustainable technologies; facilitating the access to markets for family farmers; building stronger institutions to ensure competitive, transparent and fair markets for agricultural inputs and outputs; implementing effective social protection schemes and equitable fiscal systems; and reducing illicit financial flows that drain resources from low-income countries.

… and requires strengthening access to assets for vulnerable groups.

Secure and equitable access to assets such as land, water, capital and credit will, together with improved information and enhanced skills and know-how, significantly improve the earning potential of the poorer segments of society. This is true for both people who will remain engaged in agricultural activities and for those who will move out of agriculture to engage in other productive sectors.

Food and agricultural sectors are key, but are no longer enough on their own to ensure equitable access to food.

Crops, livestock, fisheries and forestry continue to be important for employment and income generation in low- and middle-income countries. However, these sectors alone no longer provide enough jobs or income-earning opportunities. On the one hand, agriculture and family farming in particular, must be more firmly linked to the broader rural and urban economy. This can be done by developing agro-industries and setting up infrastructure to connect rural areas, small cities and towns. On the other hand, strong institutions supported by efficient fiscal systems, are needed to ensure economy-wide income-earning opportunities, effective social protection, and competitive and equitable domestic and international markets for inputs and outputs. All these aspects are critical to improve the efficiency and equity of economic systems and facilitate their structural transformation. In addition, interventions to reduce GHG emissions in agriculture will not pay off significantly if efforts to boost energy-use efficiency are not simultaneously undertaken on an economy-wide basis.

WHAT CAN BE DONE TO MANAGE FOOD DEMAND AND CHANGE PEOPLE'S DIETARY PREFERENCES?

KEY MESSAGES

Managing consumer demand through awareness raising and proper regulations can help contain the expansion of agricultural sectors.

Food and non-food agricultural production is expected to rise because of population and income growth. However, the expansion of agricultural sectors can be significantly contained by, for instance, rasing consumer awareness on environmentally sustainable diets, regulating and discouraging food waste, enforcing more efficient food pricing and limiting the use of biofuels.

Demand management through consumer awareness and education is also essential to reduce the "triple burden" of malnutrition.

Consumer awareness and education regarding the nutritional content of food and diet-related diseases are also critical to reduce the "triple burden" of malnutrition that is, undernourishment, micronutrient deficiencies, and overweight and obesity, that often exist within a single country or even community, and to achieve a shift towards generally healthier diets.

Food prices should be "right".

Food prices should reflect the inherent nutritional value of food as well as the full range of costs associated with their production and consumption along the entire food value chain. This includes environmental costs such as biodiversity loss, land degradation, water depletion, GHG emissions, which are often not accounted for. This can help limit the growth of food demand and reduce food losses and waste, while contributing to the preservation of natural resources and the improvement of nutrition.[2] However, as higher food prices may hamper poor people's ability to buy food, targeted and efficient strategies are needed to raise their purchasing power.[3]

Dietary patterns of high-income countries need balancing.

While moving towards sustainable food systems, neither restrained expansion of production nor increased food prices would substantially impinge on global food availability – including in low- and middle-income countries – if high-income countries were to consume fewer animal products and food waste and loss were considerably reduced. Raising consumer awareness on this issue could be key. Balanced diets are critical for reducing all types of malnutrition, including undernourishment but also overweight and obesity, often causing non-communicable diseases.

International trade may help exploit production potential and fill food deficits.

Sustainably expanding the supply of food in countries whose population is expected to increase significantly is essential to ensure adequate food availability. Trade has an important role to play here, and imports may well be needed to fill domestic deficits in case natural resource constraints are an issue. However, strong global and national institutions are needed to coordinate efforts across countries and prevent unfair competition against those countries that adopt more stringent environmental and social regulations.

HOW TO ADDRESS THE SCARCITY AND REDUCED QUALITY OF LAND AND WATER RESOURCES IN A SUSTAINABLE MANNER?

KEY MESSAGES

Sustainable agricultural intensification is key to saving land.

Due to increasing agricultural production and unsustainable practices, the demand for land might exceed the available reserve of very suitable and unprotected land for rainfed crops, as is already the case in specific regions such as the Near East and North Africa, or in selected countries in East Asia and the Pacific. This could entail environmental problems or additional production costs from using lower-quality land and/or building additional infrastructures. As shown by the findings of this report, the sustainable intensification of agricultural sectors can potentially lower the expansion of demand for land while maintaining soil quality.

[2] Economists have traditionally regarded unpaid environmental costs as "environmental externalities", which lead to a suboptimal economy-wide outcome. Achieving optimal results in the presence of externalities implies making sure that economic agents face the correct prices for their actions (Varian, 1992).

[3] Legitimate concerns regarding the purchasing power of poor people, as well as possible strategies to increase it, are addressed in the following section.

Avoiding further land degradation and encouraging land rehabilitation helps tackle land constraints.

Although limited, available information on land degradation suggests that current agricultural practices lead to productivity losses that require an increase in the input intensity. Efforts to rehabilitate degraded land and practices that limit degradation are required to maintain the resource base and reduce the use of inputs.

Using water more efficiently is increasingly becoming a must.

Many countries already exploit their water resources at unsustainable rates, thereby jeopardizing the potential for future production. Climate change and population growth may exacerbate water scarcity. Under these conditions, increasing the efficiency of water use is becoming increasingly crucial.

Trading off agricultural yields and sustainability.

The adoption of sustainable agricultural practices might require forgoing certain yield increases, particularly when such increases lead to the overuse of water resources, a reduction in soil fertility, the loss of biodiversity and higher GHG emissions. However, some recovery in yield growth could materialize in the long run, due to a restored natural resource base, or as the result of an improvement in farmers' expertise.

All the above does not come for free: significant investments are needed.

To ensure that sufficient land and water resources are available to meet total demand from agriculture, significant investments are required in the research and development of sustainable technologies and practices, infrastructure and human capital.

WILL POVERTY, INEQUALITY AND UNEMPLOYMENT CONTINUE TO CONSTRAIN FOOD ACCESS AND HAMPER THE ACHIEVEMENT OF FOOD SECURITY AND NUTRITION GOALS?

KEY MESSAGES

Defeating undernourishment requires reducing poverty and inequalities.

The findings of this report show that much more than "business as usual" will be required to defeat undernourishment. A bold move towards a more equitable income distribution – to be achieved through diverse strategic options, including by ensuring a more equitable access to assets for the poor people, with a focus on poor family farmers – is the most effective way to ensure that the reduction in undernourishment seen in the past years continues uninterrupted in the future.

Environmental sustainability and food security can go hand in hand.

While moving food and agricultural systems towards sustainability drives food prices up and restrains global agricultural output, the per capita food availability in low- and middle-income countries can substantially expand if a more equitable distribution of income within and across countries is pursued.

A more equitable income distribution allows for improved and healthier diets.

The consumption of healthy items, such as fruits and vegetables is likely to increase if income is more equally distributed within and across countries, and particularly low- and middle-income countries. Overall, cereals would remain the most important source of calories.

Moving towards sustainability may help increase farm profitability and/or agricultural employment.

Sustainable agricultural practices can raise farm profitability and/or labour opportunities in agricultural sectors. This would contribute to a more equitable distribution of income, which may in turn be critical to improve food security and nutrition.

Food and agricultural sectors are key, but no longer enough on their own to ensure equitable access to food.

Agricultural sectors continue to be important for employment and income generation in low- and middle-income countries. However, they alone no longer provide enough jobs or income-earning opportunities. On the one hand agriculture and family farming in particular, must be more firmly linked to the broader rural and urban economy. This can be done by developing agro-industries and setting up infrastructure to connect rural areas, small cities and towns. On the other hand, strong institutions supported by efficient fiscal systems, are needed to ensure economy-wide income-earning opportunities, effective social protection, competitive and equitable domestic and international markets for inputs and outputs.

HOW WILL CLIMATE CHANGE AFFECT AGRICULTURE AND RURAL LIVELIHOODS, AND CAN AGRICULTURE HELP REDUCE GHG EMISSIONS?

KEY MESSAGES

Climate change will incrementally affect all the agricultural sectors.

Climate change already has negative effects on crop yields, livestock production and fisheries, particularly in low- and middle- income countries. Such impacts are likely to become even stronger later in this century.

If left unaddressed, climate change will exacerbate poverty and inequalities.

Unaddressed climate change, which is associated, inter alia, with unsustainable agricultural practices, is likely to lead to more land and water use, disproportionately affecting poor people and exacerbating inequalities within and between countries. This carries negative implications for both food availability and food access.

Climate change impacts go well beyond crop yields.

Climate change also affects soil quality, fish habitats and stocks, the biodiversity of landscapes, and the epidemiology and antimicrobial resistance of pests and diseases. There are great uncertainties about the combined effects of these impacts.

Agricultural sectors can only reduce their greenhouse gas emissions through more investment.

Agricultural sectors can adapt to climate change and lower their GHG emissions while producing enough food for all. However, for this to be possible, substantial investments must be made to develop and implement more resource-saving and climate-friendly technologies.

Efforts in agricultural sectors are not enough – drastic economy-wide greenhouse gas reductions are needed.

Although agricultural sectors have a significant potential for climate change mitigation through the adoption of better practices such as land conservation, increasing livestock efficiency, afforestation and reforestation, efforts in agriculture alone are not enough. Boosting energy-use efficiency and reducing GHG emissions per unit of energy must happen on an economy-wide basis.

Alternative pathways to 2050

Introduction

The future of food and agriculture – Alternative pathways to 2050 provides a forward-looking perspective on the development of global and regional food and agricultural systems. This development, and its related challenges, will depend on underlying long-run trends in supply and demand, which will continue to shape global food and agriculture.

The overarching concern regarding the future of food and agriculture is whether global systems will be able to sustainably feed humanity up to 2050 and beyond, while at the same time accommodating the demand for non-food agricultural commodities. This concern arises because current trends are calling into question the economic, social and environmental sustainability of food and agricultural systems.

Increased population, income and urbanization, all drive up the demand for food and change people's dietary preferences towards more resource-intensive animal products and processed food.

The global demand for food and non-food agricultural products continues to grow, reflecting dietary changes, driven by population growth, a rise in income and increased urbanization. For example, the share of meat and dairy products in people's diets has increased with economic growth, while the share of cereals has diminished. This has prompted concerns about the sustainability of diets, as well as about their health implications, particularly – but not exclusively – in high-income countries (HIC) where both adult and child obesity show a dramatic increasing trend. At the same time, the incidence of diet-related non-communicable diseases is on the rise (GBD 2015 Risk Factors Collaborators, 2016; GBD 2016 DALYs and HALE Collaborators, 2017).

Persistent poverty, inequality and unemployment constrain the access to food and hamper the achievement of food security and nutrition goals.

The unequal distribution of income and access to assets, persistent extreme poverty and the lack of earning opportunities for hundreds of millions of people cause food insecurity to persist. While much progress was made over the past years to reduce hunger, more than 821 million people are still chronically hungry, and the evidence points to persistent undernourishment in the future. More than two billion people suffer from various forms of micronutrient deficiencies. For example, more than 600 million women of reproductive age still suffer from anaemia, which is often caused by iron deficiency, while several hundred thousands of children go blind every year due to vitamin A deficiency.

Persisting inequalities other than those relating to income – including access to resources such as land and water, or to the benefits that high-value resources such as oil and minerals generate – not only force people to live in an unfair world, but also trigger conflicts that in turn can exacerbate extreme poverty and food insecurity. Indeed, the marked surge in the number of global conflicts observed during the last decade is a major driver of food insecurity and malnutrition (FAO, IFAD, UNICEF, WFP and WHO,

2017) and conflict-induced negative impacts on human welfare are no longer limited to specific regions.[4]

Agricultural production growth is constrained by the increased scarcity and diminished quality of land and water resources.

What can be produced and whether growing and changing food requirements can be met will depend on the availability and productivity of resources, and notably of land and water. These resources are already under pressure, and although technical progress has raised productivity, evidence suggests that productivity growth, or at least growth in crop yields, is slowing. Moreover, food loss and waste put unnecessary pressure on land, water and energy resources along the food value chain; addressing this will improve environmental sustainability throughout the food system.

Unless supported by adequate investments, technical changes in food and agricultural systems will not lead to sustainable productivity improvements.

Questions arise as to whether the future demand for agricultural products will be compatible with the urgent need for greater sustainability in resource use. To meet the increasing demand for agricultural products in a more sustainable way, food and agricultural systems need more investment, including in research and development, to promote technical change. This is especially true for regions that currently lag behind in productivity and are also among the most food-insecure, such as sub-Saharan Africa. However, financing for investment is limited and priorities need to be identified to achieve productivity improvements which are sustainable in social, environmental and economic terms.

Unaddressed climate change is increasingly affecting yields and rural livelihoods, while food and agricultural systems, as well as the economy at large, continue to emit GHGs.

Climate change manifesting itself in the form of extreme weather events already negatively affects yields in crop production, livestock rearing and fisheries, particularly in low- and middle-income countries (LMIC). This adds pressure on natural resources and shifts the distribution of what can be produced and where. The fact that GHGs from human activities are the most significant driver of climate change observed since the mid-20th century is problematic. Food and agricultural systems are among the major contributors to GHG emissions, and are therefore crucial to efforts towards the mitigation of climate change. Changes in agricultural production systems aimed at climate change mitigation and adaptation would be expected to reverberate positively throughout food systems. So far, GHG emissions within the economy at large have not been reduced. This implies that the agriculture sector needs to adapt to climate change, while climate change needs to be mitigated.

Understanding the possible pathways towards sustainability in the face of these challenges necessitates a long-term foresight exercise with alternative scenarios.

No doubt, the challenges for global food and agricultural systems discussed above provide grounds for concern and raise questions about how to face them if we want to move towards sustainability, or what is at stake if we move in the opposite direction. The challenges are

[4] Rather, such impacts have become a global issue with the displacement of people and migration, such as in the case of the ongoing civil war in the Syrian Arab Republic. Conflicts, violence and natural disasters are among the root causes of migration and forced displacement. However, many migrants are forced to move because of socio-economic factors including poverty, food insecurity, a lack of employment opportunities, limited access to social protection, natural resource depletion, and the adverse impacts of environmental degradation and climate change.

complex and diverse. While some of them are inherent to food and agricultural systems and depend on the way in which these systems are – and will be – organized (e.g. increasing pressure on land, water and energy use), others are essentially systemic, impacting food and agricultural systems from elsewhere (e.g. economy-wide unemployment, conflicts, climate change, urbanization and migration). Additional complexities arise because inherent and systemic challenges may be intertwined, displaying incremental and multiplicative effects in the medium- to long-run. Together, these challenges create an uncertain future for food and agriculture.

A long-term foresight analysis is needed to understand the evolution of global food and agricultural systems against a background of multiple uncertainties, depending on our ability (or lack thereof) to face the various challenges. The core of this foresight exercise is to compare alternative scenarios in which these challenges are tackled to different degrees. This comparison helps understand the potential implications of the strategic options and interventions underlying each scenario for food and agricultural systems.

In a study such as this one, the scenarios are not forecasts or predictions, or even stand-alone projections, but rather possible, plausible and consistent pathways of what the future might look like at some, usually distant, point in time. Pathways differ depending on the evolution and interaction of the many factors that determine the dynamics and performance of socio-economic and environmental systems, such as income growth and distribution, population trends and demographic changes, technology, agroecological conditions and natural resources, GHG emissions and climate change. These factors may evolve depending on different policies and interventions. The objective of the foresight exercise is therefore not necessarily to obtain the most precise future estimates of food and agriculture variables, but rather to depict comprehensive and consistent frameworks that highlight how certain decisions can influence the unfolding of development pathways.

In many instances, a foresight analysis provides a scenario that essentially builds on past long-term trends of the factors that determine the dynamics and performance of socio-economic and environmental systems. Such a scenario is typically regarded as a "business as usual" and often considered as a "baseline" against which alternative scenarios are compared. Past trends already capture the observed impacts of a host of contingent, short-term events, such as temporary economic downturns, climate extremes, price spikes or reductions, international trade crises, local surges of pests and diseases, or temporary social unrest and conflicts, among others. Naturally, a long-term foresight analysis is unable to predict the future occurrence of such contingent, short-term events. Nonetheless, the holistic analysis does help identify "weak signals" of changes that are already present in the current situation. Such changes may progressively increase in magnitude or frequency in the future, and may potentially lead to significant shifts, for example in consumer preferences, technological changes or natural resource use.

This report presents a foresight exercise that builds on the expertise, skills and data of FAO and its partners, to help inform decision-making processes.

The methodology of this report is different from that of previous FAO exercises, which provided agricultural projections based on a single scenario. Building upon the FAO report *The future of food and agriculture – Trends and challenges* (FAO, 2017a), which highlighted how recent trends in key variables present challenges for food security and nutrition, the present report explores three different scenarios based on alternative trends for key drivers of the future of food and agriculture, including income increase and distribution, population growth, technical progress in agriculture and climate change.

The report provides quantitative and qualitative analyses of challenges facing food and agricultural sectors. The quantitative analysis relies on both economy-wide and sector-specific simulation models. For each scenario at the regional and global levels, the results of the model-based exercise provide separate and comparative (across scenarios) analyses of key variables and indicators, including the share of agriculture in total value added, the supply and demand for a set of food and agricultural products, long-term price trends, performance in the field of food security and nutrition, natural resource use, the net trade positions of various regions for selected groups of products, and GHG emissions.[5]

The analysis of the scenarios led to quantitative findings that were scrutinized also in light of complementary qualitative analyses. The latter were developed on the basis of existing background studies and other literature in specific domains including food demand, natural resource use and GHG emissions, as well as on reports by FAO and other organizations investigating challenges to food security and nutrition in all its dimensions.

This report is the result of a corporate process led by FAO's Global Perspectives Studies team that relied heavily on in-house expertise, skills and data, but also involved partnerships with external institutions. It builds upon the experience gained in foresight exercises by colleagues from FAO and from other international institutions including the International Fund for Agricultural Development (IFAD), the Organisation for Economic Co-operation and Development (OECD), the International Food Policy Research Institute (IFPRI) and the European Union, and upon knowledge and practices developed by the international community to support the work of the Intergovernmental Panel on Climate Change (IPCC), to name but a few.[6] The report forms part of FAO's efforts to provide evidence-based support to decision-making processes. Therefore, it should be seen as a comprehensive assessment of alternative prospects of food and agricultural sectors that without any pretense to be exhaustive, goes well beyond mere model-based projections and aims to contribute to the foresight work of the international community at the science-policy interface.

This report was much needed to bridge a knowledge gap regarding the long-term future of food and agriculture. For the first time, a report provides a globally consistent foresight exercise based on scenarios designed specifically to investigate challenges for food security and nutrition, while taking into account the future economy-wide context and possible climate change pathways. In accurate but accessible language, the report provides solid evidence regarding possible strategic options and directions to achieve the SDGs of eradicating hunger, improving nutrition and ensuring the sustainability of agriculture. Therefore, it helps understand how to move towards "a world in which food is nutritious and accessible for everyone and natural resources are managed in a way that maintain ecosystem functions to support current as well as future human needs" (FAO, 2014). Hopefully, this publication will be of use to everyone interested in long-term foresight assessments of global food and agricultural systems, including decision-makers and analysts in governments, international organizations, civil society organizations, the private sector, and academic and research institutions.

[5] Supplementary material including detailed commodity balances and other statistical tables is available online at: www.fao.org/3/CA1564EN/CA1564EN.pdf

[6] Annex I of the full report provides a comparative review of the key foresight exercises that inspired this publication.

1 | Challenges ahead for food and agriculture

Global food and agricultural systems are currently facing the following major challenges, which will persist for the next decades:

- providing sufficient food and other agricultural products to meet growing and changing global demands;
- eradicating hunger and food insecurity;
- preserving and enhancing the productivity and sustainable use of available natural resources;
- adapting to the impacts of climate change;
- contributing to climate change mitigation.

The future of the global food and agricultural system will be shaped by how it meets these five challenges, through efforts to make room for a sustainable future rather than submitting to trade-offs for short-term benefits.

This chapter provides a detailed review of recent trends affecting food and agriculture, related to the challenges outlined above. These trends can be summarized into four main areas of concern:

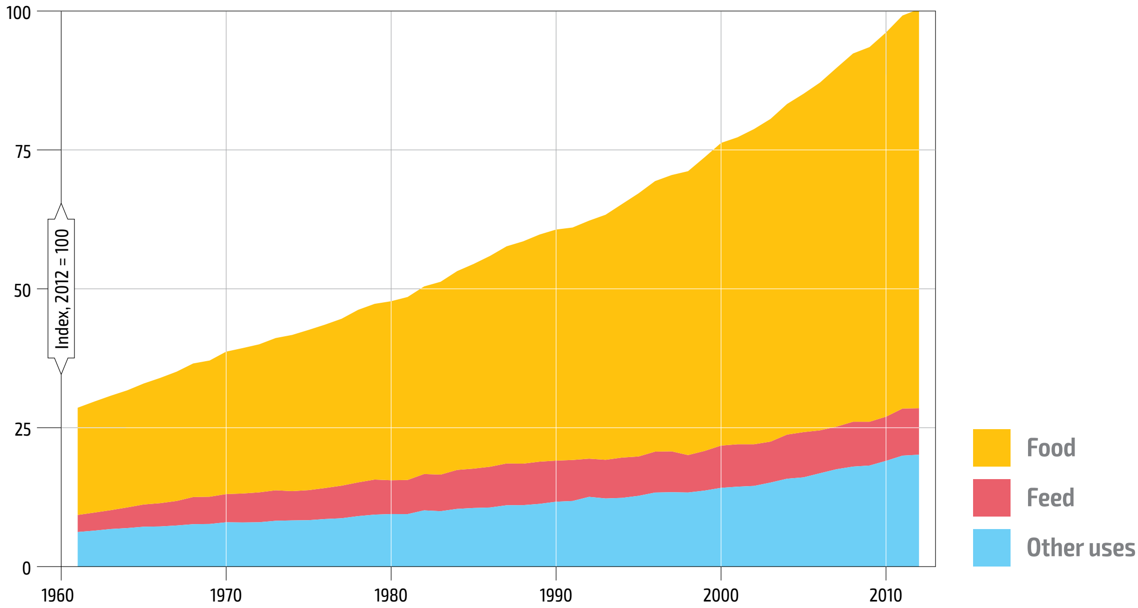
1. Population and income growth continue to drive up food demand and change people's dietary preferences.
2. Persistent poverty, inequality and unemployment constrain food access and hamper the achievement of food security and nutrition goals.
3. Agricultural production growth is constrained by increased scarcity and lower quality of land and water resources, as well as insufficient investment in sustainable agriculture.
4. Unaddressed climate change increasingly affects yields and rural livelihoods, while agriculture continues to emit GHGs.

The final part of this chapter presents a thorough analysis of these trends and the concerns they raise for the future of food and agriculture, laying the foundations for the forward-looking exercise presented in this report.

1.1 Population and economic growth as drivers of future agricultural demand

A significant part of agricultural production is devoted to satisfying food demand for human consumption. This refers to the direct use of agricultural products to produce food, and the use of crops and other vegetal and animal matter to produce feed for animals, which are in turn utilized for food production (see Figure 1.1).

Figure 1.1 Food and non-food agricultural demand: historical trends



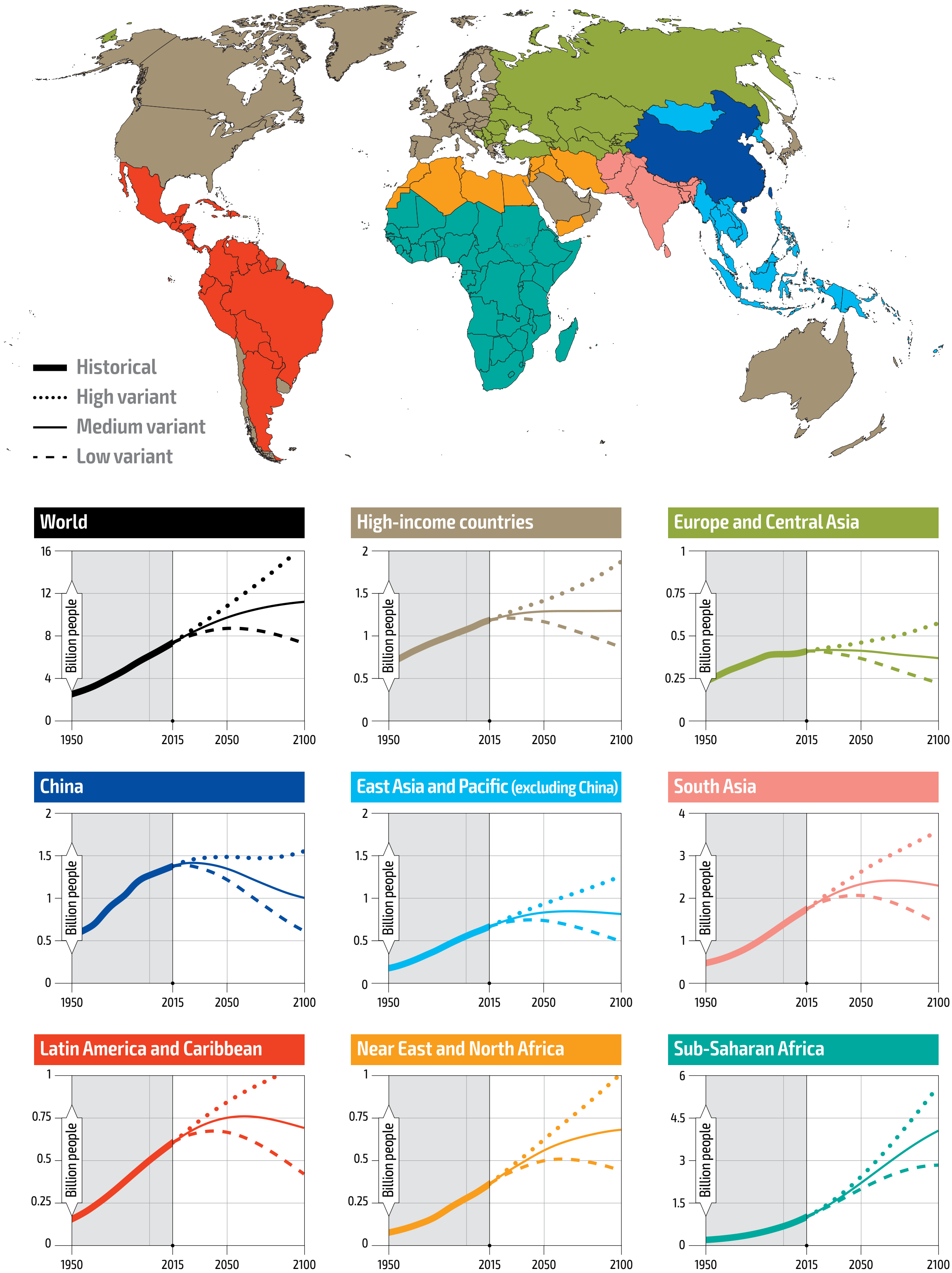
Note: The index 2012=100 is based on the volume of food demand expressed in monetary terms at 2012 prices.
Source: FAO Global Perspective Studies, based on FAOSTAT (various years).

Global population growth is slowing but will increase in Africa and Asia

Population increases over the last century led to a substantial rise in food demand. The United Nations projects that the world's population will be 9.7 billion by 2050, 10.8 billion by 2080, and 11.2 billion by 2100. Compared to approximately 7.3 billion people in 2015, the population will increase by around 32 percent, 47 percent and 53 percent in those three future periods, respectively (see Figure 1.2).[7] While these projections actually suggest a slowdown in the overall global population growth, significant and persistent increases are expected in Africa and South Asia: by 2100, these two regions may well be home to a total population of 9 billion of the projected 11 billion people on the planet. Driven by these important demographic forces, the demand for food is expected to significantly increase, particularly in Africa and South Asia.

[7] UN (2015) provides three alternative scenarios of population projections (a low, a high and a medium variant). This data refers to the "medium variant". This report uses the 2015 revision instead of the more recent 2017 one, which was not yet available at the time of the running of the scenario simulations. No significant differences in the results of analysis are to be expected.

Figure 1.2 Global population by region: historical and projected, 1950–2100



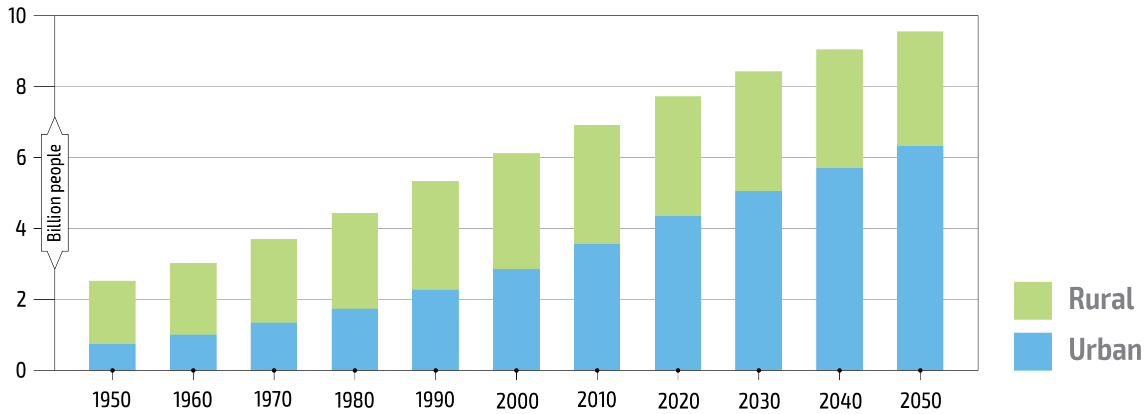
Notes: Country grouping is based on the World Bank Country Groups of July 2016, downloaded on 2 August 2016 from http://databank.worldbank.org/data/download/site-content/CLASS.xls as specified in Annex III, Table A 3.4 of the full report. High-income countries (HIC) are classified in a single group, regardless their geographical location. All other countries, qualified as low- and middle-income countries (LMIC), are classified by geographical region, notably Europe and Central Asia (ECA), East Asia and the Pacific (EAP), South Asia (SAS), Latin America and the Caribbean (LAC), Near East and North Africa (NNA) and sub-Saharan Africa (SSA). If not otherwise specified, LMIC and EAP include China (mainland only). Country groups and China are hereafter generally referred to as "regions".

Source: UN, 2015.

Urbanization and other demographic shifts will change the composition of food demand

Food demand changes are also expected to be influenced by evolving demographic structures and spatial locations of populations. For instance, between 2015 and 2050 the number of people aged 15 to 24 projected to be living in low- and middle-income countries (LMIC) is expected to rise from about 1 billion to 1.2 billion. Meanwhile other regions, particularly those formed by HIC, will have to adjust to rapidly-ageing populations. Furthermore, by 2050, two-thirds of the global population could be living in urban areas (Figure 1.3). The different food requirements of young and old people, as well as the different consumption patterns, jobs and living conditions of urban and rural populations, will affect the demand for and quality of various food items and minimum dietary energy requirements. Population dynamics will therefore be a critical determinant of future food demand.

Figure 1.3 Global urban and rural populations: historical and projected



Note: Projected figures from 2015 onward refer to the medium variant scenario.

Source: UN, 2015.

Changes in food demand and its composition may occur as income grows

Agricultural demand is also affected by the expanding global economy and increases in per capita annual income, which raise and change food demand. Globally, the income of the average world citizen nowadays is almost USD 11 000/year, which is twice the 1970 level of just over USD 5 500.[8] However, there are marked regional differences. In HIC, the average per capita income reached almost USD 43 000 in 2014, compared with USD 3 900 in LMIC. In China, where in the 1970s and 1980s the per capita income was well below USD 1 000, it progressively expanded to reach USD 7 200 in 2014 (Figure 1.4 a). This was a result of very high growth rates for more than three decades, ranging between 4 and 14 percent. The comparison between China and all other LMIC – whose per capita income growth rates in the same period ranged between 0 and 4 percent – is striking.

A more detailed analysis of available data (Figure 1.4 b) reveals starkly diverging growth patterns among LMIC. From 1970 to 2014, Latin America and Caribbean countries (LAC), South Asia (SAS) and the other East Asia and Pacific (EAP) countries (excluding China) exhibited quite dynamic expansions of per capita income, at annual

[8] Per capita gross domestic product (GDP) or how much GDP economic systems produce per person is hereafter referred to as per capita income. All prices are measured in USD, 2012 exchange rates.

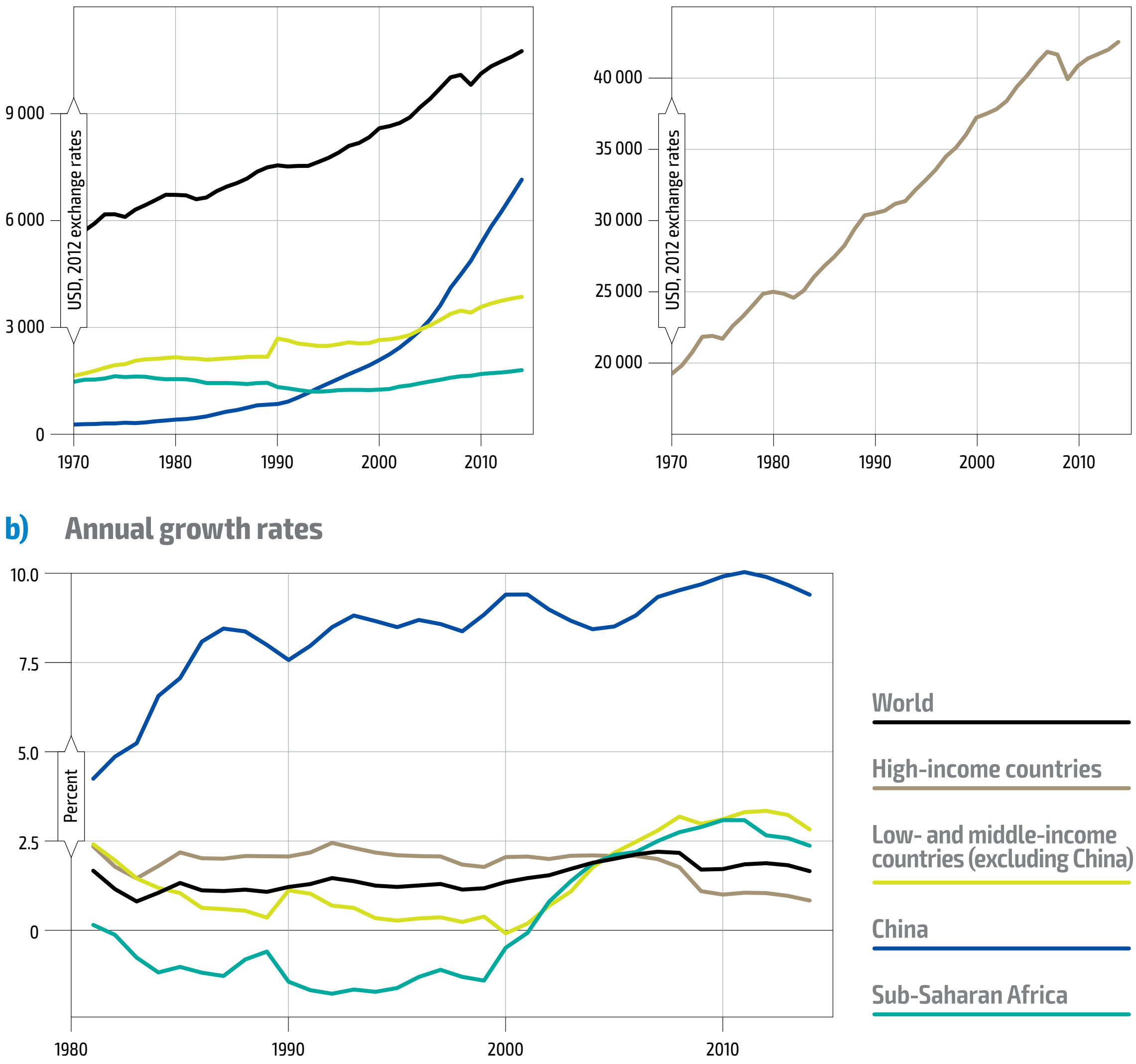
rates of between 1.5 percent and 3 percent, compared with the meagre 0.4 percent of sub-Saharan Africa (SSA) from 2004 to 2014. Per capita income in SSA, however, showed some dynamism from 2002 to 2012, with a growth rate of 2.6 percent compared with a negative average growth rate of -0.3 percent from 1970 to 2002.

Economic growth prospects are shrouded in great uncertainty and depend on a wide range of interrelated factors. These include the respective behaviours of producers and consumers, technological changes, the availability and productivity of natural resources and all other factors of production, population dynamics, climate change and policy responses, public and private investments, fiscal as well as other policies aimed at strengthening institutions and social stability and development. However, should per capita income grow at sustained rates in LMIC (excluding China), as observed in China, in upcoming decades, food demand will expand substantially in those countries.[9]

Figure 1.4 Per capita gross domestic product: globally and for selected regions

a) Monetary values

b) Annual growth rates



Note: Growth rates are calculated as (previous) ten-year moving averages.

Source: FAO Global Perspectives Studies, based on data from UN, 2016.

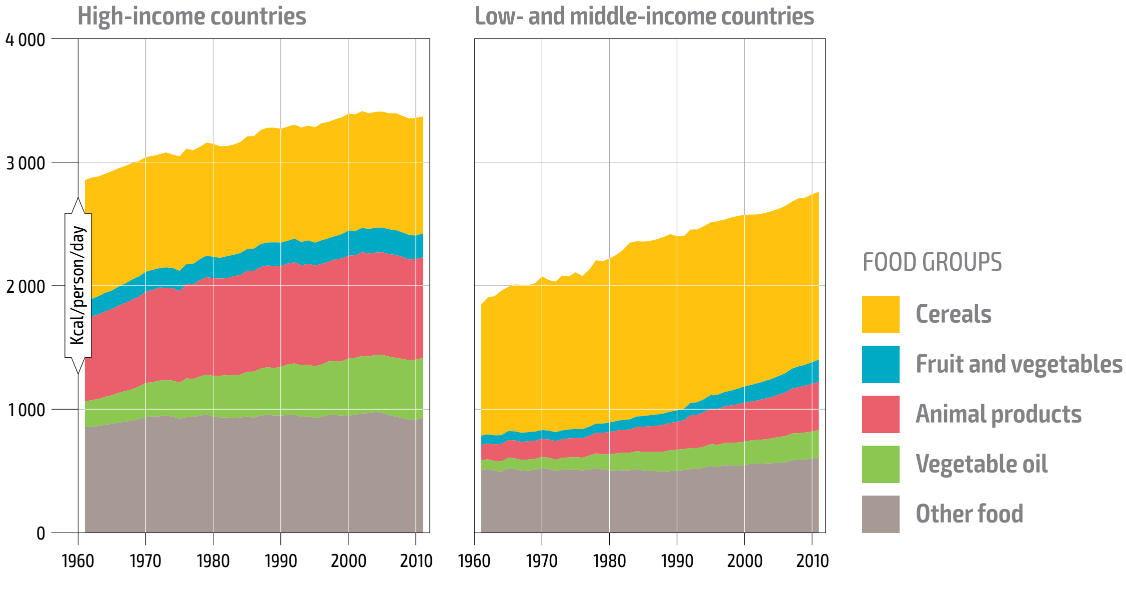
[9] The next chapters will explore different patterns of economic growth that will bear specific implications for food and agriculture in the future.

What increasing calorie intake and changing diets may bring in the future

Income growth, urbanization, relative price changes, technological change, value chain developments and globalization have all contributed to an increase in per capita calorie intake, as well as to a shift in the composition of diets. Rapid income growth in emerging countries has given rise to a global middle class, with food consumption preferences characterized by a greater demand for meat, fish and dairy products and other more resource-intensive items. While progress in increasing overall calorie availability globally is welcomed, concerns have arisen about the accompanying shifts in dietary patterns away from staples such as cereals, roots and tubers and towards increasing consumption of livestock products, vegetable oils, sugar, and processed and fast foods. This "nutrition transition" has also been seen as a tendency towards the convergence of diets to the Western European or North American model, and in turn linked to the increasingly widespread prevalence of overweight, obesity and non-communicable diseases.[10]

A study of food consumption by food group reveals that in the last 50 years per capita caloric availability and the diversity of foods consumed have increased in both HIC and LMICs. Although the average dietary energy supply (DES) in LMIC remains well below that of HIC, the gap is gradually closing (Figure 1.5). In 1961, the DES of LMIC was only 68 percent of that in HIC, but rose to 81 percent in 2011. Across all groups of food items, dietary patterns in the two groups of countries tend to converge (FAO, 2017a).

Figure 1.5 Trends in food demand by income group



Source: FAO Global Perspective Studies, based on FAOSTAT (various years).

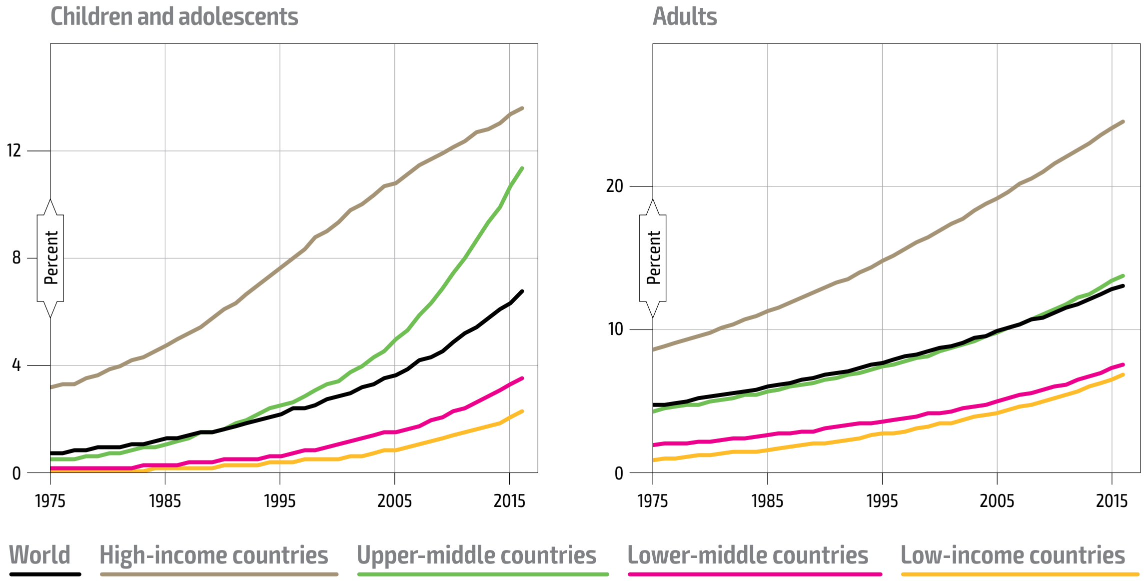
At the same time, as food becomes relatively cheaper and consumers opt for more diversity, food waste at both the retail and household levels is on the rise (FAO, 2017a). Therefore, consumer behaviour in different regions and at various levels of income is expected to influence the future prospects of food and agriculture. Shifts in per capita food

[10] Smill (2001) characterizes these developments as two stages in the evolution of food consumption patterns. The first is an "expansion" effect: increased energy supplies, with these extra calories coming from cheaper foodstuffs of vegetable origin. The second is a "substitution" effect: a shift in the consumption of foodstuffs with no major change in the overall energy supply from carbohydrate-rich staples to vegetable oils, livestock products and sugar.

consumption and preferences towards more livestock products by LMIC add to concerns regarding the sustainability of the global food and agricultural system, particularly when taking into account the above-mentioned expected population dynamics.

As mentioned above, a further topic of concern is the globally rising prevalence of overweight and obesity. While obesity varies widely across regions of the world, the problem is most severe in HIC but is worsening also in LMIC. This applies both to adults and children and adolescents (Figure 1.6). For instance, in Northern America, Europe and Oceania 28 percent of adults are classified as obese, compared with 7 percent in Asia and 11 percent in Africa. In Latin America and the Caribbean, roughly one-quarter of the adult population is currently considered obese (FAO, IFAD, UNICEF, WFP and WHO, 2017). Obesity can be attributed to increased consumption of foods that are high in energy, fats, added sugars or salt, and an inadequate intake of fruits, vegetables and dietary fibre. This aspect of the "nutrition transition" reflects rapid urbanization, the increased consumption of processed food, and more sedentary lifestyles (FAO, 2017a). At the same time, the incidence of diet-related non-communicable diseases is on the rise (GBD 2015 Risk Factors Collaborators, 2016; GBD 2016 DALYs and HALE Collaborators, 2017). Globally, 44 percent of adult diabetes cases, 23 percent of ischaemic heart disease and 7 to 41 percent of certain cancers are attributable to overweight and obesity.[11] The economic price of malnutrition is billions of dollars lost in productivity and health care costs (FAO, 2017a).

Figure 1.6 Prevalence of obesity among children and adults by region



Note: Regions are arranged into income groups as defined in WHO Global Health Observatory data (WHO, 2018). Children and adolescents are those between 5 and 18 years of age, adults are those aged 18 and above.

Source: WHO, 2018.

[11] Almost two-thirds of the world's population live in countries where overweight and obesity kill more people than underweight. Between 2000 and 2015, the prevalence of overweight among children under 5 years rose from 5.1 to 6.2 percent. If this trend continues, by 2025 the percentage of overweight, including obese, children under five will reach 11 percent, or 70 million. Childhood obesity increases the risk of early onset of obesity-related health complications, which were once thought to be only problems for adults. The early occurrence of these diseases can have serious consequences on children's future risk of non-communicable diseases (FAO, 2017a).

1.2 Food security amid persistent inequality and transformation of agrifood systems

Despite evident progress in reducing both the absolute number and the global percentage of undernourished people in recent decades (i.e. the prevalence of undernourishment – PoU), the objectives that the international community has set have so far barely been achieved, if at all. For example, the Millennium Development Goal to halve the 1990–1992 PoU by 2015 was hardly achieved at the global level. Furthermore, the 1996 World Food Summit goal to halve the number of undernourished by 2015 fell short of its target by around 265 million people. The significant achievements made in EAP (mainly China) were partially offset by very subpar progress in SAS and a deteriorating trend in SSA (FAO, IFAD and WFP, 2015a).

As of 2017, it is estimated that more than 820 million people, approximately one out of every nine people in the word, are still undernourished, as documented in the recent report *The State of Food Security and Nutrition in the World 2018* (FAO, IFAD UNICEF, WFP and WHO, 2018). Worse still, after a prolonged decline both the absolute number of undernourished and the PoU seem to be on the rise again, signalling a possible reversal of trends in global hunger.

If current trends continue, the outlook is not particularly promising. The most recent FAO projections provided in the report *Achieving Zero Hunger* (FAO, IFAD and WFP, 2015b) highlight that under a business as usual scenario, by 2030 more than 650 million people will be undernourished, of which almost 640 million will be living in LMIC (Figure 1.7). Under these assumptions, even the recently-established objective of eradicating hunger by 2030, set by the 2030 Agenda for Sustainable Development, will not be met (see Box 1). Globally, food systems produce enough food for everybody, but not everybody has enough purchasing power to obtain sufficient food. This gives rise to the most extreme form of inequality, that occurring between those who have access to enough food and those who are forced to go hungry.

BOX 1 Food and agriculture in the 2030 Agenda for Sustainable Development

On 25 September 2015, the 193 Member States of the United Nations adopted the 2030 Agenda for Sustainable Development, including 17 Sustainable Development Goals (SDGs).[a] One lesson from the Millennium Development Goals (MDGs) is that it is no longer possible to look at food, livelihoods and the management of natural resources separately. The fundamental connection between people and the planet, sustainable food, and agriculture are at the heart of the 2030 Agenda. Tied to the principle of leaving no one behind, the broad priorities of FAO in the 2030 Agenda are to:

- end poverty, hunger and malnutrition;
- enable sustainable development in agriculture, fisheries and forestry;
- respond to climate change.

The comprehensive vision of SDG2, which is to "End hunger, achieve food security and improved nutrition and promote sustainable agriculture," is mutually interlinked with several SDG targets, including those related to poverty eradication (SDG1), good health and well-being (SDG3), gender equality (SDG5), clean water and sanitation (SDG6), decent work and economic growth (SDG8), industry, innovation and infrastructure (SDG9), reduced inequalities (SDG10), responsible production and consumption (SDG12), climate action (SDG13), oceans and seas (SDG14), ecosystems, biodiversity and forests (SDG15), and peace, justice and strong institutions (SDG16).

A significant factor in the success of the SDGs will be new and effective ways of collecting data, monitoring targets and measuring progress. FAO, together with its valued partners, is the "custodian" of several indicators related to undernourishment, rural income, sustainable agriculture, biodiversity, land and water use and ownership, as well as fisheries and forests (FAO, 2017b).

Sustainable Development Goals and food and agriculture

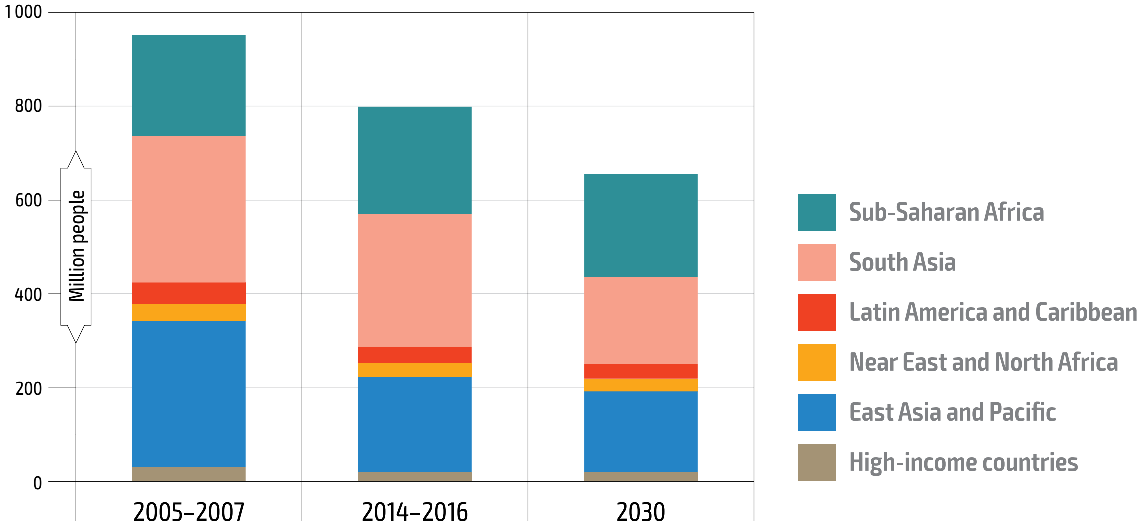
Source: FAO, 2017b.

[a] United Nations General Assembly, Resolution adopted by the General Assembly on 25 September 2015. Transforming our world: the 2030 Agenda for Sustainable Development.

The possibility of achieving food security targets is influenced by the level of inequality globally, which is to say levels *between countries*, and the levels among different layers of society, *within countries*.[12]

This is why *Achieving Zero Hunger* calls for a twin-track approach. Such an approach would merge investments in social protection to immediately raise the food consumption levels of the extremely poor with pro-poor investments in productive activities to sustainably increase the income-earning opportunities and purchasing power of poor people.[13] Implementing the message of *Achieving Zero Hunger* would therefore also result in important reductions of between-country and within-country inequalities.

Figure 1.7 Undernourishment under a business as usual scenario, 2005–2030



Source: FAO, 2017a, based on data from FAO, IFAD and WFP (2015a) for the periods 2005–2007 and 2014–16; and FAO, IFAD and WFP (2015b) for year 2030.

The substantial differences in per capita income levels between LMIC and HIC and large inequalities in within-country income distribution make it more difficult to achieve targets on food security and poverty reduction.[14]

In recent decades different growth patterns across regions have led to inequality in per capita income across countries. Despite the global drop in overall inequality observed

12 *Between-countries* inequality reflects different average per capita incomes across countries relative to total income globally, thereby contributing to determining the annual per capita food intake of each country *vis-à-vis* all the others. *Within-country* income inequality contributes to determining the purchasing power of households and individuals within a given country, thus reflecting inequality in access to food; in other words, how annual per capita food intake is distributed across a population. As we shall analyse further in Chapter 4, our calculation of the PoU shows that income distribution between countries influences the level of per capita income as well as Daily Energy Consumption (DEC) through food demand, i.e. per capita (average) energy consumption at country level. Income distribution within a country influences food distribution, reflected by the Coefficient of Variation (CV). See Annex III for more details on the calculation of the PoU.

13 Both measures are also expected to favourably influence nutrition. Social protection in particular directly contributes to the reduction of poverty, hunger and malnutrition by promoting income security and improving access to better nutrition, health care and education. By improving human capital and mitigating the impacts of shocks and crises, social protection also fosters the ability of poor people to participate in growth through employment creation (FAO, 2017a).

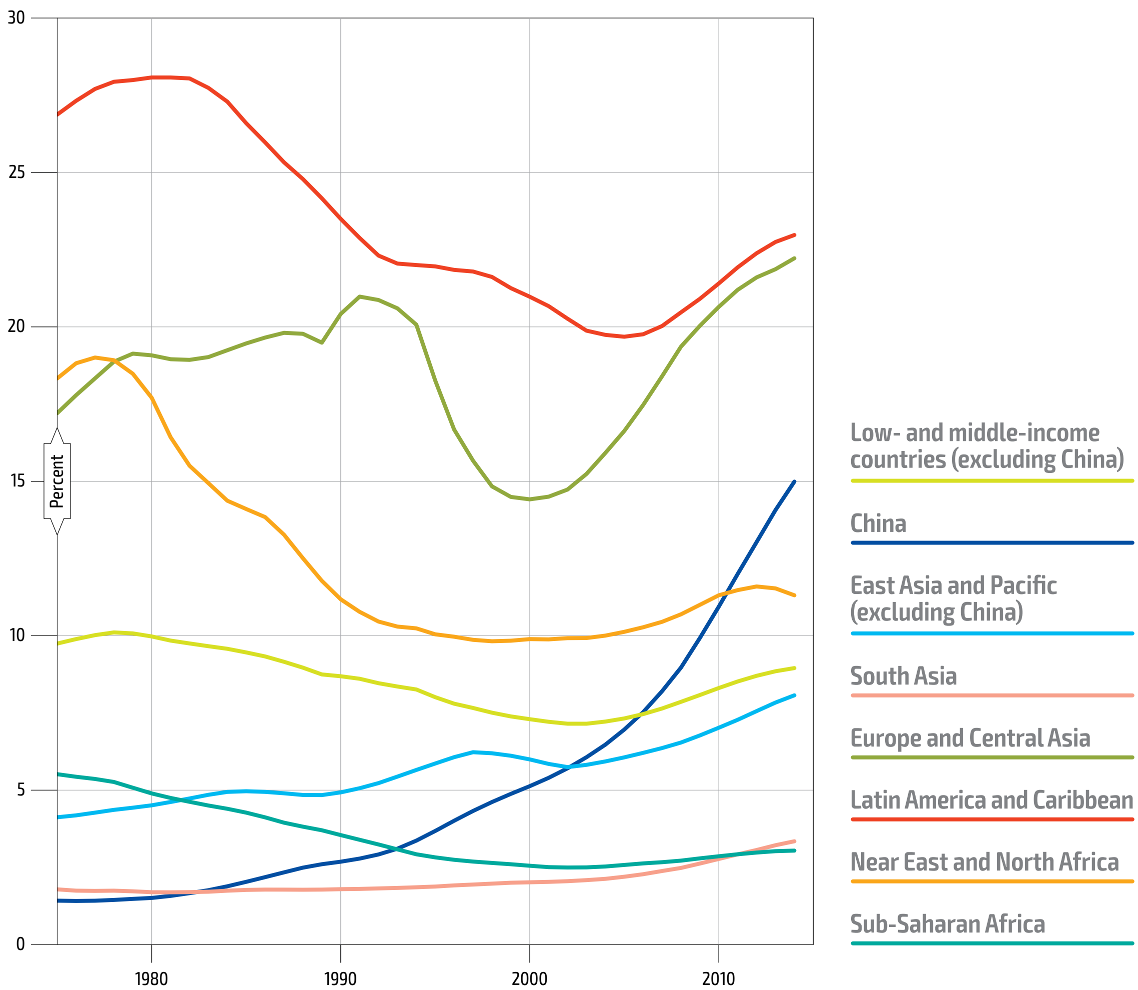
14 Other things being equal, the greater the inequality, the larger the amount of global income required to reduce the PoU, as LMIC have lower incomes and can therefore only afford lower DEC.

in recent years (World Bank, 2016), the gap between per capita income in LMIC and in HIC has not shrunk.

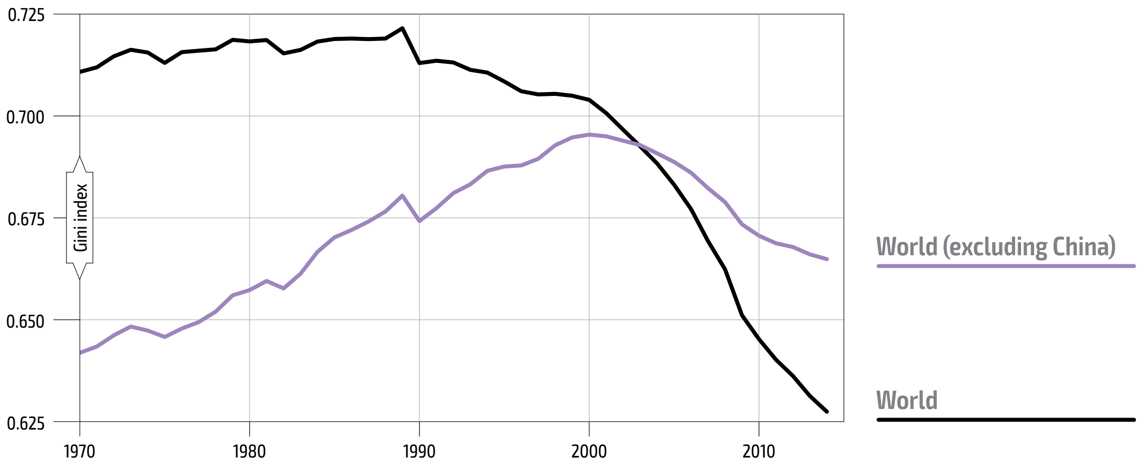
The figure below (Figure 1.8 a) shows the ratios of per capita income in LMIC (excluding China), China, SAS, and SSA relative to HIC. The ratio for LMIC (excluding China) ranged between 7 percent and 10 percent over the period 1970–2014, although overall it dropped from 9.5 percent in 1970 to 9 percent in 2014, signalling very limited or no convergence of incomes between the two groups of countries. The situation is particularly severe in SSA, where the ratio dropped over the same period from 7.7 percent to 4.2 percent, and in SAS where despite a steady increase of the ratio from a very low 2 percent in 1970, it was still below 4 percent in 2014. From 1970 to 2000, the cross-country Gini index, calculated with per capita income weighted by population by country, ranged above 0.70. This sets it closer to 1.0, representing maximum inequality of income distribution across countries, and far from 0.0 (a state of perfect equality). The Gini index dropped in the 2000s to reach 0.63 in 2012 (Figure 1.8 b), a dynamic largely explained by per capita income increases in China. The same index calculated without China shows a significant increase until 2000, and a more modest drop in recent years, down to 0.67 in 2012.

Figure 1.8 Per capita income inequalities across regions, 1970–2014

a) Per capita income in low- and middle-income countries as percentage of high-income countries



b) Cross-country per capita income Gini coefficient



Source: FAO Global Perspectives Studies, based on data from the UN, 2016.

At the current pace of convergence, very high per capita income differentials between HIC and LMIC could persist for many decades, unless effective action is taken towards a more equitable distribution of income, assets and opportunities.[15]

Persisting trends in other inequalities beyond those of per capita incomes – including access to resources such as land and water or the benefits that high-value resources such as oil and minerals generate – not only force people to live in a more unfair world, but also trigger conflicts that in turn can exacerbate extreme poverty and food insecurity. Indeed, the marked surge in the number of global conflicts observed during the last decade is a major driver of food insecurity and malnutrition (FAO, IFAD, UNICEF, WFP and WHO, 2017) and conflict-induced negative impacts on human welfare are no longer limited to specific regions.[16]

People whose livelihoods depend largely on agriculture, and who are politically excluded in very poor countries affected by adverse climatic events, appear to be particularly prone to conflict and violence. New research on the "climate-conflict nexus" has identified correlations between weak institutions, pre-existing social fragility and climate change vulnerability (FAO, IFAD, UNICEF, WFP and WHO, 2017; UN OCHA, 2016).[17]

Focusing on the future dynamics of income and food distribution and the degree of between- and within-country inequality are critical to understanding possible future patterns of food security, as well as extreme poverty. This is particularly true in light of ongoing transition processes in agriculture and rural areas, which to date have hosted a disproportionate share of extremely poor people.

15 It has been acknowledged that the objective of lifting people out of extreme poverty by 2030 will not be achieved without reducing inequality (World Bank, 2016). High inequality is impeding further poverty reduction, and thus far economic growth has not been sufficiently "pro-poor".

16 Rather, such impacts have become a global issue with the displacement of people and migration, such as in the case of the ongoing civil war in the Syrian Arab Republic. Conflicts, violence and natural disasters are among the root causes of migration and forced displacement. However, many migrants are forced to move because of socio-economic factors including poverty, food insecurity, a lack of employment opportunities, limited access to social protection, natural resource depletion, and the adverse impacts of environmental degradation and climate change.

17 Although the forward-looking analysis in this report does not explicitly take into account the risks of conflicts, distress and economic migration, it is developed with a focus on inequalities in income and food distribution to capture the degree of social sustainability of the alternative future scenarios and their food security outcomes.

Rural employment and incomes may critically reduce food insecurity going forward

Reducing poverty and food insecurity and improving nutrition outcomes cannot be achieved without increased employment and income. While food availability at the national level may be ensured by domestic production and imports (if required), households and individuals only have access to food if they can earn or are entitled to enough income to buy or produce enough to feed themselves (see Box 2).[18] Employment and earning opportunities are particularly lacking in agricultural and rural areas, where extreme poverty strikes most. The World Bank estimated that in 2010, 78 percent of extremely poor people were living in rural areas (Olinto *et al.*, 2013), a concentration that is common across regions, despite differences in overall poverty rates (FAO, 2015a). Across all LMIC, a person living in a rural area is almost three times more likely to live in extreme poverty than someone living in an urban area (World Bank, 2013). This relative deprivation among rural dwellers is reflected in a wide range of socio-economic welfare indicators. For example, child malnutrition (measured by the prevalence of underweight in children under five years of age) is worse in rural areas in virtually every country for which data are available (FAO, 2015a).

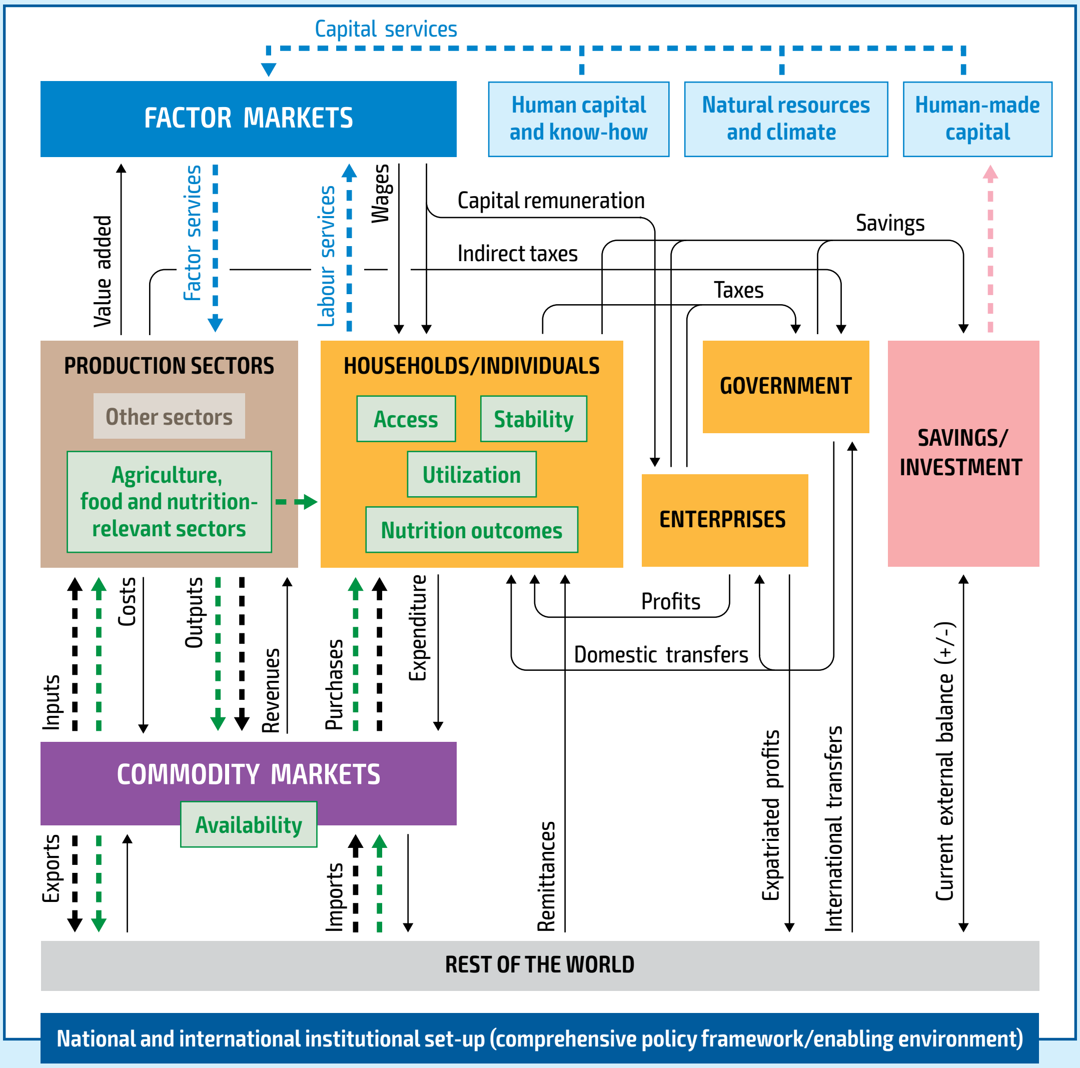
These disadvantages in rural areas are well understood in view of the almost worldwide process of structural transformation that has occurred over the past 30 years, which has led to a decrease of the relative contribution of agriculture to GDP. In many instances, this process has led to a reduction in the number of people engaged in agriculture, contributing significantly to urbanization (see Figure 1.9 a,b). At the same time, however, demographic dynamics are expected to result in a spike in the number of young people who will join the ranks of the labour force, particularly in rural areas. The pressure will be enormous for some regions, such as SSA and South Asia, where jobs are likely to be scarce. Without sufficient employment opportunities, this population trend may lead to faster rates of outmigration and urbanization, and possibly to conflicts (FAO, 2017a).

18 The analytical framework for food security and nutrition adopted in this report, as summarily portrayed in Box 2, highlights the links between economy-wide income and earning opportunities materializing through labour and capital markets, and food security and nutrition outcomes.

BOX 2 Food security and nutrition: the analytical framework

In economies where goods and services are exchanged on markets, food availability, access, stability, utilization and resulting nutritional outcomes all depend on complex interactions among diverse agents and institutions. These actors comprise households, governments, enterprises, production sectors, foreign investors and other agents within and outside of the food and agricultural system. This report considers these interactions directly and indirectly, both through quantitative modelling and qualitative assessments, to analyse the evolution of food and agricultural systems in an economy-wide system and their implications for food security and nutrition.

Food security and nutrition in the economy-wide context



Note: Physical flows of goods and services are represented by dashed lines, while income flows in monetary terms occurring in the opposite direction are represented by solid lines. Food security and nutrition-relevant flows and items are reported in green. Not all the flows of good and services and countervailing payments are represented.

Source: Adapted from Dervis, de Melo and Robinson, 1982.

In this framework, **food availability and stability at national level** is ensured by domestic production and/or the ability of the country to pay for imports. Both domestic production and imports (net of exports) flow into domestic markets. The same applies for *nutrition-relevant goods* (cookers, energy, cleaning products, storing facilities, medicines, products for personal hygiene, etc.) and *services* (health care, education, know-how for food utilization, etc.).[a]

Food access and stability at household level, as well as **access to nutrition-relevant goods and services** is ensured by income that provides households with the purchasing power to buy food on the market at prevailing market prices.[b] Income (value added) is distributed by the production sectors to households as remuneration of labour (wages) and capital services (profits, net of expatriated profits that remunerate foreign investors). Transfers from the government (such as pensions or social protection payments) and/or from citizens abroad (remittances from the "rest of the world") complement household income.[c]

The government collects taxes from the production sectors (indirect taxes, net of subsidies), households (income, consumption taxes) and enterprises (corporate taxes), as well as taxes on transactions with the rest of the world (e.g. import tariffs and taxes on exports). The government can influence food prices through sector-specific and international trade policies, while through social and fiscal policies (income taxes, transfers, provision of public services, social protection policies) it shifts the purchasing power of households up or down. The possibilities for a government to implement selected food security and nutrition-relevant policies depend on macroeconomic and institutional conditions, such as the state of the budget and/or efficiency of the fiscal system.

The specific socio-economic status of a household and its location (rural, urban or intermediate areas) contribute to determining its potential to achieve more or less positive nutrition outcomes, the earning opportunities for its members, as well as their food requirements, tastes and dietary patterns.

The capital assets required to run production activities, including food-related ones, are funded by the savings of households, enterprises, government and foreign investors. Human-made capital is complemented by the natural resource base, including land, water, biodiversity, climate, and non-material capital such as know-how. The possibility for a country to domestically produce food and nutrition-relevant goods and services, or to produce other goods and services in exchange, is largely determined by its capital assets. Macroeconomic policies and the institutional set-up of a country contribute to determining the saving-investment potential of households and enterprises. Through savings and investments, households accumulate capital and smooth their consumption patterns, ensuring stability of food *access and availability at household level*, thus reinforcing their long-term food *stability*.

The national and international institutional set-up and the quality of governance contribute to determining the overall food security and nutrition performance of a socio-economic system.

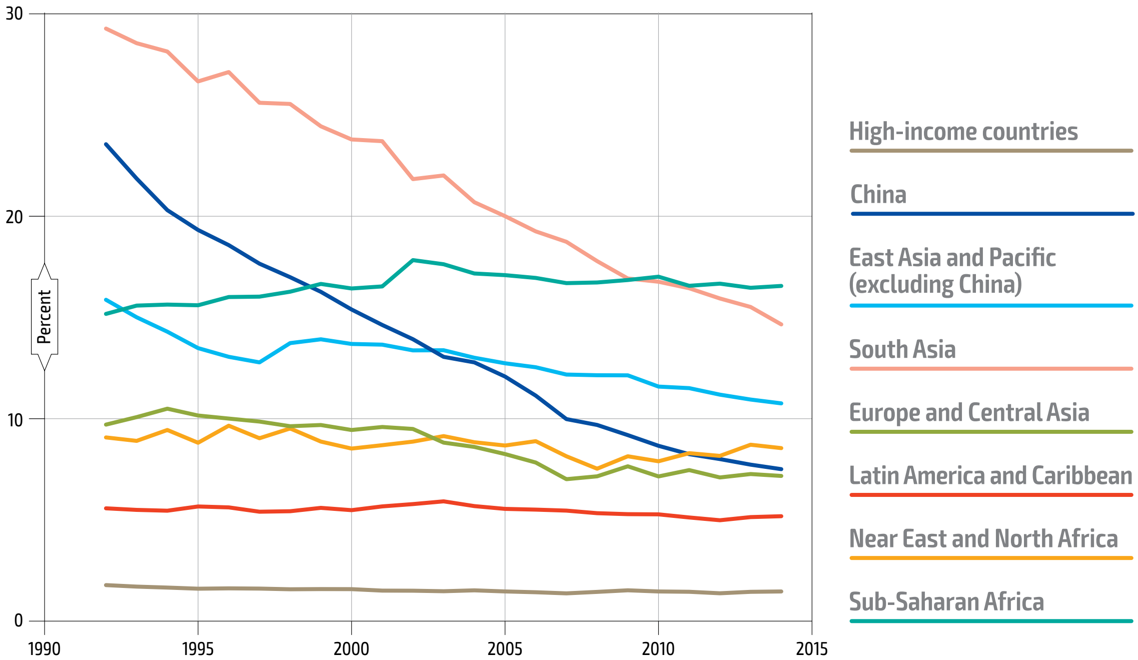
[a] In the case of self-production, food flows directly from the agriculture sector to households without transiting through markets. The possibility for a country to import food and nutrition-relevant goods and services is constrained by its external balance, which in turn is determined by the capacities to export, the capacity to borrow from abroad and/or benefit from other foreign flows such as international transfers, grants and remittances.

[b] In case of food self-consumption, access is ensured by the possibility to buy food and tradable inputs, access to land and water and the availability of agricultural labour.

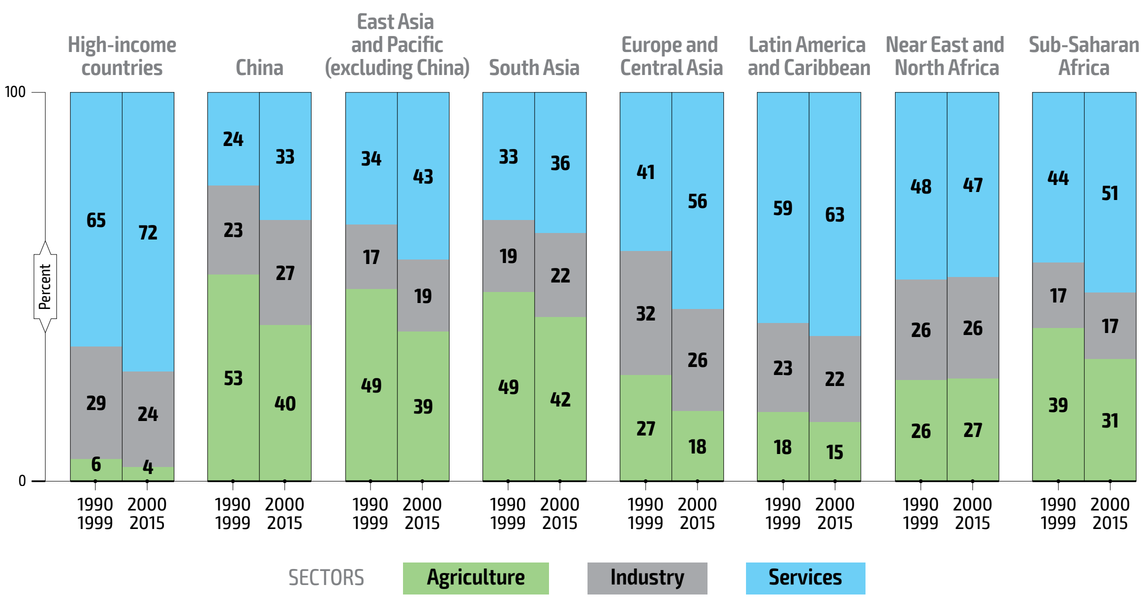
[c] This framework reflects in a simplified way the United Nations System of National Accounts (UN, 2016).

Figure 1.9 Share of agriculture, fisheries and forestry in the total economy

a) Value added in total gross domestic product by region



b) Sectoral employment shares, 1990–2010



Note: The share of agriculture, fishery and forestry value-added in total GDP by region is calculated by dividing the sum of the value-added in USD at constant 2012 prices across countries belonging to the specific region by the sum of the GDP for the same countries at constant 2012 prices.

Sources: FAO Global Perspective Studies based on UN, 2016 for value added and GDP; and FAO, 2017a for employment shares.

Employment prospects in rural areas and their impact on the welfare of rural people should also be seen in the light of transformations occurring in the food system. Food value chains are increasingly characterized by vertical coordination – or integration – of input supply, primary production, processing and distribution, automation of large-scale processing, and higher capital and knowledge intensities. Food-value chains have lengthened dramatically as the physical distance from farm to final consumption has increased. Furthermore, the consumption of processed, packaged and prepared foods has increased in all but the most isolated rural communities (FAO, 2017a).[19]

The transformation of agrifood chains may create barriers for family farmers

These developments have implications in a number of areas, including the allocation and use of natural resources, labour, land and capital. The transformation of agrifood chains in LMIC offer new employment opportunities, particularly downstream, in processing, packaging and transporting phases, as well as in wholesale and retail activities. In many cases, however, transformation has also created barriers to the participation of family farmers and small-scale agro-processors in local, national and global markets.[20] Emerging agrifood chains often require standardized agricultural products in terms of quality, size, delivery time, and so forth. In many instances, standardized products can be more efficiently produced by more capital-intensive commercial farms. They require less labour per unit of product than the traditional ones (Neven *et al.*, 2009). Whether the creation of new jobs in downstream segments of agrifood chains will exceed the reduction of employment associated with the commercialization of primary agriculture, with a net positive employment effect, depends on market and country-specific circumstances. In any case, barriers to family farmers' access to supermarket channels, combined with reduced labour requirements in primary agriculture, may undermine their livelihoods if they do not manage to participate in new downstream agrifood activities or diversify into other rural off-farm activities. This could ultimately hinder rural transformation.[21]

Fewer agents are progressively supplying increasing market shares of inputs

As already highlighted more than ten years ago, "concentration in agricultural biotechnology is giving the largest corporations unprecedented power *vis-à-vis* growers and other stakeholders" (UNCTAD, 2006).[22] In recent years, further concentration in the seed industry has occurred, with the ten largest companies covering more than 65 percent of the seed market (Wesseler *et al.*, 2015).[23]

[19] "Vertical coordination" involves establishing some form of contractual relationship between the agents in subsequent segments of the value chain – such as marketing and production contracts. Marketing contracts are agreements between a contractor and a grower that specify some form of price (system) and outlet *ex ante*. Production contracts are more extensive forms of coordination and include detailed production practices, extension services, inputs supplied by the contractor, and the quality and quantity of a commodity and a price. The upper limit of "vertical coordination" is "integration," which involves the unique ownership of two subsequent segments.

[20] Changes in retail channels are triggering significant impacts upstream in the value chain. Supermarkets require standardized, industrially-processed food, which implies the creation of large-scale automated food processing plants that require the standardization of agricultural output, which in many cases has implied the concentration of primary production and the consolidation of farmland.

[21] Labour mobility and young people's unwillingness to remain in the sector lead to increases in the average age of farmers, as well as stagnant or lower yields and productivity. In many cases, regardless of the type of sectoral transition, unequal distribution of resources, especially capital, can result in less efficient outcomes and occasionally in social tension.

[22] "In particular, the privatization and patenting of agricultural innovation (gene traits, transformation technologies, and seed germplasm) have supplanted traditional agricultural understandings on seed and on farmers' rights, such as the right to save and replant seeds harvested from the former crop" (UNCTAD, 2006).

[23] A precise estimate of the worldwide number of seed companies is difficult to get. For instance, Bonny (2017) reports a worldwide total number of approximately 7 500. Wessler *et al.*(2015) report 6 794 companies in 2010 only in Europe, although the authors raise doubts about the actual functioning of them all.

The concentration of the agriculture input sector has been further exacerbated by recent mergers, which raise concerns for competition in agricultural input markets.[24] In addition, a merger that would create the world's largest integrated pesticides and seeds company, has raised "concerns that the proposed acquisition could reduce competition in a number of different markets, resulting in higher prices, lower quality, less choice and less innovation" (European Commission, 2017c).

The speed, modalities and directions of economy-wide structural transformation and the changes affecting the agricultural sector are specific to each country and region.[25] However, in all regions future access to sufficient and adequate food for poor people currently living in rural areas will depend on the impact of such transformations on poor people's earning and employment opportunities, within and outside the agricultural sectors.

1.3 Binding natural resource constraints and insufficient investment

Agricultural production more than tripled between 1960 and 2015, owing in part to productivity-enhancing Green Revolution technologies and a significant expansion in the use of land, water and other natural resources for agricultural purposes. The same period witnessed remarkable increases in the industrialization and globalization of food and agriculture (FAO, 2017a). Even though agriculture at the global level has become more efficient, expanding food production and economic growth have often come at the cost of the natural environment. In fact, almost half of the forests that once covered the planet are now gone, groundwater sources are increasingly under pressure, biodiversity has been severely eroded and bodies of water and groundwater have been polluted with nitrates, herbicides and pesticides. Every year, the burning of fossil fuels emits billions of tonnes of GHG emissions into the atmosphere, leading to global warming and climate change (FAO, 2017a).

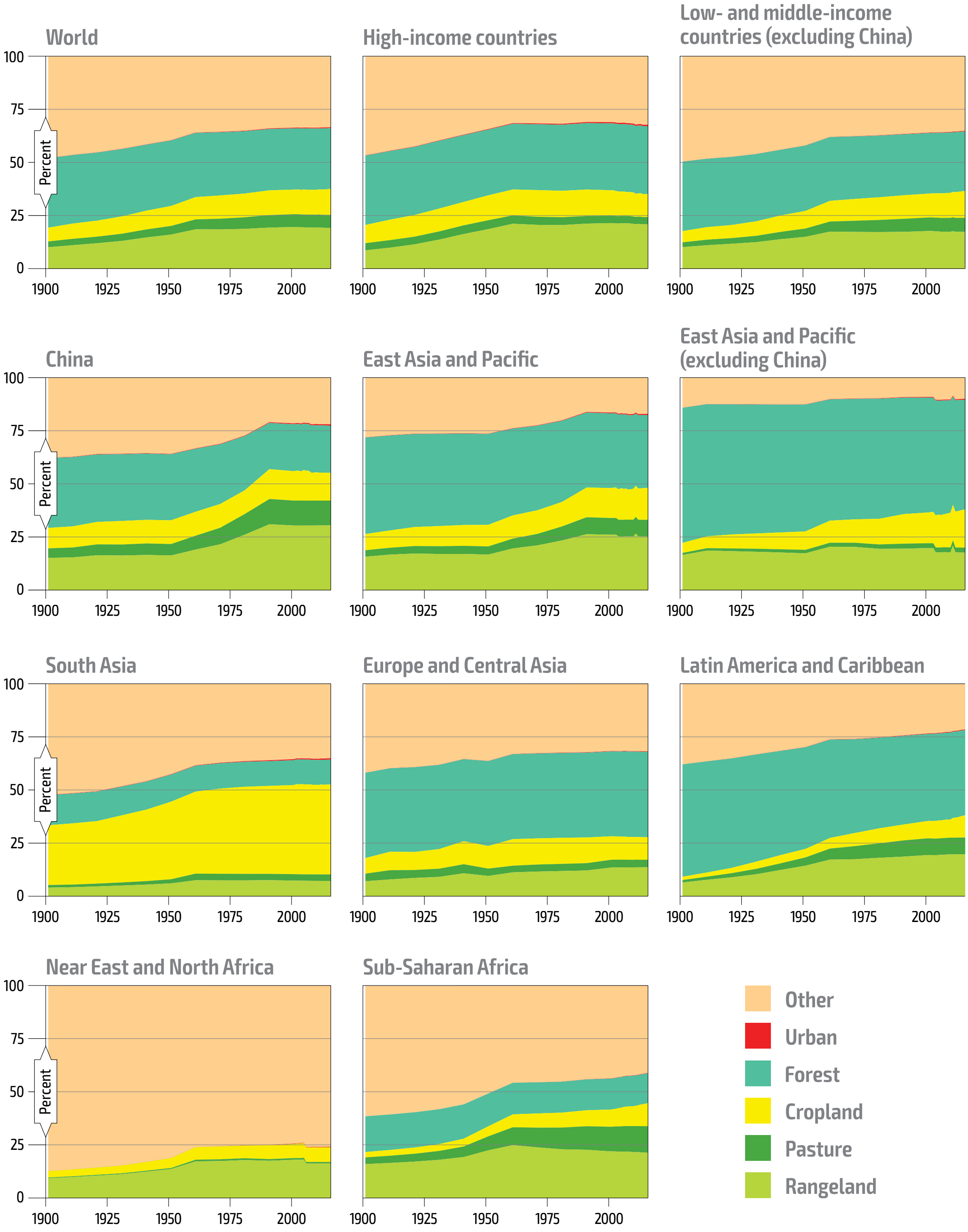
Paradoxically, some efforts aimed at reducing GHG emissions have led to more rampant competition for land and water resources. This is the case where countries have moved towards the production of resource-intensive bioenergy instead of choosing other available – and more sustainable – energy sources. The demand for cereals, oilseeds and sugarcane to produce biofuels has risen, as has the use of biomass as a substitute for petrochemicals. Greater competition between food and non-food uses of biomass has intensified the interdependence between food, feed and energy markets. For example, around two-thirds of bioenergy used worldwide involves the traditional burning of wood and other biomass for cooking and heating, much of which is unsustainably produced and inefficiently burned (FAO, 2017a). In almost all regions apart from HIC (see Figure 1.10), there were marked increases in global agricultural land (crop, pasture and rangeland) over the last decades of the twentieth century. However, when compared with trends in the first half of the last century, this growth has slowed down globally in recent decades, limiting the loss in forest areas (Table 1.1). Gains in forest areas were nonetheless limited

[24] Two mergers were approved by the EU's anti-trust regulator, albeit under the condition that some activities be sold to a third party (European Commission, 2017 a,b).

[25] All of these changes depend on initial conditions, demographic trends (population growth, urbanization, spikes in the youth age bracket, ageing and migration), geography, natural resource constraints, competition for water, land and forest resources, environmental threats, agricultural labour shortages and surpluses, changing dietary patterns, and policies and strategies. Indeed, agricultural policies play an important role in pro-poor growth and could support boosting productivity and profitability in a number of ways (e.g. by providing efficient extension and advisory agricultural services, improving coordination along value chains, and ensuring that the weaker segments in the chain reap the benefits of integrating agriculture into markets).

to boreal and temperate zones, where the area devoted to agriculture has declined. In tropical and subtropical regions, annual forest losses still amounted to 7 million ha between 2000 and 2010, while agricultural area expanded in the same period by 6 million ha per year (FAO, 2015b). Low-income countries experienced both the largest annual net loss of forest area and an annual net gain in agricultural areas.

Figure 1.10 Land by use: percentage in total land, 1901–2015



Note: The share of the total world land by region is the following: HIC 26, LMIC 74, China 7, EAP ex China 5, SAS 4, ECA 17, LAC 15, NNA 7 and SSA 19.

Sources: Hurtt *et al.* (forthcoming). Data downloaded from the Land-use harmonization website, available at http://luh.umd.edu. Accessed October 2017.

Table 1.1 Global land by use and land-use change

	million hectares			2015 = 100		percent	
	AREA			INDEX		MEAN ANNUAL GROWTH RATE	
LAND-USE	1901	1961	2015	1901	1961	1901–1961	1962–2015
Urban	8	20	54	16	38	1.46	1.79
Other	6 131	4 587	4 269	144	107	-0.47	-0.13
Forest	4 193	3 878	3 676	114	106	-0.13	-0.10
Cropland	829	1 345	1 557	53	86	0.80	0.27
Pasture	349	598	786	44	76	0.89	0.50
Rangeland	1 297	2 379	2 465	53	96	1.00	0.07

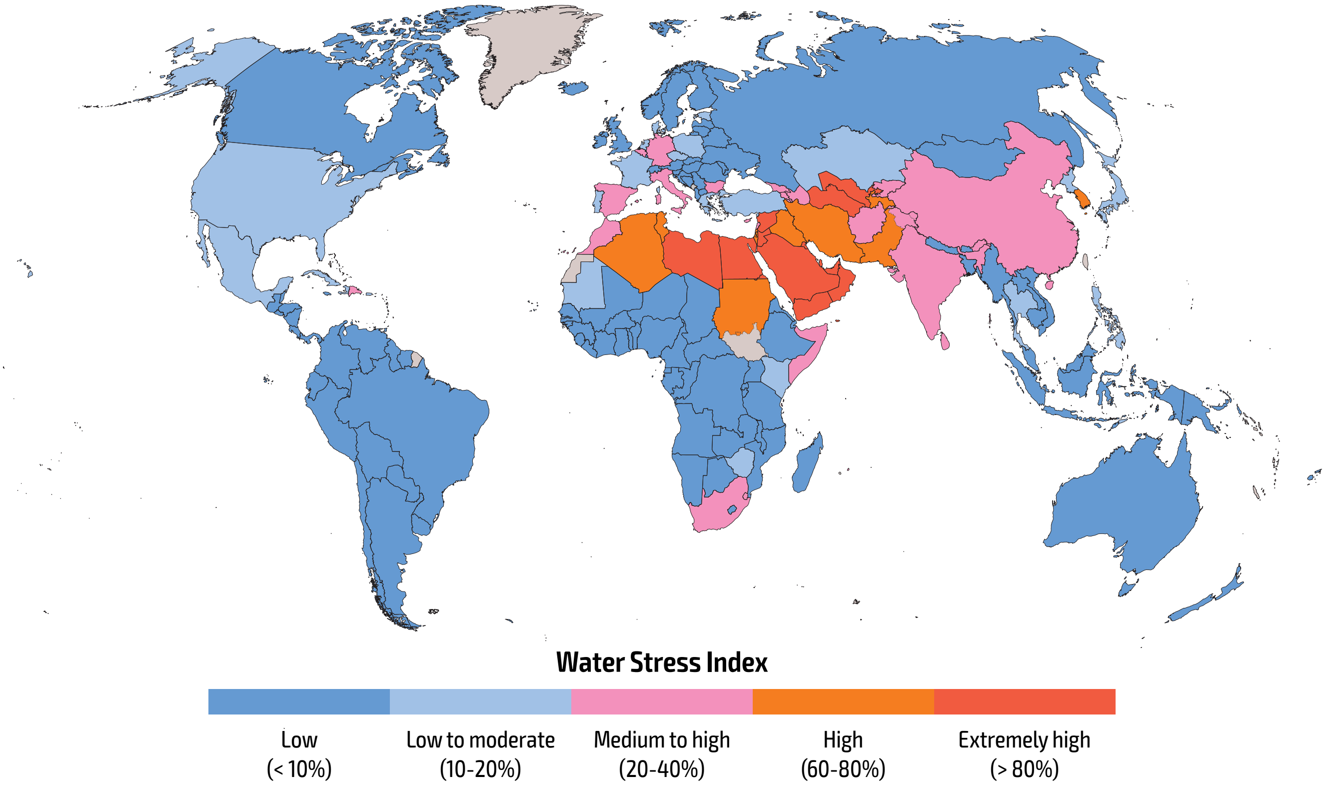
Sources: Hurtt *et al.* (forthcoming). Data downloaded from the Land-use harmonization website, available at http://luh.umd.edu. Accessed October 2017.

World's farmland is being degraded, water resources are under stress

Approximately one-third of the world's farmland is moderately to highly degraded (FAO, 2017a). This degradation particularly affects dryland areas and negatively impacts the quality of local inhabitants' livelihoods as well as the long-term health of ecosystems. Globally, there are few opportunities left for further expanding agricultural areas. Moreover, much of the available land is not suitable for agriculture, and using it for agricultural production would incur heavy environmental, social and economic costs (FAO, 2014).

Industry, households, and agriculture are the main consumers of water, with agriculture alone being responsible for 70 percent of all water withdrawals. In many low-rainfall areas of the Near East, North Africa and Central Asia, as well as in India and China, farmers use much of the available water resources, resulting in the serious depletion of rivers and aquifers (see Figure 1.11). In some of these areas, 80 percent to 90 percent of water is used for agricultural purposes. In this context, FAO estimates that over 40 percent of the world's rural population lives in river basins that are classified as water-scarce (FAO, 2011a). Due to water scarcity, the rate of expansion of land under irrigation is slowing substantially in these areas.

Figure 1.11 **Freshwater withdrawals as a percentage of total renewable water resources**



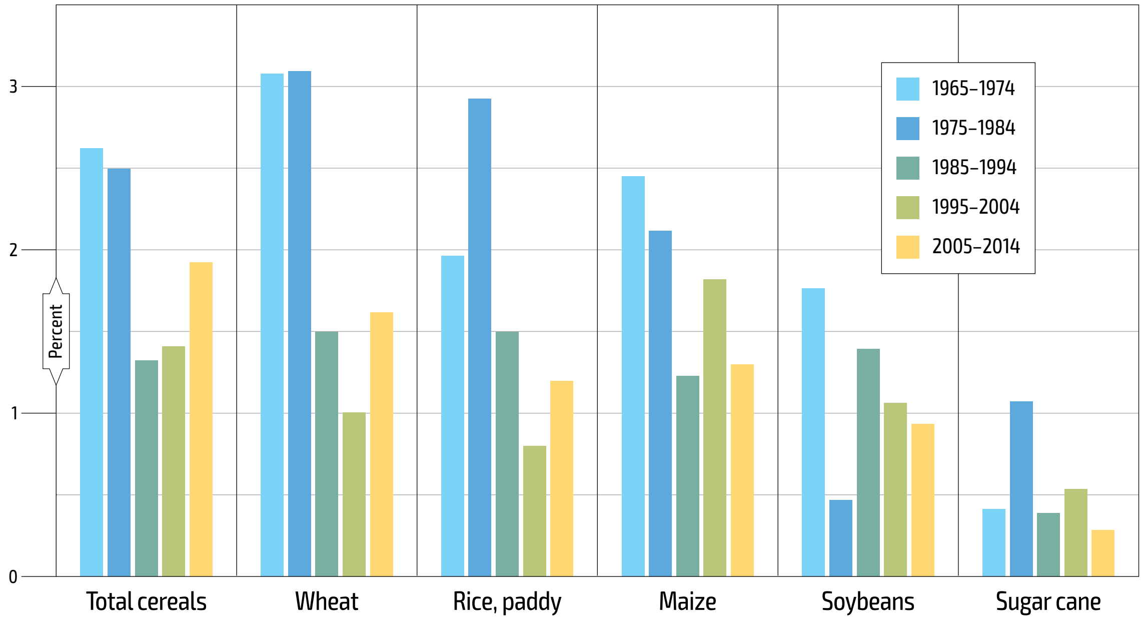
Note: Countries are considered water-stressed if they withdraw more than 25 percent of their renewable freshwater resources. The countries approach physical water scarcity when more than 60 percent of their water is withdrawn, and face severe physical water scarcity when more than 75 percent is withdrawn.

Source: FAO Global Perspectives Studies, based on FAO AQUASTAT (various years).

Higher yields are needed but yield growth has slowed

Given these limitations in land and water resources, it is likely that the additional amounts of food needed in the coming decades will have to be produced mainly through yield increases, rather than through major expansions in cultivated areas. Unfortunately, since the 1990s average annual increases in the yields of maize, rice and wheat at the global level have reached just over 1 percent (much lower than in the 1960s), while those of soybeans and sugarcane were below 1 percent (FAO, 2017a). In the last 20 years, yield growth has slowed (see Figure 1.12), with recent studies even suggesting that in selected regions yields are already close to their maximum potential (Grassini, Eskridge and Cassman, 2013; Lin and Huybers, 2012; Liu, Pan and Li, 2015).

Figure 1.12 Average annual growth rates for selected crop yields



Note: Growth rates are estimated using the ordinary least squares regression of the natural logarithm of crop yields on time and a constant term. The commodity group "Cereals (total)" is from FAOSTAT and includes the following: wheat, rice (paddy), barley, rye oats, millet, sorghum, buckwheat, quinoa, fonio, triticale, canary seed, as well as grains and mixed cereals not specified elsewhere.

Source: FAO, 2017a.

In addition, despite increased efficiency in recent decades, in the animal production sector there has been an alarming increase in the number of outbreaks of transboundary pests and animal diseases. Together with increasing antimicrobial resistance, this jeopardizes the food security of affected areas and has broader economic, social and environmental impacts as well.[26]

Resource conservation agricultural practices, such as organic agriculture, conservation agriculture, climate-smart agriculture, agroforestry and agro-ecology, may help stabilize or even boost agricultural productivity in the long run. However, research and investment are needed to adapt such technologies to local contexts and render them suitable for family farmers.

Agricultural performance and sustainability will not improve without more investment, particularly in LMIC

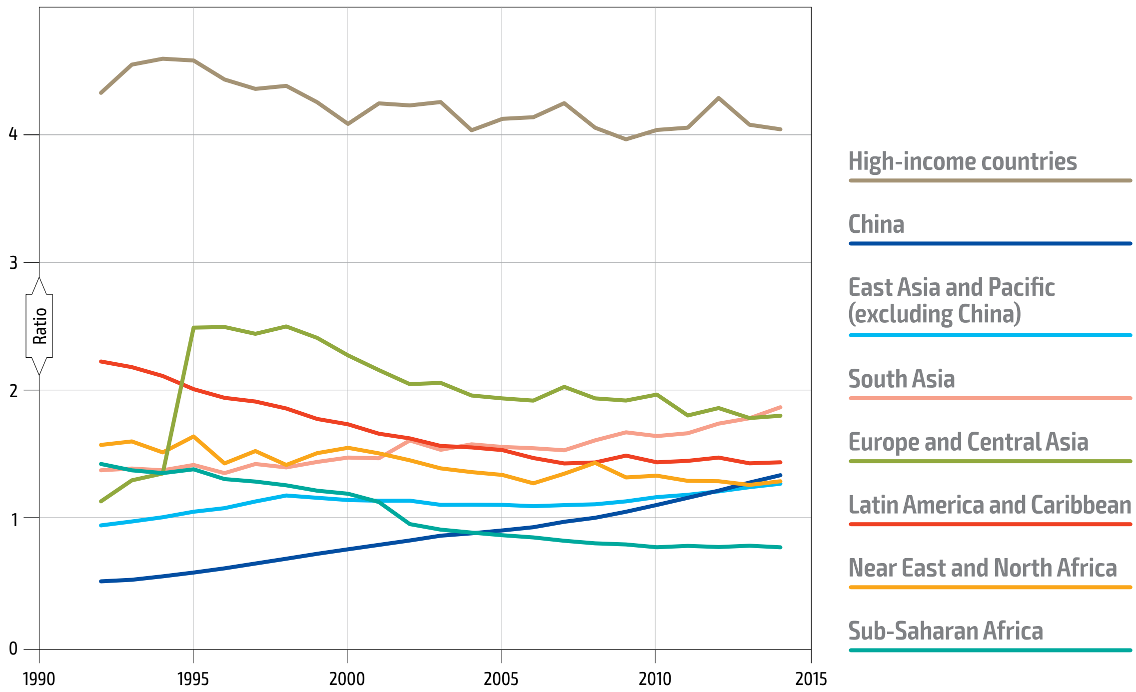
Additional investments in agriculture may contribute to overcoming the limitations of natural resources, while matching increasing food and agricultural demand and reducing food losses. To date, in absolute terms, LMIC have invested in agriculture almost as much as HIC – around USD 190 billion in both cases. However, agriculture in HIC is significantly

[26] Bovine spongiform encephalopathy (foot-and-mouth disease), highly pathogenic avian influenza and swine flu are examples of recent pandemics. The spread of such outbreaks in wider geographic locations is increasing as more people, animals, plants and agricultural products move within and between countries and production systems become more intensive (FAO, 2017a). The potential impact of animal diseases on human health is further magnified by increasing levels of resistance in bacteria, parasites, viruses and fungi to antimicrobial drugs such as antibiotics, antifungals, antivirals, antimalarials and anthelmintics. Antimicrobial resistances are spreading globally, undermining the ability to treat common infectious diseases and resulting in prolonged illness, disability and death (O'Neill, 2016). Changing climatic conditions are meanwhile creating a better environment for diseases to thrive in (see for example Kilpatrick and Randolph, 2012; de la Rocque *et al.*, 2011; Avelino *et al.*, 2014; Bebber, Ramotowski and Gurr, 2013).

more capital-intensive: it requires four units of capital to generate one unit of value added, whereas LMIC need only around 1.5 units of capital because their agriculture is more labour intensive (see Figure 1.13).

In EAP (including China), SAS, ECA, the capital-intensity of agricultural production is on the rise. This increase may indicate a possible convergence towards the type of agriculture found in HIC, with capital progressively replacing other inputs and factors, particularly labour. In fact, the share of labour employed in agriculture in these regions is shrinking. In contrast, in the Near East and North Africa (NNA), SSA, and LAC, capital intensity has fallen (Figure 1.13).[27]

Figure 1.13 Agricultural net capital-output (value added) ratio, 1990–2015



Note: The agricultural capital-output ratio is defined as the value of the net capital stock in agriculture per unit of agricultural value added.

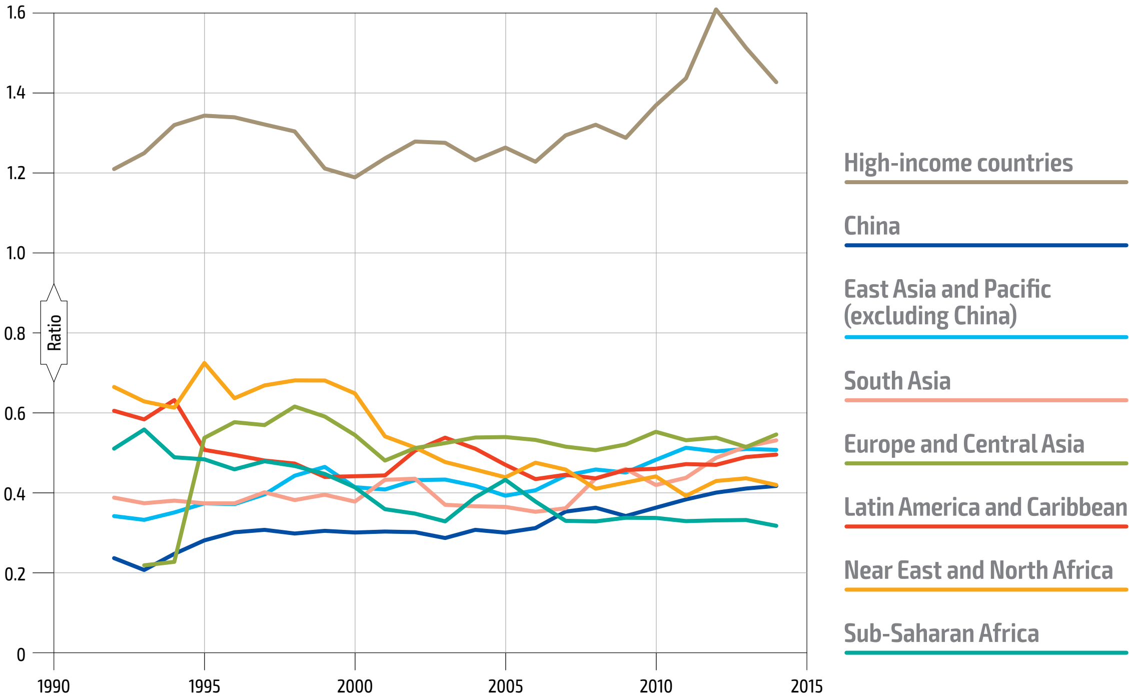
Source: FAO, 2017a.

The share of agricultural investment in total investment compared with the share of agricultural value added in GDP (i.e. the "agricultural investment orientation ratio") reveals important structural and dynamic differences across groups of countries. First, in recent decades only in HIC has the agricultural investment share been systematically larger than the agricultural value added share, meaning the agricultural investment orientation ratio has remained consistently above 1 (see Figure 1.14). Meanwhile the ratio is much lower in LMIC, at around 0.4. Second, diverging patterns across regions have

[27] The capacities of people and countries – particularly LMIC – to invest in agriculture is a key factor for determining the evolution of food systems. The persistent income inequalities highlighted above not only slow down the achievement of food security targets established in the 2030 agenda, but determine huge differences in asset ownership, which is already extremely polarized. According to Oxfam, in 2016, just eight individuals possessed the same wealth as the bottom half of the world's population (Oxfam, 2017), and the World Bank highlights that polarization is even more extreme in Africa (World Bank, 2016). Inequalities in asset ownership may in turn feed future income inequalities, particularly if poor people are not granted opportunities to earn decent incomes, save and invest.

developed in the past two decades: while the investment orientation ratio is increasing in HIC, China, EAP (excluding China), SAS and ECA, it is on the contrary decreasing in NNA, SSA, and, to some extent, LAC. The reduced investment impinges on agricultural productivity growth in LMIC, specifically in SSA and SAS and contributes to maintain the productivity gap with HIC (USDA ERS, 2018).

Figure 1.14 Agricultural investment orientation ratio by region, 1990–2015



Note: The agricultural investment orientation ratio is defined here as the ratio of the share of gross fixed capital formation in agriculture in total gross fixed capital formation over the share of agricultural value added in total GDP.

Source: FAO, 2017a.

Limited investment in LMIC agriculture is a worrying sign

The extent, quality and timeliness of investment, including in research and development (R&D), will influence various countries' agricultural performance, their ability to adapt to climate change, their innovative potential along a sustainability pattern, and the extent of cross-country convergence of yields, employment and income-generation potential. The currently limited level of investment in agriculture in LMIC is a worrying sign, particularly considering that there are significant yield gaps with respect to HIC, and that almost all private research takes place in HIC (FAO, 2017a). Moreover, decreasing growth rates of global crop yields (Figure 1.12), land degradation and water overuse, as well as increasing levels of crop and animal diseases and growing antimicrobial resistance, all raise concerns and call for more investment in agriculture.[28]

[28] "Investments in agriculture, fishery and forestry, and spending on research and development need to be stepped up, particularly in and for low-income countries. This is required to promote the adoption of sustainable production systems and practices, including integrated crop-livestock and aquaculture-crop systems, conservation agriculture, agroforestry, nutrition-sensitive agriculture, sustainable forest management and sustainable fisheries management" (FAO, 2017a).

1.4 Climate change challenges for all dimensions of food and agriculture

Climate change will critically determine the future state of natural resources, as well as the future conditions of and constraints to agricultural production, thereby affecting food availability and the stability of food supplies.[29] In addition, as climate change affects countries and sectors differently, it will change the distribution of income, natural resource endowments and earning opportunities. This is likely to impinge on access to safe food and nutrition-related goods and services, including health, education and social services, thus raising concerns over food access, utilization and nutritional outcomes. In fact, different social groups and countries display varying degrees of vulnerability to climate change, depending on their exposure to climate variation (changing temperatures, rainfall levels, etc.), the sensitivity of their livelihoods to climate change (percentage of income or GDP made up of agriculture, forestry or fishing), and their adaptation capacity (proximity to flood plains, length of coast line, etc.) (van Vuuren *et al.*, 2012).

One direct impact of climate change on agriculture is that it jeopardizes crop. A meta-analysis of 1 090 studies (primarily on wheat, maize, rice and soybeans) under different climate change conditions indicates that climate change may significantly reduce yields in the long run (Porter *et al.*, 2014). Further analysis found quite distinct patterns for LMIC in tropical areas and for HIC in temperate zones (FAO, 2016a). For the former, most studies estimate negative crop yield impacts, while for the latter positive impacts.[30] A further negative outcome is that the elevated levels of carbon dioxide in the atmosphere that are likely by 2050 are associated with substantial declines in the zinc, iron and protein content of staple crops such as wheat, rice, field peas and soybeans (FAO, 2016a).

Furthermore, climate change is already affecting the aquatic environment, for example through changes in sea-surface temperature, ocean circulation, waves and storm systems, salinity content, oxygen concentration and acidification. This will all have an impact on global – and particularly regional – fisheries. Specifically, a background study for the last IPCC assessment report of 2014 (IPCC, 2013) stated with a high degree of confidence that in low-latitude regions, temperature increases of 3 °C will cause local extinctions of some fish species at the edges of their ranges.[31] Higher levels of carbon dioxide in the atmosphere are also making the oceans more acidic, negatively impacting on important aquaculture species.[32] These changes can all have a major impact on local fisheries, with consequent effects on food security. Moreover, extreme weather events and sea level rises are anticipated to impact fisheries-related infrastructure such as ports and fleets,

[29] In this report, climate change can refer to changes in weather, climate variability or climate change itself. These three phenomena operate on different time scales but are all related to the way the climate changes. Weather includes current atmospheric conditions such as rainfall, temperature, and wind speed, which occur at a particular place and over hours, days or months. Climate variability occurs over longer time spans, say years or decades. This includes, for example, El Niño which on a regular basis causes a reversal of wind patterns across the Pacific, drought in Australasia, and unseasonal heavy rain in South America. Climate is the average pattern of weather for a particular place over several decades.

[30] Further to the direct impacts on crop yields, climate change will disrupt complex interactions among species, potentially affecting ecosystem services such as pollination and the control of crop pests by natural predators. Plant and animal pests and diseases may spread to areas where they were previously unknown, but important knowledge gaps remain in this area (Porter *et al.*, 2014).

[31] Impacts occur as a result of both gradual atmospheric warming and associated physical changes (sea-surface temperature, ocean circulation, waves and storm systems) and chemical changes (salinity content, oxygen concentration and acidification) in the aquatic environment.

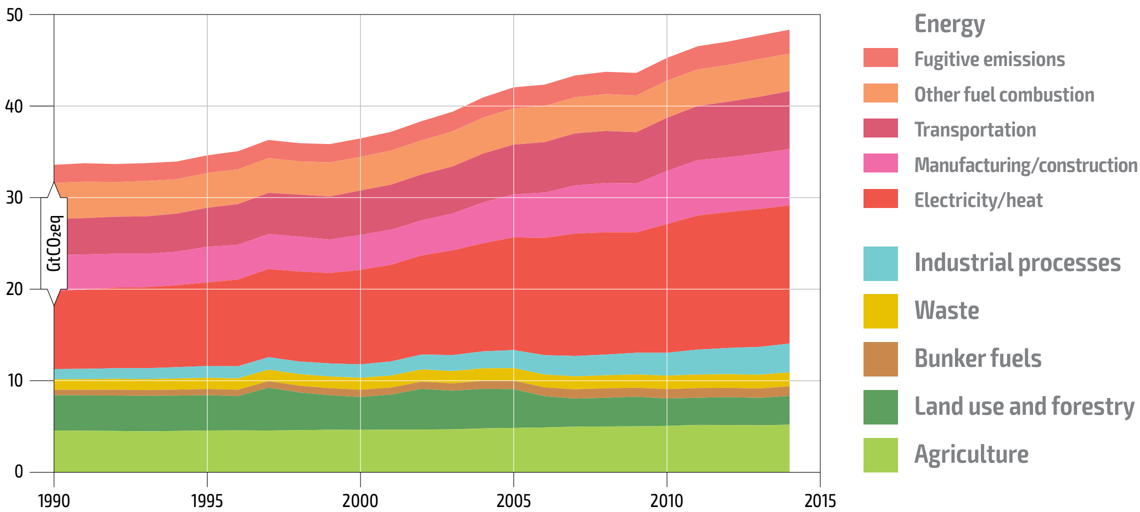
[32] Acidity will reduce the ability of selected species (e.g. mussels, clams and oysters) to form and maintain shells or increase the metabolic cost of shell production and slow down or even prevent the growth of coral reefs, which provide an important habitat for fish.

further raising the costs of fishing, processing, and distribution activities (OECD and FAO, 2016). The impacts of climate change are also expected to affect aquaculture, including through the gradual warming and acidification of seawater, sea level rises and resultant salt water intrusion, as well as through extreme events such as changes in the frequency, intensity and location of storms.

Higher temperatures and less reliable supplies of fresh water are also expected to create severe hardships for small-scale livestock producers, particularly in arid and semi-arid grassland and rangeland ecosystems at low latitudes (Hoffman and Vogel, 2008). Furthermore, higher temperatures and water scarcity will have a direct impact on animal health and reduce the quality and supply of feed and fodder (FAO, 2009).

To a large extent, human-induced climate change is generated by GHG emissions. Since 2005, GHG emissions have broadly approximated levels projected for the most severe climate change scenario considered by the Intergovernmental Panel on Climate Change. According to the IPCC's 2014 assessment report, anthropogenic emissions of GHGs are now at the highest levels in history (Porter *et al.*, 2014) (see Figure 1.15).

Figure 1.15 Annual greenhouse gas emissions by sector, 1990–2014



Note: "Bunker fuels" refers to emissions from international aviation and maritime transport. "Other fuel combustion" includes biomass combustion, and stationary and mobile sources. "Fugitive emissions" refers to flaring of gas and emissions from coal mining. "Waste" includes emissions from landfills, wastewater treatment, human sewage and other waste.

Source: WRI, 2014.

Food and agriculture are impacted by and contribute to climate change

The food and agricultural sectors will not only be impacted by climate change, they are also among its main contributors. Although GHG emissions resulting from agriculture, forestry and other land-use (AFOLU) have almost stabilized over the past 25 years, the agricultural sector still produces close to 20 percent of total global GHG emissions (see Figure 1.15). And although forests help to mitigate climate change by removing GHG from the atmosphere through biomass growth, they can only do so much.[33]

[33] The removal of GHG by forests has fallen from 2.8 Gt annually in the 1990s to an estimated 1.8 Gt in 2014 (FAO, 2016a). The decline is believed to be linked to increasing variability in climate and atmospheric composition.

Most of agriculture's methane emissions are produced by rice cultivation and enteric fermentation during the digestive processes of ruminant animals. The nitrous oxide emissions originate mainly from the application of nitrogen-based fertilizers for food and feed production and animal manure management, while carbon dioxide is released from the clearing of forests for cropland and pasture (Gerber *et al.*, 2013; FAO, 2016a).[34]

The wide range of emission factors across countries and regions suggests that there is potential to lower GHG from food and agricultural sectors. This implies jointly examining the overall impacts of the agrifood sector, which includes food and feed demand, food loss and waste, other uses of agricultural outputs (fibres, biofuels, etc.), water usage and its effects on soil health, ecosystem services and biodiversity. For instance, there is a growing recognition that diets rich in meat – particularly ruminants such as cattle – are associated with both higher environmental costs and higher GHG emissions. National dietary guidelines recommending lower red meat consumption, particularly to consumers largely exceeding recommended dietary intakes, could significantly help to reduce GHG emissions (IFPRI, 2015). Also, it is estimated that emissions from the livestock sector could be reduced by at least 30 percent if producers adopted the practices applied by those with the lowest emission intensity (Gerber *et al.*, 2013).

However, evolving food systems increasingly lead to intensive production and longer food supply chains, which can be associated with higher GHG emissions from both production inputs (e.g. fertilizers, machinery, pesticides, veterinary products and transport) and activities beyond the farm gate (e.g. transportation, processing and retailing; FAO, 2017a). Overall, future GHG emissions from agriculture and the extent to which reducing them can contribute to reducing global GHG emissions will be contingent upon the amount of agricultural output that will have to be produced to satisfy demand, at different degrees of food loss and waste, as well as the types of technologies that will be adopted for crop and livestock production.

1.5 Trends and challenges in a nutshell

This chapter's discussion of recent trends and the challenges facing global food and agriculture provides grounds for concern. Adequately feeding an increasing population that demands more resource-intensive food while also accommodating an increasing demand for agricultural raw materials and bioenergy will require a significant expansion in agricultural output. At the same time, already depleted land and water resources are increasingly under pressure, while unsustainable agricultural practices and other human activities jeopardize biodiversity and ecosystems in general. The multiple impacts of climate change due to unabated GHG emissions add to pressure on the natural resource base while exacerbating inequalities between and within countries. Expanding food demand, particularly if left unmanaged, may put an upward pressure on prices, thus raising concerns for the achievement of food security and nutrition objectives and calling into question the results obtained so far, unless the purchasing power of the poorer layers of society is increased.

It is unlikely that high-input, resource-intensive farming systems – which have been blamed for deforestation, depletion of land and water resources, loss of biodiversity and high levels of GHG emissions – will deliver sustainable agricultural production.

[34] Ruminant production has other significant social and environmental impacts, including comparatively higher withdrawals of freshwater, more pollution and greater antimicrobial use (which carries the risk of increased antimicrobial resistance and potentially more outbreaks of zoonotic diseases).

Innovative systems are therefore needed to protect and enhance the natural resource base while boosting productivity. However, moving food and agricultural systems along a more sustainable development path and understanding the trade-offs between sustainability and food security objectives requires knowledge of the complex interrelationships among producer and consumer behaviour, technological changes, resource availability, productivity, population dynamics and the impacts of climate change. In practice, these are known only imperfectly and with a significant degree of uncertainty. The same goes for responses by policy and institutional change. With a great deal of uncertainty, it is therefore complex to try and trace what the future development of food and agriculture may look like. It makes more sense to explore different scenarios that reflect alternative assumptions about how factors affecting the future of food and agriculture might evolve.

2 | Looking into the future: scenarios for food and agriculture

How much the challenges identified in the previous chapter will affect food and agricultural systems will depend on how societies, the economy and the environment will evolve in future and on the policies and interventions that can effectively be put in place to shift course towards sustainability. These possible pathways for food and agriculture can be represented through scenarios. A foresight exercise is developed, whereby alternative scenarios are analysed to inform about how, and in which direction, food and agriculture may evolve in upcoming decades. This chapter describes how these scenarios are constructed, and how they are further explored in the subsequent chapters.

Each scenario is anaylsed using indicators that characterize the evolution of food and agriculture, including economic importance, projected growth pathways, price changes, efficiency of natural resource use, income distribution, dietary patterns, and food security and nutrition outcomes.

2.1 The approach

An aspiration of the 2030 Agenda for Sustainable Development is to realize prosperous and equitable societies, where production processes rely on scarce resources in ways that do not jeopardize the welfare of future generations and the planet. As such a desirable future is just one of the (virtually infinite) futures that may materialize. Looking towards the long-term future is not about "predicting" or "forecasting" a given course of events but rather understanding how the world may look, depending on the level of commitment and effectiveness in addressing the challenges ahead.

The foresight exercise considers three scenarios specifically designed to investigate the challenges and possible strategic options for sustainable food and agriculture

As the future is uncertain, foresight exercises usually consist of the analysis of selected alternative scenarios that represent different futures against a range of uncertainties. These scenarios are generated in various ways, for example by giving prominence to historical trends; by assuming that existing challenges are tackled to different degrees, while adding expert judgement to form plausible narratives; or by emphasizing and magnifying one or more “weak signals” of change that are already detected in the current situation.

Most of the forward-looking exercises in areas relevant to sustainable development were carried out in recent years by the "climate-change community" (van Vuuren *et al.*, 2014),[35] in support of or as a follow-up to the work of the Intergovernmental Panel on Climate Change, notably to its Fifth Assessment Report (AR5) (IPCC, 2013). In defining the scenarios for a forward-looking exercise, a "back-casting" approach is typically followed (Vergragt and Quist, 2011).[36] This process begins with the identification of a particular outcome or "end-state" of interest for the specific domain under investigation. Socio-economic, climatic, biophysical, institutional, cultural, and policy dynamics are then detailed that may lead from the current situation to the aforementioned end-state. This approach results in a multilayered, interrelated structure that integrates climate change hypotheses, socio-economic patterns and policy assumptions. In the language adopted by the climate-change community, these structures are known as "integrated scenarios" (O'Neill *et al.*, 2014).

The international community has outlined climate change futures through the so-called "Representative Concentration Pathways" (RCPs). There are scenarios that provide alternative patterns of GHG concentration in the atmosphere and expected average temperature changes, depending on diverse trends and evolutions of socio-economic systems (Box 3). To complement this work, various potential patterns of socio-economic systems are set out in the so-called "Shared Socio-economic Pathways" (SSPs), which are narratives that describe alternative global socio-economic futures (Box 4). No one-to-one relationship has been established between RCPs and SSPs, and several combinations are considered possible. Moreover, so far no systematic work has been undertaken to propose different sets of policy responses to climate change and sustainability concerns, which would represent "Shared Policy Assumptions" (van Vuuren *et al.*, 2014).

[35] This includes academia and institutions working on climate change with Integrated Assessment Models (IAMs), the Climate/Earth System Modelling (ESM) community and the Impacts, Adaptation and Vulnerability (IAV), community, which corresponds to the three working groups in the IPCC, as described in van Vuuren *et al.*, (2014).

[36] Vergragt and Quist (2011) claim that the SSPs are formulated following a "backcasting" approach, as SSPs had to end up with pre-determined socio-economic outcomes such that the different level of challenges for mitigation and adaptation clearly emerge across SSPs.

BOX 3 Representative concentration pathways (RCPs)

RCPs outline alternative scenarios for the concentration of CO_2, other GHGs and pollutants in the atmosphere by the year 2100 (van Vuuren *et al.*, 2011), which are typically used by climate models (Global Circulation Models – GCM) to project climate changes. The RCPs are named after the additional radiative forcing created by the GHG concentration in the atmosphere in 2100, compared to the base year 2000 and expressed in watts per square metre (W/m^2). The RCPs range from the lowest RCP2.6 (additional 2.6 W/m^2) to the highest RCP8.5 (additional 8.5 W/m^2), with two intermediates of RCP4.5 and RCP6.0.

RCPs originate from studies that were conducted independently by different teams, so there is no consistent design behind one RCP relative to the others. However, all RCPs are based on specific trajectories of population incomes, land-use changes and technologies that substantiate and differentiate them, for instance:

- **Population.** Population growth is an important driver of climate change for each RCP. RCP8.5 assumes a comparatively higher population growth, portraying around 10 billion people in 2050, while all other RCPs stay below 9 billion people by 2050.
- **Energy-related technologies.** For each RCP, specifications are made regarding energy-related technologies. For example, RCP8.5 implies lower rates of technology development, while RCP2.6 is achieved through intensive use of carbon capture and storage and a decline in the use of oil, presumably as a result of depletion and climate policies (van Vuuren *et al.*, 2011).
- **Land-use.** Cropland increases under RCP8.5, mainly due to population growth. It also increases in RCP2.6, but in this case due to biofuel production and more intensive livestock systems. This livestock change allows grassland to remain constant. In RCP4.5, forests and grassland increase from 6.5 to 8.0 billon ha from 2000 to 2100, under the assumption that CO_2 stored in forests will be remunerated thanks to appropriate global environmental policies. This implies that cropland and grassland will sharply decrease, while yields will increase and diets will become more sustainable.
- **Emissions and environmental policies.** RCP8.5 portrays the highest additional radiative forcing, reflecting a lack of mitigation policies that drive GHG up to 30 gigatonnes/year of $C0_2$, compared to 7.5 in the year 2000. RCP6 is less pessimistic but still incorporates limited implementation of mitigation policies. In contrast, RCP4.5 is achievable with a range of environmental policies, while RCP2.6 requires very stringent GHG reduction policies.

BOX 4 Shared Socio-economic Pathways (SSPs)

The backbone of the SSPs is a set of assumptions related to the future organization of societies, classified according to the challenges related to climate change adaptation and mitigation. O' Neill *et al.* (2017) describes the five SSPs that have been established and for each of which there are detailed narratives:

- SSP1: Sustainability – taking the green road.
- SSP2: Middle-of-the-road.
- SSP3: Regional rivalry – a rocky road.
- SSP4: Inequality – a road divided.
- SSP5: Fossil-fuelled development – taking the highway.

Key assumptions used in the construction of each SSP are presented in Annex I.

Regarding climate change and related policies, according to van Vuuren *et al.* (2014) SSPs are designed as follows:

1. Each SSP is defined in a bi-dimensional challenges space determined by challenges for adaptation and for mitigation (e.g. high emissions and low mitigative capacity of societies).
2. SSPs contain no explicit policies for climate change adaptation or mitigation. Indeed, they are considered only as "reference" scenarios upon which climate policies can be superimposed.
3. There is no precise correspondence between SSPs and RCPs. In fact, SSPs are intentionally broadly designed so that one SSP could give rise to a variety of RCPs, for example based on different land-uses.
4. By design, SSPs do not include the effects of climate change on socio-economic and biophysical systems (O'Neill *et al.*, 2014).

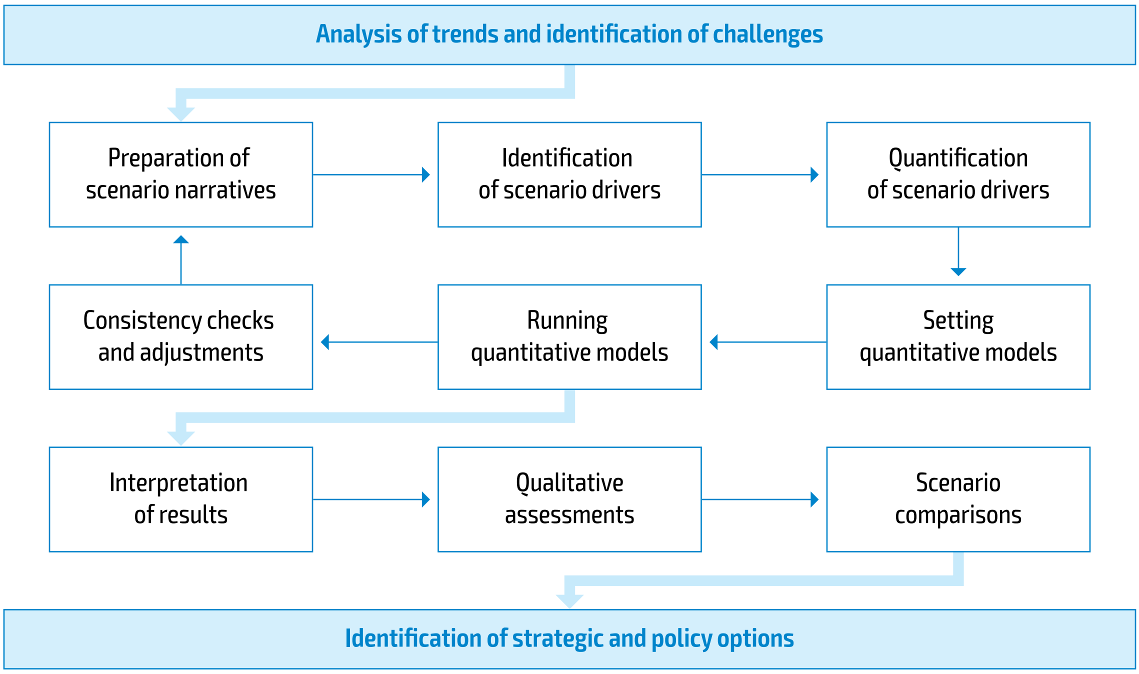
Assuming that a specific policy will be implemented in future as part of a scenario could imply changing some socio-economic assumptions in the SSP.

The methodology applied in forward-looking exercises aimed at informing global climate discussions is a valuable guide for investigating other future societal challenges. These could of course include challenges related to FAO's vision of achieving more sustainable agricultural systems that are fully capable of feeding the world. This report therefore incorporates this methodology but recasts the design of the scenarios to specifically address food and agriculture concerns.

A step-wise approach ensures the relevance of the analytical results for addressing the issues at stake

To ensure that the analytical findings of the foresight exercise are relevant for addressing the issues to be investigated – notably the future challenges for sustainable food and agriculture – a step-wise approach is adopted throughout the design and analysis of the scenarios. The overall foresight methodological approach adopted for this report is sketched in Figure 2.1 and described step-by-step below.

Figure 2.1 Step-wise approach for the foresight exercise



Source: FAO Global Perspectives Studies.

Analysis of trends and identification of challenges. Any foresight exercise aims to address specific questions regarding the future. In this case, the recent trends affecting food and agriculture analysed in the previous chapter raise concerns and highlight challenges that are the object of investigation.

Scenario narratives. Scenario narratives are qualitative descriptions of what a given period in the future may look like, and the patterns that socio-economic and environmental systems might follow to get there. The scenario narratives frame the whole forward-looking exercise.

One way of preparing an internally consistent scenario narrative is: (i) providing a "snapshot" of the state of the world in a specific end period, such as 2050 as in this exercise; (ii) describing a possible road ahead along which societies and the environment might evolve from the current situation to the specified future situation. The goal in this context is to identify a few snapshots and related pathways that are relevant to understanding how the current and near-future strategic choices of economic agents and decision-makers at all levels could address key challenges for food and agricultural systems, and influence their long-term outcomes.

Identification and quantification of scenario drivers. A key step in this exercise is the identification and quantification of drivers that would steer societies along alternative pathways. For instance, key drivers shaping the scenarios considered for this report are future population trends, economic growth, technological progress (both economy-wide and specific to agriculture), and evolving consumer preferences, as well as climate change and related shifting constraints on natural resources (e.g. availability of land and water).

Two agricultural-sector and economy-wide quantitative models provide projections and ensure their internal consistency

Setting up the quantitative models. Two economic models provide quantitative projections for the scenarios: the FAO Global Agriculture Perspectives System (GAPS) and the Environmental Impact and Sustainability Applied General Equilibrium (ENVISAGE) model. FAO GAPS is a partial equilibrium model that focuses on the relationships between production and consumption of food and agricultural goods, and food security and nutrition (flows depicted in green in Box 2). The ENVISAGE model covers the whole economy and portrays the frame for the food and agricultural sectors. Both models allow scenarios to be internally consistent, as they ensure: i) respect of certain physical and economic balances, such as the matching of demand and supply for goods and services under scenario-specific assumptions on population growth, technological progress, and natural resource constraints under changing climate conditions; ii) compliance with microeconomic theory on consumer behaviour.

FAO GAPS is mainly built on (or calibrated with) FAOSTAT Food Balance Sheets for the three-year period of 2011 to 2013, centred at 2012 as the base year of the foresight exercise.[37] For subsequent years it provides detailed projections for food and agricultural sectors (including fisheries). These include supplied and demanded quantities for agricultural commodities in each country and the associated prices that balance the respective global markets for crops, processed goods, and livestock products. Variables that adjust simultaneously are crop yields, land requirements by production system, and animal herd size by livestock production system. Once solved for the projected years (in the case of this report up to 2050), the model generates indicators for food security and checks limits on natural resource use. Some other essential features of FAO GAPS are presented in Box 5, and more detailed descriptions can be found in Annex III.

The ENVISAGE model is mainly build on the Global Trade Analysis Project (GTAP) database. It provides economy-wide indicators relevant to frame the agriculture and food sectors within broader national and international development processes.[38]

Running quantitative models, consistency checks and adjustments. Consistency between FAO GAPS and ENVISAGE is achieved by: i) careful design of the datasets underlying the models, such that ENVISAGE aggregates of countries, agricultural commodities and activities fully match the more detailed data in FAO GAPS, and that these results can be aggregated and compared with the corresponding – albeit less detailed – results from ENVISAGE; ii) assuming the same population growth and dynamics, GDP per capita and agricultural technology shifters used in each scenario for both models; iii) an iterative process of subsequent model parameter adjustments, which ensures that FAO GAPS results – such as changes in the size of the agricultural sector and price indexes, net trade positions by countries and regions, land-use, and sectoral GHG emissions – are consistent with the economy-wide results obtained with ENVISAGE, and vice versa (Figure 2.2).

[37] The 3-year period 2011 to 2013 is referred to as 2012 (the base year). Parameters of the model are set such that the solution of the model replicates the values of the variables in 2012.

[38] The indicators comprise, for instance, sector-wide equilibrium prices and quantities, labour, land and capital requirements and remunerations, imports and exports by country and good, and GHG emissions by sector. For technical explanations on the ENVISAGE model, see van der Mensbrugghe (2013).

Interpretation of models' results. Quantitative results for each scenario highlight possible future patterns of key variables, such as the quantities of different commodities demanded for food and other purposes, their prices relative to those of other agricultural and non-agricultural commodities, agricultural and non-agricultural capital, and employment, wage and land-use, among others. These quantitative results are interpreted in light of the specific scenario narratives and assumptions, which then allow for an understanding of the possible futures of food and agriculture. The scenario narratives are further explained below in this chapter, while the scenario assumptions are at the core of Chapter 3.

Scenario analysis and qualitative assessments. Models' quantitative results are carefully scrutinized and compared across scenarios and regions, to investigate global and region-specific challenges for food security and nutrition in all dimensions (access, utilization, availability and sustainability). This exercise not only considers the magnitude and direction of the results, but reads them in the light of scenario-specific assumptions that contributed to their determination. Aspects not explicitly taken into account in quantitative modelling are brought into the picture through qualitative considerations consistent with the scenario-specific narratives, which build on relevant studies, literature and practices within and outside FAO. For example, this can refer to the institutional framework implied by different equitability levels in income and food distribution, research and development required to achieve a given level of technical progress in crop and livestock production, skills needed to implement innovative technologies for reducing GHG emissions, or structural changes necessary for better integrating agriculture in the economy-wide context.

Identification of strategic options for decision-making. Findings from quantitative and qualitative analyses compared across scenarios and regions allow for the identification of possible strategic options for increasing the long-term sustainability of food and agricultural systems. They also enable evidence to be corroborated with policy directions and ways forward already highlighted in existing FAO documents and the literature.

Figure 2.2 Quantitative modelling framework

Source: FAO Global Perspectives Studies.

BOX 5 The FAO GAPS model in a nutshell

The FAO Global Agriculture Perspectives System (GAPS) is a global model of the food and agricultural sectors which allows for analysing supply, through different production systems, and intermediate and final demand of food and agricultural goods. Its main features are:

- Crop and animal products are modelled in physical quantities in detail by country.
- The supply of each crop results from the yield in physical units per unit of harvested area (yield), multiplied by harvested area.
- Crop yields increase with rising output prices and decrease with rising costs of the input mix, *ceteris paribus* (that is, chosen by the analyst).
- Crop yields are "upper-bounded" by the maximum attainable yield for that crop in the specific country. Country, crop and scenario-specific maximum attainable yields are exogenous.
- The harvested area – modelled per crop and country – increases with the price of the output.
- Livestock products supply increase with rising output prices and decrease with rising feed prices. Both output and feed prices are endogenous, that is, they result from solving the model.
- Demand for feed is derived from the demand for livestock products through technical relationships based on exogenous information.
- Some processed goods are also modelled (e.g. vegetable oils and by-products, sugar); their supply is sensitive to output prices and to assumptions regarding the "extraction rates", that is the quantity of processed output obtained with one unit of input (oilseeds, sugarcane, etc.).
- Livestock products and crops are modelled by production system (e.g. irrigated, rainfed, rangeland-based, intensive, etc.).
- Consumer demand is expressed in "primary equivalents", meaning the primary agricultural goods required to produce the consumer good (e.g. the demand for pasta is expressed in terms of wheat required to produce pasta).
- The consumer demand system respects the microeconomic theoretical regularity conditions (adding up, homogeneity, etc.).
- Adjustments of commodity prices at global level make global demand for each commodity match global supply.
- For each country, net trade (exports-imports) balances domestic demand with domestic supply of each product. Countries are characterized as net importers (exporters) when domestic demand is higher (lower) than domestic supply.
- The model is initially solved for a single period. Dynamic (time-dependent) shifters of the various functions allow modelling and solving for sequences of periods.
- "Post-solve" algorithms, that is, further calculations after after the model is solved, allow for checking the use of natural with resources (e.g. pasture by animal system, water requirements) and calculating other indicators (e.g. food security, GHG emissions).

Note: For more technical details see Annex III.

2.2 Fitting scenarios in the "challenges space": key drivers, strategies and policies

By relying on the step-wise approach for the foresight exercise, the ultimate goal of this report is to generate new knowledge that informs policy-makers and the development community pursuing efforts in the domains of sustainable agriculture, food security, and nutrition. To achive this goal, scenarios were specifically designed to sketch what the world might look like in the face of specific "mega-challenges" facing each of those domains. Two particular long-term mega-challenges of interest considered are:

1. Challenges for food access and utilization. They are incorporated into the scenarios by considering different degrees of equity challenges for realizing equitable and inclusive development processes that ensure universal access to food, adequate food utilization and satisfactory nutrition outcomes under adequate education and health conditions.
2. Challenges for food stability and availability. They comprise challenges for ensuring sustainable production patterns that allow for – in different degrees and depending on the scenario – sufficient, nutritious, safe and stable levels of agricultural food supplies.

Diverse assumptions shift the position of each scenario in the challenges space

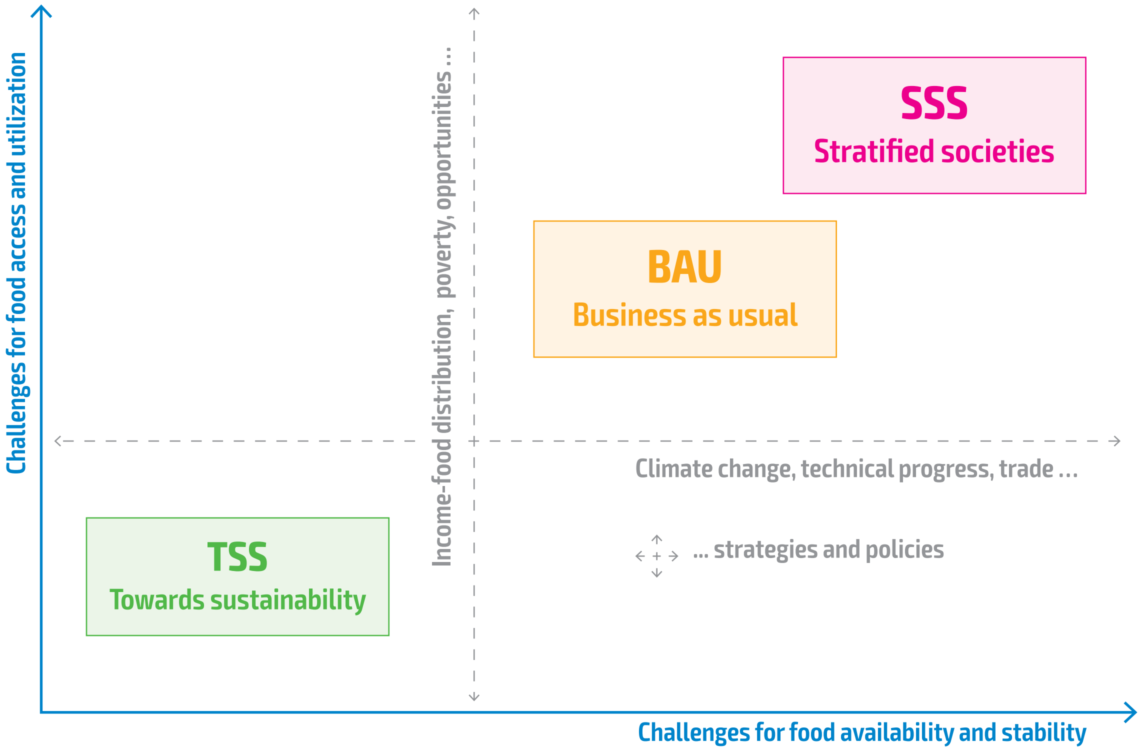
These challenges can be represented bi-dimensionally, as illustrated in Figure 2.3. The extent and depth of the challenges for societal equity and sustainable production in the future depend on where the trends of key socio-economic and environmental variables influencing food and nutrition security (as described in Chapter 1) will veer in the future.

The more that trends move scenarios away from the origin in Figure 2.3, the greater the challenges societies will face in pursuing sustainability. Assumptions regarding these critical trends need to be made in order to position alternative scenarios in the "challenges space". Variations of these assumptions shift the position of each scenario in this space.

Three alternative scenarios were designed to reflect various degrees of challenges for equitable and sustainable production within the challenges space: business as usual (BAU), towards sustainability (TSS), and stratified societies (SSS). To varying degrees, each scenario is broadly based on historical patterns, selected recent trends and emerging issues, as well as on assumptions and expectations discussed in comparable studies and the relevant literature. Each scenario rests upon alternative assumptions, which are detailed in Chapter 3.

Depending on the assumptions regarding, for instance, new technological discoveries likely to enhance total factor productivity (TFP) in agriculture, each scenario can be placed more towards the right side if we assume small improvements in TFP, or towards the left side if the opposite holds true. Assumptions regarding these key variables (drivers) therefore determine, for example, how far away the BAU scenario is from the TSS one, as well as the extent to which driving forces point societies towards more challenging scenarios, such as SSS.

Figure 2.3 Challenges to food and agricultural systems and key scenario drivers



Source: FAO Global Perspectives Studies.

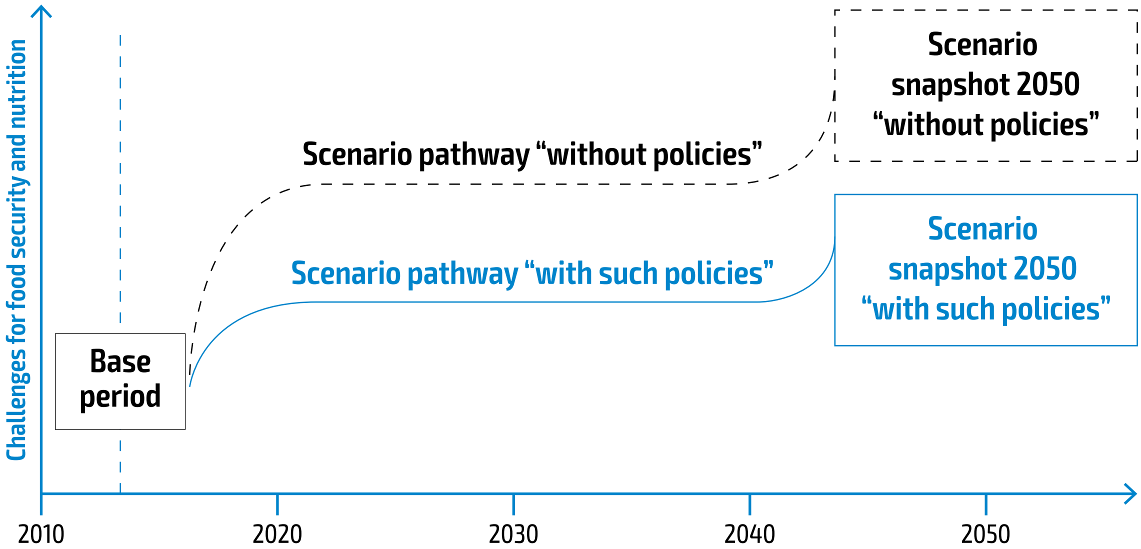
Strategic choices and policies also shift scenarios in the challenges space

Decision-makers at all levels can influence the extent of challenges for sustainable food and agriculture, through strategies, policies, programmes and other actions.

As there are three alternative "integrated" scenarios, by definition they already embody the impacts of strategies and policies that specifically address challenges for food security and nutrition (FSN) and sustainable agriculture. For example, such policies can be aimed at achieving selected FSN-related SDGs, or at increasing the environmental sustainability of agriculture. Together with other drivers, the extent to which these policies are implemented and their effectiveness at addressing the issues they are designed for contributes to determining the position of each scenario in the challenges space. A scenario "without policies" (or with ineffective policies) for reducing food insecurity and improving nutrition would result in a different position in the challenges space, compared with a scenario "with such policies", as shown in Figure 2.4.[39]

[39] In Figure 2.4, the bi-dimensional space of challenges for food security and nutrition and sustainable agriculture is collapsed in one dimension to incorporate the time dimension.

Figure 2.4 Scenario pathways without and with policies for sustainable food and agriculture



Source: FAO Global Perspectives Studies.

The foresight approach based on alternative scenarios that are explicitly designed to fit within the challenges space presented above is well suited for conducting comparative analyses of the various factors determining the sustainability of food and agricultural systems, such as: the economic importance of the sector, its projected growth pathway, food and non-food price changes, efficiency in natural resource use, income and food distribution, dietary patterns, and resulting FSN outcomes.

2.3 Scenario narratives

Scenario narratives (as defined above) have two critical roles to play in the foresight exercise. First, they define the position of each scenario in the "challenges space". Second, they constitute the qualitative consistency framework within which the quantitative modelling results for each scenario should be read and interpreted.

Scenario narratives for this foresight report build on different forward-looking exercises recently carried out within the international development community for various purposes, comprising: i) the recent trends highlighted in Chapter 1 and the related emerging challenges for food and agriculture; ii) Agenda 2030, with a specific focus on the SDGs particularly relevant to FAO's vision and work (see Box 1); iii) selected narratives designed to represent the SSPs,[40] which have inspired the overall macro-picture of socio-economic and environmental systems (see Box 4); iv) FAO's principles and vision regarding the sustainability of food and agriculture (see Box 6), which have allowed for a focus on specific aspects of sustainable agriculture sub-sectors (crops, livestock, forestry, aquaculture and fisheries); v) socio-economic and environmental features of the different RCPs (see Box 3) with a particular focus on the climate change implications of GHG emissions, both within agriculture and economy-wide.

[40] The SSP narratives help analysing broader sustainable development issues, as explained in O'Neill *et al.* (2017). The narratives for TSS, BAU, and SSS scenarios, build on SSP1, SSP2/SSP5 and SSP4, respectively, although assumptions regarding economic growth, technologies, and the use of natural resources may deviate from the SSPs to better highlight food security, nutrition and sustainable agriculture challenges.

BOX 6 Sustainable food and agriculture: trade-offs and policy principles

To present a common vision of patterns to follow for making agriculture more productive and sustainable, in 2014 FAO launched an interdisciplinary consultative process with leading specialists in crops, livestock, forestry, fisheries, aquaculture, and natural resources (FAO, 2014).[a] During the discussions – which built on the Organization's long experience in developing sustainability concepts – approaches, tools, and various types of trade-offs were highlighted:

1. **Trade-offs between human and natural systems.** For example, this can refer to the choice between satisfying human needs and preserving natural resources, climate stability, ecosystems and biodiversity.
2. **Trade-offs within human systems.** Choices that lead to more efficient production – for example by concentrating the right of access to land or fishing grounds in the hands of a few large operators – may improve efficiency but risk undermining both the livelihoods of family farmers and social stability.
3. **Trade-offs within natural systems.** This refers to situations where, for example, land-use is reduced through intensification at the cost of increased water use, or intensification of production on cultivated land occurs to spare large areas of forest, but generates increasing pollution and energy and nutrient use in other areas.
4. **Trade-offs over time.** Trade-offs in any of these categories occur over time. Immediate benefits are often traded for costs later down the line. For example, the impacts of the depletion of natural resources and ecosystem services might only be felt over the course of decades.

To address these trade-offs in food and agriculture, FAO highlighted five principles that should inspire strategic thinking in policy-making, as well as in programming and implementing investments:

1. More efficient resource usage must be developed and adopted.
2. Sustainability requires direct action to conserve, protect and enhance natural resources.
3. Agriculture that fails to protect and improve rural livelihoods, equity and social well-being is unsustainable.
4. Enhanced resilience of people, communities and ecosystems is key to sustainable agriculture.
5. Sustainable food and agriculture requires responsible, effective governance mechanisms.

[a] This corporate knowledge has also guided the identification and definition of suitable parameters for the models (FAO GAPS and ENVISAGE), including for efficiency and natural resource use coefficients, as further explained in Chapter 3.

Given that the scenario narratives were nurtured by the above-mentioned forward-looking exercises, the BAU scenario represents a pathway along which incomes around the globe grow at moderate levels, without bridging the large gaps between countries. Furthermore, mitigation and sectoral development policies are implemented, but not to the extent necessary for substantially addressing the challenges highlighted in

Chapter 1, including climate change. Moving towards sustainability, the TSS scenario envisages more equitable societies overall, whereby several SDG targets are almost universally achieved, agriculture moves towards sustainability thanks to the adoption of strategic orientations and full implementation of effective polices, GHG emissions within and outside agriculture are drastically reduced, and climate change is mitigated. On the contrary, moving further from sustainability (away from the origin of Figure 2.3), the SSS scenario emphasizes the effects of leaving the current and future challenges facing food and agricultural systems unattended.

The remainder of this chapter presents the three scenario narratives in detail. The main scenario "drivers" (growth of population and income per capita, the degree of climate change and effects on crop yields and land availability, among others) are specific for each country and region. The main quantitative assumptions for trends and drivers are described in detail in Chapter 3. Furthermore, Annex II provides synoptic tables that ease the cross-scenario comparison of key aspects of the narratives.

Business as usual (BAU)

This global future develops according to socio-economic, technological and environmental patterns that fail to address many challenges for food access and utilization, as well as for sustainable food stability and availability, despite efforts to achieve and maintain SDG targets.*

Economic growth and policy

Economic growth (per capita) is moderate, ranging globally around 1.5 percent per year, but uneven across countries. Long-term cross-country convergence of economic systems is doubtful due to varying investment patterns, technological disparities in all sectors and diverging demographic dynamics. Foreign investment continues along the north-south axis, following historical trends in each country and with current levels of impact on economies and societies. Domestic savings rates continue under current trends. Bilateral trade agreements are in place, with non-tariff border policies gaining importance.

Fiscal policies continue to provide some within-country redistribution, but incentives to move towards sustainability are limited. Credit policies have no particular interest in innovative, sustainable enterprises, and public investment remains modest as per current trends. The diverse modalities of economic transformation, the different role and size of fiscal systems, as well as the varying effectiveness of social protection mechanisms across countries lead to differentiated results in terms of reducing poverty and achieving food and nutrition security.

* The BAU scenario builds upon the narrative of SSP2, known as "the middle of the road" (see O'Neill *et al.*, 2017). However, the BAU scenario does not fully qualify as "middle of the road" in the challenges space because it leads to significant challenges for equity and sustainable production. For this reason, the BAU scenario contains some elements of SSP3, particularly regarding concentration of innovative know-how, unmanaged urbanization of disadvantaged people, the occurrence of proxy conflicts between regional blocks, a considerable level of corruption, and low priority regarding environmental and land-water conservation practices. Given that people often think about the future with a "baseline" scenario in mind, that is, to a benchmark scenario with respect to which other alternative scenarios appear to be "variants", in foresight exercises the business-as-usual is often assumed as the baseline. For more technical details about this scenario see Annex II.

International governance and conflicts

The goals of promoting just, peaceful and inclusive societies, and significantly reducing illicit financial and arms flows as well as bribery and corruption, are only partially achieved due to limited effectiveness of institutions at all levels to set up and enforce standards and regulations. Official Development Assistance (ODA) stagnates around current levels while other forms of cross-country cooperation, such as joint research, technological transfers, etc., are limited in bridging country gaps. LMIC foreign debt levels remain stable.

International institutions often fail to solve local conflicts or broader international instability, and implicit confrontation therefore prevails. Ongoing demand for fossil fuel energy mostly remains unabated and due to institutional weaknesses, energy- and other resource-related national and international conflicts continue to afflict the planet. Current trends in defence expenditure leave little room for funds to be devoted to economic transformation policies.

Human development

Countries are barely able to provide quality education. Access to health services is an ongoing challenge, and low-income countries (LIC) are sometimes unable to maintain their populations' well-being. Access to clean water and sanitation become widely available in LIC, but it is a struggle to maintain these systems. Many forms of discrimination against women and girls are brought to a permanent end, but labour-market discrimination persists in many countries.

Conservation practices, energy use and GHG emissions

Fossil fuels are the main energy source for decades, with renewable sources slowly emerging. Oil extraction rates remain relatively unchanged. The potential for GHG sequestration is limited, as uncertainty regarding future economic incentives limits R&D and the adoption of suitable practices. The adoption of conservation practices stagnates, as do investments in R&D for agriculture in LMIC. Expanding agricultural and economy-wide GHG emissions contribute to exacerbating climate change and increasing the world's average temperature, which may rise by 3–4 °C by 2100.

Welfare and lifestyle

Current moderate trends of extreme poverty reduction are maintained, and moderate food security improvements occur. Nevertheless, "zero hunger" and "no malnutrition" are not achieved by either 2030 or 2050. In terms of diets, current trends of moderate convergence towards the consumption of more nutritious food are maintained, though consumers exhibit limited willingness to pay for environmental services. Food losses and waste globally are mostly unabated and only partially reduced through specific programmes in selected LMIC and consumer campaigns in HIC.

Land and water use

Arable land (the physical area under temporary and permanent agricultural crops) expands at faster annual rates than in the last decades and land degradation is only partially addressed. Land intensity, which is to say the quantity of land per unit of output, decreases as crop and animal yields increase, but these achievements require the progressive use of chemicals. Deforestation and unsustainable raw material extraction both continue, while water efficiency improves but the lack of major changes in technology leads to the emergence of more water-stressed countries.

Agricultural policy, innovation and yields

Innovation is generated through high investments in research following historical trends, with a reduced role of the public sector. However, family farmers do not necessarily benefit due to costly input packages that have dubious effectiveness or environmental sustainability. The level of input use continues to evolve along historical levels, as do current consumer protection regulations. Agricultural yields increase but are variably affected by climate change, depending on latitude and crop. High value-added small farms and processors of high-quality food compete with large-scale, high-input producers. Current trends towards more processed foods in LIC and more fresh food in HIC continue. Agricultural prices globally show limited increases, which reflect pressure on demand and limited resources.

Towards sustainability (TSS)

Virtuous social, environmental and economic dynamics in this scenario ensure fairly generalized equity in terms of access to basic services, as well as universal and sustainable access to sufficient, safe and nutritious food mostly produced with environmentally sustainable methods. Thanks to comparatively more resource-efficient food production systems and inclusive societies, challenges for both access and utilization, as well as sustainable food stability and availability, are lower than under the BAU scenario. There is universal progress to achieve SDG targets and efforts continue after 2030.*

Economic growth and policy

Fiscal and credit policies all favour smooth growth patterns and innovative, sustainable enterprises. The world develops while addressing sustainability concerns. Globally, GDP per capita grows as in BAU but the growth rate is lower in HIC and higher in LMIC. Foreign investment is higher than in the BAU scenario, with positive impacts on local incomes. Domestic savings increase and help to finance investments in innovative technologies.

High investments lead to innovations in technologies, such as precision agriculture and applied robotics. Public investment focuses on R&D that stimulates technical progress on sustainable and pro-poor policies. Strong internal redistribution allows for the redress of income inequality and encourages access to food for the poor. Innovative, sustainable enterprises are incentivized.

International governance and conflicts

The goals of promoting just, peaceful and inclusive societies and significantly reducing illicit financial and arms flows, bribery and corruption are mostly achieved through improved governance. Almost no illicit financial flows leave LMIC for HIC or fiscal havens. Until around 2030, ODA expands to support the transition to sustainable production processes in selected LMIC and subsequently decrease as it is no longer needed. The foreign debt levels of LMIC decrease, and these countries pursue forms of international trade which boost equitable integration into markets of poorer

* The TSS scenario builds upon the narrative of SSP1, which is also regarded as "the green road" (see O'Neill *et al.*, 2017). For more technical details about this scenario see Annex II.

layers of the society. Minimal demand for fossil fuel energy means the world suffers fewer national and international energy-related conflicts. This leads to limited defence expenditures, thereby leaving room for funds to be devoted to economic transformation policies.

Population growth and inequality

Population dynamics do not change with respect to the BAU scenario. The world's population stabilizes in the second part of the century. Despite quite high population growth, particularly in SSA and SAS, extreme poverty is almost defeated and income inequality within and between countries is significantly reduced. Wage differentials across and within countries decline faster than under BAU.

Human development

Universal access to drinking water and sanitization is permanently achieved. Social welfare increases, thanks to universal primary and secondary education, universal access to health services, lower unemployment, lower wage differentials and widespread access to non-material public goods (e.g. inclusiveness, empowerment, security). Social cohesion is maintained through equitable access to basic services and strong institutions. Discrimination against women and girls no longer exists.

Conservation practices, energy use and GHG emissions

Recycling becomes the primary form of raw material supply, leading to declining extraction rates. The potential for GHG sequestration is high due to suitable crop technologies, reforestation and afforestation. Widespread conservation practices and increased R&D investments lead to a sharp decrease in GHG emissions, and the world's average temperature is very unlikely to rise by more than 3 °C by 2100. Moreover, as a result of massive investments in technology, increasing proportions of the world's energy needs are satisfied by renewable sources.

Welfare and lifestyle

Extreme poverty reduction targets are achieved by 2030 due to pro-poor investment and development, and food security and malnutrition improvements suggest more progress towards achieving "zero hunger" by 2030 compared with the BAU scenario, with developments further improved thereafter. Balanced, healthy and environmentally-sustainable diets are increasingly adopted in most countries, and consumers exhibit a high willingness to pay for non-material goods such as social and environmental services. Regulatory frameworks, R&D and investments regarding improved food storage and processing, as well as consumer awareness, drastically reduce food losses and waste. In the early years of the period under consideration, final demand and production drift towards investment due to the need to speed up technological transition to sustainable production processes.

Land and water use

Low-input processes lead water intensity to substantially decrease and energy intensity to substantially improve against the levels seen under the BAU scenario. Regarding land-use intensity, the quantity of land per unit of output drops with respect to current levels, thanks to sustainable agricultural intensification and/or other practices aimed at improving resource efficiency. This helps to preserve soil quality and restore degraded and/or eroded land. Agricultural land is no longer substantially expanded and land degradation is tackled. Water abstraction is limited to a smaller fraction of available water resources.

Agricultural policy, innovation and yields

Boosted investment ensures the transition towards a more sustainable use of natural resources and climate change mitigation compared to BAU. Low-input precision agriculture, agroforestry, intercropping, and organic agriculture and/or other resource and climate-friendly production methods contribute to moving towards "circular" economies, that is economies based on reusing goods and recycling waste, with limited impacts on ecosystems. Chemical use overall is restrained: for example, regulations on nitrate usage or fertilizer quantity and type are in place, which favours precision and/or organic agriculture. Food systems generating low GHG emissions are favoured, and fresh food consumption is promoted. Consumers receive information on the origin, content, quality, and sustainability levels of processed food. Adopting conservation agriculture, agro-ecological approaches, agroforestry, and other environmentally-friendly techniques allows yields to increase against current levels – albeit more moderately than under BAU – and to converge across countries, while food systems drastically reduce GHG emissions compared with current levels. Greater crop diversification and integrated pest management approaches strengthen resilience to shocks. Agricultural prices rise worldwide, reflecting both pressure on demand and the adoption of sustainable production practices.

Stratified societies (SSS)

In this scenario, societies are structured in separate layers. Self-protected elite classes, such as groups of people who have decisional power and use it primarily to protect their position and interests, do not feel the urgency to conserve natural resources or mitigate climate change. At the same time, increased poverty, food insecurity and poor nutrition leads to the over-exploitation of natural resources and unmanaged agglomerations. In this scenario both equity and sustainable production are more seriously challenged than under the BAU scenario.*

Economic growth and policy

Overall, economic growth is respectable, but immiserizing growth mechanisms are present. GDP per capita grows at a faster rate than in BAU, at around 2 percent per year, but is faster in HIC and lower in LMIC when compared against growth rates of the BAU scenario. Growth is led by increasingly concentrated final household consumption, as economies do not invest in transitioning towards sustainability, but rather continue to rely on fossil fuels and energy- and resource-intensive technologies. In addition to high wage differences across countries and sectors, many jobs are low-wage, manual or repetitive in the services sector or in labour-intensive, low-tech industrial sectors. The savings potential of poor countries decreases, while high tariff and non-tariff barriers create more international fragmentation. Foreign investment in LMIC is higher than in BAU, but has very limited impact on local incomes.

* The SSS scenario builds upon the SSP4 narrative ("a road divided") but differs from it in that it assumes high climate change mitigation challenges, leading to formidable challenges for sustainable production (see O'Neill *et al.*, 2017). Annex II gives more details on this scenario.

Public investment is limited and flows to non-sustainable practices that favour both fossil fuels and society's elite classes. Very weak fiscal systems prove to be ineffective at keeping within-country inequality from deteriorating. Most policies favour large commercial enterprises and corporations and limit access for small businesses. Thus, the redistributive role of the public sector progressively shrinks.

International governance and conflicts

Illicit financial flows expand and bribery and corruption distort the decision-making of public officials, thereby favouring the elite. ODA declines drastically and fiscal systems weaken globally. Conflicts over natural resource control intensify amid permanent global instability, but the international elite prevent collapse.

Population growth and inequality

Population dynamics stay unchanged relative to the previous scenarios. The world's population stabilizes in the second part of the century. Highly unequal investments in human capital, know-how, physical and financial assets generated by disparities in incomes and saving potential and uneven opportunities to invest, all lead to increasing inequalities both between and within countries.

Human development

Well-educated, internationally-connected social classes contrast with lower-income, poorly-educated social classes. Even in HIC, the poor do not have access to quality health services. Education levels are highly stratified between income groups and countries. Diets and access to food worsen for most people, due to lower purchasing power and consumer awareness when compared with the situation under the BAU scenario. Increasing inequalities, skewed access to information and almost no empowerment of large parts of the population progressively hamper social cohesion and increase injustices.

Conservation practices, energy use and GHG emissions

Limited investments flow to R&D and the intensive use of chemicals and land in agriculture, as well as fossil fuels economy-wide, all contribute to very high levels of GHG emissions. The potential for GHG sequestration is not exploited due to the continued adoption of conventional agricultural techniques, which result in high positive net GHG emissions by all economic sectors. If the trends materializing in this scenario were to continue beyond 2050, the average temperature would increase by 4–5 °C by 2100.

Welfare and lifestyle

The declining trends in hunger and malnutrition are reversed, particularly in countries with high population growth. Poverty increases in HIC, and overall trends in both poverty and extreme poverty reduction are reversed. Diets worsen for most people due to lower purchasing power and/or lower consumer awareness. Consumer preferences are dichotomous both across and within societies, as the large majority of consumers focus on covering their basic needs while only the elite are able to afford luxury goods and high-quality foods. Lower-income countries cannot ensure access to water and sanitation. The elite increasingly waste food, while the masses continue to do so at current levels.

Land and water use

The world suffers further deforestation. New agricultural land is used to compensate for increased degradation and to satisfy additional agricultural demand, which is left unmanaged. The quantity of land per unit of output decreases for commercial agriculture but remains stable or increases for family farmers, as they increasingly suffer from crop losses that are also fuelled by extreme climate events. Water is not sustainably used in many regions and little investment is made towards water use efficiency. Both water and land constraints are exacerbated by climate change.

Agricultural policy, innovation and yields

Agriculture follows diverse paths, with the coexistence of subsistence agriculture, low-quality commercial agriculture for mass consumption under concentrated control, and high-quality and luxury niches present in both HIC and LMIC. Innovation focuses more on labour-saving technologies than on sustainability. Regulations on inputs are relaxed, including on both quantity and type of herbicides, hormones, antibiotics, and other chemicals used for mass production, while agricultural input markets become increasingly concentrated, with progressively expanding oligopolies. Agricultural land significantly expands while crop diversification is low, and monoculture prevails to support mass production. Resilience to shocks is very limited for family farmers and moderate for large commercial farms for mass consumption. Heavily-processed food for mass consumption is increasingly deregulated in terms of quality labels, origin, or content. The elite, on the other hand, consume lightly-processed and/or fresh foods. Agricultural prices significantly increase globally due to decreased yields associated with resource degradation. Family farmers are particularly vulnerable and suffer from crop losses due to extreme climatic events.

3 | Scenario drivers: alternative assumptions for the future

The three scenarios introduced in Chapter 2 portray different socio-economic and environmental pathways that are co-determined by (potential) policy decisions, or a lack thereof.

This chapter presents detailed assumptions regarding the future trends of key socio-economic and environmental variables – or "scenario drivers" – such as population trends, economic growth, income distribution and climate change, which determine the long-term evolution of food and agricultural systems. To a large extent, the evolution of these scenario- and region-specific drivers is co-determined by the behaviour of individuals, certain policy decisions and/or natural factors and events.

3.1 Population

As highlighted in Chapter 1, population dynamics are a key driver of future food demand. In the three alternative scenarios that will be analysed, the population evolves according to the UN-medium variant projection, meaning the global population shows a positive, though declining, growth rate that falls to nearly zero by 2100.[41]

Population growth is projected to slow down everywhere by 2050, although at a different pace across regions

Population growth is projected to slow down in all regions. However, the various regions display very different patterns (see Figure 3.1 and Table 3.1). While in HIC annual growth rates until 2050 stay well below 0.5 percent and are close to zero by the end of the period, in many LMIC they range around 1 percent until 2030 and drop further later in the century. Notable exceptions to this pattern can be seen in SSA, which still displays annual growth rates of close to 2 percent in 2050, and China where – on the contrary – growth rates are almost zero by 2030 and become negative thereafter. Positive but shrinking annual growth rates to 2050 in all regions except China imply an expanding population in absolute terms compared to 2012. This expansion is notable in SSA, NNA and SAS, where populations are projected to increase by almost 140 percent, more than 60 percent and close to 40 percent respectively (see Table 3.1).

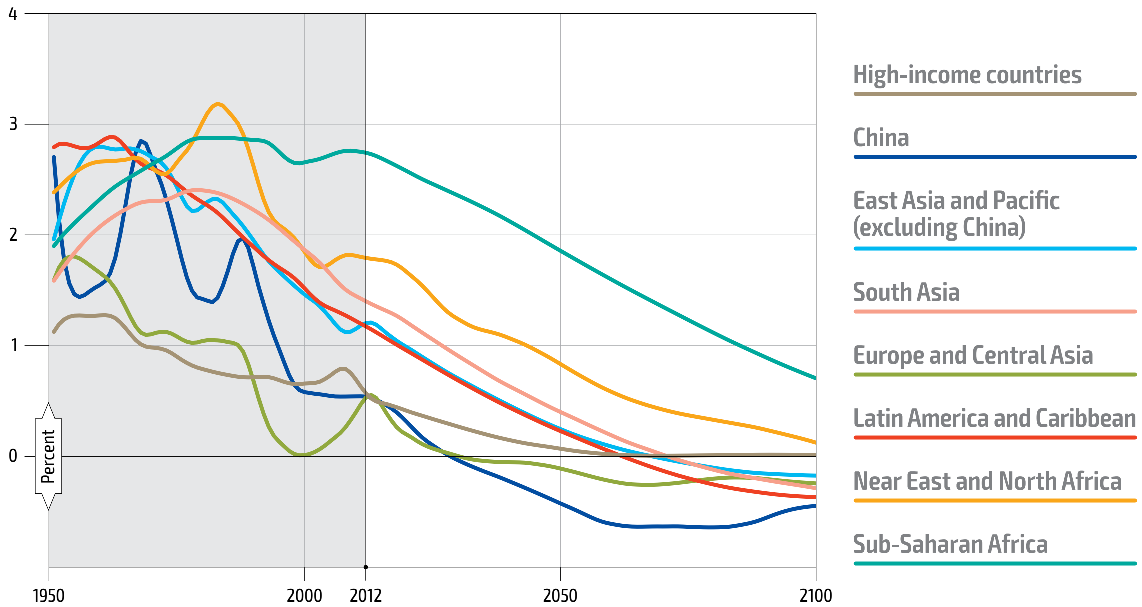
[41] Using the same population projections in the three scenarios helps maintain the focus on the possible impacts on food and agriculture of alternative patterns for consumer preferences, technologies and climate change.

Table 3.1 Population by region: historical trends and projections (medium variant)

	million people					percent				index, 2012 = 100			
	NUMBER					ANNUAL GROWTH RATES				VALUE			
REGIONS	1970	2002	2012	2030	2050	1970–2002	2003–2012	2012–2030	2031–2050	1970	2002	2030	2050
High-income countries	**855**	**1 088**	**1 167**	**1 251**	**1 288**	**0.8**	**0.7**	**0.4**	**0.1**	**73**	**93**	**107**	**110**
East Asia and Pacific	1 107	1 855	1 998	2 177	2 180	1.6	0.7	0.5	0.0	55	93	109	109
– China	809	1 284	1 355	1 416	1 348	1.5	0.5	0.2	-0.2	60	95	104	99
– East Asia and Pacific (excluding China)	299	570	643	761	832	2.0	1.2	0.9	0.4	46	89	118	130
South Asia	713	1 437	1 675	2 059	2 332	2.2	1.5	1.2	0.6	43	86	123	139
Europe and Central Asia	315	393	403	418	413	0.7	0.3	0.2	-0.1	78	97	104	102
Latin America and Caribbean	271	516	586	689	751	2.0	1.3	0.9	0.4	46	88	118	128
Near East and North Africa	129	288	344	455	559	2.6	1.8	1.6	1.0	37	84	132	163
Sub-Saharan Africa	292	705	924	1 452	2 202	2.8	2.7	2.5	2.1	32	76	157	238
Low- and middle-income countries	**2 828**	**5 194**	**5 930**	**7 250**	**8 437**	**1.9**	**1.3**	**1.1**	**0.8**	**48**	**88**	**122**	**142**
– Low- and middle-income countries (excluding China)	2 019	3 910	4 575	5 834	7 089	2.1	1.6	1.4	1.0	44	85	128	155
World	**3 682**	**6 282**	**7 098**	**8 501**	**9 725**	**1.7**	**1.2**	**1.0**	**0.7**	**52**	**89**	**120**	**137**

Source: UN, 2015.

Figure 3.1 Annual growth rates of population by region (medium variant), 1951–2100



Source: UN, 2015.

3.2 Total gross and world domestic product

Economic growth is another key factor driving the scenarios. Assumptions are specific for each scenario,[42] with the features of the various economic patterns as follows:

1. BAU is characterized by moderate gross world product growth (the sum of all countries' GDP, see last row of Table 3.2 a) at an average annual growth rate of 2.2 percent from 2012 to 2050. Gross world product grows faster until 2030 and slows down thereafter (see Table 3.2 a,b).[43]
2. In the TSS scenario, the gross world product grows at the same pace as in BAU but is more equitably distributed across countries.[44] As a result, GDP up to 2050 in LMIC is higher in this scenario compared with BAU, while the opposite is observed for HIC (see Table 3.2 a,b).
3. SSS is a relatively fast-growth scenario, with an average annual economic growth rate of 2.8 percent from 2012 to 2050. However, compared to the other two scenarios the differentials across countries are exaggerated to the advantage of HIC (see Figure 3.2).[45]

Table 3.2 Gross domestic and world product: historical trends and projections by scenario

a) Monetary values

REGIONS	billion USD, 2012 exchange rates									index, 2012 = 100		
	1970	2002	2012	2030			2050			2050		
	HISTORICAL		BASE YEAR	BAU	TSS	SSS	BAU	TSS	SSS	BAU	TSS	SSS
High-income countries	**15 679**	**41 166**	**48 671**	**69 041**	**63 712**	**72 622**	**85 421**	**62 937**	**101 780**	**176**	**129**	**209**
East Asia and Pacific	450	4 404	10 641	29 721	33 218	33 071	38 986	48 361	56 158	366	454	527
– China	221	3 128	8 471	24 515	27 487	27 415	30 864	37 383	44 853	364	440	528
– East Asia and Pacific (excluding China)	229	1 276	2 170	5 206	5 732	5 656	8 122	10 978	11 306	375	507	522
South Asia	279	1 140	2 316	5 846	6 680	6 422	9 039	14 329	13 060	388	615	561
Europe and Central Asia	205	2 341	3 768	6 802	6 908	7 305	8 508	8 301	11 214	226	220	298
Latin America and Caribbean	1 342	3 810	5 649	9 775	10 122	10 517	12 619	14 538	17 147	223	257	303
Near East and North Africa	409	1 092	1 645	3 421	3 439	3 624	5 721	6 022	7 358	354	373	455
Sub-Saharan Africa	387	946	1 603	4 075	4 603	4 048	8 431	14 236	7 956	524	885	495
Low- and middle-income countries	**3 072**	**13 733**	**25 623**	**59 641**	**64 970**	**64 987**	**83 304**	**105 788**	**112 893**	**325**	**413**	**441**
– Low- and middle-income countries (excluding China)	2 852	10 604	17 152	35 126	37 483	37 572	52 440	68 404	68 040	306	399	397
World	**18 752**	**54 898**	**74 294**	**128 683**	**128 683**	**137 608**	**168 725**	**168 725**	**214 673**	**227**	**227**	**289**

[42] GDP projections in the three scenarios are largely anchored to the SSPs described in the previous chapter (see Box 4). This facilitates comparability with other long-term, forward-looking exercises.

[43] The average annual growth rate of the world gross product in BAU is greater than the 1.4 percent that was assumed in (Alexandratos and Bruinsma, 2012). The economic growth rates at country level assumed in BAU mimic those of the SSP3 (see Box 4 and Annex I).

[44] The GDP distribution across countries mimics the distribution in SSP1 (see Box 4 and Annex I).

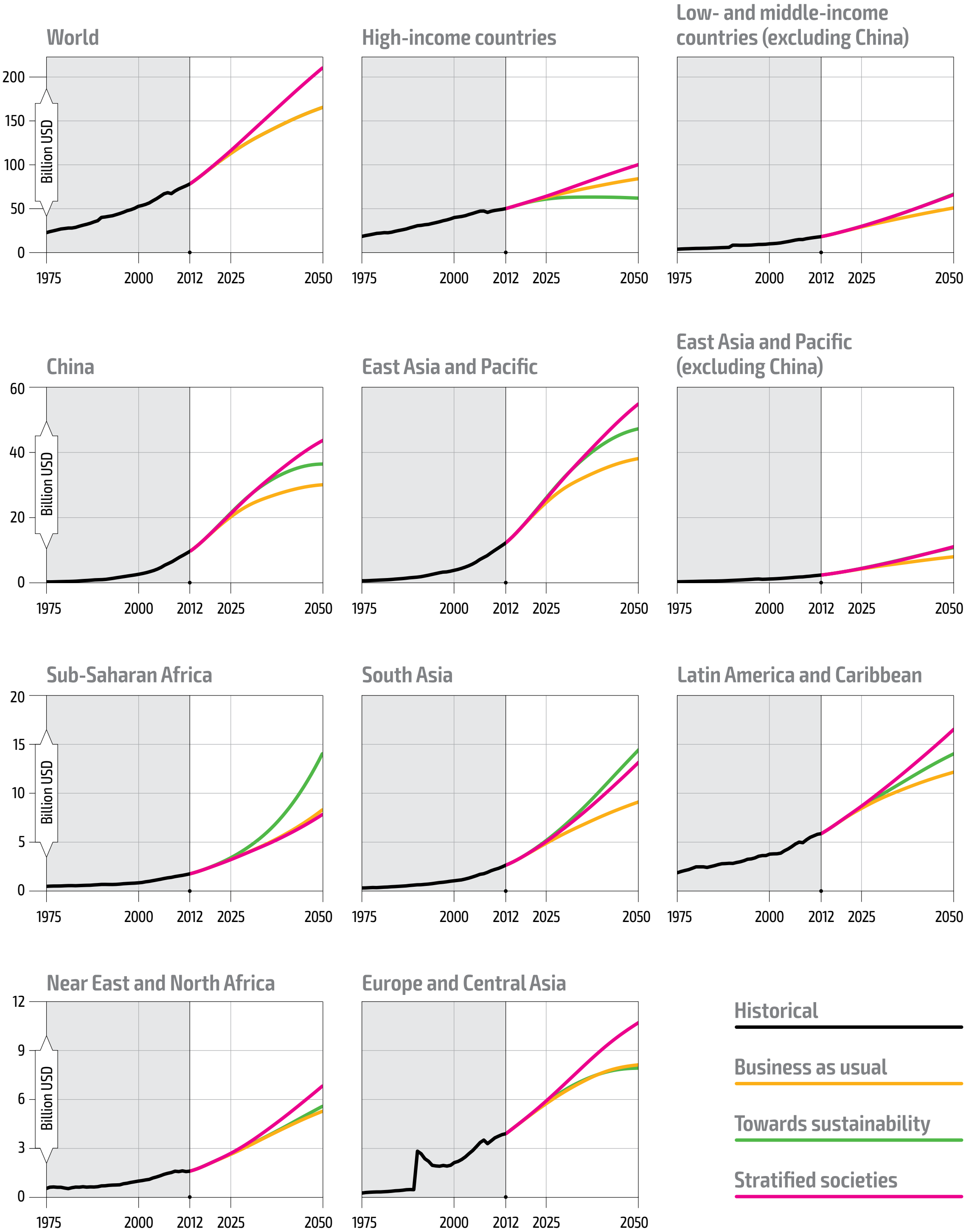
[45] Global and country growth rates replicate growth patterns in SSP4 (see Box 4 and Annex I).

b) Average annual growth rates

	percent											
	1970–2012	1970–2002	2003–2012	2012–2030			2031–2050			2012–2050		
REGIONS	HISTORICAL			BAU	TSS	SSS	BAU	TSS	SSS	BAU	TSS	SSS
High-income countries	**2.7**	**3.1**	**1.7**	**2.0**	**1.5**	**2.2**	**1.1**	**-0.1**	**1.7**	**1.5**	**0.7**	**2.0**
East Asia and Pacific	7.8	7.4	9.2	5.9	6.5	6.5	1.4	1.9	2.7	3.5	4.1	4.5
– China	9.1	8.6	10.5	6.1	6.8	6.7	1.2	1.5	2.5	3.5	4.0	4.5
– East Asia and Pacific (excluding China)	5.5	5.5	5.4	5.0	5.5	5.5	2.2	3.3	3.5	3.5	4.4	4.4
South Asia	5.2	4.5	7.3	5.3	6.1	5.8	2.2	3.9	3.6	3.6	4.9	4.7
Europe and Central Asia	7.2	7.9	4.9	3.3	3.4	3.7	1.1	0.9	2.2	2.2	2.1	2.9
Latin America and Caribbean	3.5	3.3	4.0	3.1	3.3	3.5	1.3	1.8	2.5	2.1	2.5	3.0
Near East and North Africa	3.4	3.1	4.2	4.2	4.2	4.5	2.6	2.8	3.6	3.3	3.5	4.0
Sub-Saharan Africa	3.4	2.8	5.4	5.3	6.0	5.3	3.7	5.8	3.4	4.5	5.9	4.3
Low- and middle-income countries	**5.2**	**4.8**	**6.4**	**4.8**	**5.3**	**5.3**	**1.7**	**2.5**	**2.8**	**3.2**	**3.8**	**4.0**
– Low- and middle-income countries (excluding China)	4.4	4.2	4.9	4.1	4.4	4.5	2.0	3.1	3.0	3.0	3.7	3.7
World	**3.3**	**3.4**	**3.1**	**3.1**	**3.1**	**3.5**	**1.4**	**1.4**	**2.2**	**2.2**	**2.2**	**2.8**

Sources: FAO Global Perspectives Studies, based on data from UN (2016) for the 1990–2012 period; and SSP database (2016) for the 2013–2050 period.

Figure 3.2 Gross domestic and world product: historical trends and projections by scenario (2012 exchange rates)



Sources: FAO Global Perspectives Studies, based on data from UN (2016) for the 1990–2012 period; and SSP database (2016) for the 2013–2050 period.

3.3 Per capita gross domestic and world product

Per capita gross domestic product – referred to here as per capita income – is another important variable in the scenarios, as it drives per capita consumption and savings. The long-term growth pattern observed since 1970, including recent different dynamics between HIC and LMIC, are reflected to various degrees in the patterns of per capita income that are assumed for the three scenarios.

In each scenario, the different regions display diverse patterns of per capita income

In both the BAU and TSS scenarios, global per capita income increases by more than 65 percent by 2050 compared to 2012 (see Table 3.3 a), and on average the annual growth rate is 1.3 percent (see Table 3.3 b). The prevailing assumption is that the global economic expansion observed over the last decade will slow down and get closer to historical long-term rates, particularly in LMIC. On the other hand, the SSS scenario shows a higher global growth pattern that doubles average global per capita income by 2050, with growth rates close to 2 percent per year. These different patterns across scenarios imply both temporal and regional specificities that reflect the range of assumptions on alternative socio-economic and environmental future patterns.

Table 3.3 Per capita gross domestic and world product: historical trends and projections by scenario

a) Monetary values

REGIONS	USD, 2012 exchange rates									index, 2012 = 100		
	1970	2002	2012	2030			2050			2050		
	HISTORICAL		BASE YEAR	BAU	TSS	SSS	BAU	TSS	SSS	BAU	TSS	SSS
High-income countries	**18 345**	**37 827**	**41 688**	**55 178**	**50 919**	**58 039**	**66 319**	**48 863**	**79 020**	**159**	**117**	**190**
East Asia and Pacific	407	2 375	5 326	13 655	15 262	15 194	17 880	22 180	25 756	335	416	483
– China	273	2 436	6 250	17 319	19 418	19 367	22 895	27 731	33 272	366	443	531
– East Asia and Pacific (excluding China)	768	2 238	3 376	6 841	7 531	7 431	9 757	13 189	13 582	290	392	403
South Asia	391	793	1 383	2 840	3 245	3 119	3 877	6 145	5 601	279	442	403
Europe and Central Asia	651	5 959	9 344	16 276	16 528	17 478	20 613	20 113	27 171	221	215	291
Latin America and Caribbean	4 952	7 386	9 646	14 178	14 681	15 253	16 795	19 349	22 820	174	201	237
Near East and North Africa	3 180	3 785	4 783	7 523	7 562	7 969	10 233	10 771	13 161	218	229	280
Sub-Saharan Africa	1 324	1 340	1 735	2 807	3 170	2 788	3 829	6 465	3 613	220	372	208
Low- and middle-income countries	**1 086**	**2 644**	**4 321**	**8 227**	**8 962**	**8 964**	**9 874**	**12 538**	**13 380**	**229**	**290**	**310**
– Low- and middle-income countries (excluding China)	1 412	2 712	3 749	6 021	6 425	6 440	7 397	9 649	9 598	198	258	256
World	**5 092**	**8 739**	**10 468**	**15 138**	**15 138**	**16 188**	**17 349**	**17 349**	**22 074**	**166**	**166**	**211**

b) Average annual growth rates

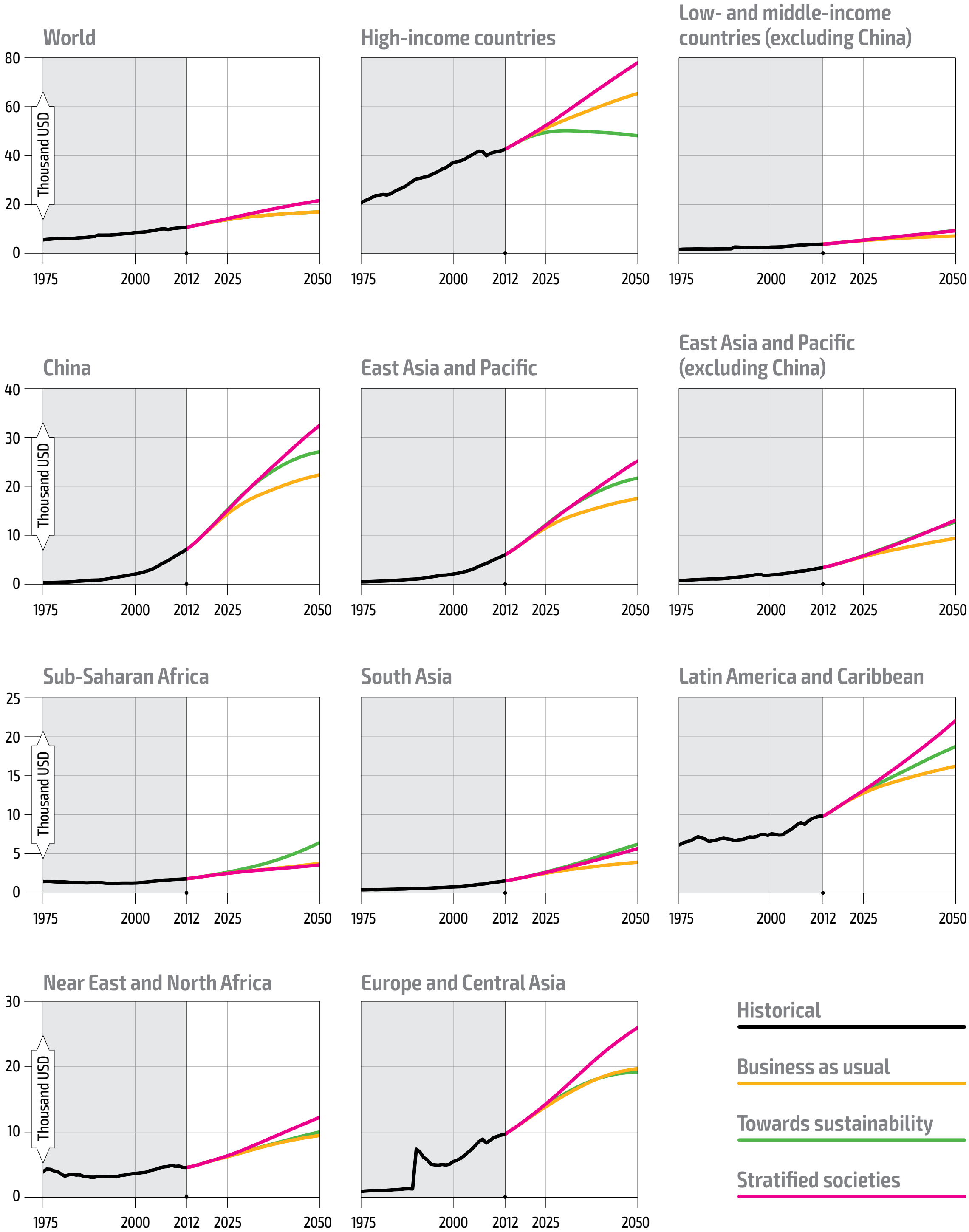
REGIONS	percent											
	1970–2012	1970–2002	2003–2012	2012–2030			2031–2050			2012–2050		
	HISTORICAL			BAU	TSS	SSS	BAU	TSS	SSS	BAU	TSS	SSS
High-income countries	**2.0**	**2.3**	**1.0**	**1.6**	**1.1**	**1.9**	**0.9**	**-0.2**	**1.6**	**1.2**	**0.4**	**1.7**
East Asia and Pacific	6.3	5.7	8.4	5.4	6.0	6.0	1.4	1.9	2.7	3.2	3.8	4.2
– China	7.7	7.1	9.9	5.8	6.5	6.5	1.4	1.8	2.7	3.5	4.0	4.5
– East Asia and Pacific (excluding China)	3.6	3.4	4.2	4.0	4.6	4.5	1.8	2.8	3.1	2.8	3.7	3.7
South Asia	3.1	2.2	5.7	4.1	4.9	4.6	1.6	3.2	3.0	2.8	4.0	3.8
Europe and Central Asia	6.6	7.2	4.6	3.1	3.2	3.5	1.2	1.0	2.2	2.1	2.0	2.8
Latin America and Caribbean	1.6	1.3	2.7	2.2	2.4	2.6	0.9	1.4	2.0	1.5	1.8	2.3
Near East and North Africa	1.0	0.5	2.4	2.5	2.6	2.9	1.6	1.8	2.5	2.0	2.2	2.7
Sub-Saharan Africa	0.6	0.0	2.6	2.7	3.4	2.7	1.6	3.6	1.3	2.1	3.5	1.9
Low- and middle-income countries	**3.3**	**2.8**	**5.0**	**3.6**	**4.1**	**4.1**	**0.9**	**1.7**	**2.0**	**2.2**	**2.8**	**3.0**
– Low- and middle-income countries (excluding China)	2.4	2.1	3.3	2.7	3.0	3.1	1.0	2.1	2.0	1.8	2.5	2.5
World	**1.7**	**1.7**	**1.8**	**2.1**	**2.1**	**2.5**	**0.7**	**0.7**	**1.6**	**1.3**	**1.3**	**2.0**

Sources: FAO Global Perspectives Studies, based on data from UN (2016) for the 1990–2012 period; and SSP database (2016) for the 2013–2050 period.

For example, in the BAU scenario different dynamics occur across countries. In HIC, the slow decline of per capita income growth rates observed in the last decade continues until 2050, albeit with some recovery from the financial crisis that occurred in 2007–2008. For the period 2013–2030, growth rates range around 1.5 percent while they average around 0.9 percent between 2031 and 2050 (see Table 3.3 b). Substantial transformations are not presumed for this scenario, as there is little innovation seen in production processes and therefore limited headway made towards sustainability, while there are hardly any changes in the energy mix. This pattern leads to a per capita income that almost moves along the historical trajectory. In LMIC (excluding China) the positive dynamics historically observed in the early 2000s – with growth rates ranging around 5 percent – are assumed to slow down to around 2.5 percent until 2030. Meanwhile China continues to display growth rates above 5 percent until 2030. Subsequently, for all LMIC the growth of per capita income further slows down significantly, with rates averaging less than 1 percent for the period 2031–2050.

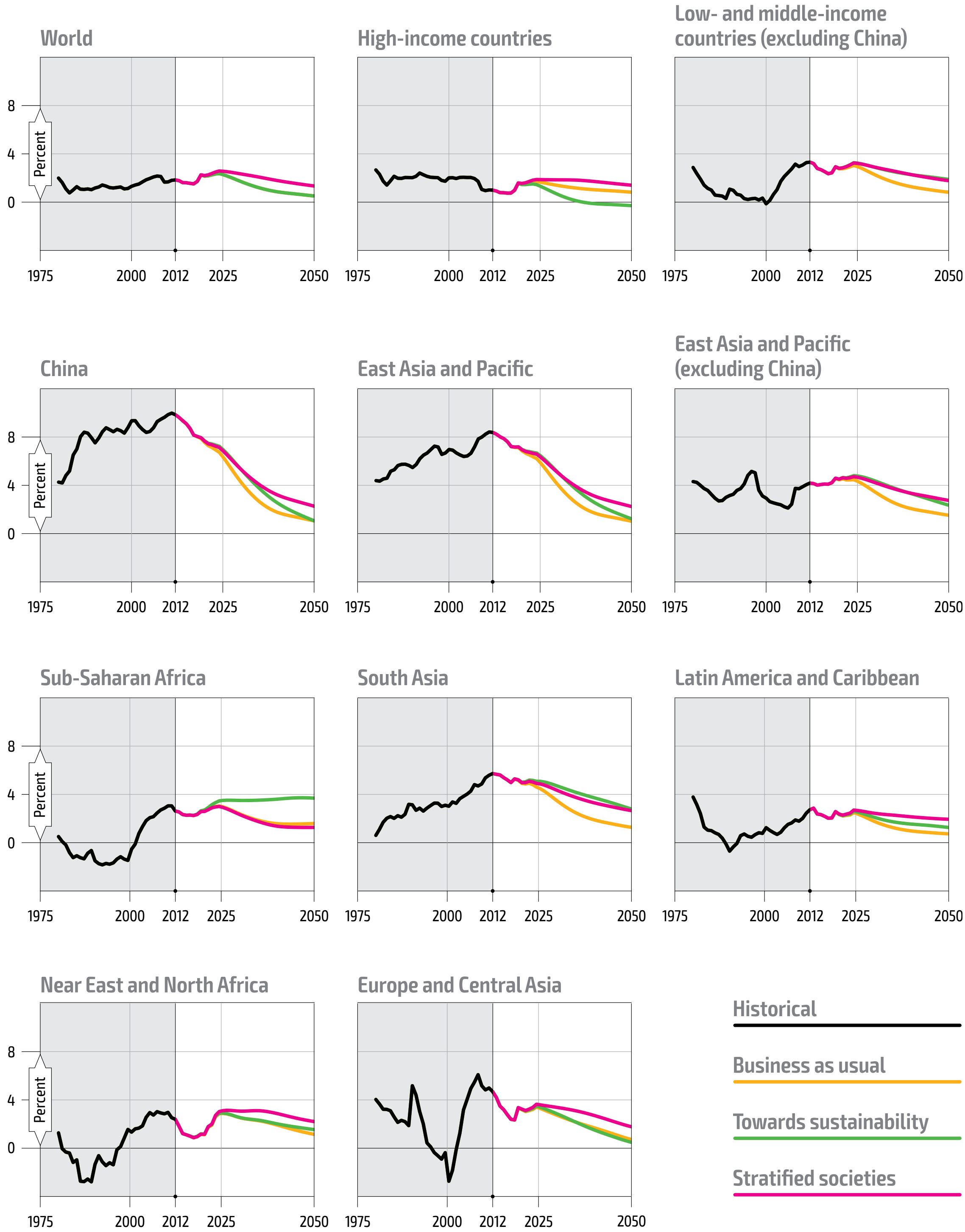
Things change in the TSS scenario, where production processes (including for energy and agriculture) experience a shift towards more sustainable, less resource-intensive technologies. In addition, consumer preferences shift towards more non-material ways of achieving welfare, which are not necessarily measured in terms of GDP per capita. Consistent with this, higher and fairer prices are paid for natural resources and raw commodities from LMIC and investment moves from HIC towards LMIC to boost economic growth in these countries. In HIC, these changes materialize in a lower per capita income growth rate than under BAU from 2013 to 2030, and a growth rate close to zero after 2030 (see Table 3.3 and Figure 3.3).

Figure 3.3 **Per capita gross domestic and world product: historical trends and projections (2012 exchange rates)**



Sources: FAO Global Perspectives Studies, based on data from UN (2016) for the 1990–2012 period; and SSP database (2016) for the 2013–2050 period.

Figure 3.4 Per capita gross domestic and world product: annual growth rates, historical and projections by scenario



Note: Historical data refer to ten-year averages.

Sources: FAO Global Perspectives Studies, based on data from UN (2016) for the 1990–2012 period; and SSP database (2016) for the 2013–2050 period.

On the other hand, more balanced development patterns and marked efforts to make progress towards sustainable development goals in LMIC stimulate investment in research, development and innovation; reduce the destruction of resources in conflicts; reinforce institutions; and enhance income-earning opportunities for the poor. All of this ultimately allows final consumption to expand, as reflected in positive per capita annual income growth rates of above or just below 2 percent until 2050. Nonetheless, dynamics are different across low- and middle-income regions: sub-Saharan Africa and SAS enjoy the largest annual per capita income growth rate at close to 4 percent between 2013 and 2050, with per capita incomes quadrupling in monetary terms (see Figure 3.4).

In all regions except SSA, per capita income growth rates are higher in the SSS scenario than for TSS or BAU (see Table 3.3 and Figure 3.3). However, there are serious concerns as to the sustainability of this growth, as it is achieved at high environmental and social cost. Use of fossil fuels leaves already fragile countries more exposed to climate change and extreme weather events: sub-Saharan Africa is particularly affected by reduced investment, relatively low agricultural growth and increasing within- and across-country inequalities. This region therefore lags behind others, with an average annual growth rate from 2012 to 2050 of 1.9 percent, compared to 2.1 and 3.5 percent under the BAU and TSS secenarios respectively.

3.4 Cross-country income inequality

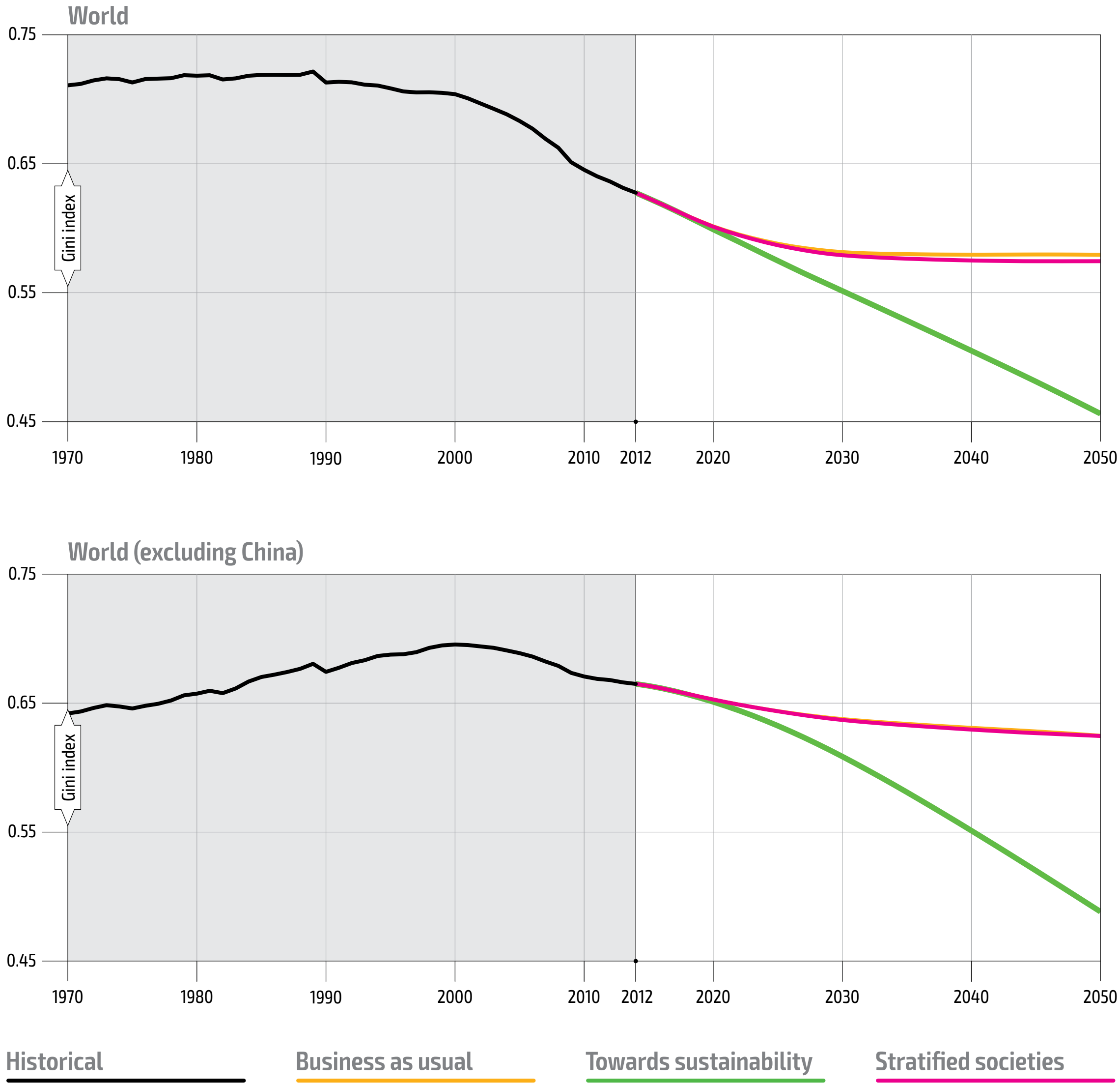
Scenario-specific regional income and population dynamics lead to varied per capita income distribution and different income convergence patterns across countries and regions.

The scenarios display diverse degrees of per capita income inequality

The BAU scenario shows quite a slow reduction of inequality up to 2050 compared with 2012, with the Gini index only dropping from 0.63 to 0.58.[46] If China is not factored into the calculation of this global inequality index, BAU portrays an even larger inequality up to 2050, with the Gini index only falling to 0.63 from an initial 0.67. The TSS scenario provides a more equitable income distribution across countries than BAU, with the Gini index significantly dropping between 2012 and 2050 to 0.46 (or 0.48 if China is excluded). As such, in TSS the downward trend observed globally in the last decade continues until 2050 (see Figure 3.5), while under SSS cross-country income inequality follows a pattern similar to the BAU scenario up to 2050.

46 The Gini index ranges from 0 (perfect equality) to 1 (maximum inequality).

Figure 3.5 Gini index of per capita income: historical trends and projections by scenario



Notes: The Gini index ranges from 0, representing perfect equality, to 1, representing maximum inequality. Values for BAU in the figure referring to World (excluding China) lie behind those for SSS.

Sources: FAO Global Perspectives Studies, based on data from UN (2016) for the 1990–2012 period; and SSP database (2016) for the 2013–2050 period. Population historical estimates and projections are based on UN (2015).

Per capita income convergence between low- and middle-income countries and high-income countries varies by scenario

Under the three scenarios, the convergence of the per capita income of LMIC to HIC, as measured by the per capita income ratio of LMIC to HIC, follows different patterns depending on the scenario and region.

Under the BAU scenario per capita income in LMIC (excluding China) shows very limited convergence, with the ratio only shifting from 9 percent in 2012 to 11 percent in 2050. This means that in 2050 the average per capita income in LMIC will be just 11 percent of that in HIC (see Table 3.4). Sub-Saharan Africa shows no convergence whatsoever, as its per capita income ratio ranges around historical trends until 2050 (see Figure 3.6). Only China exhibits a marked convergence pattern, with the ratio shifting from 15 percent in 2012 to 34 percent in 2050.

Table 3.4 Per capita gross domestic product by region, as percentage of that in high-income countries

REGIONS	percent									index, 2012 = 100		
	1970	2002	2012	2030			2050			2050		
	HISTORICAL		BASE YEAR	BAU	TSS	SSS	BAU	TSS	SSS	BAU	TSS	SSS
High-income countries	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100**	**100**	**100**
East Asia and Pacific	2.2	6.3	12.8	24.7	30.0	26.2	27.0	45.4	32.6	211	355	255
– China	1.5	6.4	15.0	31.4	38.1	33.4	34.5	56.8	42.1	230	379	281
– East Asia and Pacific (excluding China)	4.2	5.9	8.1	12.4	14.8	12.8	14.7	27.0	17.2	182	333	212
South Asia	2.1	2.1	3.3	5.1	6.4	5.4	5.8	12.6	7.1	176	379	214
Europe and Central Asia	3.5	15.8	22.4	29.5	32.5	30.1	31.1	41.2	34.4	139	184	153
Latin America and Caribbean	27.0	19.5	23.1	25.7	28.8	26.3	25.3	39.6	28.9	109	171	125
Near East and North Africa	17.3	10.0	11.5	13.6	14.9	13.7	15.4	22.0	16.7	134	192	145
Sub-Saharan Africa	7.2	3.5	4.2	5.1	6.2	4.8	5.8	13.2	4.6	139	318	110
Low- and middle-income countries	**5.9**	**7.0**	**10.4**	**14.9**	**17.6**	**15.4**	**14.9**	**25.7**	**16.9**	**144**	**248**	**163**
– Low- and middle-income countries (excluding China)	7.7	7.2	9.0	10.9	12.6	11.1	11.2	19.7	12.1	124	220	135
World	**27.8**	**23.1**	**25.1**	**27.4**	**29.7**	**27.9**	**26.2**	**35.5**	**27.9**	**104**	**141**	**111**

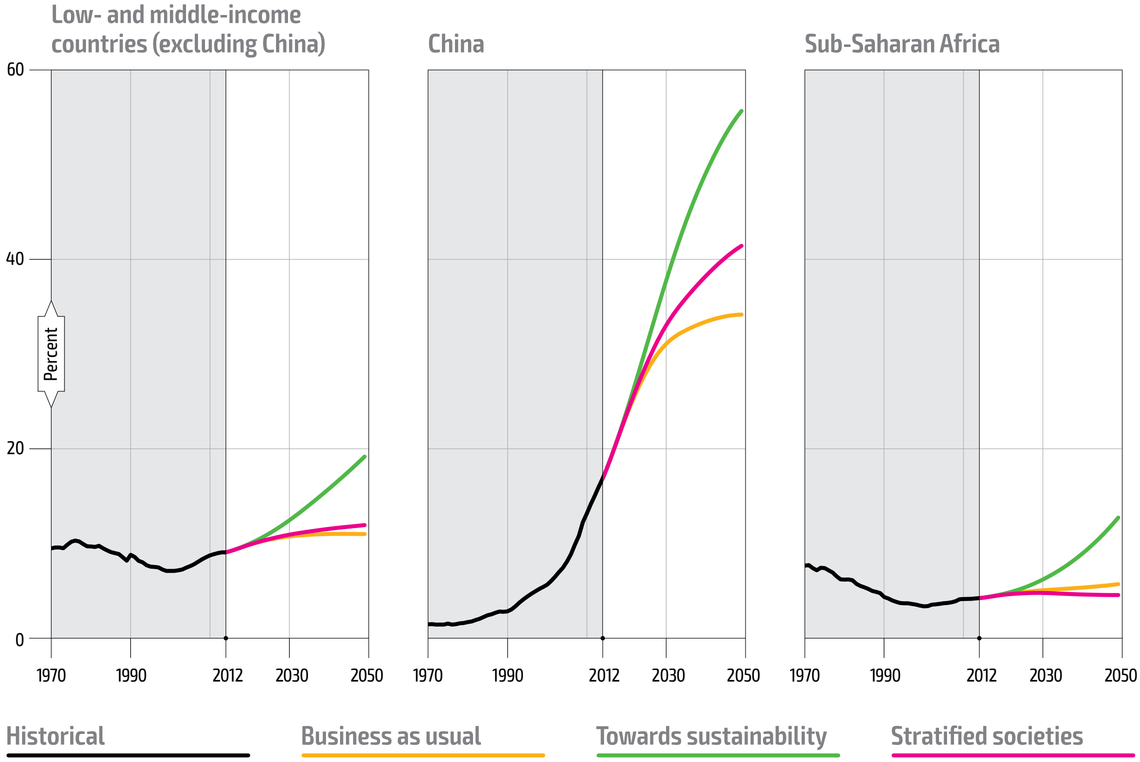
Sources: FAO Global Perspectives Studies, based on data from UN (2016) for the 1990–2012 period; and SSP database (2016) for the 2013–2050 period.

The TSS scenario shows a very different picture. Between 2012 and 2050 a significant increase in income occurs in LMIC (excluding China) relative to HIC – the ratio shifts from 9 percent in 2012 up to almost 20 percent in 2050 (see Figure 3.6). The speed of convergence is particularly marked in SSA, as the 2050 ratio nearly triples. However, even in this "low inequality" scenario the magnitude of convergence in the region is still very limited, as in 2050 per capita income remains a meagre 13 percent of HIC's (see Table 3.4). Convergence is also particularly marked in China and LAC, which see their ratios almost doubling by 2050 and per capita incomes at 56 percent and 39 percent of HIC, respectively. NNA, LAC and ECA follow positive convergence patterns as well (see Table 3.4).

The SSS scenario portrays per capita income convergence of LMIC towards HIC similar to that seen in the BAU scenario. Some regional specificities are noticeable however: while China shows stronger convergence than in BAU (but less than in TSS), SSA lags further behind (see Figure 3.6).

Overall, of the three scenarios only TSS ensures convergent growth patterns of per capita income in LMIC – including SSA – with HIC. Significant differences remain in TSS on the magnitude of this convergence however, with SSA still lagging significantly behind compared with other LMIC.

Figure 3.6 Per capita gross domestic product in low- and middle-income countries and China, as percentage of that in high-income countries



Sources: FAO Global Perspectives Studies, based on data from UN (2016) for the 1990–2012 period; and SSP database (2016) for the 2013–2050 period.

3.5 Capital intensity

Under the BAU and SSS scenarios, agriculture is assumed to remain much less capital-intensive in LMIC than in HIC. Under the BAU scenario, agricultural capital/output ratio in HIC remains around 4. For other regions excluding Africa, the ratio remains around 1.5, while for SSA it stays at around 1. The same assumptions apply for the SSS scenario.

Under the TSS scenario agriculture becomes more capital-intensive in LMIC, consistent with the convergence with HIC. Moreover, for all countries in this scenario (especially HIC) “old” capital is quickly phased out and replaced with “new” capital, as more environmentally-sustainable technologies are developed. This requires stepping up gross fixed capital formation in agriculture without necessarily increasing the net agricultural capital-output ratio, as capital is being transformed. For example, investing in land quality improvement would make it possible to: increase the organic content of the soil and limit land degradation; control transboundary diseases; manage antimicrobial resistance; transform the energy mix in agriculture towards renewable energy sources; and improve technology in livestock production to limit GHG emissions. In general, it is assumed that more investment in research and development in the medium term helps replace unsustainable agricultural practices with sustainable ones.

3.6 Food consumption, undernourishment, biomass feedstock demand and food losses

Developing scenarios also requires specifying how certain factors that drive demand for food and non-food agricultural commodities might evolve in the future. This refers to patterns of consumer preferences, demand for biomass feedstock to produce biofuel, food losses at the post-harvest, processing and wholesale levels, and key determinants of the prevalence of undernourishment, including food losses and waste in the downstream segments of food chains.

Food consumption preferences depend not only on income levels and prices, but also on consumer awareness

In long-term projections, consumer behaviour is determined by disposable income and the price of goods, amongst others. Empirical evidence suggests that: a) the share of expenditure on food consumption declines as income increases;[47] b) an income increase stimulates substitution away from carbohydrates (e.g. staple foods) towards higher value items such as vegetables and animal-based proteins; c) when income increases, the consumption of a good may increase ("normal" good), decrease ("inferior" good) or even increase faster than income itself (a special type of normal good, called "superior" or "luxury"), depending on the consumer's level of income, the price of the good, the price of other goods, and changing consumer preferences for reasons of culture or taste. While the scenarios capture these empirical observations, consumer behaviour varies across them. The diversities imply different assumptions regarding the parameters that shape food and non-food demand in all scenarios, which include income variability and "own-price" and "cross-price" elasticities, whose value changes as income and overall consumer preferences do.[48]

The BAU scenario assumes a continuation of historical trends of food preferences. As income progressively rises in HIC, income elasticities of food demand move in the opposite direction. This is more marked for animal-based foods than for staples or vegetable oils and fats. Rising incomes in HIC lead to lower consumption of animal-based food, giving way to micronutrient- and vitamin-rich foods such as fruit and vegetables. Given the relatively lower income levels in LMIC, staple foods continue to play an important role in food preferences, especially in the first half of the projection period. These countries start adopting patterns similar to HIC only after the second half of the projection period. Overweight, obesity and diet-related non-communicable diseases continue to increase worldwide following historical patterns. In HIC this is mainly due to higher consumption of processed food, while in LMIC it is due to lower incomes that do not allow consumers to switch to more high quality and nutritious food. Food waste at the consumer level is assumed to reproduce historical proportions in all regions under this scenario.

[47] Economists refer to this behaviour as "Engel's law", from the name of the German economist Ernst Engel (1821–1896) who first identified it.

[48] "Income elasticity of demand" measures the responsiveness of the quantity demanded of a good to a change in income, ceteris paribus. The categorization of goods as "normal", "inferior" or "superior" is based on the sign and magnitude of the income elasticity which can respectively be: negative, positive but lower or equal to one, or greater than one. Own- and cross-price elasticities are parameters that reflect the reaction of the consumer when the price of the good itself or that of other goods change, so that the entire elasticity matrix respects microeconomic theoretical properties of consumer behaviour. In all three simulations, price elasticities are adjusted as income elasticities change (see Annex III, Section 8.2).

Compared with the BAU scenario, TSS is characterized by lower preferences for animal-based foods and vegetable oils and fats, especially in HIC. These assumptions rely on the hypothesis that consumers are on average more educated and better informed about the health and environmental impacts of excessive consumption of animal proteins, especially meat. Dietary shifts towards more fruit and vegetables and less animal protein imply lower malnutrition, including reduced child and adult obesity. In the TSS scenario, consumers are also assumed to be more concerned about food waste than in BAU.

In the SSS scenario, consumer preferences are more oriented towards staple foods due to lower per capita income, particularly in SSA. On the other hand, preferences for animal products remain high in HIC as well as in several LMIC, not only due to higher incomes but also as they are less likely to be educated on the negative health and environmental implications of excessive meat consumption. The shift to higher consumption of animal products and foods rich in fat and sugars, combined with urban sedentary lifestyles, will further increase the risks of overweight and obesity compared to the BAU scenario. For these same reasons, consumers also waste a larger proportion of their purchased food than in the TSS scenario.

Equitability of food distribution is a determining factor in undernourishment

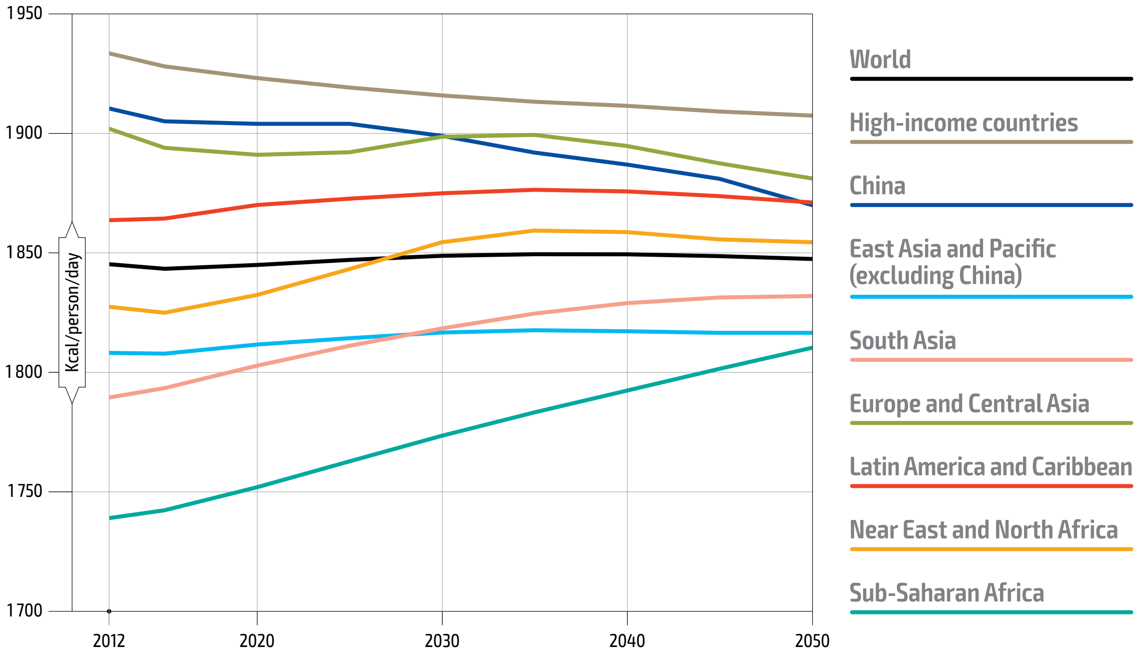
The number of undernourished people and the prevalence of undernourishment – defined as the percentage of people undernourished in a given population – are indicators used for measuring undernourishment. For this report measuring these two indicators relies on four key variables: the minimum average daily energy requirements (MDER); the variability (inequality) of food (caloric) distribution within the population, expressed by the "Coefficient of Variation" (CV); the mean level of per capita dietary energy consumption (DEC); and the mean level of per capita dietary energy supply (DES).[49]

For each country the MDER is calculated by taking into account the projected age structure of the population and the different minimum caloric requirements for the various ages. Given that projected population growth is the same in the three alternative scenarios, the MDER is also assumed to be the same across the scenarios, although it differs from country to country. Figure 3.7 shows the projected MDER for the different regions and the world.[50] Sub-Saharan Africa has the greatest expansion of MDER, due to the large number of young people that are projected to inhabit the region in the next decades. South Asia also shows strong growth in MDER, up until 2040 when it plateaus. On the other hand, ECA, HIC and China (which had the second-highest MDER in 2012) all witness a decline until after 2050, when the MDER would be expected to stabilize and converge towards the world average along with several other regions, including SSA, LAC and NNA. In 2050, all regions come closer to the world average, which remains relatively unchanged between 2012 and 2050.

[49] The methodology for calculating the prevalence of undernourishment and the number of undernourished people in the scenarios is very similar to that explained in FAO, IFAD, UNICEF, WFP and WHO (2017). For details please refer to Annex III.

[50] The minimum energy requirements for urban dwellers is 1 690 kilocalories/person/day, and 1 650 kilocalories/person/day for rural dwellers. For more details see FAO, 2008.

Figure 3.7 **Minimum dietary energy requirements in all scenarios**



Sources: FAO, IFAD, UNICEF, WFP and WHO (2017) for the base year 2012. For subsequent years: FAO Global Perspectives Studies' projections.

Unlike the MDER, the CV – which measures inequality of food (caloric) distribution – varies across both countries and scenarios. Under the BAU scenario the CV moves in the opposite direction to DEC, and the latter in turn changes with per capita income. If there is an increase in the income of consumers at different income levels, food (calorie) consumption rises more for the lower income levels, thus reducing inequality of food distribution and the CV.[51] Income inequality in the TSS scenario is assumed to be lower than in BAU both across and within countries. Given that lower income inequality is most likely to translate into lower inequality of food (calories) distribution, TSS also displays a lower CV for all countries compared with BAU, with the deviation between the two scenarios peaking in and remaining stable after 2030. The SSS scenario assumes higher between- and within-country inequality such that the CV is above that of BAU, with the deviation increasing gradually until it reaches a peak in 2030.[52]

Food losses at retail level affect consumption and undernourishment

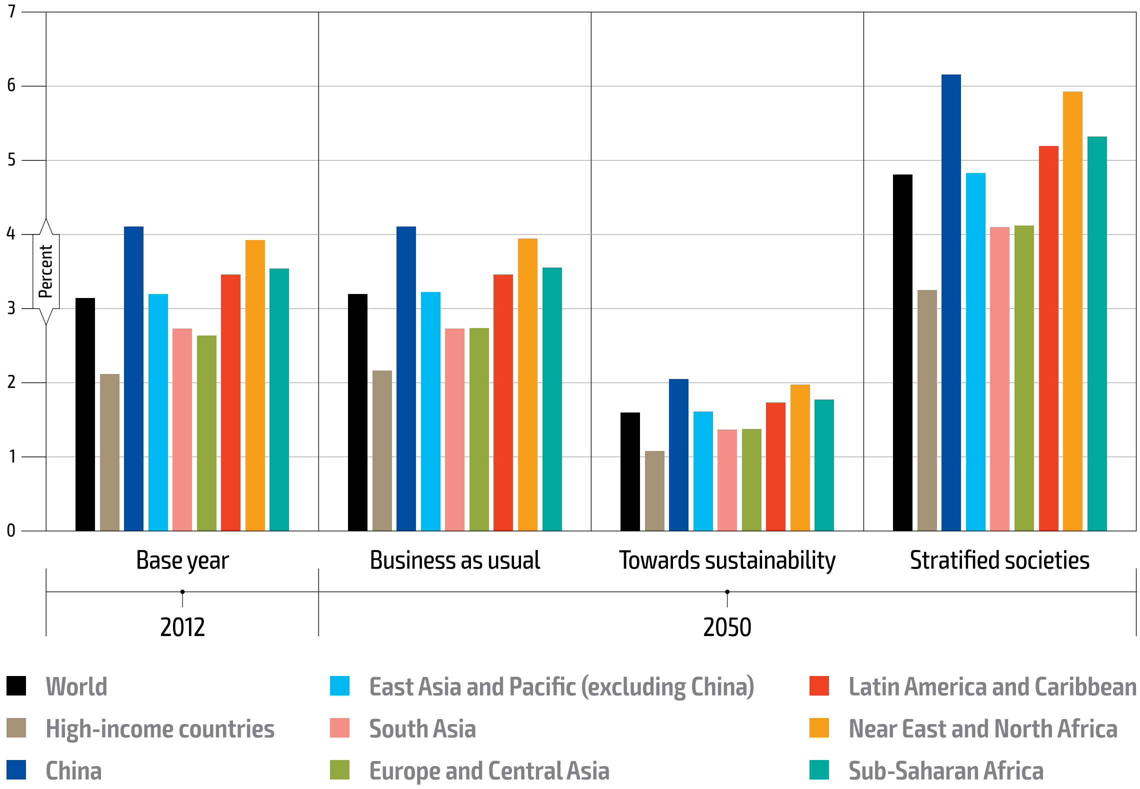
To compute per capita DEC, this foresight exercise relies on the FAO GAPS model, which provides daily per capita physical quantities of commodities for human consumption for each country and scenario. The sum of the corresponding calories is DES. DEC is calculated next by subtracting per capita food losses at the retail level from DES.

[51] The reduction of the CV when DEC increases rests on the assumption that: a) DEC increases due to a per capita income increase, which is proportionally (or at least sufficiently) distributed across the population to enable people at lower levels of food distribution to also increase their food consumption; b) "Engel's law" is at work, such that poorer people increase their food consumption more compared with richer people. An analogous assumption is made in FAO, IFAD and WFP (2015b).

[52] To ensure that food distribution over time evolves according to plausible values, all countries are clustered on the basis of their geographic region and per capita income level, and ranked according to their CV. For each cluster, the value of the CV for the third most/least equitable country (or countries) is used to impute the value of the CV for all other countries in the TSS/SSS scenario. For example, under the TSS scenario the value of the CV of Senegal and Kenya, the third most equitable countries, is imputed to all other sub-Saharan African countries.

The FAO estimate of global food losses at retail level for 2012, expressed as percentage of DES, was around 3.1 percent: in other words, globally in 2012 around 3.1 percent of food supplied was lost at retail level (see Figure 3.8). This share was lower in HIC (about 2.1 percent) and higher in LMIC. In China, some 4.1 percent of DES was lost, whereas in NNA losses were at 3.9 percent. In SSA and LAC, losses were 3.5 percent and around 2.5 percent in the rest of LMIC.

Figure 3.8 Food losses as percentage of Daily Energy Supply in all scenarios



Sources: FAO, IFAD, UNICEF, WFP and WHO (2017) for the base year 2012. For subsequent years: FAO Global Perspectives Studies' projections.

The food supplied that is lost at retail level, expressed as a percentage of DES, varies across regions and scenarios. Because BAU assumes a continuation of the 2012 percentages of food losses at retail level, in this scenario the ratio between DES and DEC remains constant throughout the simulation period.

In the TSS scenario, consumers are assumed to be more concerned about the environmental sustainability of food and agricultural systems. This leads to gradually reducing the percentage of food losses at retail level compared with BAU, until the percentage is halved in 2030 (see Figure 3.8). The percentages of food losses at retail level remain half of those in BAU throughout 2030–2050. As a consequence, the gap between DEC and DES is smaller than the gap in BAU.[53]

[53] For example, under TSS food losses at retail level between 2030 and 2050 are assumed to be about 1.6 percent of the DES globally, 1.1 percent in HIC, 2.1 percent in China, 2.0 percent in NNA and 1.6 percent in the rest of the LMIC. Under SSS they are expected to be at 4.8 percent of the DES globally, 3.1 percent in HIC, 6.2 percent in China, 5.9 percent in NNA and 5 percent in the rest of the LMIC.

The SSS scenario shows the most prominent food losses at retail level owing to a set of concurrent causes, including: boosted consumer purchasing power, particularly in HIC; lower awareness on the environmental implications of wasting food, due to generally lower education levels; and lower investments for improving existing capacities in food distribution. The percentages of food loss at retail level as a share of DES progressively increase until 2030, by some 50 percent worldwide compared with BAU and remaining at the 2030 level thereafter (see Figure 3.8). The SSS scenario then portrays a larger gap between DEC and DES.

Post-harvest losses absorb a fraction of available commodities

In addition to losses at retail level, a portion of commodities is lost in transportation and storage during the post-harvest stages and up to wholesale, due to poor and inadequate infrastructure. These losses may be considerable for perishable food that needs to be transported or stored for a long period of time in warm regions (such as tropical or temperate zones).

Base-year post-harvest losses and their future trends in different scenarios are determined by country and commodity group and on the basis of FAOSTAT commodity balance sheets (see Table 3.5).[54] For instance, in all countries the highest post-harvest losses are for fruit and vegetables: in LAC, the losses were as high as 16.5 percent of commodity availability and 11 percent in SSA.

Table 3.5 Post-harvest losses as percentage of commodity availability, 2012

REGIONS	CEREALS	FRUIT AND VEGETABLES	OILSEEDS	CASH CROPS	MEAT
High-income countries	**1.3**	**6.0**	**1.2**	**0.3**	**0.3**
East Asia and Pacific	5.9	8.9	2.6	0.4	0.1
– China	4.7	8.9	2.4	0.3	0.0
– East Asia and Pacific (excluding China)	8.2	9.1	3.2	0.9	0.3
South Asia	5.7	9.7	3.7	1.0	0.0
Europe and Central Asia	5.8	7.4	3.0	0.0	0.4
Latin America and Caribbean	9.1	16.5	1.4	2.8	1.3
Near East and North Africa	7.3	10.0	3.8	0.0	0.0
Sub-Saharan Africa	7.9	11.0	6.1	4.0	0.0
Low- and middle-income countries	**6.4**	**9.7**	**2.8**	**0.9**	**0.4**
– Low- and middle-income countries (excluding China)	7.1	10.4	2.9	1.3	0.6
World	**5.0**	**8.9**	**2.3**	**0.8**	**0.4**

Source: FAO Global Perspectives Studies, based on FAOSTAT (various years).

[54] The portion of commodities that is lost through waste is an element of FAOSTAT's commodity balances. It is calculated as a fixed percentage of availability, namely of the amount of the commodity that has been produced domestically, together with what has been imported and with what was stocked during the previous year.

BAU and SSS scenarios assume post-harvest losses remaining at 2012 levels for each commodity and region, caused by lack of infrastructural investment and handling technologies remaining inadequate to curb losses. Meanwhile in the TSS scenario, improved infrastructure (such as transport and storing facilities) and enhanced skills lead to post-harvest losses progressively diminishing until 2030, reaching 50 percent of the rates estimated in the other two scenarios and remaining thereafter stable until 2050. This change is gradually phased in to reflect the time it takes for investments in post-harvest handling to materialize. For example, this means that after 2030 in the TSS scenario, post-harvest cereal losses in SSA amount to around 4 percent of total cereal availability rather than 7.9 percent as in the other two scenarios.

Biomass feedstock demand for biofuel production competes with food and feed demand

Agricultural commodities are not only intended to meet demand for food and animal feed, but also for feedstock in biofuel production. For example, ethanol production is mostly based on sugarcane and maize, while biodiesel relies on the use of vegetable oils such as palm oil, soybean oil, rapeseed oil and jatropha oil. Biomass feedstock for these "first-generation" biofuels is in direct competition for land and water use with feed and food production, thus raising additional concerns for the overall sustainability of food and agricultural systems.

There are good reasons for identifying a separate type of demand for crops for first-generation biofuels: the demand for biofuels in recent years has been on the rise, due to a large extent to government incentives. These include mandatory blending requirements and more favourable prices for biofuel blends, which can be obtained for example through subsidies and taxes. Due to changes in these governmental incentives however, the OECD and FAO project diminishing growth for first-generation biofuel production over the next decade (OECD and FAO, 2017).[55]

The OECD and FAO (2017) projections on biofuel use of biomass were adopted to generate all three scenarios until 2026; after 2026 it was assumed that biofuel use would not be further expanded. This implies that installed capacities for first-generation biofuels will be maintained until 2050 and that any potential expansion of biofuels will be due to second-generation or emerging technologies.[56]

3.7 Greenhouse gas emissions and climate change

Each of the three scenarios in this foresight exercise presents specific levels of economy-wide and agricultural GHG emissions. To ease the projections of scenario-specific drivers and relevant variables related to climate change, the scenarios are associated with three RCPs. These are well-established, specific trajectories of GHG concentration in the

[55] On the contrary, the use of cellulosic ethanol feedstocks and wasted vegetable oils and fats is expected to grow further, whereas the use of biomass feedstock for first-generation biofuels is expected to decline.

[56] In this foresight exercise the demand for commodities that are used as feedstock for biofuel production is projected separately from that for commodities that are not for that particular use. Unfortunately, biomass feedstock use for biofuels is not a separate element in FAOSTAT's commodity balance sheets for the period 2011–2013, which are used to calibrate the quantitative models through which the scenarios are developed – it is instead part of what is called "industrial use". Information from OECD and FAO (2017) was used to calculate the share of biomass feedstock use in the domestic availability of each commodity for 2011–2013 (where domestic availability is the sum of domestic production and imports), such that biomass feedstock use for biofuels could be singled out. The quantity of each commodity used as feedstock for biofuels was then calculated by multiplying the commodity availability provided by FAOSTAT commodity balances by said share. Industrial use net of feedstock use for biofuels was then calculated by subtracting the quantity of biomass feedstock use for biofuels from "industrial use" in the FAOSTAT commodity balances, to ensure that the commodity balance was maintained for correctly calibrating the quantitative models.

atmosphere, defined by the international community working in climate research and adopted by the IPCC for its fifth assessment report (see Box 3). The lowest concentration pathway, RCP 2.6, assumes that emissions peak between 2010 and 2020 and decline substantially thereafter. Under RCP 4.5 and RCP 6.0, the peaks are assumed to occur around 2040 and 2060, whereas concentration continues to rise in RCP 8.5.

Adopting existing RCPs to build scenarios allows for the use of relevant information from existing crop and hydrological models that themselves use RCP-specific climate model data. In this foresight exercise, BAU, TSS and SSS are associated with RCP 6.0, RCP 4.5 and RCP 8.5 respectively.[57]

The required changes in annual GHG emissions to move along the three RCP trajectories by 2050 in our three scenarios are summarized in Table 3.6. Reaching these GHG concentration pathways will depend on the levels of activities in the various sectors of the economic systems, the magnitude of mitigation efforts undertaken, as well as on the timing of these efforts. Any delay in the onset of reduction measures implies more aggressive reductions later. For example, the 2015 Paris Agreement that aims to keep global warming to less than 2 °C above pre-industrial levels would roughly imply moving along an emission pattern between RCP 2.6 and RCP 4.5.[58]

Table 3.6 Changes in greenhouse gas emissions in 2050 compared to 2010 by representative concentration pathway

ppm	W/m^2	percent		°C
		CHANGE IN CO_2eq ANNUAL EMISSIONS IN 2050 COMPARED WITH 2010		
CO_2eq CONCENTRATION	RCP	From	To	2100 TEMPERATURE CHANGE RELATIVE TO AVERAGE 1850–1900
430–480	2.6	-72	-41	1.5–1.7
480–530		-57	-42	1.7–1.9
530–580		-47	7	2.0–2.3
580–650	4.5	-38	24	2.3–2.6
650–720	4.5	-11	17	2.3–2.9
720–1000	6.0	18	54	3.1–3.7
>1000	8.5	52	95	4.1–4.8

Notes: GHG concentration in the atmosphere is expressed in parts per million (ppm) of carbon dioxide (CO_2eq). The range for all parameters corresponds to the 10th to 90th percentile for all IPCC scenarios. In the table the temperature changes in degrees Celsius (°C) by 2100 referrs to the average temperature for the period 1850–1900. To relate these changes to the average temperature for the period 1986–2005, the difference between the average for 1986–2005 and 1850–1900 (0.61 °C) must be subtracted from the values reported in the table. The colours in the rows reflect the association of the different RCPs with the scenarios for this foresight exercise (see Box 3 for RCP definition).

Source: Clarke *et al.*, 2014.

57 In principle, a specific level of radiative forcing (the difference between insolation or sunlight absorbed by the Earth and the energy radiated back to space) implied by each RCP can be achieved through quite different socio-economic pathways and families of climate-related policies. Equally, the same socio-economic pathway can give rise to different changes in radiative forcing, depending on, for example, different assumptions about land-use changes. The association of specific SSPs or other socio-economic pathways and RCPs has been discussed in climate change literature (e.g. van Vuuren *et al.*, 2012 and 2014).

58 For example, moving along RCP 2.6 would require a 10 percent cut in emissions compared to 2015, and negative emissions (carbon capture and storage) in the second half of the century that led to a peak and a subsequent decline in cumulative emissions (Friedlingstein *et al.*, 2014). However, technologies to capture and store emissions are still in the early stages of development (Gasser *et al.*, 2015).

GHG mitigation in the agricultural sectors differs across scenarios

Significant uncertainties exist regarding emission targets from the agricultural sectors associated to the various RCPs. In fact, very few studies have assessed the mitigation targets for the agricultural sector. However, the targets set out above serve as rough indications for the economy-wide emissions compatible with each of the three scenarios, with different degrees of sustainability or lack thereof. Given the significant weight of the agricultural sectors in total GHG emissions (see Chapter 1), changes in these GHGs affect the pathway of total GHG concentrations.

Under the assumption that agriculture should contribute proportionally to changes in emissions (namely in analogy with the contribution from all other economic sectors) the economy-wide targets above can serve as a reference for the agricultural sector as well. Given that in 2012 global agricultural systems emitted around 5.2 gigatonnes of CO_2eq (FAOSTAT, various years), in the BAU scenario (associated with RCP 6.0) these emissions would not exceed 8.0 gigatonnes CO_2eq in 2050. In the TSS scenario (associated with RCP 4.5), GHG emissions from agriculture should broadly range between 3.2 and 6.4 gigatonnes of CO_2eq in 2050. On the other hand, SSS portrays emissions exceeding 8.5 gigatonnes of CO_2eq by the end of the period.

Calculating emissions from agricultural subsectors is another critical aspect of scenario building

In this report, emissions under the three scenarios are calculated for the crop and livestock subsectors by assigning activities (such as growing rice or rearing cattle) to emission factors that specify the amount of GHG emitted per unit of activity (such as area harvested or herd size). Emissions related to crop production considered here are methane from paddy rice cultivation, crop residues, and fertilizer;[59] these differ by country based on specific emission factors taken from FAOSTAT data.[60] Emissions from the livestock sector are calculated with animal system and country-specific factors derived from the Global Livestock Environmental Assessment Model (FAO GLEAM, 2017; Gerber *et al.*, 2013).[61]

The required reduction in total GHG emissions as production rises implies a reduction in emission factors. The large variations in emission factors across countries suggests significant potential for GHG mitigation in the agricultural subsectors even if production increases.

The scope for mitigation in this foresight exercise varies across scenarios and depends on the implementation of technological improvements, which are also specific to production systems. In the BAU scenario, it is assumed that the emissions of the 25th percentile of the lowest-emitting countries in the base year can be reached by all other countries, and emission factors are gradually reduced until 2050. For the TSS scenario, the more stringent 10th percentile applies.[62] No specific mitigation efforts are assumed in the SSS scenario.

[59] Note that this report does not provide estimated emissions from the cultivation of organic soils or from biomass burning, due to the large uncertainties related to these estimates. Emissions from energy use in agriculture are not considered here.

[60] Fertilizer application is estimated by interpolating crop-specific application rates for a limited number of crops and countries from the International Fertilizer Association (IFA and IPNI, 2017).

[61] Livestock related emissions exclude emissions related to land-use changes for feed production. FAO (2017c) documents version 2 of the GLEAM model.

[62] The assumptions underlying the statistical approach are described in detail in Gerber *et al.* (2013).

The GHG emissions calculated from the actual changes in the agricultural sectors in response to demand are compared with the assumed trajectories associated with the RCPs in Chapter 4.

3.8 Crop yields: technical change and climate change impacts

Annual crop production is a function of yields, arable land,[63] and the number of harvests per year – also known as cropping intensity. These components respond to changes in biophysical (i.e. agronomic, climate) and socio-economic conditions (i.e. technological changes, prices, demand) associated with each of the three scenarios.

This section summarizes the main assumptions regarding the components that affect crop production in the scenarios, and puts the expected changes into perspective based on the historical trends and specific characteristics of each scenario.

Technical progress influences future crop yields differently in each scenario

Future crop yield gains that result from technological improvements are scenario-specific and depend, for example, on choices made on investment in R&D, the way research is directed (e.g. towards small-scale or large-scale commercial agriculture) and the degree of innovation. In this foresight exercise, these aspects are captured in technology shifters, which can move yields up or down and are defined on the basis of existing empirical literature and past studies, as well as expert opinion (see Table 3.7 and Table S 2.1).[64]

In the BAU scenario these technology shifters cause crop yields to increase globally by some 30 percent between 2012 and 2050 due to technological progress only (see Table 3.7).

In the TSS scenario, farmers in countries with sufficient per capita income and adequate public support gradually shift towards more sustainable farming practices such as conservation agriculture, organic agriculture and/or other forms of sustainable agriculture.[65] However, limited information exists about the possible long-term impacts of large-scale adoption of these technologies on yields. Ponti *et al.* (2012) in a meta-study analysis found that yields in organic agriculture are on average 80 percent higher than in conventional agriculture. On this basis, in the absence of further research and information it was assumed that the large-scale adoption of sustainable practices under the TSS scenario is associated with lower yields (by around 10 to 20 percent) than those reached in the conventional systems assumed to prevail under the BAU scenario. This leads to an average global yield growth of almost 15 percent by 2050 compared to 2012 for all rainfed and irrigated systems, due to technical progress.

In the SSS scenario, the greater inequalities and resulting disparities in spending on R&D for agriculture translate into increasing differences in yield growth across regions: low-income regions (SSA, parts of EAP, and parts of LAC) achieve 80 percent to 90 percent of the yield growth they achieve under BAU conditions. The resulting overall yield growth by 2050 compared with 2012 and arising from technological change is close to 24 percent.

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[63] Following FAOSTAT terminology, the term "arable land" is used here for the physical area under temporary and permanent agricultural crops. The term "cropland" is hereinafter used synonymous of arable land.

[64] Tables with suffix S can be found in the supplementary material available at: www.fao.org/3/CA1564EN/CA1564EN.pdf

[65] Organic agriculture emphasizes methods such as crop rotation, natural management of pests, and a diversification of crops and livestock. Organic agriculture currently only occupies about 1 percent of the global agricultural land under organic production (Reganold and Wachter, 2016). The potential of conservation agriculture, agroforestry, organic agriculture and other innovative technologies as means to minimize the impacts of agriculture on emissions, biodiversity, fertilizer use and pollution of ecosystems, and to make food production more sustainable, deserves further investigation.

The impacts of climate change on crop yields are also diversified across scenarios

Crop yields will not only be driven by technical progress but are also expected to be impacted by climate change. Changing climatic conditions (rising temperatures, changing precipitation patterns, rising atmospheric CO_2 levels, etc.) will impact yields in a number of different ways depending on crop and location. There are considerable uncertainties associated with projections on the net impact of climate change on crop yields. For example, rising temperatures can cause faster crop development in general, but extreme temperatures can damage plant cells and lead to catastrophic losses. Some recent slowdowns in yields were in part attributed to changing climate conditions: for example rice yields in the Philippines were found to decline by 10 percent for each 1 °C increase of the minimum growing season temperatures (Peng *et al.*, 2004), while stagnating maize yields in France since 2000 were found to be associated with the number of days with a maximum temperature above 32 °C (Hawkins *et al.*, 2013).

Increasing variability of precipitation and more extreme events (floods and droughts) associated with climate change generally reduce yields (IPCC, 2014b). Rising atmospheric CO_2 levels can counteract some of the negative effects of climate change on yields through CO_2 fertilization.

The net effect of changing climate conditions depends on the balance of these effects and varies strongly by crop and region, while considerable uncertainties exist regarding the direction and magnitude of climate-change-induced impacts on crop production. Crop- and location-specific estimates of yield changes under variable climatic conditions are inferred from FAO-IIASA GAEZ data (see Box 7), which are specifically generated through simulations of attainable crop yields driven by a set of climate data from five different climate models. These model results suggest that climate change will have mostly negative impacts on yields, with reductions of around 5 percent globally by 2050 compared with 2012, with non-marginal regional variations (see Table 3.7).[66] Negative climate impacts tend to affect more LMIC (compared with HIC) because countries in this group are concentrated in the temperate zone and could even benefit from warmer temperatures. Climate change impacts on yields generally intensify with increasing GHG emissions: they are therefore expected to be highest under the SSS scenario and slightly stronger for rainfed systems than for irrigated ones.

Climate impacts and technical progress interact in determining crop yields

In general, by 2050 technical progress should outweigh the impacts of climate change (Figure 3.9 and Table 3.7).[67] Overall yield growth due to the combined effect of technical progress and climate change – other things such as prices being equal – ranges between 10 and 30 percent in 2050 compared with 2012. It also shows significant regional divergence as a result of differences in climate change impacts and technical progress.[68]

[66] The impacts of climate and technological progress on yields for important crops in each region are summarized in Table S 2.1.

[67] Climate change is expected to have more impacts on yields in the second half of the century.

[68] Actual yields not only depend on technological progress and the response to changing climate conditions, but also on economic variables such as market prices, which affect the decisions of agents regarding technical choices. The aggregated effects on yields on these three factors are discussed in Section 4.7.

BOX 7 Using information from the FAO-IIASA Global Agro-Ecological Zones (GAEZ) database

The scenarios proposed in this foresight exercise make ample reference to the FAO-IIASA Global Agro-Ecological Zones (GAEZ) database on the use and availability of natural resources and the impacts of climate change on agricultural sectors.

FAO-IIASA GAEZ is based on principles of land evaluation that were originally developed by FAO during a long-term collaboration with the International Institute for Applied Systems Analysis (IIASA). This approach uses climate data in combination with geospatial data sets of soil, terrain, and other agronomical and biophysical parameters to classify land according to its suitability for crop production, calculate potential yields, and assess related constraints on natural resources under current and future conditions. Land is classified, on the basis of a suitability index as optimal, sub-optimal, marginal or unsuitable.

The version used in this is report is 4.0 (GAEZ v4, unpublished), which is an extended update of the previous version (GAEZ v3, available at www.fao.org/nr/gaez/en and documented in IIASA and FAO, 2012). FAO-IIASA GAEZ v4 includes new baseline data on land cover, land production, protected areas and climatic conditions for the period 1961–2010. It also provides data for land suitability, yield, and other variables using recent IPCC AR5 climate model outputs for four different representative concentration pathways (RCPs) (see Box 3) at a spatial resolution of 5 arc-minutes (that is, a square of Earth surface or "pixel" of about 10 by 10 km at the equator).

The following datasets from FAO-IIASA GAEZ are used to assess natural resources in this report's scenarios.

Future attainable crop yield changes under climate change. Under future climate conditions, attainable yields are used to estimate the impact of climate change on future yields. The relative change between the base-year and future crop yields under the different climate change scenarios are applied to base-year yields obtained from FAOSTAT data. FAO-IIASA GAEZ provides crop yields both taking into account and discounting the effects of CO_2 fertilization on crops which can counteract some of the negative impacts of climate change. Not taking these effects into account generally leads to lower yields. However, FAO-IIASA GAEZ relies on a crop model and so it does not account for a number of processes that could have negative impacts on yields, such as heat stress during critical crop growth periods. In addition, it relies on simulated climate data from General Circulation Models (GCM) which may not capture small-scale and short duration features of the climate. Yields reported in this database could therefore tend to underestimate the potential impacts of climate change on crop yields. As a proxy for the processes that are not considered in FAO-IIASA GAEZ, the without-CO_2 fertilization results are used in this foresight exercise.

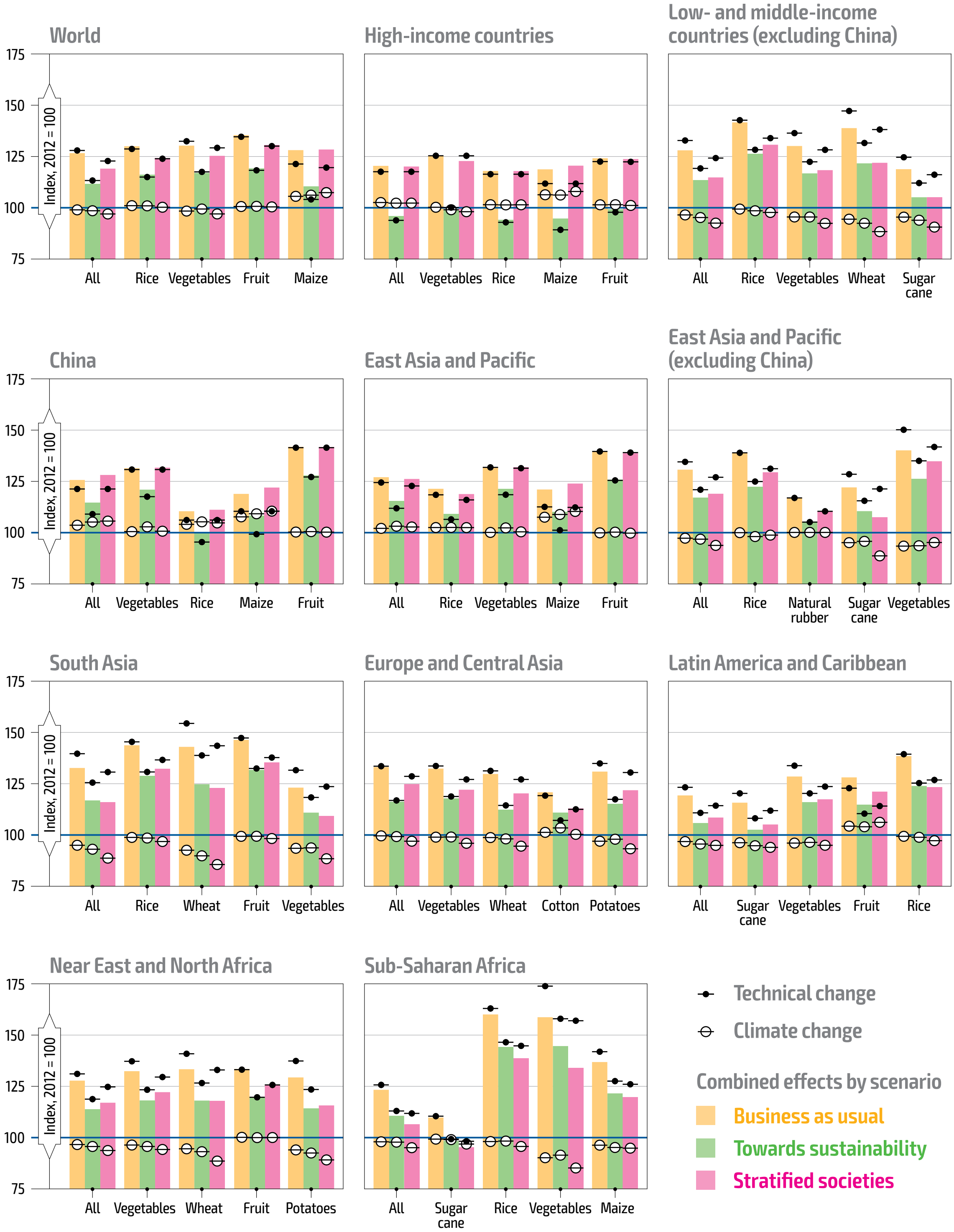
Future length of the growing period (LGP). FAO-IIASA GAEZ includes geospatial data on the LGP for a "reference crop" (a virtual crop with specific water requirements and physiological characteristics) for different climate drivers under historical and future conditions. The LGP is calculated for rainfed and irrigated areas, taking into account temperature and moisture conditions. LGP days are defined as days when actual reference evapotranspiration is greater than 50 percent of the potential evapotranspiration, and the mean daily temperature is above 5 °C. In irrigated areas the LGP is limited by the temperature threshold alone. This data is used to assess the potential changes to cropping intensity (the number of crops per year on a specific plot) in the future.

Harvested areas and yield differentials for each cropping system (irrigated and rainfed). Data on harvested areas are used to calculate the shares of irrigated and rainfed production systems by crop and yield differentials between the two systems in the base year. FAO-IIASA GAEZ includes geospatial datasets that are consistent with country-level FAOSTAT data on harvested areas, yields, and crop production. These are derived by disaggregating ("downscaling") country-level FAOSTAT production data for the period 2009–2011 to pixel level, by means of an iterative rebalancing approach that ensures matching country totals. The assignment of crops and crop systems to each pixel is based on FAO's Global Land Cover Share (Latham *et al.*, 2014), which provides high resolution land cover data, geospatial data on land equipped for irrigation (Global Map of Irrigated Areas available at www.fao.org/nr/water/aquastat/irrigationmap/index.stm, see Siebert *et al.* [2013]) and other datasets.

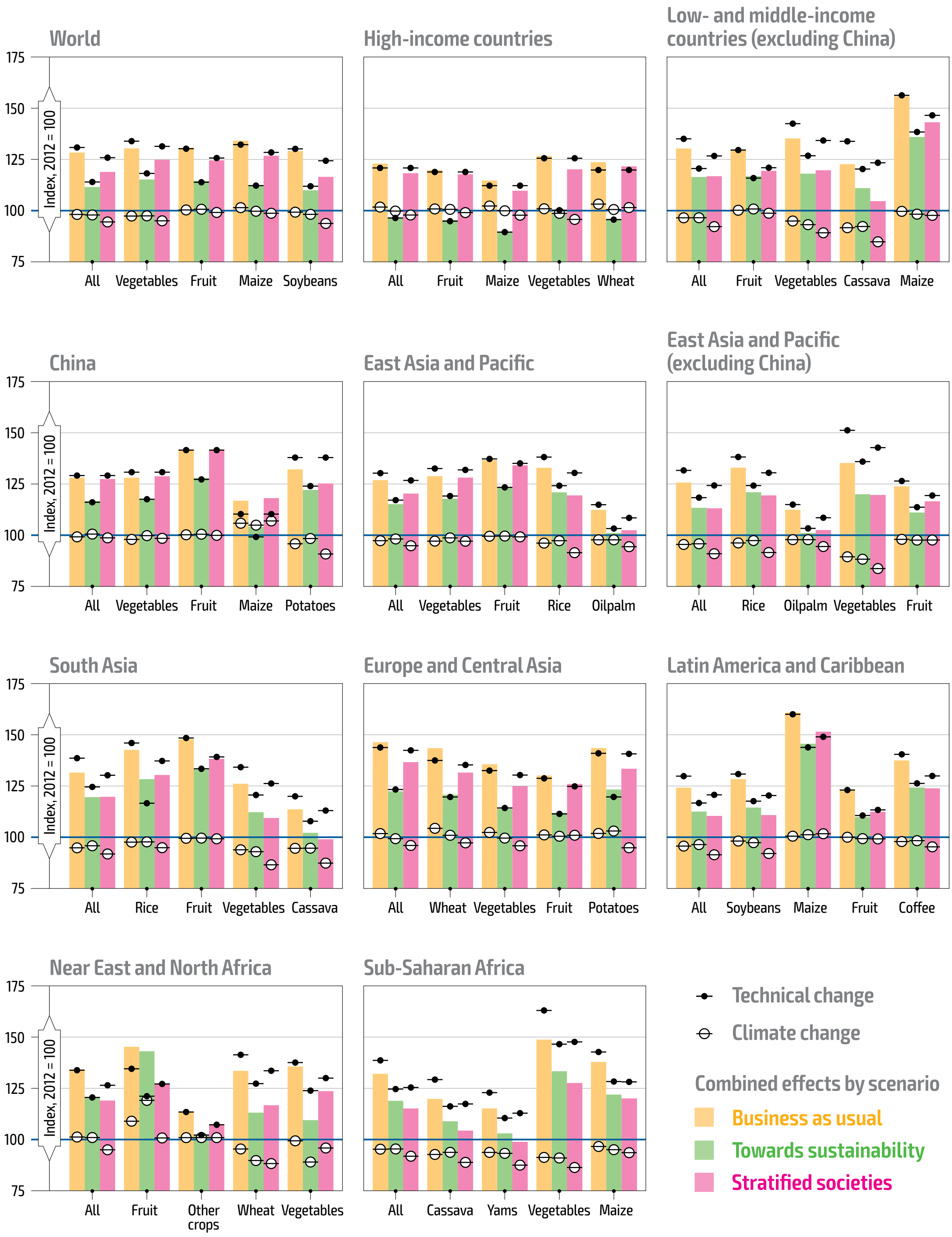
Land areas. Data on land cover is used to estimate the amount of suitable land available in the future under alternative climate scenarios. FAO-IIASA GAEZ includes pixel-level data on protected areas, based on a recent version of the World Database of Protected Areas (available at www.unep-wcmc.org), a comprehensive global dataset of marine and terrestrial protected areas that includes those under the International Union for the Conservation of Nature (IUCN) such as nature reserves and national parks, protected areas with an international designation status, such as World Heritage, Ramsar Wetlands areas, and those with national protection status. The land suitability assessment does not account for land productivity changing over time as a result of natural or man-made degradation, and may therefore overestimate potential land availability.

Figure 3.9 Yield changes from 2012 to 2050 due to climate change and technical progress

a) Irrigated systems



b) Rainfed systems



Note: Coloured bars indicate price-independent changes in yields attributed to both technical progress and climate change. The white circles indicate changes in yields arising from climate change, while the black barred dots indicate changes arising from technical progress. Climate change impacts are computed based on FAO-IIASA GAEZ v4 (scenario without CO2 fertilization, median value for five climate models). Changes in yields are shown for the four top commodities, as classified in the FAO GAPS model, in each region, and production system, ranked by value of production in 2012. In this figure, "Citrus" and "Other fruit" are aggregated into "Fruit". "All" refers to the aggregated change in production over the total harvested areas for all crops. Note that the results of research into the impacts of climate change on fruit trees are not conclusive (Ramírez and Kallarackal, 2015).

Sources: FAO Global Perspectives Studies, based on FAOSTAT (various years) for historical crop yields and value of production; FAO-IIASA GAEZ v4 for climate change shifters; and FAO expert judgement for technical shifters.

Table 3.7 **Projected yield changes from climate change and technical progress by period, production system and scenario**

REGIONS		TECHNOLOGY (index, 2012 = 100)						CLIMATE (index, 2012 = 100)						OVERALL (index, 2012 = 100)					
		2030			2050			2030			2050			2030			2050		
		BAU	TSS	SSS	BAU	TSS	SSS	BAU	TSS	SSS	BAU	TSS	SSS	BAU	TSS	SSS	BAU	TSS	SSS
High-income countries	RAINFED	**112**	**90**	**112**	**121**	**96**	**121**	**101**	**100**	**99**	**102**	**100**	**98**	**113**	**89**	**111**	**123**	**96**	**118**
	IRRIGATED	**110**	**88**	**110**	**117**	**94**	**117**	**101**	**101**	**101**	**102**	**102**	**102**	**111**	**89**	**111**	**120**	**96**	**120**
East Asia and Pacific	RAINFED	118	106	116	130	117	127	99	99	98	97	98	95	116	105	113	127	115	120
	IRRIGATED	115	103	114	124	112	123	101	101	101	102	103	103	116	105	115	127	115	126
– China	RAINFED	117	105	117	129	116	129	100	100	99	99	101	99	117	106	116	128	117	127
	IRRIGATED	113	102	113	121	109	121	102	102	103	104	105	106	115	104	116	126	115	128
– East Asia and Pacific (excluding China)	RAINFED	118	107	115	132	118	124	98	98	96	95	96	91	116	104	110	125	113	113
	IRRIGATED	120	108	116	134	121	127	99	98	97	97	97	94	118	106	113	131	117	119
South Asia	RAINFED	122	110	119	139	125	130	98	98	96	95	96	92	119	108	114	132	120	120
	IRRIGATED	122	110	118	140	126	131	98	97	95	95	93	89	119	106	112	133	117	116
Europe and Central Asia	RAINFED	127	109	127	144	123	143	101	100	98	102	99	96	128	109	124	146	122	137
	IRRIGATED	121	106	119	134	117	129	100	100	99	100	99	97	120	105	117	133	116	125
Latin America and Caribbean	RAINFED	116	105	112	130	117	121	98	98	96	96	96	91	114	103	108	124	113	111
	IRRIGATED	112	101	109	123	111	114	98	98	98	97	96	95	111	99	106	119	106	109
Near East and North Africa	RAINFED	119	107	116	133	120	126	100	100	97	100	100	94	119	107	112	134	120	118
	IRRIGATED	119	107	116	132	119	125	98	98	97	97	96	94	117	105	113	128	114	117
Sub-Saharan Africa	RAINFED	119	107	114	139	125	125	98	98	96	95	95	92	117	105	109	132	119	115
	IRRIGATED	113	102	107	126	113	112	99	99	98	98	98	95	112	100	104	123	110	106
Low- and middle-income countries	RAINFED	**119**	**107**	**116**	**134**	**120**	**127**	**99**	**99**	**97**	**97**	**97**	**93**	**118**	**105**	**113**	**130**	**116**	**119**
	IRRIGATED	**117**	**105**	**114**	**129**	**116**	**123**	**99**	**99**	**98**	**98**	**98**	**96**	**116**	**104**	**112**	**127**	**114**	**119**
– Low- and middle-income countries (excluding China)	RAINFED	120	107	116	135	120	127	98	98	96	96	97	92	118	105	112	130	116	117
	IRRIGATED	118	106	115	133	119	124	98	98	96	96	95	92	116	104	111	128	113	115
World	RAINFED	**117**	**103**	**115**	**131**	**114**	**126**	**99**	**99**	**97**	**98**	**98**	**94**	**116**	**102**	**112**	**128**	**112**	**119**
	IRRIGATED	**116**	**103**	**114**	**128**	**113**	**123**	**100**	**99**	**99**	**99**	**99**	**97**	**115**	**102**	**112**	**126**	**111**	**119**

Note: Indexes for all crops in a region are area-weighed aggregates across crops. Detailed information for the five most important crops by region is reported in Table S 2.1.

Source: FAO Global Perspectives Studies, based on FAOSTAT, for historical crop yields and value of production; FAO-IIASA GAEZ v4 for climate change shifters; and FAO expert judgement for technical change.

3.9 Cropping intensity

Cropping intensity is the average number of crop harvests on "arable land", or more precisely, the ratio of harvested area to arable land in a given year. Values above 1 indicate multiple crops per year on the same arable land; values below 1 indicate that crops were not harvested in all arable land due to economic reasons, climatic conditions, or some of the area being left fallow or used for rotation purposes, among others. Indeed, while the amount of arable land increased by 14 percent between 1961 and 2012, harvested areas globally increased by more than 37 percent, largely driven by higher cropping intensity.

Growth in cropping intensities has historically contributed an estimated 9 percent to the increase in crop production (Ray and Foley, 2013) and is frequently seen as one of the important mechanisms through which agricultural production can be expanded without using more land (Wu, You and Chen, 2015; Siebert, Portmann and Döll, 2010). For example, Alexandratos and Bruinsma (2012) projected that by 2050 cropping intensity would constitute 10 percent of the global increase in crop production, with the remainder being attributed to yield increases and expansion of arable land. Country-specific information on the potential cropping intensity under future climate change conditions is therefore of critical importance.

There is potential for increasing cropping intensity if appropriate investment is undertaken

Data on cropping intensity is not routinely reported and there are significant uncertainties in its development over time, particularly on a larger scale owing to issues related to its definition and inconsistent datasets. At the country level, base-year cropping intensities for irrigated and rainfed production systems can be compiled by matching data on harvested areas by production systems, obtained from the joint use of FAO-IIASA GAEZ v4 (see Box 7) and FAOSTAT, arable land from FAOSTAT, and area equipped for irrigation from FAO AQUASTAT. Merging these datasets to compute cropping intensities reveals significant variations by production system and region (see Table 3.8). Globally, cropping intensity in irrigated areas is generally larger (1.35) than under rainfed systems (0.74). Given the average cropping intensity of 0.86, there is potential to increase crop production through intensification in areas where only one growing season is possible, but this requires investing in suitable technologies and infrastructures.

Potential cropping intensity is much greater than the observed, actual cropping intensity. Using satellite and meteorological data to estimate cropping intensity for 2000, Wu, You and Chen (2015) found a global average cropping intensity gap of 0.48 for regions where the temperature is too low for some time during the year, and 0.17 for regions where the growing season is limited by temperature and moisture conditions. Potential future cropping intensites will respond to climate and weather.

Table 3.8 Average cropping intensities: historical, base year and projections by scenario

REGIONS	PRODUCTION SYSTEM	cropping intensity								index, 2012 = 100		
		1970	2012	2030			2050			2050		
		HISTORICAL	BASE YEAR	BAU	TSS	SSS	BAU	TSS	SSS	BAU	TSS	SSS
High-income countries	**IRRIGATED**		**1.03**	**1.12**	**1.28**	**1.17**	**1.20**	**1.38**	**1.33**	**117**	**134**	**129**
	RAINFED		**0.59**	**0.62**	**0.70**	**0.63**	**0.65**	**0.73**	**0.67**	**109**	**123**	**114**
	TOTAL	**0.50**	**0.64**	**0.69**	**0.77**	**0.70**	**0.73**	**0.80**	**0.77**	**113**	**125**	**119**
East Asia and Pacific	IRRIGATED		1.67	1.76	1.98	1.76	1.82	2.04	1.86	109	123	112
	RAINFED		1.02	1.03	1.17	1.02	1.02	1.17	1.01	100	115	99
	TOTAL	1.12	1.25	1.32	1.47	1.29	1.35	1.50	1.33	108	120	107
– China	IRRIGATED		1.79	1.91	2.17	1.93	2.01	2.30	2.08	112	128	116
	RAINFED		1.13	1.18	1.34	1.18	1.20	1.38	1.23	106	121	109
	TOTAL	1.33	1.44	1.57	1.74	1.56	1.68	1.83	1.70	117	127	118
– East Asia and Pacific (excluding China)	IRRIGATED		1.41	1.44	1.63	1.42	1.45	1.63	1.42	102	115	100
	RAINFED		0.94	0.94	1.06	0.92	0.94	1.05	0.91	100	112	97
	TOTAL	0.85	1.05	1.07	1.20	1.04	1.06	1.20	1.02	101	115	98
South Asia	IRRIGATED		1.33	1.36	1.55	1.34	1.37	1.58	1.35	103	119	101
	RAINFED		0.90	0.92	1.04	0.90	0.91	1.04	0.91	102	115	101
	TOTAL	0.91	1.10	1.14	1.27	1.10	1.14	1.27	1.11	104	115	101
Europe and Central Asia	IRRIGATED		1.13	1.24	1.43	1.27	1.34	1.57	1.43	119	139	127
	RAINFED		0.54	0.56	0.64	0.55	0.58	0.65	0.57	107	120	104
	TOTAL	0.65	0.59	0.62	0.70	0.61	0.64	0.72	0.63	108	122	106
Latin America and Caribbean	IRRIGATED		1.28	1.33	1.50	1.31	1.35	1.54	1.34	106	120	105
	RAINFED		0.76	0.76	0.86	0.74	0.75	0.84	0.71	99	111	94
	TOTAL	0.74	0.81	0.83	0.93	0.80	0.83	0.93	0.78	102	114	96
Near East and North Africa	IRRIGATED		1.19	1.24	1.39	1.22	1.27	1.43	1.27	107	120	107
	RAINFED		0.58	0.58	0.65	0.56	0.57	0.63	0.52	97	109	90
	TOTAL	0.62	0.77	0.78	0.85	0.74	0.76	0.81	0.71	99	106	92
Sub-Saharan Africa	IRRIGATED		1.13	1.19	1.38	1.16	1.22	1.44	1.20	108	128	106
	RAINFED		0.91	0.93	1.05	0.91	0.93	1.05	0.90	102	115	99
	TOTAL	0.68	0.92	0.94	1.06	0.91	0.94	1.06	0.91	103	116	99
Low- and middle-income countries	**IRRIGATED**		**1.41**	**1.47**	**1.67**	**1.46**	**1.50**	**1.72**	**1.51**	**107**	**122**	**108**
	RAINFED		**0.80**	**0.82**	**0.92**	**0.80**	**0.82**	**0.93**	**0.80**	**103**	**116**	**100**
	TOTAL	**0.85**	**0.93**	**0.96**	**1.07**	**0.93**	**0.97**	**1.08**	**0.93**	**104**	**116**	**100**
– Low- and middle-income countries (excluding China)	IRRIGATED		1.29	1.34	1.52	1.32	1.36	1.56	1.35	105	121	104
	RAINFED		0.77	0.80	0.90	0.78	0.81	0.90	0.78	104	117	101
	TOTAL	0.80	0.87	0.90	1.00	0.87	0.91	1.01	0.87	104	116	100
World	**IRRIGATED**		**1.35**	**1.42**	**1.61**	**1.41**	**1.46**	**1.67**	**1.48**	**108**	**124**	**110**
	RAINFED		**0.74**	**0.77**	**0.87**	**0.76**	**0.78**	**0.88**	**0.77**	**105**	**119**	**104**
	TOTAL	**0.71**	**0.86**	**0.90**	**1.00**	**0.88**	**0.92**	**1.02**	**0.90**	**106**	**118**	**104**

Note: In FAO AQUASTAT data for "irrigated areas" and "areas equipped for irrigation" are not reported for all countries and years. Data for the most recent year were used.

Source: FAO Global Perspectives Studies, based on FAO AQUASTAT (various years), FAOSTAT (various years) for historical and base-year values and FAO-IIASA GAEZ v4 for projected data.

Climate conditions will define different pathways for cropping intensities

Climate and weather influence cropping intensities in different ways. In regions where the length of the growing season is limited by temperature conditions, warmer temperatures can increase the areas where multiple crops can be grown in one year. In other regions, changing rainfall patterns may increase or decrease the length of the growing season – and therefore the potential cropping intensity under rainfed conditions – and this response to climate conditions may or may not point in the same direction as yield changes.

Changes in the potential cropping intensity in the future can be inferred from changes in the number of annual growing period days reported in FAO-IIASA GAEZ v4. In addition, the cropping intensity can increase in response to technological progress, a factor that is added in defining the different scenario narratives.

In the BAU scenario, the combined effect of those drivers results in a gradual intensification up to a total increase of 8 percent in 2050 compared with 2012, with significant increases in SSA and China (Table 3.8).

In the TSS scenario, the cropping intensity rises substantially in all regions thanks to the adoption of sustainable agricultural intensification technologies, which ensure sufficient nutrient availability in the soil as less synthetic fertilizer is used. It is important to note that achieving sustainable agricultural intensification implies a substantial paradigm shift towards reconciling rising human needs with the need to strengthen the resilience and sustainability of landscapes and the biosphere (Rockström *et al.*, 2017). This requires bold changes in the technological aspect of production systems, with a view to improving their ecological efficiency. Combined with the variations resulting from climate change, all this results in a global shift in cropping intensity from 0.86 to 1.02, respresenting an increase of nearly 20 percent, with significant regional differences (see Table 3.8).[69]

The SSS scenario resembles the global increase in cropping intensity seen in the BAU scenario, although the regional disparities in investments lead to higher intensification in HIC, China, and ECA, and reductions in NNA, LAC and EAP excluding China, relative to 2012.

3.10 Land and water expansion and boundaries

Cropland currently covers almost 13 percent of the Earth's land surface. Historically, the expansion of agricultural areas (cropland and pasture) has tremendously impacted natural ecosystems (Chapter 1). Such expansion generally took place at the cost of natural grassland and forest (Goldewijk, 2001), with large regional variations. Globally, arable land increased by 15 percent – from 1 380 million ha in 1961 to 1 585 million ha in 2014. FAOSTAT data suggests that on average 1.8 million ha of arable land have been added every year since 1991.

Additional agricultural land still available shapes future agricultural pathways

Determining how much additional land is available for agricultural purposes is of fundamental importance in foresight exercises on the future of food and agriculture, as it determines the feasibility and sustainability of alternative scenarios.

[69] Increasing cropping intensity generally requires more use of inputs such as fertilizer and water that could have additional impacts on water quality and aquatic ecosystems. Therefore, if the increase in the intensity is not accompanied by adequate measures to maintain the quality of land resources, intensification can lead to short-term gains in productivity but to a long-term deterioration of land resources, resulting in losses in yield and environmental conditions (Ray and Foley, 2013).

The availability of arable land in the future depends on a number of biophysical constraints such as soil suitability and land degradation due to natural bio-physical phenomena that are under the influence of changing climate conditions, as well as on socio-economic development and policy interventions such as area requirements for urban expansion, extent of conservative land management under the pressure of demand for land-based products or policies to protect valuable ecosystems (see Box 8). Land available for agriculture can be estimated by summing up areas where the land suitability data from FAO-IIASA GAEZ v4 indicates high potential for achieving yields.

The land available globally for irrigated and rainfed agricultural systems is equivalent to 2 735 million and 2 107 million ha, respectively.[70] However, many portions of these areas are either protected or already being used as cropland, or cannot be converted to cropland as they are allocated to other uses, for example to host urban populations.

Excluding protected areas (615 million ha today globally, according to FAO-IIASA GAEZ v4) and land cover classes that are already being used alternatively,[71] reduces suitable areas for rainfed crop production expansion to around 400 million ha (Table 3.9 and Figure 3.10). More than two-thirds of this land is located in LMIC. Of this, half is located in SSA (29 percent) and LAC (21 percent).[72]

BOX 8 The linkages between land and water management, economy-wide development patterns, climate change and societal welfare outcomes

Land and water availability and management practices are strongly influenced by socio-economic developments and climate change, which in turn have an impact upon the demand and supply of products that require land and water as inputs. The consumption of these products determines the degree to which societal welfare goals dependent on land and water systems are achieved.

The achievement of social goals such as food security and nutrition, but also to the creation of opportunities for income generation, equitable income distribution and several other SDG targets, is determined largely by production processes and outputs based on land and water resources, including food, raw materials, energy and a range of environmental services.

As such, the future achievement of land- and water-dependent societal welfare goals will be highly influenced by how land and water availability are affected by climate change; by how technical processes to produce land- and water-dependent products are managed; and by the extent to which development strategies and policies move land- and water-based production systems towards social, economic and environmental sustainability.

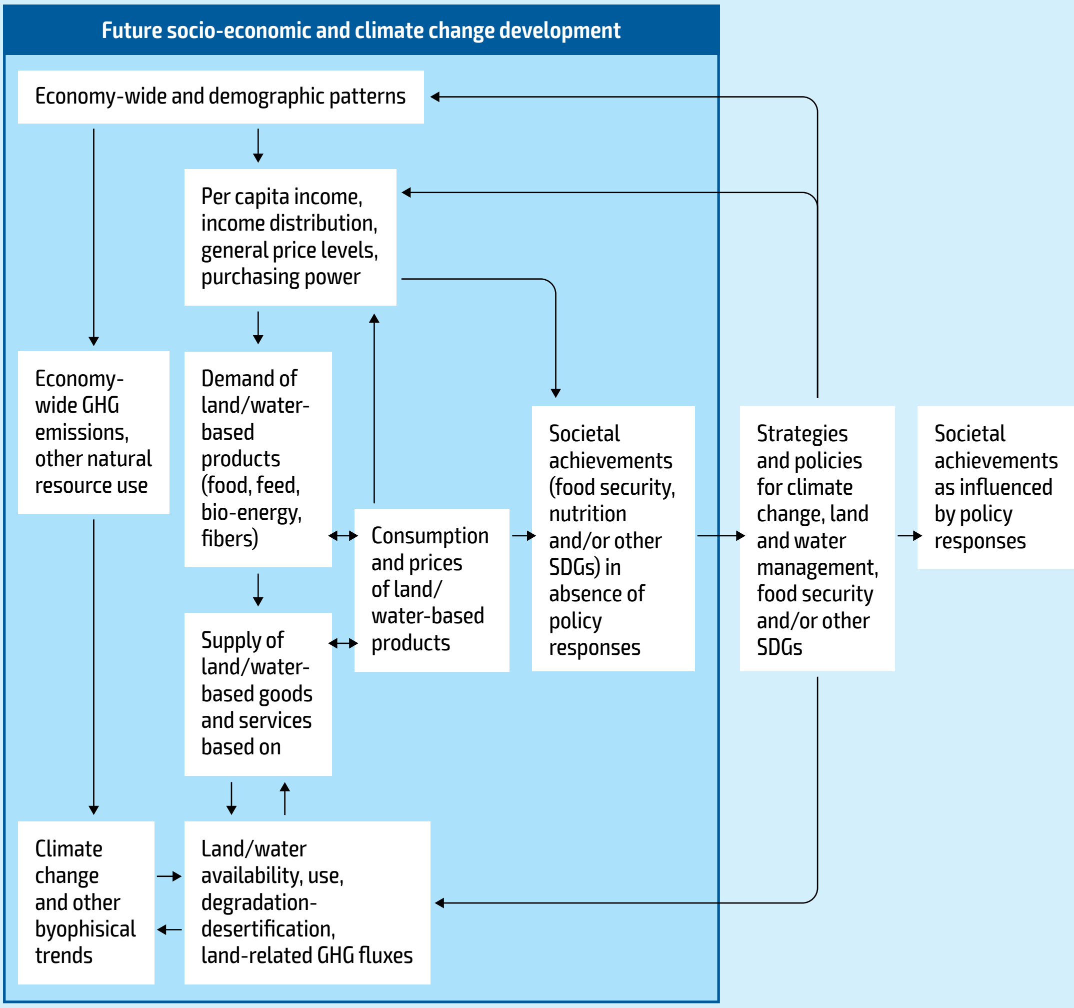
70 Note that these two systems may partly overlap in the same area. Also, the potential for irrigated systems does not consider water constraints as a result of which the effectively suitable area available may be lower.

71 Some land cover classes are excluded because of their own nature: “artificial surfaces”, “herbaceous, regularly flooded land”, “permanent snow and glaciers”, “water”, “mangroves” and “cropland”. “Tree covered areas” are excluded to limit deforestation.

72 These estimates of land availability are broadly consistent with other estimates but are strongly dependent on underlying assumptions. For example, intersecting earlier FAO-IIASA GAEZ v4 data with population density estimates and considering only 5 major crops, Deininger and Byerlee (2010) estimate that there are 445 million ha of land currently uncultivated, non-forested and not too densely populated (< 25 person/km^2) that would be suitable for rainfed production under current climate conditions. Considering only areas that are located within 6 hours from the next market would reduce the suitable area available to 263 million ha.

The design and implementation of effective strategies for the sustainable management of land and water resources and the achievement of welfare goals, including food security and improved nutrition, requires an understanding of the cause–effect and impact interrelationships between these factors (see the figure below).

Climate change, land, water and welfare outcomes in the economy-wide context



Source: FAO Global Perspectives Studies.

Future economic and demographic trends will determine changes in income earning opportunities, income distribution and thus people's purchasing power; this purchasing power will in turn condition the consumer demand for goods and services dependent on land and water resources. Economic and demographic patterns will also determine the dynamics of GHG emissions, which will affect land and water availability.

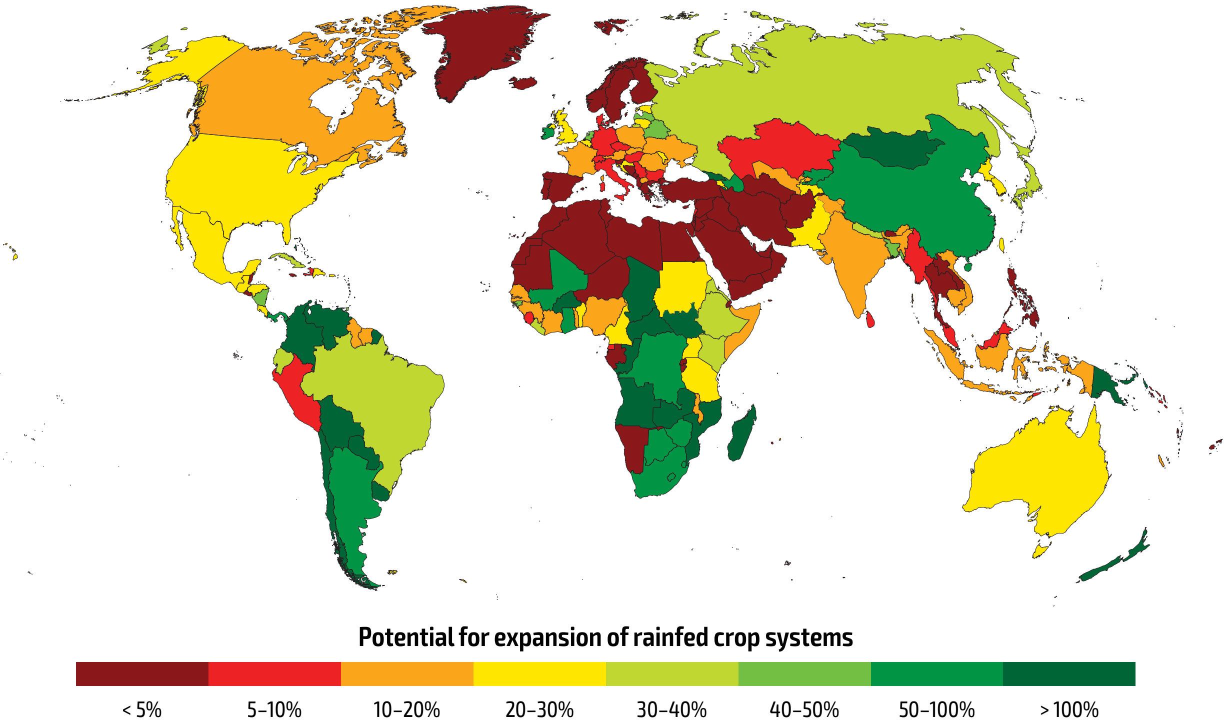
The demand for goods and services dependent on land and water resources impels the supply of such goods and services. The land and water input requirements of this supply – and thus the pressure upon available land and water resources and the amount of GHG emissions caused – are influenced by technologies and management practices with an impact on the productivity of land and water resources.

The interplay between the supply and demand of land- and water-dependent products and services determines the actual production and consumption of these products and services, as well as their prices.

The achievement of land- and water-dependent societal welfare goals is determined by the consumption of land- and water-dependent (and other) products, as well as by the income generated throughout their production processes.

Strategies and policies to mitigate climate change, improve land and water management systems, achieve food security, improve nutrition and achieve other SDG targets influence the production processes of land- and water-dependent goods and services; they feed into economy-wide processes and influence the income distribution. The response of the socio-economic agents involved in land- and water-dependent production and consumption processes influences the achievement of land- and water-related objectives and societal welfare targets that would not be reached in the absence of such strategies and policies.

Figure 3.10 Potentially highly suitable additional land for rainfed cropping systems, 2012



Note: Data refers to available areas that are not protected or already in use, under current climatic conditions. Note that these estimates consider neither degradation nor urbanization. Percentage changes refer to current rainfed areas by country.

Sources: FAO Global Perspectives Studies, based on FAO-IIASA GAEZ v4 and Latham *et al.* (2014).

The estimate of about 400 million ha of highly suitable land available for rainfed agriculture expansion represents 26 percent of the arable area in use today.[73] However, it should be noted that this is a net balance of newly-cultivated areas and areas that are no longer cultivated because the productivity of significant portions of land has decreased due to degradation.

[73] The potential cropland under irrigation can also be calculated from FAO-IIASA GAEZ v4, but it would not be based on actual water constraints so it is not meaningful to assess the actual land potential.

The term "land degradation" is typically used to indicate a deterioration of the biophysical value of the environment that can be caused by human-induced or natural processes. Such processes include desertification, salinization, compaction, or encroachment of invasive species (Gibbs and Salmon, 2015). The numerous definitions of degraded land contribute to uncertainties regarding its extent and severity, with estimates varying from less than 1 billion ha to over 6 billion ha (Gibbs and Salmon, 2015). FAO estimates that 33 percent of the world's farmland is moderately to highly degraded (FAO, 2014), while Lambin and Meyfroidt (2011) estimate that between 1 million and 2.9 million ha of land per year become unsuitable for cultivation, with high rehabilitation costs. Despite the important challenge degraded land poses to sustainable development, no globally consistent or georeferenced database on land degradation exists.[74]

Cultivated areas are not only abandoned when they lose some of their productivity potential, they can also be converted into land for other purposes. For example, it is estimated that urban expansion will result in a loss of croplands of between 1.8 percent and 2.4 percent, mostly in Asia and Africa (Bren d'Amour *et al.*, 2017), which corresponds to an annual loss of 1.6 million to 3.3 million ha per year (Lambin and Meyfroidt, 2011). Furthermore, increases in herd size (see Chapter 3.11) will require additional grazing land that could compete with land for crop production.

Changing climate conditions lead to regional variations in future land suitability for crop production. The different scenarios designed for this foresight exercise therefore portray various possibilities of additional land available for cropping.

Data from FAO-IIASA GAEZ v4 used in the design of the BAU scenario suggest that around 360 million ha of additional, unprotected, and highly suitable areas for rainfed crop production will be available by 2050. A net loss of around 6 percent due to climate change compared with 2012, particularly in EAP and NNA (Table 3.9). Lower emissions in the TSS scenario result in overall loss similar to BAU, but different geographic distribution.

The SSS scenario assumes very little mitigation, with climate change leading to a loss of around 14 percent of highly suitable land, particularly in EAP, SSA and NNA.[75]

The boundaries for additional very suitable and unprotected cropland, although not strictly binding for the expansion of arable land, are considered in Chapter 4, where the feasibility and sustainability of alternative scenarios for the future of food and agricultural systems are assessed.

[74] Reducing degradation is one of the targets of SDG 15: "By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world. The related indicator 15.3.1 – proportion of land that is degraded as fraction of total area."

[75] However, note that climate change impacts might exacerbate losses in land productivity through degradation and other mechanisms, but that these are not explicitly considered here. For example, a sizeable fraction of cropland (12 percent) is currently located within 100 km of the coastline (Kummu *et al.*, 2016). The productivity of those areas might be affected by the impacts of sea level rises. The projections of sea level rises by the IPCC under the RCP 6.0 scenario are between 0.32 and 0.63m (Church *et al.*, 2013). Besides the immediate impacts of sea level rises on coastal areas (submergence, increased flooding, saltwater intrusion), longer-term effects include increased erosion and saltwater intrusion to groundwater. These impacts are more apparent in densely-populated coastal areas in Africa, and South, Southeast and East Asia, and for small island states (Nicholls and Cazenave, 2010) but are not considered in our estimates.

Table 3.9 Potential additional, unprotected, and highly suitable areas for rainfed crop production: base year and projections by scenario

	million hectares				index, 2012 = 100		
	2012	2050			2050		
REGIONS	BASE YEAR	BAU	TSS	SSS	BAU	TSS	SSS
High-income countries	**82**	**78**	**87**	**75**	**95**	**105**	**92**
East Asia and Pacific	41	41	43	35	99	104	85
– China	32	33	34	30	100	105	93
– East Asia and Pacific (excluding China)	8.7	8.1	8.7	4.8	92	100	55
South Asia	13	12	13	11	94	101	85
Europe and Central Asia	51	51	52	49	100	103	96
Latin America and Caribbean	80	76	78	68	94	97	85
Near East and North Africa	0.20	0.07	0.16	0.04	34	79	19
Sub-Saharan Africa	114	103	111	90	90	97	79
Low- and middle-income countries	**300**	**282**	**297**	**254**	**94**	**99**	**85**
– Low- and middle-income countries (excluding China)	267	250	263	223	93	98	84
World	**382**	**360**	**384**	**329**	**94**	**100**	**86**

Note: Data refer to available areas that are not protected or already in under current conditions. These estimates have considerable uncertainties and should therefore only be taken as rough indicators.

Sources: FAO Global Perspectives Studies, based on FAO-IIASA GAEZ v4 and Latham *et al.* (2014).

Irrigation potential is critical for understanding productivity and climate adaptation possibilities

Irrigation, both full and supplemental, plays an important role in enhancing productivity compared to rainfed cropland, and in minimizing the impacts of extreme climate events on crop production. How much cropland can be irrigated under future conditions is therefore a key question for determining food production.

Ultimately, the potential for converting rainfed land to irrigated land is determined by the amount of water resources that will be available. Following the FAO AQUASTAT methodology (Kohli and Frenken, 2015), the total renewable water resources (TWR) in a country are composed of internally-generated resources (the balance of precipitation and evapotranspiration) and water resources that flow into a country from rivers (excluding river water flows that cannot be exploited due to treaties). All of these water sources are likely to be affected by fluctuations in precipitation and temperature as a result of changing climate conditions. To estimate TWR under future conditions – scenario and country-specific – we used geospatially-explicit output from hydrological models and a global river network (Fekete, Vörösmarty and Lammers, 2001).[76]

[76] These include hydrological models participating in the Inter-Sectoral Model Intercomparison (ISI-MIP), a large-scale research effort to assess climate change impacts on different sectors (Warszawski *et al.*, 2014).

Estimates shows decreases in TWR for NNA of around 20 percent, while countries in ECA, EAP, and LAC record additional water availability of around 10 percent. Depending on the scenario, future changes in TWR can be highly significant for individual countries, while important regional differences can also be present within each country.

Not all available water resources can be used for irrigation, and in order to avoid water stress, total water abstraction, that is, the total water withdrawn from existing sources, should not exceed a given threshold of available resources. This threshold is frequently set to 20 percent of TWR, but in many regions that suffer from water stress – such as the Sahel, India, Pakistan, North East China or the Central U.S. – water resources are already exploited at much higher rates (WMO, 1997).[77]

Assuming constant irrigation demand per unit area,[78] the future irrigation potential was limited in the BAU, TSS and SSS scenarios so that water abstractions in each country would not exceed 60 percent, 30 percent, and 60 percent of available water resources, respectively, thus allowing for maximum levels of water stress that differ by scenario.

There is potential for increasing irrigation efficiency

The potential for expanding irrigated areas can also be increased by changing the efficiency of water use, as envisaged by SDG Target 6.4.[79] In irrigated agriculture, irrigation water-use efficiency is defined as the ratio of water requirements of a crop over the amount that needs to be abstracted from surface water and groundwater resources. Irrigation efficiency values in 2012 range from 30 percent to 50 percent for surface irrigation, 75 percent for sprinkler irrigation, and around 90 percent for drip irrigation. With the majority of irrigated areas under surface irrigation, the global average is around 40 to 50 percent and indicates great potential for improving water-use efficiency.

This foresight exercise assumes scenario-specific changes in irrigation efficiency that reflect changes in income (saving potential) and willingness to invest in agriculture, as outlined in the scenario narratives in Chapter 2. Under the BAU scenario, irrigation efficiency for all countries increases by 5 percent, between 2012 and 2050, whereas large investments in irrigation under the TSS scenario lead to efficiency gains of around 25 percent.[80] Under the SSS scenario irrigation efficiency will increase only in HIC, by 5 percent.

3.11 Livestock systems

Livestock development patterns are influenced by assumptions on expected impacts of technical progress and increased know-how on yields of livestock products per animal, herd dynamics by animal system (e.g. backyard, semi-intensive, intensive in the case of pigs and poultry), and responsiveness of herd size and animal productivity to prices of animal outputs. Information on past trends, per capita income dynamics, ongoing work and expert opinions were used to identify the key variables for livestock development patterns in the scenarios.

77 Additional pressures on water resources may result from the future expansion of livestock. Although currently only representing less than one percent of total freshwater use (FAO, 2006), water use for the livestock sector can contribute significantly to water stress in certain regions.

78 Actual demand will depend on local weather conditions. Studies suggest generally an increasing trend in water demand depending on the degree of warming (see Wada *et al.,* 2013).

79 "Target 6.4: By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity. Related indicators are: 6.41. Change in water-use-efficiency over time and 6.4.2: Water stress, expressed as freshwater withdrawal as a proportion of available water resources."

80 Increasing irrigation efficiency has downstream effects that need to be considered (Grogan *et al.*, 2017) and is only one metric to express productivity of water.

The efficiency and sustainability of livestock systems varies across scenarios

Under the BAU scenario, recent trends and per capita income dynamics are the main determinants of assumptions for technical progress and know-how. Rising per capita income is presumed to enhance capacities for investing in the economy at large and agriculture in particular. This in turn leads to technical progress that renders animal systems more efficient. More specifically, it is assumed that: a) as income rises, the share of "backyard" animal systems progressively declines, leaving room for more capital-intensive and knowledge-based systems; b) the physical efficiency of animal systems (that is, the quantities of animal products such as milk, meat or eggs per head of animal) is different across scenarios, irrespective of the prices of animal outputs.

The TSS and SSS scenarios follow criteria similar to those used in designing the BAU scenario with regard to livestock systems, but assumptions are further shaped by the degree of compliance with the "principles" for sustainable food and agriculture (FAO, 2014).

Under the TSS scenario, the first sustainability principle ("Improving efficiency in the use of resources") is reflected by modulating animal yields. It is assumed that technical progress and increased know-how, promoted through human capital development and investment policies, translate into changes in the input mix and in efficiency in the use of the inputs and factors (feed, equipment, labour, etc.) so that animal systems become more sustainable. This entails an initial loss of productivity up until 2030 due to the abandonment of highly productive – albeit unsustainable – practices. However, this loss of productivity is more than fully recovered in the years after 2030, once further knowledge and investment on sustainable practices materialize. Due to limited information on the possible evolutions and impacts of sustainable practices, this dynamic is prudently kept within limited boundaries (+/- 10 percent compared with the BAU scenario), with downward shifts in the initial decades until 2030 in HIC and China and upward shifts after 2030 in LMIC.[81]

The sustainability principle to "conserve, protect and enhance natural resources" is also reflected in the TSS scenario through an across the board 10 percent reduction in the share of ruminant systems based on grassland. This is under the assumption that, as suggested by the principles for sustainable food and agriculture, grazing fees are consistently applied. Finally, the principle of "responsible and effective governance mechanisms" – which favours more effective participation in decision-making processes, the formation of associations, consultations among stakeholders and the creation of decentralized capacity – translates into a stronger responsiveness of livestock activity to market signals. The underlying assumption is that improved institutions for the livestock sector will enable farmers to implement production plans more flexibly than under the BAU scenario.

In contrast, the SSS scenario is built on the assumption that animal productivity is pushed further towards biophysical limits in all regions, albeit most notably in HIC and China. This increase in animal productivity reaches its limit by 2030 and begins to diminish thereafter in response to increased vulnerability to animal diseases. Again, the downward dynamic is set to be more pronounced in HIC and China, while productivity reductions in LMIC are less dramatic, mirroring the lower level of productivity increases prior to 2030. Under the TSS scenario, animal yields in HIC drop by 10 percent by 2050 compared with BAU. In BAU, yield levels are reduced due to unsustainable practices.

[81] These assumptions have to be considered as expert-based. Further scenarios and/or fine-tuning can be developed based on additional information on experimental evidence, pilot experiences or best practices.

3.12 Fish production

Production of capture fisheries and aquaculture in marine and freshwater environments will continue to be affected by climate change. The effects of climate change on fish supply are discussed in a vast body of literature (see Barange *et al.*, 2014; Cochrane *et al.*, 2009; Merino *et al.*, 2012). There is some evidence that global warming has already affected the distribution of some marine fish species, as warm-water species with free distributions shift towards the poles (FAO, 2013a). Studies such as FAO (2013a) and Cheung *et al.* (2010) provide evidence on the effects of global warming on marine fish species and potential catch, respectively. Projections point to a declining catch potential in tropical countries by as much as 40 percent when driven only by temperature preferences, whereas in high-latitude waters there could potentially be an increase in the range of between 30 and 70 percent Cheung *et al.* (2010). The IPCC Fifth Assessment Report states with high confidence that in low-latitude regions, temperature increases of 3 °C will cause local extinctions of some fish species at the edges of their ranges (Porter *et al.*, 2014). Changes in temperature and rainfall will also alter the productivity of inland fish species. However, quantifying these effects on aquaculture activities is more challenging, given the fact that aquaculture takes place under systems that are easier to monitor, which can adapt to climate change to varying extents by using different management practices.

Distribution and number of fish species may be profoundly altered by climate change

The modelling framework used to generate our three scenarios identifies fish as a separate commodity, sourced from capture and aquaculture sectors combined.[82] The supply of this commodity follows changes in potential catch due to climate change and expectations on the growth of aquaculture. Fish consumption, on the other hand, depends on available income and prices of fish as well as other food substitutes.

FAOSTAT's commodity balance sheets for the years 2011 to 2013 are fully reproduced in the modelling framework. Data on fish production from aquaculture for this period are derived from FAO (2016b) and OECD and FAO (2017). Data on fish production from capture fisheries is calculated residually so that aggregates from FAOSTAT are fully replicated.

Projections of fish production rely on OECD and FAO (2017) for aquaculture supply until 2026, after which the aquaculture supply grows at the average rate seen for the period 2012 to 2026.[83] Regarding capture fisheries, changes in the potential catch of fish by 2050 in all Exclusive Economic Zones (EEZ)[84] are based on updates from Cheung *et al.* (2010), according to RCP 2.6 and 8.5 – the emission scenarios noted in Box 3. The percentage changes in the potential catch of fish between 2000 and 2050 were first translated into changes per country based on the size of each EEZ. These were assumed to be distributed evenly to all years between 2012 (the base year used in this report) and 2050. The BAU and SSS scenarios use RCP 8.5 changes for the potential catch of fish, whereas the TSS scenario uses RCP 2.6.

[82] Hereafter "fish" refers to all commodities produced from capture and aquaculture sectors that are used as food (for example also shellfish).

[83] Countries identified in our modelling framework which are not considered separately in OECD and FAO (2017) but are included in a regional aggregate are assumed to follow the same growth rates as those of the corresponding regional aggregate.

[84] An EEZ is a sea zone, defined by the United Nations Convention on the Law of the Sea, over which a state has special rights to explore and to use marine resources.

Although the three scenarios of our foresight analysis imply that different climatic conditions will prevail, they incorporate the effects of climate change only on potential catch and assume that aquaculture could expand to the same degree in all three scenarios, albeit at different implied rates of adaptation.

3.13 Remarks on scenario assumptions

The scenario-specific assumptions illustrated in this chapter cover different domains, such as demographic dynamics, economic growth, per capita income changes, crop and livestock yields under different climate change and technical progress conditions, different GHG emission coefficients per unit of output, the evolution of consumer preferences, and diverse patterns for food losses and waste. These assumptions substantiate the scenario narratives illustrated in the previous chapters, are fully consistent with them and delineate key features of the different scenarios, which feed into quantitative models. These models produce scenario-specific results which are thoroughly analysed in the next chapter. The findings of such an exercise allow assessing the extent to which (and why) each scenario is more or less conducive to sustainable and equitable food systems and sustainable agriculture.

4 | Scenario findings

This chapter presents the results of the three alternative scenarios, discussing the impacts on agricultural sectors, prices, wages, food consumption, undernourishment, international trade, natural resource use and GHG emissions. To understand these results, the reader may need to recall aspects of the analytical framework that was used to develop the foresight exercise (see Figure 2.1) and the quantitative tools embedded in it (see Figure 2.2). The results will be more understandable by recalling some of the key assumptions underlying the generation of the scenarios (see Chapter 3), such as those related to modelling consumer preferences, technical progress, climate change, and natural resource use. Further information can be found in Annex II, which provides detailed assumptions underlying the scenarios' narratives, as well as Annex III, which illustrates selected modelling features for the food and agricultural sectors.

4.1 Size of agriculture within the economy

The demographic and economic dynamics underlying the three scenarios influence both the growth and size of the crop, livestock, fisheries and forestry sectors. While population growth directly influences additional food requirements, economic growth drives change in consumer incomes and thus in their preferences, as well as in the investment and export potential of economic systems. The relative size of agriculture within the economy, which is typically represented by the share of agriculture sectors' value added of the total value added, is displayed in Figure 4.1 for all three scenarios.[85]

Under the BAU scenario the agricultural sectors become smaller in LMIC, with the share of value added diminishing from about 9.5 percent in 2012 to about 5 percent in 2050. The economy as a whole grows faster than the agricultural sectors – in other words, non-agricultural sectors expand more than agricultural ones. On the other hand, agricultural sectors' share of total value added is already low in HIC: in 2012 it is close to 2 percent and decreases gradually to around 1 percent by 2050. Changes in supply and demand in these countries are not strong enough to trigger any visible difference in the evolution of the agricultural sectors across the scenarios.

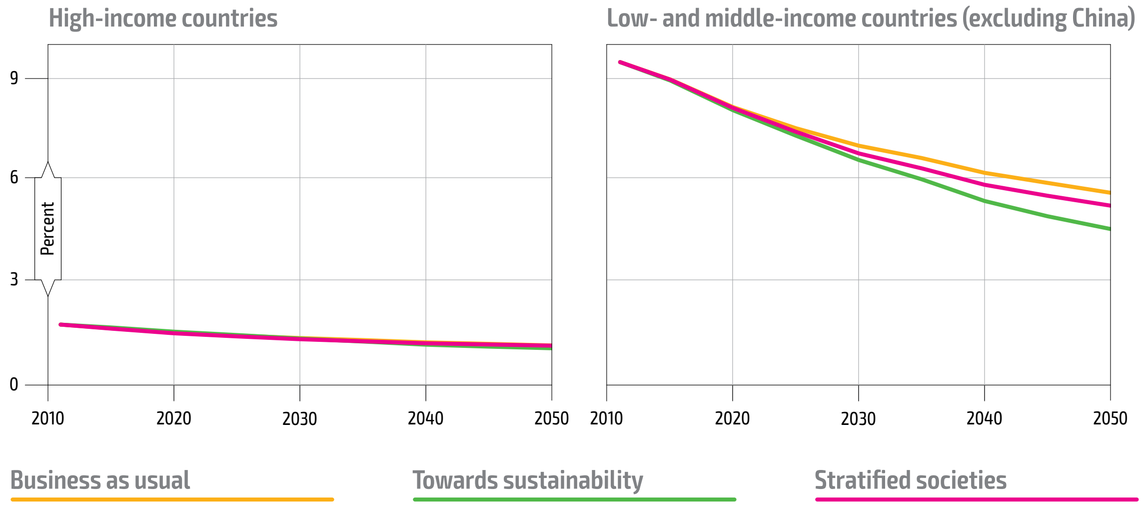
Agriculture's share of total value added in LMIC decreases even more in the TSS scenario. This is particularly apparent in SSA, which in this scenario enjoys markedly higher economic growth. Domestic demand grows faster in non-agricultural sectors, boosting structural changes in economic systems. In HIC no substantial differences emerge compared to BAU, due to agriculture's already very limited share of value added in the base year.

85 This share reflects the amount of final goods and services that agricultural sectors produce in a given period, net of the inputs consumed by the sectors, relative to the total amount of products and services produced in the economy in the same period, also net of the inputs consumed by the economy. As goods and services cannot logically be summed up or subtracted in physical terms, they are usually measured in monetary terms.

Under SSS, the shrinking of agricultural sectors' share of value added is less marked than in BAU for LMIC (excluding China). These countries – particularly those in SSA – lag behind in the structural transformation processes that lead to the faster growth of non-agricultural sectors. In fact, compared with BAU the most dynamic global economic growth is mostly concentrated in HIC and China. Agricultural sectors in LMIC (excluding China) suffer from a lack of investment and increasing climate change, which limit expansion. In addition, more skewed income distribution limits demand for food items in LMIC, thus contributing to the limited expansion of agriculture's value added in these countries.

Overall, regardless of the specificities of each scenario, agricultural sectors' diminishing share of value added suggests that it alone will not be able to create employment and generate income for the entire population, particularly in regions where demographic dynamics will be considerable, such as SSA and SAS. Economy-wide, pro-poor development will thus be essential to ensure that everyone has sufficient income to purchase food and enjoy a decent life.

Figure 4.1 **Share of agriculture, fisheries and forestry value added of total value added (base-year prices)**



Source: FAO Global Perspectives Studies, based on simulations with the ENVISAGE model.

4.2 Gross agricultural output

Future agricultural supply will respond to demand from growing populations, increasing per capita incomes and changing consumer preferences, albeit to varying degrees according to the scenario. Although each scenario in this report assumes the same demographic patterns, agricultural output exhibits different dynamics as it is influenced by the other determinants.

Under BAU, the world's gross agricultural output (in terms of value) is projected to grow by around 50 percent between 2012 and 2050, with marked differences across regions (see Table 4.1). While gross agricultural output in HIC and China is projected to grow less than in the rest of the world, much higher growth is expected mainly in SSA (due to high population growth, the potential of achieving higher yields and expanding agricultural land) but also in LAC and ECA, which also have the potential to expand agricultural land, albeit to a lesser extent.

While the overall expansion of gross agricultural output is lower than in the past 50 years, achieving this growth may still be challenging given the potential upheavals from climate change, which could exacerbate the scarcity of natural resources, particularly in those regions where land and water constraints are already felt (see Figure 1.10 and Figure 3.10).[86]

Table 4.1 Gross agricultural output at base-year prices

REGIONS	index, 2012 = 100					
	2030			2050		
	BAU	TSS	SSS	BAU	TSS	SSS
High-income countries	**120**	**104**	**131**	**130**	**106**	**139**
East Asia and Pacific	128	121	134	135	130	141
– China	127	120	135	130	125	139
– East Asia and Pacific (excluding China)	130	125	130	149	147	147
South Asia	137	125	131	156	142	149
Europe and Central Asia	143	133	152	169	157	175
Latin America and Caribbean	132	125	138	156	146	157
Near East and North Africa	127	117	124	145	131	139
Sub-Saharan Africa	168	166	172	251	264	241
Low- and middle-income countries	**135**	**128**	**139**	**157**	**151**	**158**
– Low- and middle-income countries (excluding China)	139	132	141	170	163	167
World	**132**	**122**	**137**	**150**	**140**	**153**

Note: Gross agricultural output is measured as the sum of all primary agricultural commodities as defined in Annex III Table A 3.3, multiplied by their corresponding base-year prices. Note that this excludes natural rubber but includes both feed and animal products. Fish, on the other hand, is excluded to maintain comparability of this indicator with previous FAO studies. Details for specific regions are given in Table S 2.2.

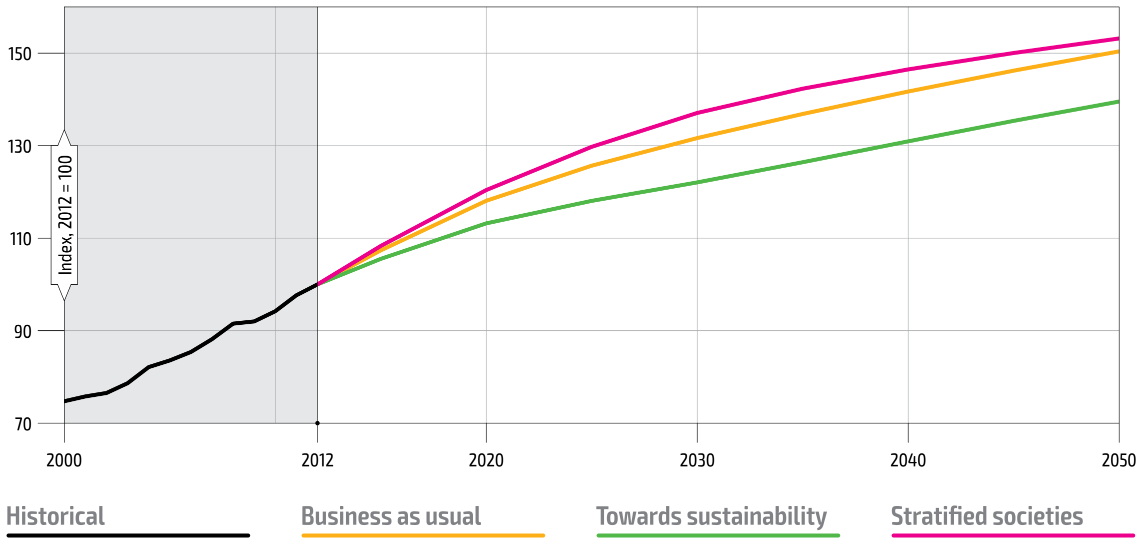
Source: FAO Global Perspectives Studies, based on simulations with the FAO GAPS model.

The TSS scenario presents lower levels of agricultural production compared to BAU (a 40 percent increase between 2012 and 2050 as opposed to 50 percent), mostly due to lower food loss and waste and diminished demand for livestock feed. Not surprisingly, pressure on natural resources is relatively lower in TSS, however SSA maintains its gross agricultural output growth as per capita income rises, and there is strong potential to expand yields and agricultural land.

[86] A major factor contributing to the smaller increase of gross agricultural output in projections to 2050 compared with the past 50 years is lower population growth (see Table 3.1) and the relatively modest growth of food consumption. This is due to the fact that in several parts of the world the per capita calorie intake is on average already well above the minimum daily energy requirements (see Section 4.5). The slowdown of gross agricultural output projected under BAU is in line with existing medium-term expectations (OECD and FAO, 2017). However, the diminishing role of primary agriculture sectors in total value added (see Section 4.1 and Figure 4.1) does not exclude but rather confirms that food expenditure may increase as buying it might involve services (e.g., restaurants) and processing (for example, ready-to-eat meals).

On the other hand, the SSS scenario presents a greater expansion of gross agricultural output worldwide compared with BAU (a 53 percent increase by 2050). This larger expansion is required due to greater food loss and waste as well as to satisfy relatively higher food demand, particularly for animal products in HIC and China, which in turn generates larger demand for feed. Marked regional differences are also observed for SSS compared to BAU. The output expands more in HIC and China and less in LMIC (excluding China), with SSA and SAS projected to lag behind. Limited expansion in these regions combined with population growth poses important challenges for food security.

Figure 4.2 Gross agricultural output at base-year prices



Note: Gross agricultural output is measured as the sum of all primary agricultural commodities as defined in Annex III, Table A 3.3, multiplied by their corresponding base-year prices. Note that this excludes natural rubber but includes both feed and animal products. On the other hand, fish is excluded to maintain comparability of this indicator with previous FAO studies. Details for specific regions are given in Annex III, Table A 3.4.

Source: FAO Global Perspectives Studies, based on simulations with the FAO GAPS model.

Overall, comparing scenarios reveals that changes in consumer preferences towards more balanced diets, reduced food loss and waste, more equitable income distribution, and food price increases (see next section) could contain gross agricultural output expansion over the next decades. The legitimate concern as to whether this relative restraint of agricultural output could jeopardize overall calorie and protein intake and the achievement of food security is addressed in Section 4.5.

4.3 Agricultural prices

Future agricultural prices will depend on how production systems accommodate any future changes in food and non-food consumption in an environment of tightening resources and climate change. They will also depend on how far agricultural trade will help adapt to this changing environment. Meanwhile, prices will determine consumer behaviour as demand adapts to changes in purchasing power, in turn determined by real per capita income.

Higher prices are expected to restrain and reorder consumer demand. Meanwhile producers would be able to expand supply, with this then leading market prices to fall. The equilibrium prices reported in this section are the result of an interplay between adjustments in market supply and demand (see Figure 4.3). The long-term nature of the three scenarios means that producers can also adjust their schedules through investment, which might take time to materialize. On the other hand, in the long run consumers adjust their preferences based on changes in taste, education, and awareness – factors that can take time to affect spending patterns.[87]

In the BAU scenario, agricultural prices (expressed in USD, 2012 exchange rates) remain fairly stable in the first half of the simulation period. This is because crop and animal yields and cropland are able to expand to satisfy increasing demand for food and other products such as feed, fibres, feedstock for bioenergy, etc. In the second half of the projection period prices begin to rise steadily, and by 2050 they are 13 percent higher than in 2012. Prices shift because production processes face increasing natural resource constraints as well as the effects of climate change, requiring additional inputs per unit of output and greater investment to put new land to work. This applies particularly in some regions (for example NNA) that are already approaching their upper boundaries for land and water resources. Constraints on resources and investments increasingly curtail yields and supply. Moreover, unabated food loss and waste and continued demand for resource-intensive commodities, such as animal products and the related feed demand, all exert upward pressure on agricultural prices.

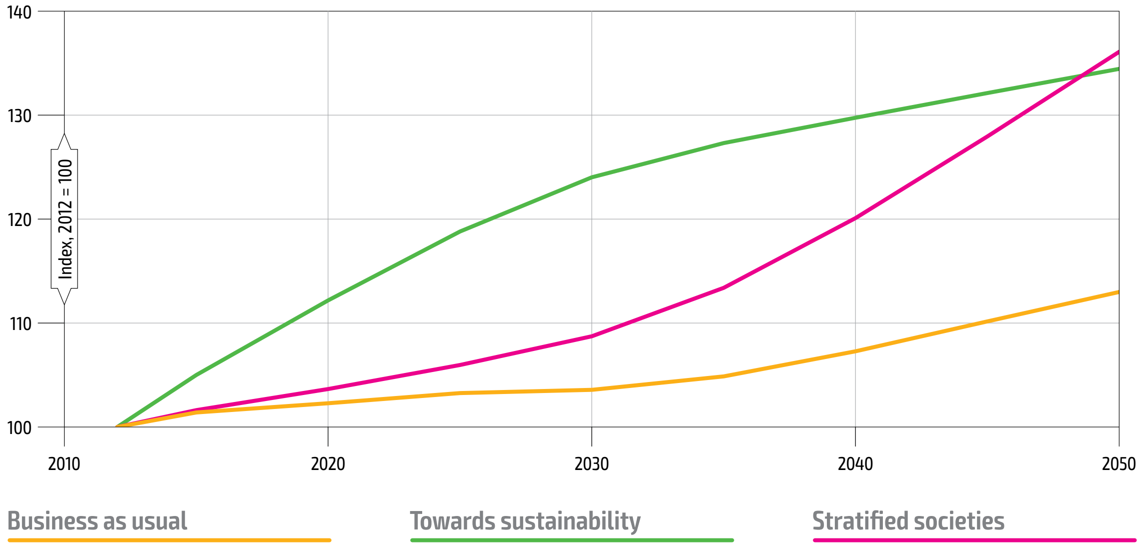
In the TSS scenario, prices increase rapidly at the outset of the projection period due to the adoption of more sustainable agricultural practices, including sustainable intensification. This transformation implies investing more in innovative technologies but obtaining lower yields, at least at the early stages. The related additional costs reverberate on prices, which in the first part of the simulation period increase at faster rates than in BAU. However, in the second part of the simulation period prices increase more slowly compared with BAU. This is thanks to presumed progressive restoration of soil fertility and water quality, which allows for yield gaps to be reduced and the impacts of climate change mitigated compared to BAU. These improvements support the sustainable expansion of production. The early price increase in the TSS scenario is also due to simultaneous changes in demand in LMIC regions (see Section 4.5), where income growth stimulates higher food consumption than under BAU. By 2050, prices tend to stabilize at 35 percent above 2012 levels.

In the SSS scenario prices increase only moderately in the first years of the simulation period, expanding much faster thereafter compared to BAU and reaching a level that by 2050 is 35 percent higher than in 2012. These more exacerbated price dynamics are the result of more severe climate change effects on yields (see Section 4.7 below) and the increasing production costs associated with a progressive scarcity of land and water resources in many regions, due to unsustainable practices and climate change itself. In HIC and some LMIC, such as China, more pronounced per capita income increases than in BAU raise demand for resource-intensive items, such as animal products. Meanwhile there is little consumer awareness about reducing food loss and waste, resulting in further upward pressure on prices (see also Section 4.5 below).

[87] Although in recent years FAO's real food price index has remained above the levels seen in the 1990s and 2000s, its long-term evolution by and large suggests there has been substantial stability since 1960, albeit with differences between commodities. Food price fluctuations received substantial attention in the wake of the food-price crisis of 2007/2008, just as they did when they spiked during the 1970s. Indeed, price surges during the 2000s and 2010s were above levels seen in previous decades, which is why price volatility during the last two decades is considered comparable with that seen in the 1970s (FAO, 2017d).

Overall, the three scenarios portray significantly different price dynamics, which reflect the extent to which sustainability challenges are addressed. In BAU, prices increase later on but at increasing growth rates, particularly in the second part of the period. SSS exacerbates this trend and the costs of unsustainability are even more marked. In TSS, addressing sustainability challenges implies facing increasing prices early on, although these tend to level off in the long run.

Figure 4.3 Projected agricultural producer price index



Note: This index is calculated by dividing the value of a set of agricultural commodities at current-year prices by the value of the same set at base year (2012) prices (Paasche agricultural producer price index).

Source: FAO Global Perspectives Studies, based on simulations with the FAO GAPS model.

4.4 Wages in agricultural and non-agricultural sectors

One of the key questions at the beginning of this report relates to the extent to which the poorer layers of society will have enough income to access sufficient and adequate (usable, nutritious and safe) food, move out of extreme poverty and/or stay permanently out, save and invest sufficiently to increase their asset base, become more resilient to economic shocks and, ultimately, actively contribute to transformative and developmental processes. Of further concern is how much, and under what circumstances, agriculture will contribute to these earning opportunities for poorer people in the future.

While the analytical approach adopted for this report does not permit an explicit investigation into how income distribution across different layers of society could change under the various scenarios, some considerations on the degree of equity in income distribution can be inferred by looking at the scenario-specific dynamics of wages for unskilled labour, compared to the base year. Assuming that unskilled workers are among the poorer layers of the population, larger increases in wages for this work imply better income for the poor (all other things being equal). Furthermore, wage dynamics in the agricultural sectors (which mostly reflect wages in rural areas) can be compared with wage dynamics in non-agricultural sectors (which mostly reflect wages in urban areas). Relatively stronger growth of unskilled labour wages in the agricultural sectors against non-agricultural ones highlights the role agriculture can play in promoting equitable income distribution across society.

BAU projects 70 percent higher unskilled agricultural wages in 2050 than in 2012 for LMIC (except China). Relatively, wages grow much faster in agricultural sectors than in non-agricultural ones, such that the "urban premium" (the wage differential enjoyed by non-agricultural sectors) progressively shrinks.[88] Among other factors, this is due to the internal migration from rural (agricultural) to urban (non-agricultural) areas associated with urbanization (see Figure 4.4), which increases the supply of unskilled labour in urban areas. The drop in the urban premium is very pronounced in SAS, where wages for unskilled agricultural labour increase by almost 100 percent by 2050 while non-agricultural wages only do so by 25 percent. On the contrary, in SSA the urban premium is left almost unabated and wages in both agricultural and non-agricultural sectors increase at a very slow pace (see Figure 4.4). This is due to the high population increase projected for the region (see Figure 3.1), including in rural areas, which translates into a significant labour supply.

The TSS scenario portrays quite a different picture compared with BAU (and SSS). First, in LMIC (excluding China) both agricultural and non-agricultural unskilled labour wages increase faster than in BAU. Particularly in SAS (and to a lesser extent in SSA), greater economic growth (compared with BAU) pushes unskilled labour wages along a much more dynamic path.[89] Higher wages for unskilled workers are a sign that, other things being equal, TSS presents a better income for the poor than BAU. Wages for unskilled labour also grow in a more "balanced" way across sectors in TSS than in BAU, as agricultural and non-agricultural wages up to 2050 grow more or less at the same pace. This signals that in TSS the non-agricultural sectors productively absorb the unskilled labour migrating from rural to urban areas and pay higher wages than in BAU. This is particularly the case in SSA.

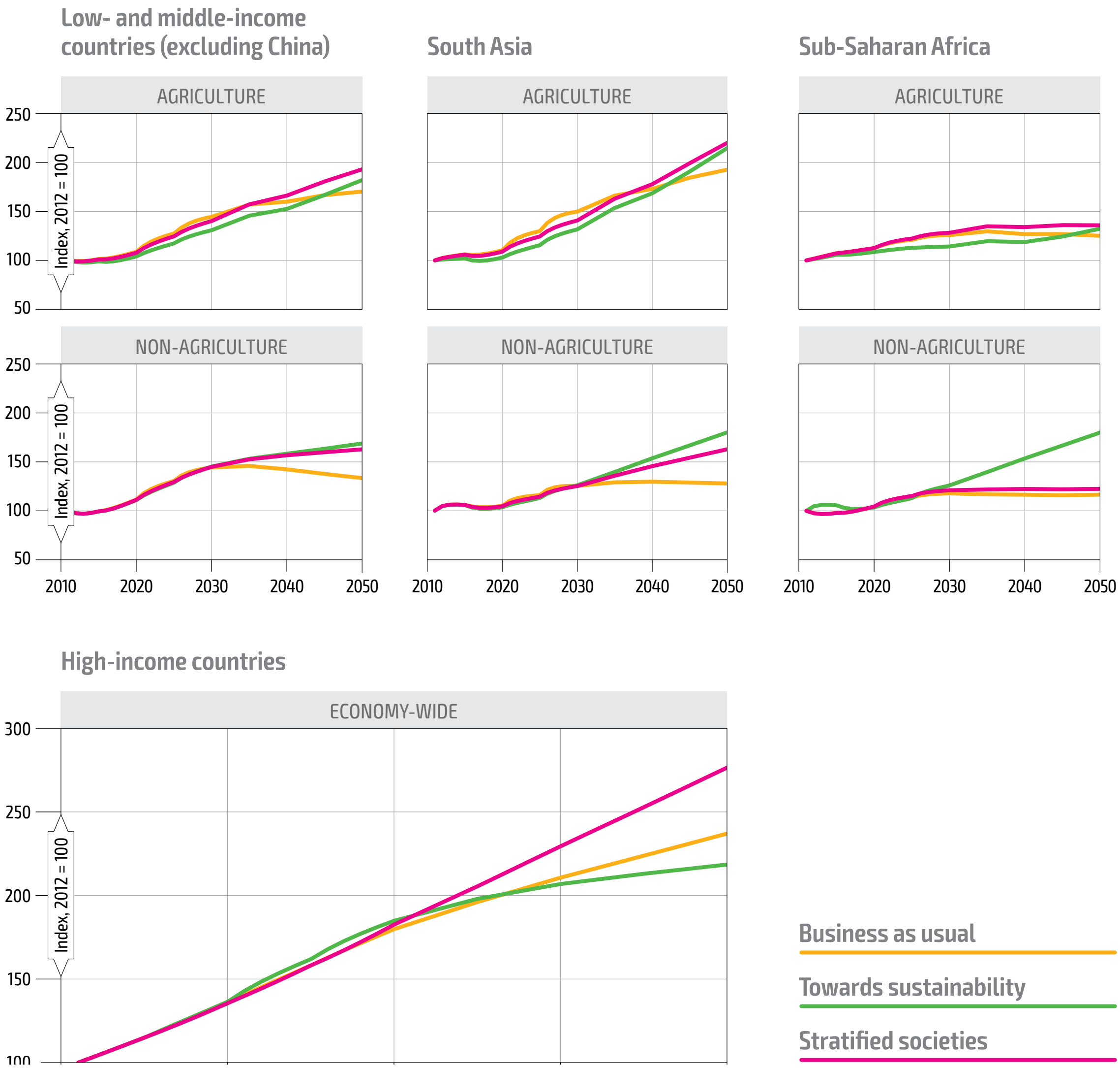
Under SSS, despite the assumed significantly higher economy-wide growth in almost every region (except SSA), agricultural wages in LMIC (except China) increase at similar rates as in both BAU and TSS. At the same time, non-agricultural wages in SSS underperform compared with TSS, particularly in SAS and SSA. This highlights that the higher economy-wide growth of SSS does not translate into greater benefits for unskilled workers in LMIC (excluding China).

Overall, moving towards sustainability boosts the earning potential of unskilled workers, specifically in LMIC, both in non-agricultural and agricultural sectors.

88 Within the framework of the modelling exercise the labour market is segmented by sector and wages are endogenously determined by the balance between labour demand and supply in each sector. This results in wage differentials across sectors, potentially leading to migration of labour from sectors with lower wages to those with higher ones. Therefore, in regions where labour markets are segmented and an "urban premium" exists, labour tends to migrate from rural (agriculture) to urban (non-agriculture) areas.

89 As already noted, in these projections the population and their participation in the workforce are the same across scenarios, implying that labour supply does not change across scenarios.

Figure 4.4 Average wages for unskilled labour in agricultural and non-agricultural sectors



Note: No distinction is made between agricultural and non-agricultural wages in the case of HIC; in these countries, the market for unskilled labour is assumed to exhibit very limited segmentation between agriculture and non-agriculture sectors.

Source: FAO Global Perspectives Studies, based on simulations with the ENVISAGE model.

4.5 Consumption patterns and undernourishment

The evolution of per capita food consumption in terms of both calories and variety is a key element in measuring and evaluating the global and regional food situation. Also important are the number and prevalence of undernourished people, which provide insight on the likelihood of SDG 2 (and in particular target 2.1) being achieved under alternative future development patterns.[90]

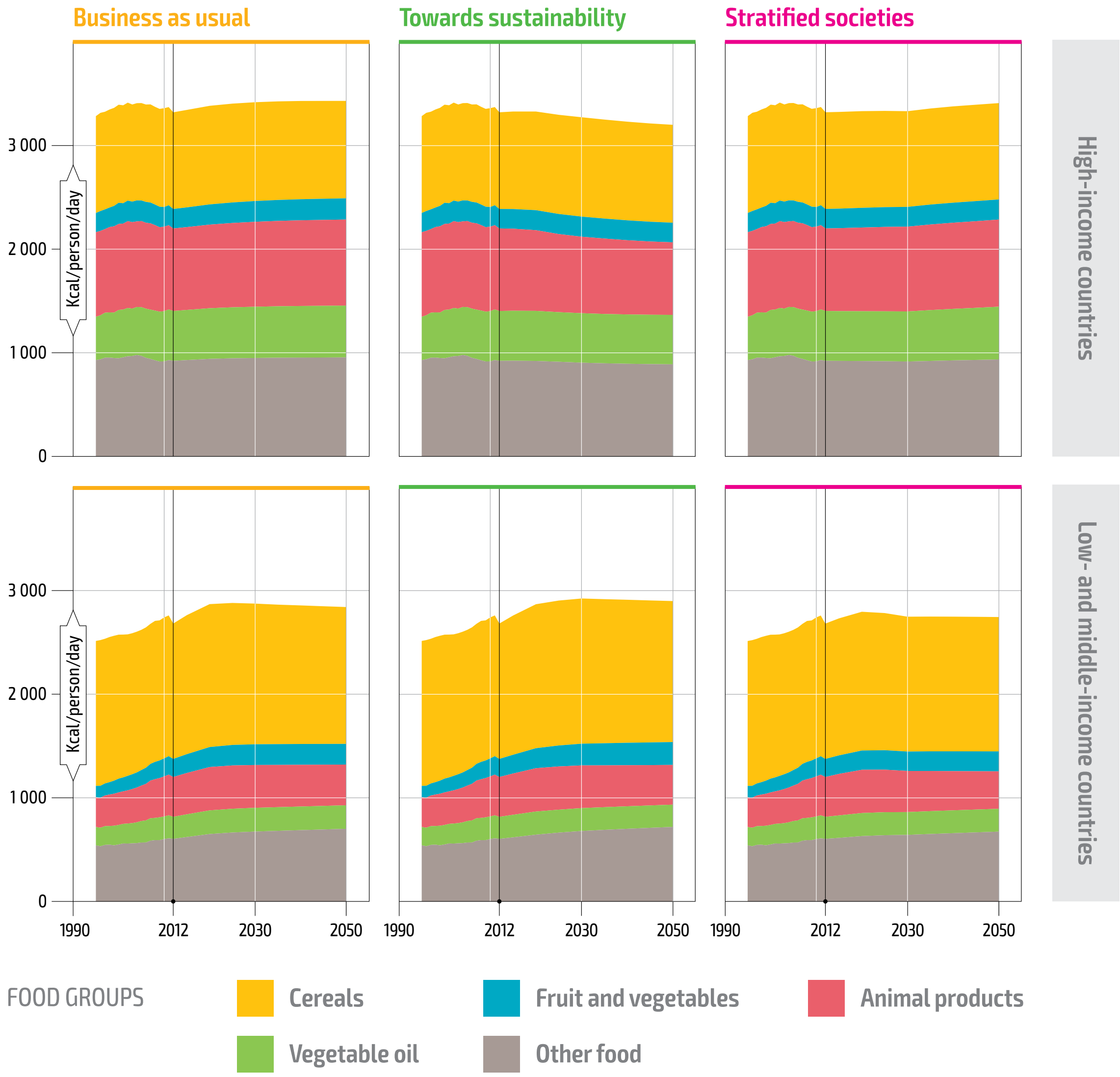
In the BAU scenario, LMIC and HIC end up enjoying higher per capita daily energy consumption (DEC) by the end of the projection period (Table 4.2).[91] HIC reach a "saturation

[90] This section refers to "apparent" per capita food consumption, i.e. country average consumption as derived from FAOSTAT Food Balance Sheets rather than from household or individual surveys.

[91] DEC is defined in Section 3.6. The terms "per capita food consumption", "per capita food intake" and "per capita calorie intake" are hereafter used as synonyms for DEC.

level" at approximately 3 400 kilocalories per person per day (kcal/person/day) early in the simulation period and maintain this until 2050. LMIC see an early and significant expansion of DEC up to 2 860 kcal/person/day, and are then affected by a downward trend (see Figure 4.5)[92] due to sluggish per capita income growth and progressively pronounced price effects (see Section 4.3). At the same time, the per capita intake of fruit, vegetables and animal-based food in HIC expands at a faster pace than that of the other food items, while in LMIC per capita staple food consumption slows down at a very low pace and continues to play a significant role due to the relatively low-income levels of these countries (see Table S 2.3).

Figure 4.5 Daily energy consumption by source and scenario



Note: Data before 2012 refer to daily energy supply; after 2012, data refer to daily energy consumption. The food groups are detailed in Annex III, Table A 3.5.

Source: FAO Global Perspectives Studies, based on simulations with the FAO GAPS model and FAOSTAT (various years).

[92] The term "saturation" is used here to describe the point at which calorie intake is highest, beyond which no further per capita food consumption is regarded as necessary or desirable. Indeed, in several HIC the 2012 DEC was already much higher than the minimum daily energy requirements (MDER). Trends in per capita income are discussed in Section 3.2.

Compared with BAU, the TSS scenario projects different consumption patterns in all regions. HIC display a progressively decreasing DEC, which by 2050 is 7 percent lower than BAU. After reaching saturation level around 2030, China also shows a 3 percent reduction of its DEC compared with BAU. Interestingly, DEC continues to expand in LMIC (excluding China), with hardly any change after 2030 until it is 4 percent higher by 2050 than in BAU. Under this scenario, HIC and China consume less animal products per capita due to shifting consumer preferences and increased awareness on the environmental sustainability of different diets (see Table 4.3). Meanwhile LMIC significantly expand their per capita consumption of fruit and vegetables, as consumers can afford to diversify their diets thanks to greater expansion of their per capita income (see Table 4.4).

Table 4.2 Historical dietary energy supply and projected dietary energy consumption

	kcal/person/day								index, 2012 = 100		
	1961	2012	2030			2050			2050		
REGIONS	HISTORICAL	BASE YEAR	BAU	TSS	SSS	BAU	TSS	SSS	BAU	TSS	SSS
High-income countries	**2 855**	**3 311**	**3 408**	**3 271**	**3 303**	**3 421**	**3 198**	**3 380**	**103**	**97**	**102**
East Asia and Pacific	1 528	2 850	3 046	3 050	2 951	2 974	2 927	2 950	104	103	104
– China	1 414	2 971	3 202	3 168	3 104	3 137	3 029	3 120	106	102	105
– East Asia and Pacific (excluding China)	1 847	2 594	2 755	2 830	2 667	2 709	2 761	2 675	104	106	103
South Asia	2 024	2 376	2 602	2 673	2 474	2 626	2 735	2 519	111	115	106
Europe and Central Asia	2 921	3 171	3 338	3 355	3 212	3 305	3 332	3 221	104	105	102
Latin America and Caribbean	2 248	2 876	3 007	3 039	2 822	3 004	3 032	2 841	104	105	99
Near East and North Africa	1 915	3 019	3 195	3 236	2 994	3 155	3 228	3 027	104	107	100
Sub-Saharan Africa	2 011	2 363	2 664	2 810	2 468	2 683	2 831	2 490	114	120	105
Low- and middle-income countries	**1 850**	**2 674**	**2 866**	**2 923**	**2 724**	**2 833**	**2 898**	**2 720**	**106**	**108**	**102**
– Low- and middle-income countries (excluding China)	2 055	2 587	2 784	2 863	2 632	2 775	2 873	2 644	107	111	102
World	**2 117**	**2 779**	**2 946**	**2 974**	**2 809**	**2 910**	**2 938**	**2 807**	**105**	**106**	**101**

Note: Data for 1961 refer to per capita kilocalorie supply. Data for 2012 and thereafter refer to per capita kilocalorie consumption. Detailed information by region is reported in Table S 2.3.

Sources: FAO Global Perspectives Studies, based on simulations with the FAO GAPS model and FAOSTAT (various years).

Moving on to the SSS scenario, results show that greater income inequalities across countries (compared to BAU) reverberate on food consumption. In HIC and China, DEC essentially remains at BAU levels by 2050. In LMIC (excluding China) the DEC remains anchored at 2012 levels and by 2050 it is by more that 4 percent lower than under BAU. In SSA the DEC expands by 7 percent less that under BAU between 2012 and 2050. Compared with BAU the per capita consumption of animal products further expands in HIC. Meanwhile it shrinks significantly in LMIC together with per capita consumption of fruit and vegetables, resulting in a less diversified diet than in BAU or TSS.[93]

93 Per capita consumption of proteins by region and scenario is reported in Table S 2.4.

Table 4.3 Historical animal product supply and projected per capita animal product consumption

	kcal/person/day								index, 2012 = 100		
	1961	2012	2030			2050			2050		
REGIONS	HISTORICAL	BASE YEAR	BAU	TSS	SSS	BAU	TSS	SSS	BAU	TSS	SSS
High-income countries	**669**	**796**	**820**	**738**	**818**	**830**	**700**	**841**	**104**	**88**	**106**
East Asia and Pacific	62	521	596	577	563	580	551	537	111	106	103
– China	46	632	733	697	688	723	665	669	115	105	106
– East Asia and Pacific (excluding China)	106	288	340	356	329	347	366	323	121	127	112
South Asia	122	238	274	280	266	276	278	260	116	117	109
Europe and Central Asia	402	622	656	646	643	649	630	624	104	101	100
Latin America and Caribbean	307	564	603	599	584	605	587	566	107	104	100
Near East and North Africa	157	287	321	316	317	321	313	305	112	109	106
Sub-Saharan Africa	124	175	207	227	199	230	231	192	131	132	109
Low- and middle-income countries	**125**	**385**	**413**	**412**	**397**	**393**	**383**	**362**	**102**	**100**	**94**
– Low- and middle-income countries (excluding China)	162	312	336	343	326	330	330	303	106	106	97
World	**269**	**452**	**473**	**460**	**459**	**451**	**425**	**425**	**100**	**94**	**94**

Note: Data for 1961 refer to per capita kilocalorie supply. Data for 2012 and thereafter refer to per capita kilocalorie consumption.
Sources: FAO Global Perspectives Studies, based on simulations with the FAO GAPS model and FAOSTAT (various years).

Table 4.4 Historical fruit and vegetable supply and projected per capita fruit and vegetables consumption

	kcal/person/day								index, 2012 = 100		
	1961	2012	2030			2050			2050		
REGIONS	HISTORICAL	BASE YEAR	BAU	TSS	SSS	BAU	TSS	SSS	BAU	TSS	SSS
High-income countries	**139**	**188**	**200**	**194**	**191**	**205**	**189**	**194**	**109**	**101**	**103**
East Asia and Pacific	69	257	316	332	296	324	348	318	126	135	124
– China	65	316	400	421	375	419	448	411	133	142	130
– East Asia and Pacific (excluding China)	78	133	159	165	150	171	186	166	129	140	125
South Asia	51	107	128	133	123	135	151	136	126	140	127
Europe and Central Asia	224	212	246	255	238	260	278	266	123	132	125
Latin America and Caribbean	105	139	153	162	139	158	183	139	113	131	100
Near East and North Africa	127	258	285	290	265	298	310	289	116	120	112
Sub-Saharan Africa	82	92	111	118	100	122	149	107	133	162	117
Low- and middle-income countries	**76**	**174**	**200**	**209**	**188**	**200**	**221**	**192**	**114**	**127**	**110**
– Low- and middle-income countries (excluding China)	81	132	152	158	142	158	178	151	119	134	114
World	**93**	**177**	**200**	**207**	**188**	**200**	**217**	**192**	**113**	**123**	**109**

Note: Data for 1961 refer to per capita kilocalorie supply. Data for 2012 and thereafter refer to per capita kilocalorie consumption.
Sources: FAO Global Perspectives Studies, based on simulations with the FAO GAPS model and FAOSTAT (various years).

Convergence of food consumption across countries

Comparing food consumption dynamics across regions is critical for understanding the extent to which different future pathways can lead to more or less convergence of consumption patterns.[94] Doing so allows for determining the extent to which the overall per capita calorie intake and consumption of specific food items such as meat and fruit and vegetables converge between LMIC and HIC, comparing across scenarios.

The BAU scenario portrays a limited convergence of DEC between LMIC (excluding China) and HIC. DEC in LMIC (excluding China) represents around 80 percent of HIC DEC throughout the simulation period (see Table 4.5). Limited convergence also occurs on the consumption of fruit and vegetables and animal products.

Table 4.5 Historical per capita supply and projected per capita consumption in low- and middle-income countries (excluding China) as share of high-income countries

	ratio, high-income countries = 1							
	1961	2012	2030			2050		
COMMODITY GROUPS	HISTORICAL	BASE YEAR	BAU	TSS	SSS	BAU	TSS	SSS
Cereals and products	1.21	1.38	1.42	1.46	1.40	1.41	1.45	1.39
Fruit and vegetables	0.58	0.70	0.76	0.82	0.75	0.77	0.94	0.78
Animal products	0.24	0.39	0.41	0.46	0.40	0.40	0.47	0.36
Vegetable oil	0.47	0.47	0.48	0.51	0.46	0.47	0.50	0.43
Other food	0.62	0.69	0.75	0.79	0.73	0.77	0.85	0.75
Total food	**0.72**	**0.78**	**0.82**	**0.88**	**0.80**	**0.81**	**0.90**	**0.78**

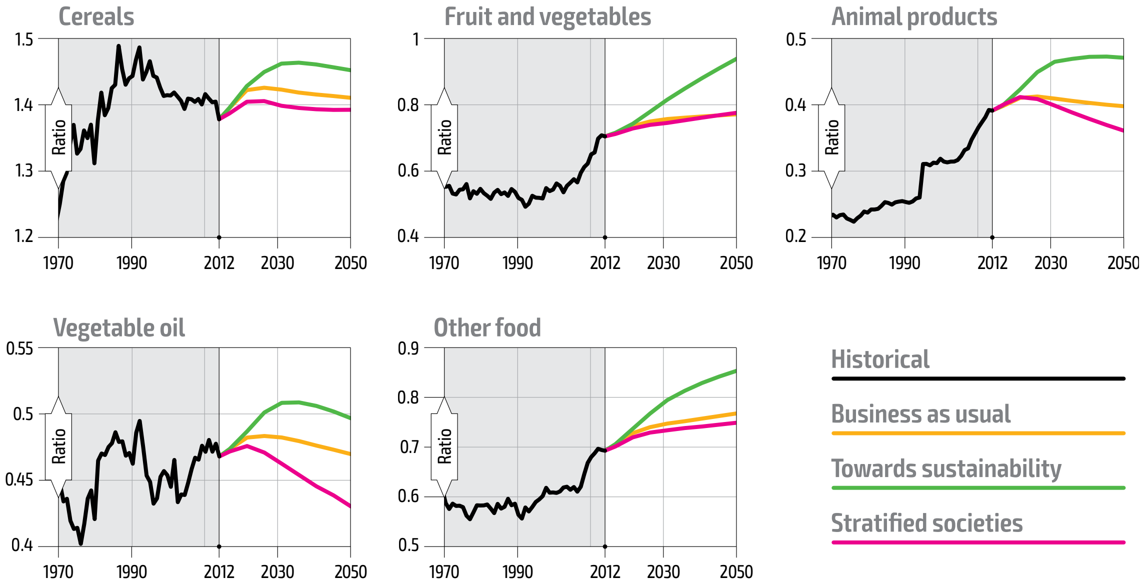
Note: Shares are based on per capita "apparent" food consumption, meaning country average consumption as derived from the FAOSTAT Food Balance Sheets. A ratio higher (lower) than 1 suggests that per capita kilocalorie intake from the specific food item is higher (lower) in LMIC than in HIC, whereas a ratio close to 1 suggests that dietary patterns of LMIC and HIC converge. Data for 1961 refer to per capita kilocalorie supply. The data for 2012 and thereafter refer to per capita kilocalorie consumption. Food groups are detailed in Annex III, Table A 3.5.

Sources: FAO Global Perspectives Studies, based on simulations with the FAO GAPS model and FAOSTAT (various years).

In the TSS scenario DEC progressively converges between LMIC (excluding China) and HIC, in fact moving in opposite directions in both regions. This is largely influenced by higher economic growth in LMIC and increased consumer awareness about sustainability, prompting the adoption in HIC of more balanced diets based less on animal products (see Figure 4.6). Consumers eat more food rich in micronutrients, such as fruit, vegetables and pulses. Indeed, increased consumption of pulses is the main reason for the convergence of the "other food" category. Thanks to higher per capita income in TSS than in BAU, LMIC address their immediate food security needs by increasing their consumption of cereals until 2025–2030, thus reversing historical dietary convergence. The overall dietary convergence under TSS reflects improved equity among countries and regions, to the benefit of LMIC.

[94] FAO (2004) provides a definition of dietary convergence, essentially referring to that of LMIC towards HIC: "Dietary convergence is occurring as a result of increased reliance on a narrow base of staple grains, increased consumption of meat and meat products, dairy products, edible oil, salt and sugar, and a lower intake of dietary fibre."

Figure 4.6 Per capita kilocalorie consumption in low- and middle-income countries (excluding China) as a share of that in high-income countries



Note: The grey, vertical line represents the base year 2012. A ratio higher/lower than 1 suggests that the per capita kilocalorie intake from fruits and vegetables in LMIC is higher/lower than in HIC, whereas a ratio close to 1 suggests that the dietary patterns of LMIC and HIC converge. The data before 2012 refer to per capita kilocalorie supply. The data for 2012 and thereafter refer to per capita kilocalorie consumption. Food groups are detailed in Annex III, Table A 3.5.

Sources: FAO Global Perspectives Studies, based on simulations with the FAO GAPS model and FAOSTAT (various years).

On the contrary, the SSS scenario is a pathway of divergence between HIC and LMIC. By 2050, DEC in LMIC (excluding China) lags behind that of HIC by more than 20 percent, much as in 2012. The dietary transition towards fewer animal products in HIC does not materialize. At the same time lower income growth, particularly in SSA, and much higher food prices compared to BAU do not allow LMIC (excluding China) to expand consumption of animal products, vegetable oils or even cereals. As HIC reduce their fruit and vegetable consumption, the convergence ratio remains close to that seen in BAU.

A generally applicable "ideal" level of calorie intake and mix of food items does not exist as such, since diets depend on lifestyles, culture, tradition, climate, local food availability, and so forth. Therefore, global convergence of diets per se can imply both benefits and costs, depending on whether it is towards balanced, micronutrient-rich diets (Regmi and Unnevehr, 2006). However, compared with BAU and SSS, the greater convergence between HIC and LMIC under TSS points to: a rebalancing of per capita calorie intake, with a net increase of DEC in LMIC; a rebalancing of consumption (in per capita terms) of animal products between HIC and LMIC, with the former reducing it and the latter increasing it, thus lowering inequalities in the overall distribution of animal proteins; and a pronounced increased consumption of fruit and vegetables in LMIC compared with HIC. All these elements substantiate the achievement of a better nutritional status under TSS.

Per capita food expenditure as share of per capita income

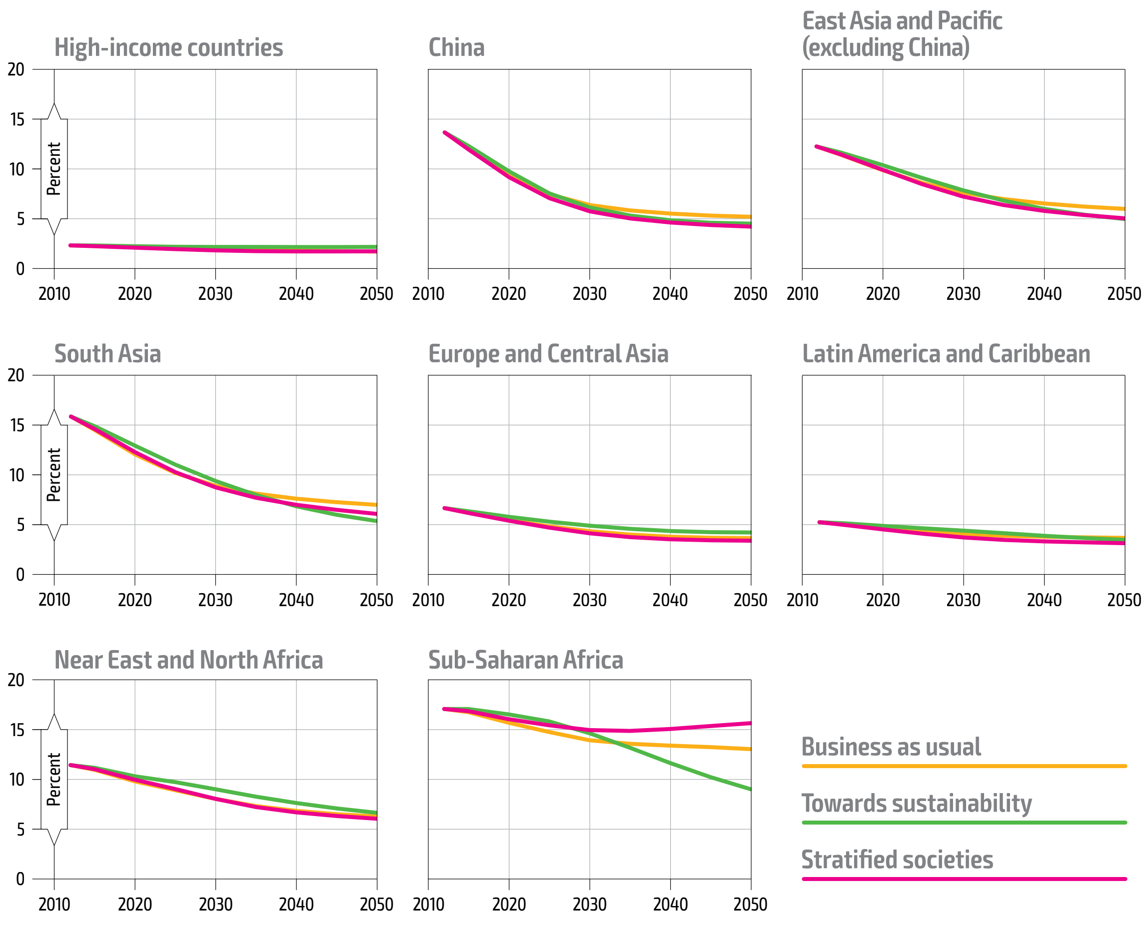
The combined changes in per capita food consumption, prices, and per capita income generate different projections for per capita food expenditure. Figure 4.7 shows that the shares of per capita food expenditure in per capita income present fairly small differences across scenarios, with the exception of SSA, which depicts the highest share. However, the dynamics over time are driven by different factors in each scenario.

Under BAU, food expenditure shares remain stable in HIC and decrease in all LMIC regions. A marked exception is SSA, where by 2050 food expenditure is still above 13 percent due to the combination of limited income increases and food price rises.

The TSS scenario portrays similar patterns as BAU, both for HIC and for almost all LMIC regions. In LMIC however, although the dynamics of food expenditure are similar to BAU they are determined by a much faster increase of both prices and per capita income (see Section 4.3). SSA stands out as an exception, where per capita income growth more than compensates for rising prices, thus leading to a significant drop in the food expenditure share compared with BAU while allowing increased calorie intake.

Despite much higher global income growth in SSS, substantial food price rises mean that per capita food expenditure share of per capita income remains in the same range as in BAU (see Figure 4.3). SSA is the only region where income rises less than in BAU and TSS (see Table 3.3). Prices are substantially higher than in BAU by 2050 and slightly higher than in TSS (see Figure 4.3), leading to a significantly increased per capita food expenditure share in SSA compared with BAU, which by 2050 is at levels comparable to 2012.

Figure 4.7 Projected shares of per capita food expenditures in per capita income



Sources: FAO Global Perspectives Studies, based on simulations with the FAO GAPS model.

Undernourishment

FAO estimates suggest that in 2012 (the base year for this foresight exercise) the worldwide PoU was 11 percent, almost on a par with 2016 levels and averaged 13 percent in LMIC with a peak in SSA at 20 percent (FAO, IFAD, UNICEF, WFP and WHO, 2017).[95]

In the BAU scenario the PoU decreases to about 7 percent in 2030, which is well above the SDG2 target of eliminating hunger by 2030. In the years after 2030, as population increases and higher food prices contribute to reducing DEC, the trend is reversed and the PoU is on the rise, reaching almost 8 percent in 2050 (see Table 4.6 and Figure 4.8). SDG2 targets are therefore not met even by 2050, and if anything food security deteriorates.

Table 4.6 Prevalence of undernourishment

	percentage of population							index, 2012 = 100		
	2012	2030			2050			2050		
REGIONS	BASE YEAR	BAU	TSS	SSS	BAU	TSS	SSS	BAU	TSS	SSS
High-income countries	**1.2**	**0.7**	**0.4**	**3.1**	**0.7**	**0.6**	**2.1**	**58**	**55**	**181**
East Asia and Pacific	11.2	6.6	2.3	7.9	7.6	3.3	7.4	68	29	66
– China	10.8	5.9	1.5	6.1	6.6	2.3	5.2	61	21	48
– East Asia and Pacific (excluding China)	12.0	7.8	3.6	11.2	9.2	4.8	11.0	76	40	91
South Asia	16.3	8.9	6.4	15.2	8.7	5.5	14.2	53	34	87
Europe and Central Asia	2.7	1.2	0.6	2.8	1.4	0.7	2.6	51	25	96
Latin America and Caribbean	6.5	4.9	4.7	7.7	4.9	4.9	7.2	76	76	112
Near East and North Africa	8.9	7.4	7.1	10.2	8.7	7.4	10.1	98	83	114
Sub-Saharan Africa	20.4	11.1	2.6	25.4	12.2	2.5	25.7	60	12	126
Low- and middle-income countries	**12.9**	**7.7**	**3.9**	**13.3**	**8.6**	**4.0**	**14.0**	**67**	**31**	**109**
– Low- and middle-income countries (excluding China)	13.5	8.2	4.5	15.1	9.0	4.3	15.7	67	32	116
World	**11.0**	**6.7**	**3.4**	**11.8**	**7.6**	**3.5**	**12.4**	**69**	**32**	**113**

Source: FAO Global Perspectives Studies, based on simulations with the FAO GAPS model; FAO, IFAD, UNICEF, WFP and WHO (2017); UN (2015).

In BAU, the reduction of the PoU from 11 percent in 2012 to about 7 percent in 2030 brings the number of undernourished people to below 600 million. However, population growth and a slight increase in the PoU partially undo this reduction and the number of undernourished goes up to 737 million people by 2050. This trend is more pronounced in SSA, where population growth is higher than elsewhere and the number of undernourished in 2050 ends up exceeding current levels (268 million people).

[95] FAO estimates of undernourishment measure the extent of energy deficiencies in DEC. However, these estimates do not account for malnutrition due to other causes such as micronutrient deficiencies or inadequate absorption of energy in food. The PoU depends on the average DEC, the difference between DEC and the MDER, and the degree of equality or inequality when distributing the average DEC across the entire population. Assumptions made in this report for each of the variables used to calculate the PoU are presented in Section 3.6.

These results suggest that "business as usual" is not a desirable option if food security is to improve, and certainly not if the SDG2 target is to be met. SSA remains the most food-insecure region, with the highest prevalence of undernourishment if trends continue.

Trends are different under the TSS scenario: the PoU drastically decreases compared with both the base year and the BAU scenario (to 3.4 percent by 2030) as income inequality is reduced within and across countries, presumably in response to efforts to meet the SDG targets. The PoU shows a slight upward trend after 2030, although it stays close to the 2030 percentage as higher food prices and lower per capita income growth cause a reduction in DEC that was noted earlier (see Table 4.6 and Figure 4.8).

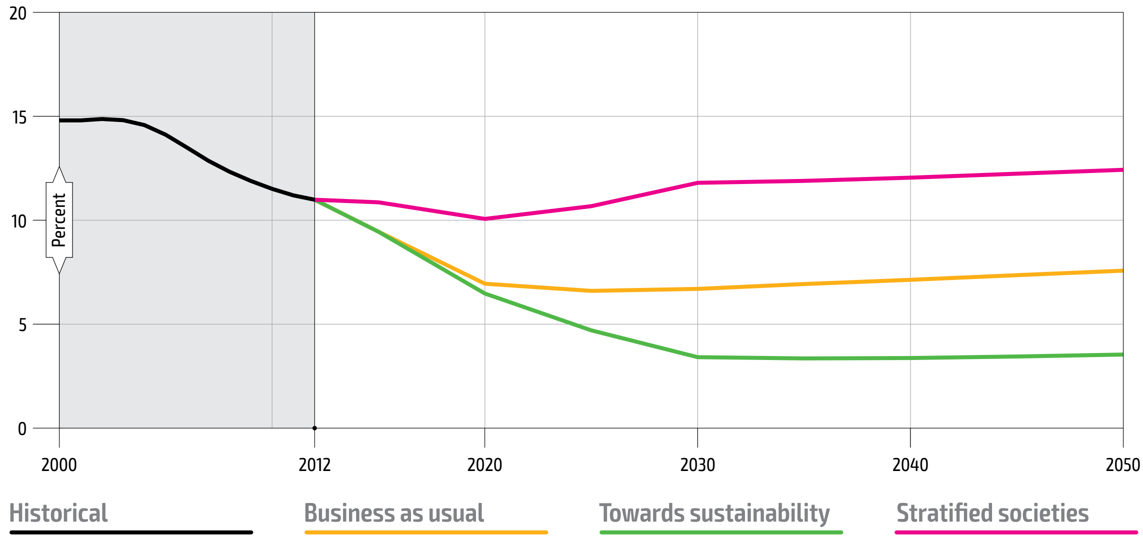
This overall improvement in food security compared with BAU is most visible for SSA (which displays a PoU below 3 percent by 2030 and thereafter), for a number of reasons: higher economic growth, which translates into increased food consumption; less food is wasted because it is more valuable; increased awareness leading to consumer purchases being more in line with their needs; and improvements in food distribution across countries and regions.[96] Although the projected PoU for 2030 is above the target for SDG2, the TSS findings suggest that sustainable production and behaviours need not come at the expense of food security: on the contrary, higher equality and more considerate use of natural resources and food leaves the world better off.

Improvements in food security under TSS – as reflected in the sharp decline of the PoU by 2030 – more than halve the number of people chronically undernourished compared with 2012. Price increases only slightly reverse this trend and add some 75 million undernourished people by 2050, half of whom are in SSA and the remainder mostly in EAP. These results suggest that efforts to realize the more sustainable world depicted in TSS can certainly help in reaching the halfway point of achieving SDG2 (zero hunger), but that these efforts need to be intensified after 2030 if we are to maintain the reduction in the number of undernourished in spite of high population growth.

On the other hand, SSS projects almost no decrease in the PoU from the 2012 benchmark. Around 1 billion people are projected to be undernourished by 2030, and more than 1.2 billion by 2050. The deterioration is most dramatic in SSA and SAS, where compared with BAU the number of undernourished increases 1.7 and 2.1 times respectively by 2050. This is a result of lower income growth (particularly in SSA), high food losses in retail distribution due to poor marketing facilities, unsustainable consumer behaviour and highly unequal food distribution. The only country showing a reduction of its PoU is China, thanks to significant per capita income growth.

96 In TSS, countries that lag behind in food distribution equality under BAU, are assumed to behave as neighbouring countries do where food distribution is more equitable. As a result, under TSS PoU levels are lower across countries and regions than under BAU.

Figure 4.8 Prevalence of undernourishment: global, historical and projected



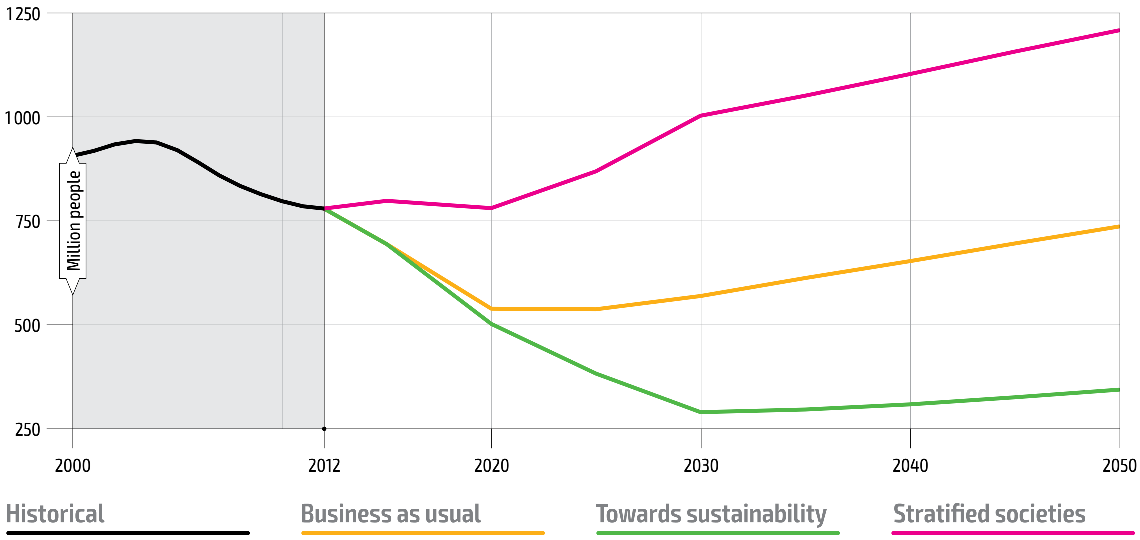
Source: FAO Global Perspectives Studies, based on simulations with the FAO GAPS model; FAO, IFAD, UNICEF, WFP and WHO (2017); UN (2015).

Table 4.7 Number of undernourished people

	million people							index, 2012 = 100		
	2012	2030			2050			2050		
REGIONS	BASE YEAR	BAU	TSS	SSS	BAU	TSS	SSS	BAU	TSS	SSS
High-income countries	**14**	**9**	**6**	**38**	**9**	**8**	**28**	**64**	**60**	**200**
East Asia and Pacific	224	143	49	171	165	71	161	74	32	72
– China	146	84	21	86	89	31	70	61	21	47
– East Asia and Pacific (excluding China)	77	59	28	85	76	40	91	99	52	118
South Asia	273	183	131	314	203	127	332	74	47	122
Europe and Central Asia	11	5	3	12	6	3	11	52	25	98
Latin America and Caribbean	38	34	32	53	37	37	54	98	98	144
Near East and North Africa	31	34	32	46	49	41	56	160	135	185
Sub-Saharan Africa	188	161	37	369	268	56	566	142	30	301
Low- and middle-income countries	**764**	**560**	**284**	**965**	**728**	**336**	**1 181**	**95**	**44**	**155**
– Low- and middle-income countries (excluding China)	618	476	263	879	639	305	1 111	103	49	180
World	**780**	**569**	**290**	**1 003**	**737**	**344**	**1 208**	**94**	**44**	**155**

Sources: FAO Global Perspectives Studies, based on simulations with the FAO GAPS model; FAO, IFAD, UNICEF, WFP and WHO (2017); UN (2015).

Figure 4.9 Number of undernourished people: global, historical and projected



Sources: FAO Global Perspectives Studies, based on simulations with the FAO GAPS model; FAO, IFAD, UNICEF, WFP and WHO (2017); UN (2015).

The results presented in this section regarding the type of diets and the equality in food distribution also suggest that the TSS scenario, while allowing for a significant reduction of undernourishment, could lead to achieving other nutritional goals. In this scenario, in HIC, by 2050 the per capita dietary energy consumption drops, compared to 2012, due to a reduction of animal products and fats while the consumption fruit and vegetables stabilizes (see Tables 4.2 and S 2.3) and the inequality of calories distribution across the population diminishes. This, other things being equal, should lead to more balanced diets, likely to imply a reduction of obesity, overweight and associated non-communicable diseases.[97]

On the contrary, the BAU scenario, and even more so the SSS scenario, should lead to negative implications for obesity, overweight and associated non-communicable diseases because of higher per capita dietary energy consumption of animal products in HIC and less diversified diets in LMIC.[98]

4.6 Commodity balances and net international trade

This section explores the extent to which domestic production of agricultural commodities matches domestic absorption (the sum of demand, combining food, feed, feedstock, loss and other uses) in alternative scenarios and across regions. Net trade is calculated as the difference between domestic production and domestic absorption and highlight whether a region or country is a net exporter or a net importer of a specific commodity, in other words defining the "net-trade" position of a region or country. The ratio between domestic

[97] Although eliminating adult obesity is not as such an SDG target, reducing adult obesity helps decreasing incidences of cardiovascular and other associated non-communicable diseases and so it helps reaching SDG targets that relate to ensuring health lives (for example SDG target 2.2. on ending all forms of malnutrition – including overweight – and 3.4 on reducing non-communicable diseases and enhance well-being).

[98] Quantification of obesity and overweight indicators has not been carried out in this report due to lack of quantitative information regarding the relationships between per capita Daily Energy Consumption and the different malnutrition dimensions. In fact, overweight, obesity and malnutrition in general depend not only on calorie intake or the type of food consumed but also on the way food is prepared, the metabolism of each person and other factors such as health and living conditions, occupation etc. Still, qualitative assessments can be inferred from the data portrayed in this report.

production and domestic absorption defines the self-sufficiency ratio. Particularly for food commodities such as cereals and meat, the self-sufficiency ratio has often been considered a strategic target variable, and thus heavily influences food and agricultural policies. The magnitude, quality and mix of domestic production can be determined by technology, expertise, resource availability, infrastructure, prevailing policies and the institutional environment, as well as by access to markets, prevailing prices and demand, which are in turn influenced by income, preferences and demographic trends. As these determinants of commodity balances and their future trends differ under alternative scenarios and across regions, commodity balances and related self-sufficiency ratios vary significantly as well for various commodity groups.

Historically, domestic production of food commodities such as cereals, fruit, vegetables and meat has been driven by aggregate domestic demand, meaning that countries with the highest demand tended to be the largest producers. Thus, international trade of food commodities has always been a small fraction of total production and domestic absorption. In 2012 HIC produced about 24 percent of the world's food and agricultural commodities and imported only 3.4 percent of what they needed, thus recording a self-sufficiency ratio of 0.97. LMIC (excluding China) accounted for 50 percent of global production, exported 4 percent of what they produced and their self-sufficiency ratio was 1.04. China produced the remaining 26 percent of global food and agricultural commodities while its net imports represented less than 4.3 percent of its demand, such that its self-sufficiency ratio was 0.96 (see Table 4.8). Developments in per capita food demand (see Section 4.5) together with economic and population growth (see Sections 3.2 and 3.1, respectively) under natural resource constraints (see Sections 3.7 to 3.12) lead to scenario-specific changes in both the size and composition of commodity balances.[99]

In BAU total agricultural production (value measured at base-year prices) expands between 2012 and 2050 by some 28 percent in HIC, 64 percent in LMIC (excluding China) and 35 percent in China (see Table 4.8). Despite this large expansion of production in LMIC (excluding China), natural resource constraints and insufficient investment in agriculture do not allow production to increase as much as domestic absorption, thus leading these countries to slightly reduce their self-sufficiency by 2050 and change their trade status from net exporters to net importers. Among other things, this is due to the increasing deficit in SSA of cereals, fish, fruit and vegetables, in NNA of cereals and in EAP (excluding China) of meat (see Tables S 1.1 to S 1.8). Deficit of fruit and vegetables in particular may well impact on nutrition, including shifting consumption towards "empty calories" (food rich in sugar, fats or oil), with detrimental effects such as obesity and related diseases, unless deficit countries have sufficient purchasing power to import them.

HIC and China are projected to raise their production more than their domestic absorption due essentially to the persistence of input- and natural-resource-intensive agriculture on the supply side, and population slowdown on the demand side. These dynamics lead those regions to move from a position of net importers in 2012 to net exporters in 2050.

[99] To provide a comprehensive overview and highlight fundamental trends, this section discusses the aggregate agricultural commodity balances. Detailed commodity balances by scenario and region for cereals, meat, fruit and vegetables, oilseeds, cash crops, dairy products, eggs and fish are presented in Chapter 1 of the Supplementary material (available at www.fao.org/3/CA1564EN/CA1564EN.pdf).

Table 4.8 Balance of total agricultural commodities

REGIONS	BALANCE ITEMS	billion USD, 2012 exchange rates							index, 2012 = 100		
		2012	2030			2050			2050		
		BASE YEAR	BAU	TSS	SSS	BAU	TSS	SSS	BAU	TSS	SSS
High-income countries	Production	**1 168**	**1 384**	**1 217**	**1 497**	**1 489**	**1 237**	**1 570**	**127**	**106**	**134**
	Food	839	925	820	954	961	787	1 008	115	94	120
	Feed	142	160	123	178	161	113	153	113	79	108
	Other uses	229	321	298	329	350	317	365	153	138	159
	Net trade	-42	-21	-24	36	17	21	44	–	–	–
	Self-sufficiency ratio	0.97	0.99	0.98	1.02	1.01	1.02	1.03	105	105	107
China	Production	**1 281**	**1 661**	**1 596**	**1 744**	**1 732**	**1 679**	**1 828**	**135**	**131**	**143**
	Food	1 003	1 225	1 167	1 256	1 172	1 100	1 218	117	110	121
	Feed	137	194	156	228	189	147	188	138	107	138
	Other uses	201	238	199	238	254	208	256	127	103	127
	Net trade	-60	4	73	22	117	224	166	–	–	–
	Self-sufficiency ratio	0.96	1.00	1.05	1.01	1.07	1.15	1.10	112	121	115
Low- and middle-income countries (excluding China)	Production	**2 439**	**3 322**	**3 169**	**3 356**	**4 001**	**3 871**	**3 942**	**164**	**159**	**162**
	Food	1 660	2 329	2 339	2 387	2 884	2 913	2 881	174	175	174
	Feed	160	271	236	312	424	435	428	265	272	268
	Other uses	521	705	643	716	828	767	843	159	147	162
	Net trade	98	17	-49	-58	-135	-245	-211	–	–	–
	Self-sufficiency ratio	1.04	1.01	0.98	0.98	0.97	0.94	0.95	93	90	91
World	Production	**4 888**	**6 366**	**5 982**	**6 597**	**7 222**	**6 786**	**7 340**	**148**	**139**	**150**
	Food	3 501	4 479	4 327	4 596	5 016	4 800	5 107	143	137	146
	Feed	438	624	514	718	774	695	769	177	158	175
	Other uses	948	1 264	1 140	1 283	1 432	1 291	1 464	151	136	154
	Net trade	0	0	0	0	0	0	0	–	–	–
	Self-sufficiency ratio	1.00	1.00	1.00	1.00	1.00	1.00	1.00	100	100	100

Note: Total agricultural commodities refers to all primary commodities as defined in Annex III, Table A 3.3, excluding paddy rice and including milled rice and fish. More details for specific regions can be found in Table S 2.5. Net trade is calculated as domestic production net of domestic absorption, i.e. the sum of demand for food and for "other uses". "Other uses" in the figure refers to the sum of non-food domestic uses, including: feed, seed, food loss, non-food processing (e.g. biofuels) and other demand. Positive (negative) net trade denotes net exports (imports).

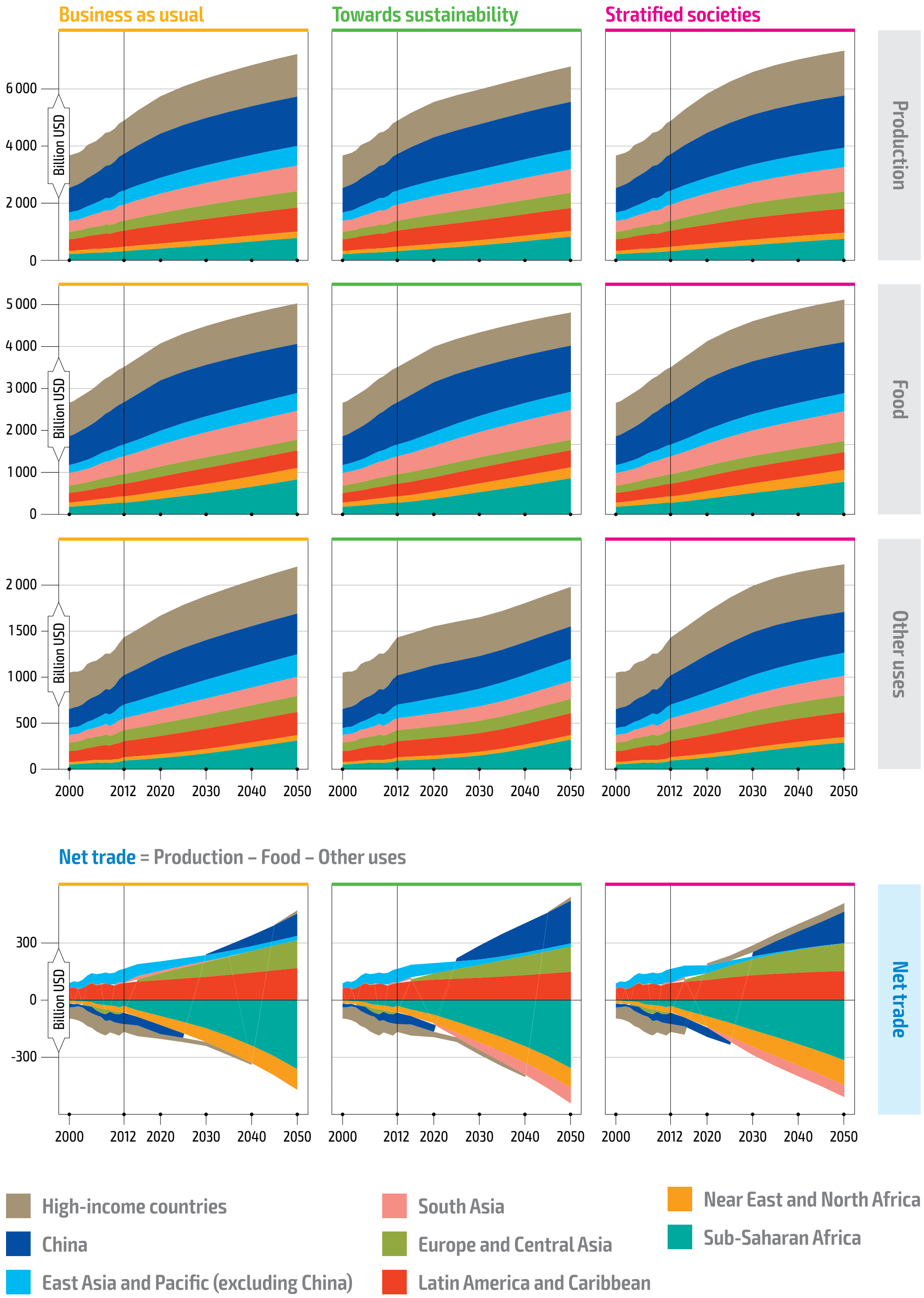
Source: FAO Global Perspectives Studies, based on simulations with the FAO GAPS model.

In TSS, the self-sufficiency of LMIC (excluding China) is much lower by 2050 compared with BAU. These countries display higher net imports due to their higher absorption of food and feed, as particularly apparent from increasing net imports in SSA (cereals and oilseeds), NNA (cereals, fruit and vegetables) and SAS (cereals, meat, fruit and vegetables). This is due to increased and more equitably distributed per capita income, which enables LMIC (excluding China) to improve their food security. On the other hand, self-sufficiency and trade balances improve in China and HIC, where less food and feed are demanded compared with BAU. As a result of their lower domestic absorption, HIC and China are able to compensate for the food deficits of LMIC (excluding China). Lower self-sufficiency in TSS does not imply increasing undernourishment or worsening malnutrition (see Section 4.5) since the higher economic growth of LMIC, compared to BAU and SSS, should provide them the necessary purchasing power to import food.

The SSS scenario is characterized by increasing disparities in production and consumption between HIC and China on one side, and LMIC (excluding China) on the other. By 2050 agricultural production in HIC and China expands more than in any other scenario, with the same applying to their domestic absorption of food and their feed demand. This is due to SSS portraying higher economic growth globally compared with the other scenarios, from which these regions benefit the most. Higher incomes and lower environmental awareness and health concerns prompt more people in these countries to consume more meat and other animal-based food, with negative implications on obesity and related diseases. On the other hand, in SSS, the absorption of agricultural products for food in LMIC (excluding China) is lowest of all the other scenarios. This disparity is particularly apparent in SSA (for details by region and commodity see Tables S 1.1 to S 1.8 and S 2.5). Despite their very high domestic absorption, by 2050 HIC and China consolidate their agricultural net exporter positions towards LMIC (excluding China) compared with BAU. This comes at a cost to the environment however, as in this scenario somewhat unsustainable practices prevail and GHG emissions are highest (see Section 4.10). Excess supply in HIC and China offsets excess demand elsewhere, although a price is paid in terms of food security. For example, in SSA diminished self-sufficiency and slower economic growth are reflected in substantially increased levels of undernourishment.

Overall, the three scenarios provide different pictures of the balance of total agricultural commodities and the underlying causes of these future dynamics (see Figure 4.10). While a trend towards agricultural deficits in LMIC (excluding China) features prominently in all three scenarios (due to much stronger demographic dynamics in these regions compared with those in HIC and China), the reasons for these deficits and their implications differ across scenarios. Moving towards sustainability implies that LMIC satisfy their increasing domestic food demand as far as possible through domestic production, boosted by adequate research and infrastructural investment and within the limits imposed by their natural resource base. The gap can be bridged through imports from regions where populations are no longer increasing, natural resources are available to sustainably produce agricultural surpluses, and food demand is oriented towards less resource-intensive items and restrained by low waste. This of course implies that, thanks to a more equitable distribution of income and earning opportunities across (and within) countries, LMIC (and their citizens) dispose of increasing purchasing power to import the goods required to fill their agricultural deficits. Although limited in size, under these conditions international trade takes on a strategic role in moving food and agricultural systems towards economic, social and environmental sustainability.

Figure 4.10 Balance of total agricultural commodities (2012 exchange rates)



Note: Total agricultural commodities refers to all primary commodities as defined in Annex III, Table A 3.3, excluding paddy rice and including milled rice and fish. More details for specific regions can be found in Table S 2.5. Net trade is calculated as domestic production net of domestic absorption, i.e. the sum of demand for food and for "other uses". "Other uses" in the figure refers to the sum of non-food domestic uses, including: feed, seed, food loss, non-food processing (e.g. biofuels) and other demand. Positive (negative) net trade denotes net exports (imports).

Source: FAO Global Perspectives Studies, based on simulations with the FAO GAPS model.

4.7 Crop yields and harvested areas

In response to growing demand for food and feed, either crop yields are raised (higher output per hectare of harvested area) or harvested areas expand, or both. Raising crop yields depends on several concurring factors, including: the extent of expansion of agricultural demand; changes in output prices which, other things being equal, trigger different input use per unit of land, thus shifting crop yields up or down; technological shifts, which change yields without affecting production costs;[100] and climate change, which alters the productivity of land and/or the availability of water, thus variably influencing yields. Expanding harvested areas meanwhile depends on factors including: the possibility of intensifying the use of existing cropland; the potential for expanding areas to be cultivated; the quality of additional land available; and the required investment for such expansion. As all these factors are scenario- and location-specific, the different scenarios portray diverse patterns for crop yields and harvested areas in different regions, as highlighted in this section.

Crop yields

Under BAU, average yields for cereals (wheat, rice and maize) increase globally by around 30 percent between 2012 and 2050, equivalent to an annual average rate of growth of around 0.7 percent. This is well below the rates observed in the last decades, which were in the order of 1–2 percent per year (FAO, 2017a). Similar rates apply globally to fruit and vegetables and to dominant crops in selected regions, such as soybeans in LAC, cassava and yams in SSA and sugarcane in EAP and LAC (see Table 4.9). However there are notable regional differences: for example, growth rates in LMIC are larger than in HIC for wheat and maize, as HIC are already close to their maximum potential. Nonetheless, significant crop yield gaps between HIC and LMIC still remain by 2050, due to limited technical progress in LMIC and differential climate change impacts across regions (Figure 3.9). For example, maize and vegetable yields in LMIC (excluding China) in 2012 are less than half those in HIC throughout the period. The gap is particularly high and persistent in SSA, where maize and vegetable yields are about one-quarter of those in HIC for the entire period.

Crop yield growth is generally lower in TSS compared with BAU, but yield gaps are relatively less important across regions. HIC display almost no growth, while LMIC – and in particular SSA – enjoy positive growth rates. Despite high population growth, LMIC can then expand their supply to contain their food imports (see Section 4.6), which in turn contributes to reducing interregional yield gaps for all the main crops. The overall limited yield growth in this scenario is due to progressively phasing in more sustainable agricultural practices of lower input intensity (particularly in HIC), as well as to the more widespread adoption of land and water conservation technologies that, although more expensive than conventional ones, are still profitable in the face of higher agricultural prices. While these technological changes focus more on the sustainability of yields than on their growth, they still set yields on an upward path until 2050.

Crop yield patterns in SSS resemble BAU as far as HIC are concerned, but not so much for LMIC, for which crop yields grow less. This widens yield gaps between HIC and LMIC.

[100] The potential changes in yield levels as a result of technological progress are generally higher in regions with low yields, while the contrary is true in regions where yields are already closer to the theoretical maximum values. At the same time, regional disparities in investments in research and development in agriculture lead to significant regional differences in yield changes.

Stronger negative climate change impacts on yields compared with BAU and persisting unsustainable natural resource use require an increasingly higher use of inputs per unit of output. This leads to progressively higher unit production costs, which reflect on progressively increasing agricultural prices, as highlighted in Section 4.3.

Overall, the future patterns of crop yields reflect the different states of the world portrayed by the alternative scenarios (see Figure 4.11). Moving towards sustainability implies adopting sustainable cropping patterns, which lead to comparatively lower growth rates of crop yields worldwide and on average, and higher unit production costs. However, yield growth patterns will be more balanced across regions, thanks partly to more evenly distributed technological changes and mitigated climate change impacts.

Table 4.9 Crop yields, major crops by region

		tonnes per hectare							index, 2012 = 100		
		2012	2030			2050			2050		
REGIONS	CROPS	BASE YEAR	BAU	TSS	SSS	BAU	TSS	SSS	BAU	TSS	SSS
High-income countries	All	6.3	7.4	5.9	7.5	8.3	6.6	8.5	131	104	134
	Vegetables	28.8	33.9	27.1	33.7	38.0	29.9	37.3	132	104	130
	Fruit	11.8	13.2	10.9	13.3	14.6	12.1	14.9	124	103	126
	Maize	8.9	9.9	7.9	9.9	10.6	8.3	10.5	119	94	119
	Wheat	3.8	4.3	3.4	4.3	4.8	3.8	4.8	126	100	126
	Soybeans	2.8	3.2	2.6	3.2	3.6	2.9	3.5	130	103	124
East Asia and Pacific	All	8.6	10.2	9.4	10.2	11.3	10.6	11.3	132	123	132
	Vegetables	21.8	26.0	23.8	26.0	29.7	27.4	29.8	137	126	137
	Rice	5.2	5.9	5.4	5.9	6.4	5.9	6.3	124	114	121
	Fruit	10.1	12.6	11.6	12.6	14.0	13.0	14.0	139	129	139
	Maize	5.5	6.4	5.8	6.5	7.1	6.4	7.2	129	117	131
	Sugar cane	69.2	80.9	76.5	82.8	90.4	85.7	96.3	131	124	139
China	All	9.4	11.0	10.2	11.1	12.1	11.4	12.7	130	122	136
	Vegetables	23.6	28.2	25.8	28.3	32.6	29.9	32.9	138	127	139
	Fruit	10.2	13.1	12.0	13.2	14.7	13.5	14.9	144	132	146
	Rice	6.7	7.1	6.5	7.2	7.3	6.8	7.5	109	101	112
	Maize	5.9	6.7	6.0	6.8	7.2	6.5	7.4	122	111	126
	Wheat	5.0	5.7	5.2	5.8	6.0	5.5	6.1	120	111	123
East Asia and Pacific (excluding China)	All	7.5	9.2	8.4	8.8	10.2	9.4	9.4	136	125	125
	Rice	4.2	5.1	4.7	5.0	5.8	5.4	5.4	137	127	127
	Palm oil	18.7	20.8	18.9	20.3	22.4	20.4	20.9	119	109	112
	Vegetables	10.9	13.4	12.3	12.8	15.4	14.3	14.0	141	130	128
	Sugar cane	69.5	79.3	75.4	77.8	85.7	81.7	81.9	123	118	118
	Natural rubber	1.1	1.2	1.1	1.2	1.3	1.2	1.3	117	104	115

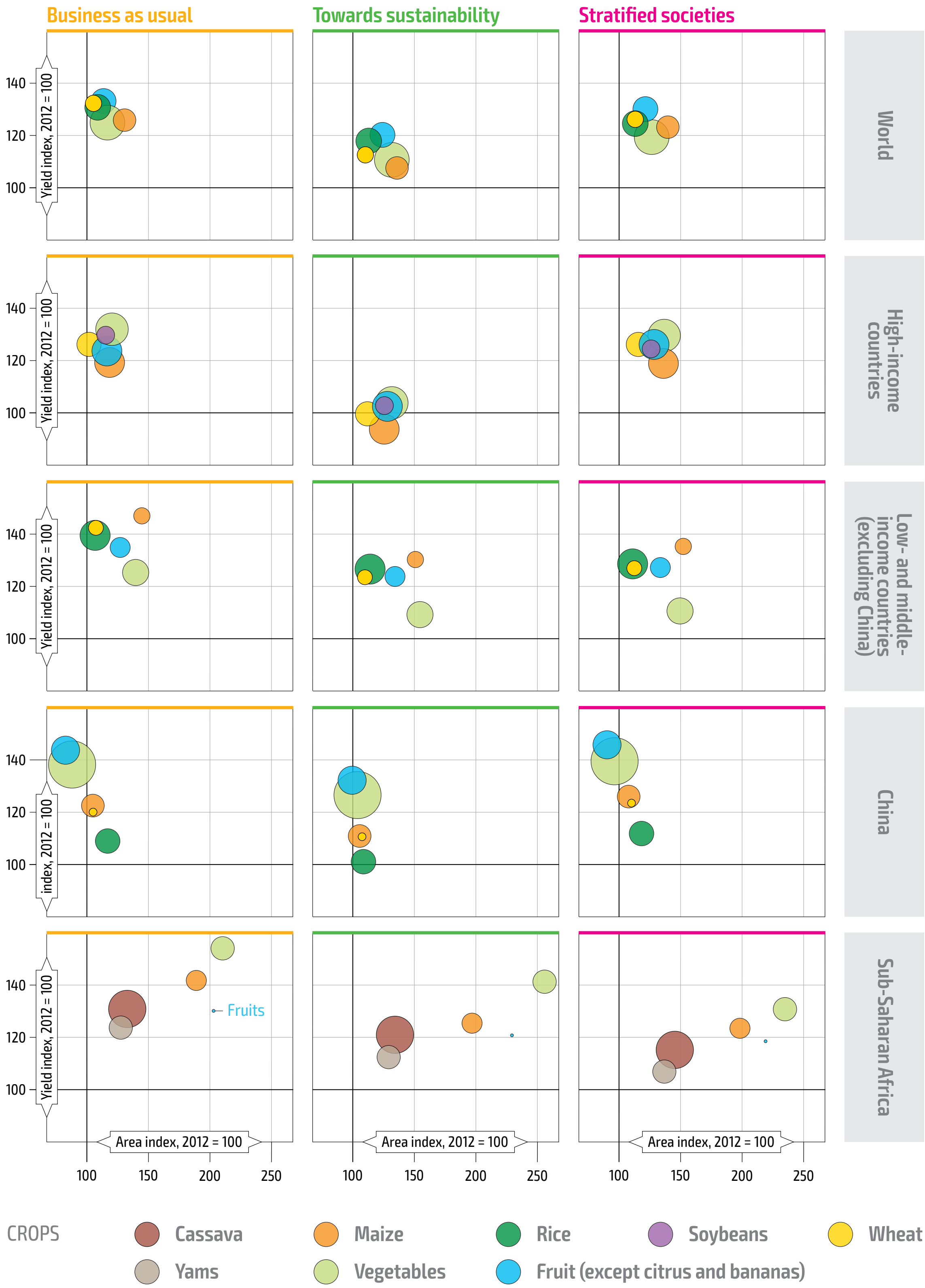
REGIONS	CROPS	tonnes per hectare							index, 2012 = 100		
		2012	2030			2050			2050		
		BASE YEAR	BAU	TSS	SSS	BAU	TSS	SSS	BAU	TSS	SSS
South Asia	All	5.0	6.2	5.4	5.8	7.1	6.0	6.2	142	120	124
	Rice	3.8	4.8	4.3	4.6	5.4	4.8	5.0	144	129	134
	Wheat	2.9	3.7	3.3	3.5	4.2	3.7	3.7	144	126	124
	Vegetables	13.6	15.9	14.0	14.8	17.6	15.3	15.2	129	112	111
	Fruit	8.2	10.5	9.5	10.2	12.6	11.5	11.8	153	140	144
	Cotton	1.7	2.3	2.0	2.2	2.6	2.2	2.3	150	131	136
Europe and Central Asia	All	4.0	5.3	4.5	5.1	6.0	5.2	5.7	149	128	141
	Vegetables	20.7	25.3	21.9	24.2	28.5	24.5	26.2	138	118	127
	Wheat	2.3	2.8	2.4	2.7	3.2	2.8	3.0	143	124	133
	Potatoes	16.0	20.0	17.5	19.5	23.2	20.5	21.8	145	128	136
	Fruit	7.6	9.2	8.1	9.1	9.9	8.9	9.7	130	117	128
	Maize	5.0	6.8	5.5	6.6	7.9	6.2	7.3	158	123	145
Latin America and Caribbean	All	10.2	11.6	10.8	10.8	12.7	12.0	11.2	125	118	110
	Soybeans	2.7	3.1	2.8	3.0	3.5	3.2	3.1	130	118	114
	Sugar cane	73.2	81.0	78.5	80.4	87.7	85.4	85.6	120	117	117
	Maize	4.2	5.6	5.2	5.5	7.0	6.4	6.5	165	152	154
	Fruit	12.8	14.8	13.6	14.3	16.6	15.4	15.4	130	120	120
	Vegetables	16.1	19.1	17.6	18.2	21.4	19.9	19.4	132	124	120
Near East and North Africa	All	5.3	6.4	5.7	6.1	7.0	6.0	6.5	130	112	122
	Vegetables	23.2	28.2	25.0	27.1	31.2	26.8	28.9	135	116	125
	Fruit	9.0	10.8	9.9	10.6	12.3	11.2	11.7	136	124	130
	Wheat	2.1	2.6	2.2	2.4	2.8	2.3	2.4	130	110	115
	Other crops	1.5	1.7	1.6	1.7	1.7	1.6	1.8	117	110	117
	Rice	6.7	7.4	6.8	7.3	7.8	7.2	7.5	115	106	111
Sub-Saharan Africa	All	3.0	3.4	3.1	3.2	3.9	3.5	3.4	130	119	114
	Cassava	9.4	10.7	9.8	10.2	12.3	11.3	10.8	130	120	115
	Vegetables	6.6	8.5	7.7	7.9	10.2	9.4	8.7	154	141	131
	Yams	7.7	8.6	7.8	8.1	9.5	8.6	8.2	123	112	107
	Maize	1.8	2.1	1.9	2.0	2.5	2.2	2.2	141	125	123
	Fruit	8.3	9.5	8.8	9.1	10.8	10.0	9.8	130	121	119
Low- and middle-income countries	All	6.2	7.2	6.5	6.9	7.9	7.1	7.3	127	116	118
	Rice	18.2	20.9	18.9	20.4	22.6	20.4	21.4	131	119	124
	Vegetables	4.4	5.3	4.8	5.1	5.8	5.3	5.5	124	112	117
	Fruit	9.4	11.4	10.5	11.3	12.8	11.8	12.3	136	125	131
	Maize	4.0	4.8	4.2	4.7	5.3	4.7	5.1	134	119	127
	Wheat	2.9	3.5	3.1	3.4	3.9	3.5	3.6	136	120	126

		tonnes per hectare							index, 2012 = 100		
		2012	2030			2050			2050		
REGIONS	CROPS	BASE YEAR	BAU	TSS	SSS	BAU	TSS	SSS	BAU	TSS	SSS
Low- and middle-income countries (excluding China)	All	5.6	6.5	5.9	6.2	7.2	6.5	6.4	129	116	115
	Rice	3.9	4.8	4.4	4.6	5.4	4.9	5.0	139	127	129
	Vegetables	13.9	16.0	14.1	15.1	17.4	15.1	15.3	125	109	111
	Fruit	9.1	10.8	9.9	10.5	12.2	11.2	11.5	135	124	127
	Maize	3.3	4.2	3.7	4.1	4.9	4.3	4.5	147	130	135
	Wheat	2.5	3.1	2.7	2.9	3.6	3.1	3.2	142	123	127
World	All	6.2	7.2	6.4	7.0	7.9	7.0	7.5	128	114	121
	Vegetables	19.1	22.0	19.6	21.6	23.8	21.1	22.8	125	111	119
	Rice	4.5	5.3	4.8	5.2	5.9	5.3	5.6	131	118	124
	Fruit	9.9	11.8	10.6	11.7	13.1	11.9	12.8	133	120	130
	Maize	5.1	6.0	5.1	6.0	6.5	5.5	6.3	125	107	123
	Wheat	3.2	3.8	3.2	3.7	4.2	3.6	4.0	132	113	126

Notes: Crops are ranked on the basis of their gross production value, expressed as physical output in the base year times base-year prices in USD. In this table "Fruit" excludes citrus and bananas.

Source: FAO Global Perspectives Studies, based on simulations with the FAO GAPS model.

Figure 4.11 Yields and harvested areas for the five major crops, by region: changes 2012–2050



Note: The figures show changes in harvested area (x-axis) and yield (y-axis) for the five most important crops in each region in 2050 relative to the base year. Crops are ranked on the basis of their production value, calculated as the physical output at the base year multiplied by base-year prices in USD. Circle sizes are proportional to the share of production value in the base year.

Source: FAO Global Perspectives Studies, based on simulations with the FAO GAPS model.

Harvested areas

Under BAU, harvested areas are projected to increase globally by around 238 million hectares (around 18 percent) between 2012 and 2050 (see Table 4.10).[101] This expansion takes place early in the simulation period to address the needs of a growing population, although there is a slowdown later as population growth rates decline. Globally, among the top five crops, maize absorbs a significant proportion (more than 22 percent) of the additional harvested area by 2050 (see Table S 2.6). Substantially different growth patterns are observed among regions: much higher increases are expected in SSA (up by 62 percent), lower increases in LAC (up by 20 percent), and very limited increases in other regions (less than 10 percent). NNA is the only region where harvested areas could shrink by 2050, as limited water availability constrains irrigated production systems, which play a significant role in the region. Globally, harvested areas in irrigated systems are expected to rise during 2012 and 2050 by 22 percent (Table 4.10), growing at a higher pace than rainfed ones (15 percent increase). However, despite this growth differential the share of irrigated harvested areas by 2050 only reaches 32 percent (compared with 30 percent in 2012), with SSA remaining below 5 percent (more or less as in 2012).

Table 4.10 Harvested area by production system

IRRIGATED	million hectares							index, 2012 = 100		
	2012	2030			2050			2050		
REGIONS	BASE YEAR	BAU	TSS	SSS	BAU	TSS	SSS	BAU	TSS	SSS
High-income countries	**48**	**59**	**56**	**67**	**64**	**58**	**76**	**134**	**122**	**160**
East Asia and Pacific	142	168	165	165	175	171	173	123	121	122
– China	103	124	118	123	129	120	130	126	116	126
– East Asia and Pacific (excluding China)	39	44	47	42	46	52	43	117	133	111
South Asia	138	154	143	148	158	138	150	115	100	109
Europe and Central Asia	24	27	28	27	27	29	28	116	124	119
Latin America and Caribbean	25	33	34	31	37	42	35	146	165	139
Near East and North Africa	21	22	20	21	20	17	20	95	79	96
Sub-Saharan Africa	9	13	15	13	17	21	16	182	222	176
Low- and middle-income countries	**359**	**416**	**405**	**406**	**434**	**417**	**423**	**121**	**116**	**118**
– Low- and middle-income countries (excluding China)	256	292	287	283	305	298	293	119	116	115
World	**406**	**475**	**461**	**473**	**498**	**476**	**499**	**123**	**117**	**123**

[101] Note that these projections differ from previous FAO foresight exercises due to different assumptions regarding population growth, dietary preferences, crop yield growth, and others, as specified in Chapter 3.

RAINFED	million hectares							index, 2012 = 100		
	2012	2030			2050			2050		
REGIONS	BASE YEAR	BAU	TSS	SSS	BAU	TSS	SSS	BAU	TSS	SSS
High-income countries	**195**	**209**	**231**	**227**	**204**	**231**	**225**	**105**	**119**	**116**
East Asia and Pacific	157	155	171	165	139	162	157	88	103	100
– China	73	67	79	73	52	72	61	71	99	84
– East Asia and Pacific (excluding China)	84	88	92	93	87	90	96	103	107	114
South Asia	104	107	120	116	104	123	119	100	118	114
Europe and Central Asia	123	129	141	139	130	143	142	106	116	116
Latin America and Caribbean	125	137	145	148	144	152	160	115	121	127
Near East and North Africa	24	24	26	25	24	26	25	100	109	108
Sub-Saharan Africa	210	279	298	297	340	366	370	162	174	176
Low- and middle-income countries	**743**	**831**	**900**	**890**	**880**	**972**	**973**	**118**	**131**	**131**
– Low- and middle-income countries (excluding China)	671	765	821	817	829	900	912	124	134	136
World	**938**	**1 040**	**1 131**	**1 116**	**1 084**	**1 203**	**1 198**	**116**	**128**	**128**

ALL SYSTEMS	million hectares							index, 2012 = 100		
	2012	2030			2050			2050		
REGIONS	BASE YEAR	BAU	TSS	SSS	BAU	TSS	SSS	BAU	TSS	SSS
High-income countries	**242**	**268**	**287**	**294**	**268**	**290**	**301**	**111**	**120**	**124**
East Asia and Pacific	299	323	337	330	313	334	330	105	112	110
– China	176	191	198	195	181	192	190	103	109	108
– East Asia and Pacific (excluding China)	123	132	139	135	133	142	139	108	115	113
South Asia	242	261	263	264	262	261	269	108	108	111
Europe and Central Asia	146	157	168	166	157	172	170	108	117	116
Latin America and Caribbean	151	170	179	179	181	194	195	120	128	129
Near East and North Africa	44	45	46	47	43	42	45	97	95	102
Sub-Saharan Africa	220	293	312	310	357	387	386	163	176	176
Low- and middle-income countries	**1 102**	**1 248**	**1 305**	**1 295**	**1 314**	**1 389**	**1 396**	**119**	**126**	**127**
– Low- and middle-income countries (excluding China)	926	1 057	1 108	1 100	1 133	1 198	1 205	122	129	130
World	**1 344**	**1 515**	**1 592**	**1 589**	**1 582**	**1 679**	**1 697**	**118**	**125**	**126**

Source: FAO Global Perspectives Studies, based on simulations with the FAO GAPS model.

In TSS harvested areas expand by 335 million hectares by 2050, which is almost 25 percent higher than 2012. This expansion is more significant than in BAU and helps to partially compensate for limited yield growth. As in BAU, maize still absorbs a significant proportion of the additional harvested area (around 18 percent), but more prominence is given to expanding the area for fruit, vegetables and rice than in BAU (see Table S 2.6). Expanding harvested areas is also more diversified across regions and farming systems than in BAU, as it takes into consideration the different potential in various regions and the stress of water resources. For example, under this scenario rainfed harvested areas in SSA expand by 74 percent with respect to 2012 (compared with 62 percent in BAU) in order to better exploit existing land expansion potential. Furthermore, tighter restrictions on the use of water resources lead to a limited expansion of irrigated harvested areas in water-stressed regions such as China and SAS, and even a sharp decline in NNA. On the other hand, larger investments in SSA make it possible to exploit water resources where they are available, which allows for irrigated areas to be more than doubled by 2050, although they remain a fraction of the total harvested areas in the region.

In SSS harvested areas expand by 343 million hectares globally, which is more than 25 percent compared with 2012. This expansion is more significant than in BAU, but the allocation of additional areas to the different crops resembles BAU, with prominence given to maize and wheat (see Table S 2.6). In HIC, irrigated harvested areas expand significantly thanks to the higher potential of investing in irrigation infrastructure, water management expertise, and comparatively higher water availability due to relatively less severe climate change impacts. Irrigated harvested areas expand much less in LMIC (excluding China), which allows HIC to gain a major role in the production and export of commodities such as cereals, fruit, and vegetables (see Section 4.6), thus exacerbating the divergences between the two regions. Furthermore, despite water scarcity due to exacerbated climate change in NNA, irrigated harvested areas do not shrink by 2050 compared with 2012, thus implying additional water stress in already water-scarce areas (see Figure 1.11).

Overall, the joint analysis of crop yields and harvested areas highlights that these two variables have to adjust mutually to accommodate additional agricultural demand. While in the quest for sustainability yield expansion could be restrained by adopting less resource- and input-intensive technologies, harvested areas would need to grow comparatively more (other things being equal) to compensate for this limited yield expansion. On the other hand, greater harvested areas do not automatically translate into additional cropland requirements. In fact, if sustainable agricultural practices are associated with higher cropping intensity, the expansion of physical cropland can be restrained, despite increasing harvested areas, as highlighted in Section 4.9.

4.8 Animal herds

The livestock sector contributes around 40 percent to the global value of agricultural output and ensures the livelihoods and food security of almost 1.3 billion people who depend on it.[102] The sector has been growing at an unprecedented rate over the past few decades, faster than other agricultural sectors. This growth and the accompanying transformation processes offer opportunities to reduce poverty and increase food security, although there is also the risk of family farmers being marginalized. Natural resources could also be exposed to more unsustainable practices, as land used for livestock production (including

[102] www.fao.org/animal-production/en

pasture, rangeland, and cropland) represents almost 80 percent of all agricultural land, with feed production taking up roughly one-third of total cropland.

In general, changes in animal herd sizes are driven by changes in productivity, prices, demand for animal products, and natural resource restrictions. Analysis of recent trends suggests that the size of animal herds tends to follow national demographic dynamics, given that most animal products consumed are produced domestically. Herd sizes are also related to economic growth: evidence suggests that the consumption of animal products rises with per capita income, at least at low- and medium-income levels. Because these determinants are diversified across scenarios and regions, the livestock sector presents quite different dynamics.

By 2050 in the BAU scenario, animal herds (expressed in livestock units)[103] globally are 46 percent more numerous than in 2012 (see Table 4.11). The largest expansion by far takes place in SSA (185 percent), followed by EAP (excluding China) and ECA. Drastic changes in population numbers and more meat-rich diets are the drivers in SSA, under the assumption that increasing domestic demand will be met by domestic production, rather than by imports. Poultry, pigs, and large and small ruminants increase at annual average rates of 4.8, 3.2, 2.3 and 2.4 percent respectively:[104] this translates to more than quintuple the poultry numbers, triple for pigs and double for both large and small ruminants (see Figure 4.12 and Tables S 2.7 to S 2.10).[105] Still, total pig herds in SSA remain limited, particularly compared to China, which remains the largest producer of pigs. This presupposes that China will increase domestic production capacities to maintain a low dependency on meat imports.

103 Livestock units (used for aggregating the numbers of different categories of livestock) are derived in terms of relative feed requirements. Conversion ratios are generally based on metabolisable energy requirements, with one unit being considered as the needs for maintenance and production of a typical dairy cow and calf (FAO, 2011b).

104 Large ruminants include cattle and buffaloes. The projected growth rates in SSA are close to observed rates for 1970–2012, amounting to 3.7, 2.5 and 3.1 percent for pigs, large ruminants and small ruminants respectively. The projected average annual growth rate for poultry exceeds the 3.6 percent observed for 1970–2012.

105 Other contributing factors to the expansion of poultry herds in SSA are area limitations for ruminant herds and country-specific food habits that may exclude pork consumption for a large proportion of the population. Other forward-looking exercises (e.g. Herrero *et al.*, 2014) also project expansions of the livestock sectors in SSA within such orders of magnitude.

Table 4.11 Total animal herd size

REGIONS	million livestock units							index, 2012 = 100		
	2012	2030			2050			2050		
	BASE YEAR	BAU	TSS	SSS	BAU	TSS	SSS	BAU	TSS	SSS
High-income countries	**377**	**393**	**357**	**411**	**397**	**331**	**383**	**105**	**88**	**101**
East Asia and Pacific	404	463	425	488	483	428	477	120	106	118
– China	302	336	306	356	330	286	325	109	95	108
– East Asia and Pacific (excluding China)	102	127	119	132	154	142	152	151	139	149
South Asia	263	317	292	300	321	293	319	122	111	121
Europe and Central Asia	83	107	97	115	122	108	120	148	131	145
Latin America and Caribbean	334	413	386	433	468	411	464	140	123	139
Near East and North Africa	59	70	65	71	84	75	80	142	127	136
Sub-Saharan Africa	226	397	372	421	582	556	552	258	247	245
Low- and middle-income countries	**1 368**	**1 767**	**1 638**	**1 829**	**2 060**	**1 871**	**2 012**	**151**	**137**	**147**
– Low- and middle-income countries (excluding China)	1 066	1 431	1 331	1 473	1 731	1 585	1 687	162	149	158
World	**1 745**	**2 160**	**1 995**	**2 241**	**2 548**	**2 203**	**2 395**	**146**	**126**	**137**

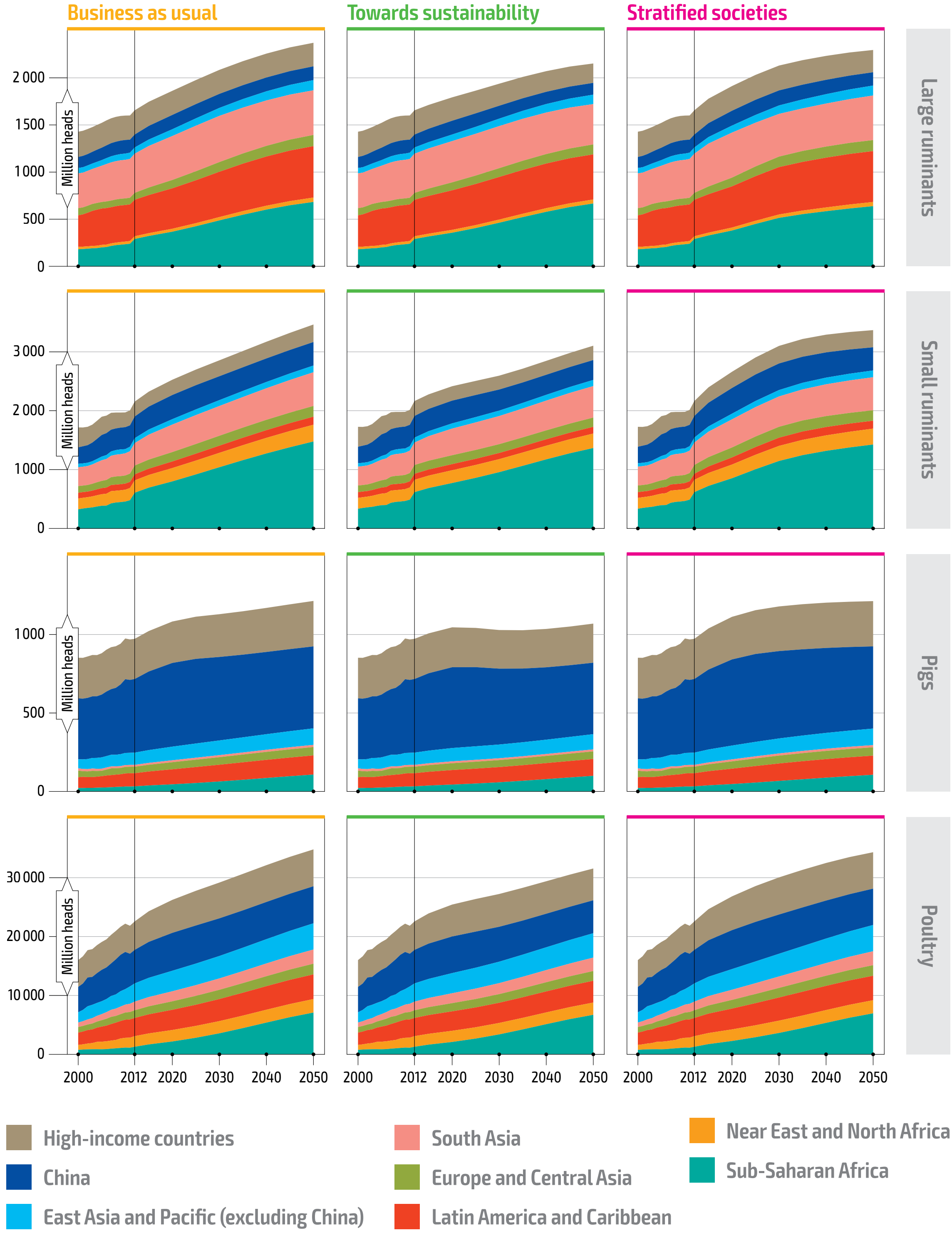
Note: Livestock units are calculated as in FAO, 2011b.

Source: FAO Global Perspectives Studies, based on simulations with the FAO GAPS model and FAOSTAT (various years).

The TSS scenario portrays a more moderate global increase in herds (26 percent) by 2050 than BAU, owing to more static dietary preferences, particularly in HIC and China where herd sizes actually decline. This is due not only to the comparatively lower demand for animal products, but also because of less intensive production systems in most regions. Furthermore, herd sizes show a generally increasing pattern on a global scale, albeit lower than under BAU. As in BAU, in TSS the most pronounced growth in animal herds is in SSA. This is largely due to higher per capita income (compared with BAU) and the resulting increased demand. In contrast to other regions, animal productivity in SSA is higher than under BAU, presumably due to the adoption of sustainable intensification practices (see Section 3.11) and increased agricultural investment, thus diminishing the need for animals to satisfy domestic demand. Without this, the population and income impacts in SSA could cause even larger herd sizes. The TSS scenario was also designed to include more severe restrictions on stocking densities in order to ensure the sustainable use of grazing land. This contributes in particular to a smaller expansion in ruminant herds compared with BAU (see Tables S 2.7 and S 2.8).

In SSS the total herd size in livestock units is projected to rise by 37 percent between 2012 and 2050, placing the SSS findings between the other two scenarios. The largest increases across regions are projected for SSA, much as in the TSS scenario but for different and contrasting reasons: in SSS per capita income is lower than in TSS, such that there is less demand for animal products compared with the other two scenarios. However, lack of investment and continued less sustainable practices cause animal productivity (output per animal) to be lower, with an increasing effect on herd sizes to compensate for the reduced output from each animal.

Figure 4.12 Total animal herds by livestock category



Source: FAO Global Perspectives Studies, based on simulations with the FAO GAPS model and FAOSTAT (various years).

In summary, animal herds show a general tendency to grow globally, following human population projections. Nonetheless, there are some substantial differences across scenarios and regions. Moving food and agricultural systems towards economic, social and environmental sustainability implies lower growth rates of animal herds in HIC and China compared to LMIC (excluding China). While the consumption rates continue to rise in LMIC, a shift towards less animal-intensive diets, particularly in HIC, restrains the growth of herd sizes. However a number of LMIC, particularly in SSA, continue to be net importers of meat, irrespective of their impressive growth in herds (see Table S 1.2). Meanwhile their domestic demand for tradable feed commodities expands, particularly for cereals, as a result of which their dependency on cereal imports also rises (see Table S 1.1).

4.9 Land and water use

Land requirements

The changes in harvested areas discussed above have important implications for arable land demand.[106] With generally increasing cropping intensities in the future, net demand for physical area could be expected to grow at a slower rate than harvested areas.[107]

The BAU scenario projects arable land to rise globally by 165 million hectares (11 percent), from 1 567 million hectares in 2012 to 1 732 million hectares in 2050 (see Table 4.12).[108] This would be a continuation of trends seen in 1970 and 2012, when 107 million hectares of arable land were added at annual growth rates of 0.2–0.3 percent. Regional disparities in arable land requirements are mostly driven by variations in food and feed demand. The largest increase occurs in SSA (58 percent between 2012 and 2050), where food demand and animal production expand the most. Conversely, in HIC and China – but also in NNA and ECA to a lower extent – arable land is projected to stay at similar or at slightly lower levels than in 2012 as food demand expansion is limited (see Section 4.5) while yield expansion and higher cropping intensities allow for as much supply as needed.

In the TSS scenario the assumptions on reduced yield growth due to sustainable agricultural practices (see Section 3.8) would translate into larger area requirements to produce the same amount of food, other things being equal (Muller *et al.*, 2017). However, sustainability concerns lead to reduced food loss and waste and lower food consumption, especially of animal products (compared to BAU), as well as increased cropping intensity. This contributes to limiting the increase in arable land-use to only 6 percent from 2012 to 2050. This is almost half the increase projected under BAU. Regional disparities in the projected growth of arable land (already highlighted under BAU) are also observed in TSS, with the biggest expansion seen in SSA compared with all other regions. On the other hand, HIC, China, NNA and ECA reduce their arable land largely due to a lower expansion of livestock, as the demand for meat and the resulting demand for crops used as animal feed decrease compared with BAU.

[106] There are obvious implications because the demand for arable land is the ratio of harvested area and cropping intensity. As noted earlier, cropping intensity shifts with changing climate conditions and scenario assumptions (see Section 3.9). Following FAOSTAT terminology, the term “arable land” is used here for the physical area under temporary and permanent agricultural crops.

[107] In this section, variations of arable land refer to the balance of land that needs to be converted from other uses and land areas that are abandoned as a result of decreased productivity or conversion to other uses (net demand).

[108] Note that these projections differ from previous FAO foresight exercises due to different assumptions regarding population growth, dietary preferences, crop yield growth, and others, as specified in Chapter 3.

Table 4.12 Arable land by production system

		million hectares								index, 2012 = 100		
		1970	2012	2030			2050			2050		
REGIONS	PRODUCTION SYSTEMS	HISTORICAL	BASE YEAR	BAU	TSS	SSS	BAU	TSS	SSS	BAU	TSS	SSS
High-income countries	**IRRIGATED**		**46**	**52**	**44**	**58**	**53**	**42**	**57**	**114**	**91**	**123**
	RAINFED		**330**	**336**	**329**	**360**	**316**	**318**	**334**	**96**	**96**	**101**
	TOTAL	**423**	**376**	**388**	**373**	**418**	**369**	**360**	**391**	**98**	**96**	**104**
East Asia and Pacific	IRRIGATED		85	95	83	93	96	84	93	113	99	109
	RAINFED		154	150	146	162	136	139	155	88	90	100
	TOTAL	178	239	245	229	255	232	222	248	97	93	104
– China	IRRIGATED		57	65	55	64	64	52	62	112	91	109
	RAINFED		64	57	59	61	43	52	49	67	82	77
	TOTAL	103	122	122	114	125	107	104	112	88	86	92
– East Asia and Pacific (excluding China)	IRRIGATED		28	30	29	30	31	32	30	114	115	110
	RAINFED		90	93	87	100	93	86	105	104	96	117
	TOTAL	75	117	123	115	130	125	118	136	106	100	116
South Asia	IRRIGATED		105	114	93	112	116	88	113	111	84	108
	RAINFED		117	118	117	130	115	120	132	98	102	113
	TOTAL	217	222	232	210	241	231	208	245	104	94	110
Europe and Central Asia	IRRIGATED		21	22	20	21	20	19	20	98	89	94
	RAINFED		227	229	221	250	225	220	251	99	97	111
	TOTAL	290	247	251	241	272	245	239	271	99	96	109
Latin America and Caribbean	IRRIGATED		20	25	23	24	28	27	26	138	137	132
	RAINFED		165	179	169	200	190	181	224	115	109	135
	TOTAL	116	185	204	192	224	218	208	250	118	112	135
Near East and North Africa	IRRIGATED		18	17	14	18	16	12	16	88	66	89
	RAINFED		40	41	39	45	42	41	49	103	100	120
	TOTAL	53	58	59	54	63	57	52	64	99	90	111
Sub-Saharan Africa	IRRIGATED		8	11	11	11	14	14	14	168	174	165
	RAINFED		231	300	284	327	365	349	410	158	151	178
	TOTAL	163	239	311	295	338	379	364	424	158	152	177
Low- and middle-income countries	**IRRIGATED**		**256**	**284**	**244**	**279**	**289**	**244**	**281**	**113**	**95**	**110**
	RAINFED		**934**	**1 017**	**977**	**1 115**	**1 073**	**1 049**	**1 220**	**115**	**112**	**131**
	TOTAL	**1 118**	**1 190**	**1 302**	**1 221**	**1 394**	**1 362**	**1 293**	**1 501**	**114**	**109**	**126**
– Low- and middle-income countries (excluding China)	IRRIGATED		199	219	189	215	225	192	218	113	96	110
	RAINFED		870	961	917	1 054	1 030	997	1 171	118	115	135
	TOTAL	1 015	1 069	1 180	1 107	1 269	1 255	1 188	1 389	117	111	130
World	**IRRIGATED**		**302**	**337**	**288**	**336**	**342**	**286**	**338**	**113**	**95**	**112**
	RAINFED		**1 264**	**1 353**	**1 306**	**1 475**	**1 389**	**1 367**	**1 554**	**110**	**108**	**123**
	TOTAL	**1 438**	**1 567**	**1 690**	**1 594**	**1 812**	**1 732**	**1 653**	**1 892**	**111**	**106**	**121**

Source: FAO Global Perspectives Studies, based on simulations with the FAO GAPS model and cropping intensities (see Section 3.9, Table 3.8).

In SSS, a 20 percent increase in arable land from 2012 to 2050 is required to meet increased demand for agricultural products, as a result of changes in food and feed consumption and other uses. This is nearly twice that required in BAU. Such a high and rapid expansion of arable land raises sustainability concerns, as in regions such as NNA the projected arable land by 2050 is well above current estimates of rainfed land suitable for cropping.

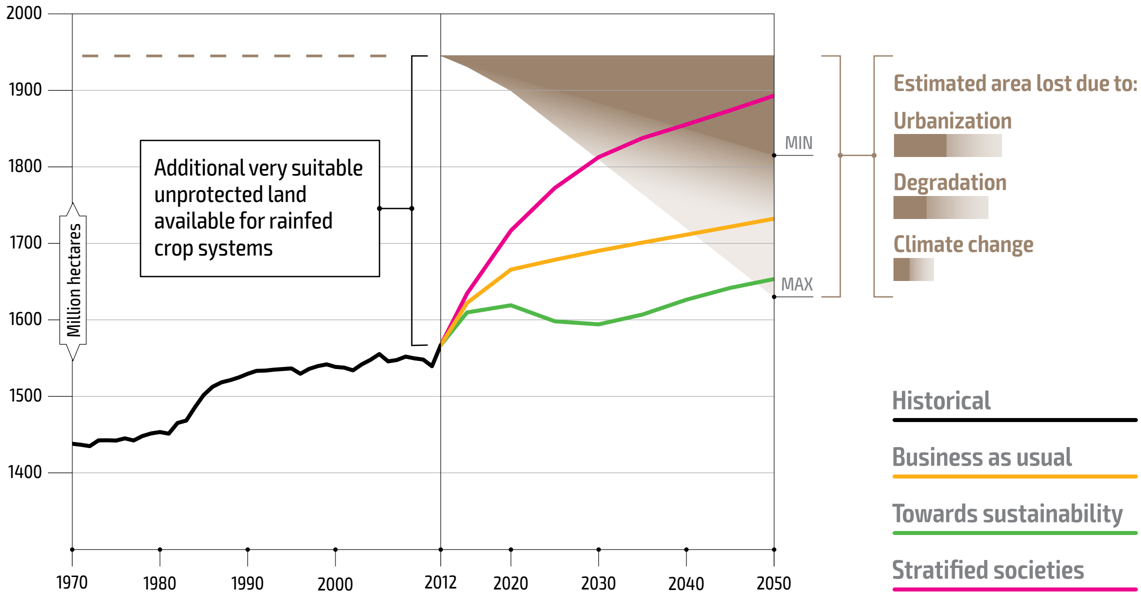
The different paces of arable land expansion under the various scenarios and across countries have different impacts on available land and water resources. It is therefore instructive to relate projected land-use for crops with land area that is very suitable for crop production and not already used as cropland, or for other uses that cannot easily be converted.

Land availability

By 2050 demand for additional arable land is projected to be 165 million hectares under BAU, a significant increase at the global level. In principle, this would still be within the availability boundaries of very suitable and unprotected land, factoring in a global reserve of at least 400 million hectares of such land that could be brought under rainfed cultivation (see Section 3.10). However, the picture changes when accounting for loss of very suitable agricultural land due to urbanization and degradation. Assuming these losses as well as those from changing climate conditions rendering land less suitable to total around 3 million hectares per year (the upper end of the estimated range in Lambin and Meyfroidt, 2011), more than 250 million hectares of that reserve could be lost under BAU; this would progressively push land requirements towards the availability limit of very suitable and unprotected land for rainfed crops (see Figure 4.13). Under SSS, this boundary could indeed be reached within the simulation period.

Note that the land reserve mentioned above should be taken as a rough estimate that is surrounded by considerable uncertainties. On the one hand, other competing uses not considered here, such as the possible need to increase protected areas, additional land resources required for industrial purposes, or additional demand for pasture, among others, might further reduce the land available for cropland expansion. On the other hand, reaching the boundary does not necessarily imply that no more expansion is possible. However, the implications are that infrastructure maintenance and investments will be needed, including for irrigation, provided water resources are not limited; more inputs may be necessary to achieve the same crop yields under less favourable environmental conditions; and/or the expansion of arable land could come at the expense of other land-uses, especially forests or protected areas, as past experience has shown.

Figure 4.13 Global arable land requirements by scenario and estimated loss of agricultural areas to urbanization, degradation and climate change

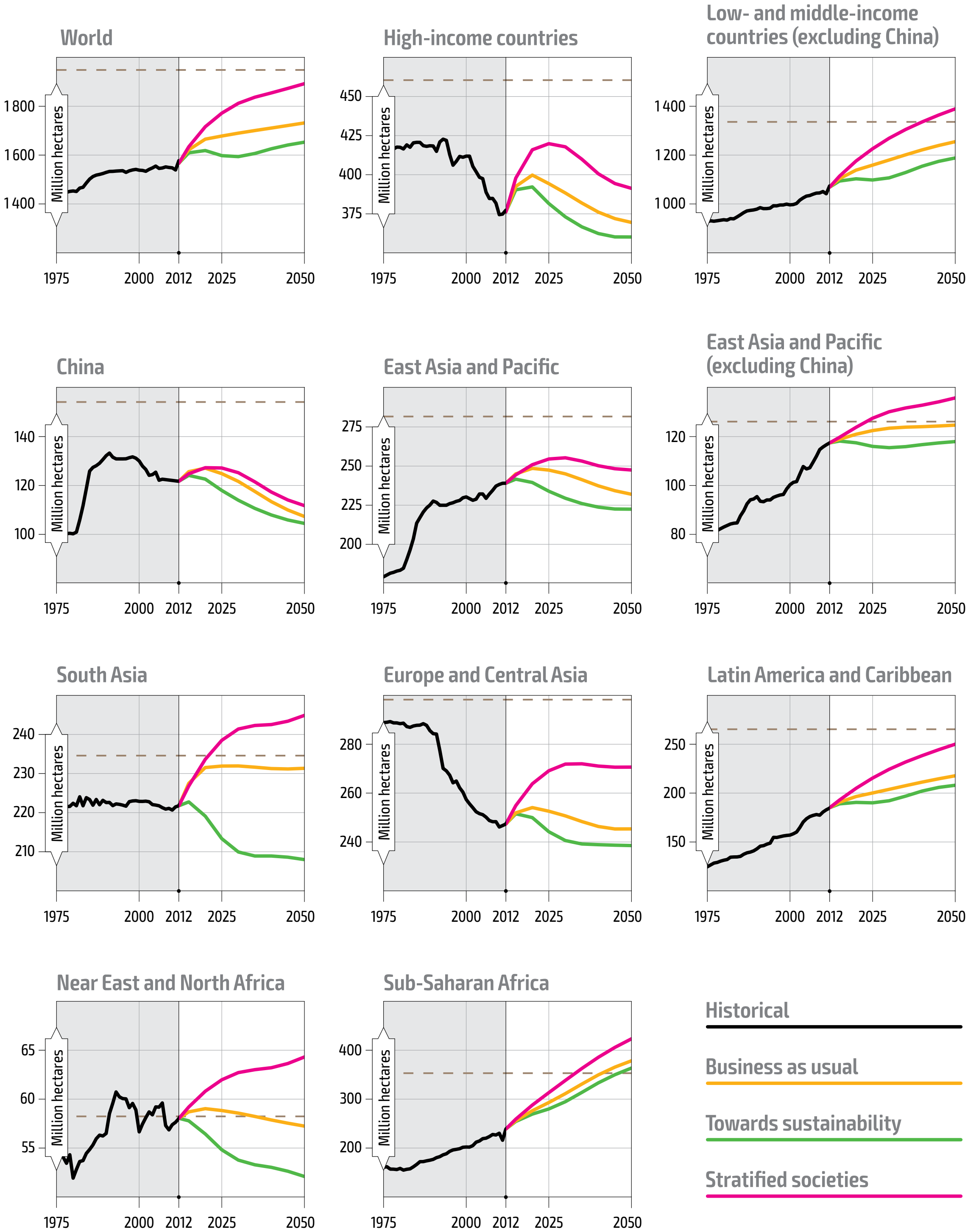


Note: "Additional very suitable and unprotected land" represents the base-year amount available and not currently in use in the highest suitability class for rainfed crops, as provided by FAO-IIASA GAEZ v4 (see Box 7 and Section 3.10). Adding this to arable land in use in 2012 (irrigated and rainfed) provides an estimate of the maximum potentially available very suitable unprotected agricultural land (dashed line), given 2012 irrigation conditions. Expanding cropland beyond that limit requires progressively increasing investments. The faded wedge indicates the range of potential land loss (minimum – dark brown, maximum – light brown). Loss due to urbanization (in the range of 1.6 million–3.3 million hectares per year) and degradation (in the range of 1.0 million–2.9 million hectares per year) are taken from Lambin and Meyfroidt (2011). Loss due to climate change (in the range of 0.5 million–1.4 million hectares per year) refer to the RCP scenarios – 4.5 (min) and 8.5 (max) – and are based on the FAO-IIASA GAEZ v4.

Sources: FAO Global Perspectives Studies, based on simulations with the FAO GAPS model and FAOSTAT (various years).

Even if enough very suitable arable land were available globally, in some regions there is limited potential to claim more very suitable unprotected land for crop production (see Section 3.10 and Figure 3.10). Quantifying regional losses to degradation and urbanization is challenging, but it has been estimated that 80 percent of cropland loss due to the expansion of urban areas will occur in Africa and Asia and will occupy fertile cropland that is more than twice as productive as the global average (Bren d'Amour *et al.*, 2017). Without considering losses to urbanization and degradation, the arable land in use today already comes close to the amount of very suitable unprotected available land in NNA and EAP (excluding China) (dashed lines in Figure 4.14). Under BAU arable land might become scarce by 2050 in SSA and SAS, or even earlier, as observed under SSS.

Figure 4.14 Arable land requirements



Note: Projected arable land is calculated with time-varying cropping intensities. The dashed lines indicate the maximum potentially available very suitable and unprotected land for rainfed crop systems in 2012 for each region, as provided in FAO-IIASA GAEZ v4 (see Box 7 and Section 3.10).

Sources: FAO Global Perspectives Studies, based on simulations with the FAO GAPS model and FAOSTAT (various years).

Irrigated areas

Irrigation is important for adapting to climate change and variability as well as for increasing land productivity, and will therefore no doubt play a critical role going forward. Understanding how projections of irrigated areas might affect the future of food and agriculture is a central aspect of this foresight exercise.

Although irrigated areas only occupy around 20 percent of the total arable area in the base year (see Table 4.12), they generate more than 40 percent of total production value globally (see Table 4.13). This disproportionate contribution is attributed to greater productivity in irrigated areas as a result of higher and more stable yields and more intense cropping (see Section 3.9), as well as to the cultivation of higher-value crops compared with rainfed cultivation.

In areas where irrigated rice is the dominant crop, such as SAS and China, irrigation contributes to more than half of the total value of production. Conversely, irrigated areas in SSA occupy less than 3 percent of total arable area and only 8 percent of value produced.

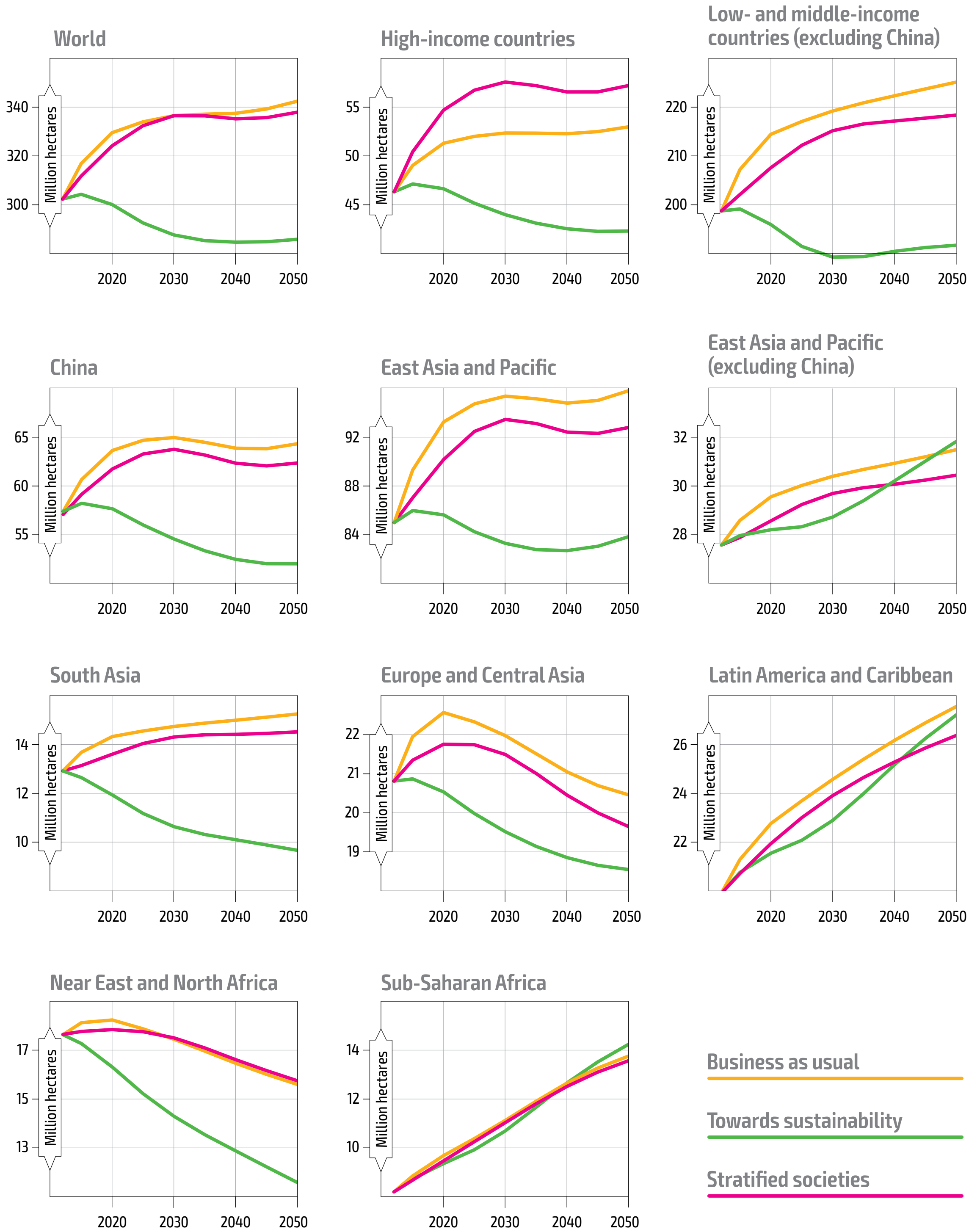
Table 4.13 Production in irrigated areas, percentage in total production value

	percent						
	2012	2030			2050		
REGIONS	BASE YEAR	BAU	TSS	SSS	BAU	TSS	SSS
High-income countries	**35**	**37**	**34**	**39**	**40**	**34**	**43**
East Asia and Pacific	50	56	52	54	61	54	58
– China	55	62	56	60	69	59	66
– East Asia and Pacific (excluding China)	37	38	38	36	39	41	36
South Asia	69	71	67	69	73	65	69
Europe and Central Asia	35	36	34	34	35	35	34
Latin America and Caribbean	28	30	30	28	31	33	28
Near East and North Africa	62	62	58	62	60	53	60
Sub-Saharan Africa	7.4	8.2	8.4	7.5	8.6	9.5	7.7
Low- and middle-income countries	**44**	**47**	**44**	**45**	**48**	**44**	**46**
– Low- and middle-income countries (excluding China)	38	38	36	36	37	36	35
World	**42**	**45**	**42**	**44**	**46**	**42**	**45**

Note: The value of production is calculated by aggregating all crops and using base-year prices.
Source: FAO Global Perspectives Studies, based on simulations with the FAO GAPS model.

Under BAU, irrigated areas globally are projected to grow slightly faster (13 percent) than rainfed areas (10 percent) by 2050 (see Table 4.12). This is particularly the case in regions where arable land is projected to expand and sufficient water resources are available, such as EAP (excluding China) and selected countries in LAC and SSA, where the largest increases in irrigated areas are projected (see Figure 4.15). In these regions, irrigated areas are expected to expand partly through the development of new areas but mostly through the conversion of rainfed ones. However, significant expansion or very limited reduction of irrigated areas is also projected for regions where water resources are already under stress, such as SAS, NNA and parts of ECA (see Figure 1.11). The percentage of production in irrigated areas is projected to increase compared with the base year, particularly in HIC and China, while remaining broadly stable in LMIC (excluding China).

Figure 4.15 Projected irrigated areas



Source: FAO Global Perspectives Studies, based on simulations with the FAO GAPS model.

Overall irrigated areas are less vast in TSS than in BAU. This is a consequence of combined significant expansion in some regions, such as EAP (excluding China), LAC and SSA, and a contraction in SAS, NNA, and ECA. TSS assumes that where water is under stress countries face tighter constraints to achieve more sustainable use. Despite these constraints, the global share of crop output from irrigated areas in total crop output is maintained throughout the projection period (see Table 4.13), thanks to increased water-use efficiency due to greater investment in research and irrigation infrastructure.[109] Clearly, the percentage of production in irrigated areas varies in all regions depending on water availability under TSS.

In the SSS scenario, different assumptions regarding investments in agriculture lead to different trajectories of irrigation in HIC and LMIC (excluding China). Whereas irrigated areas expand substantially in HIC, expansion in LMIC is more restrained than under BAU. The share of irrigated areas in HIC rises from 12 to 15 percent by 2050, whereas in LMIC (excluding China) it remains constant at around 10 percent. The percentage of production in irrigated areas shrinks in SAS and NNA in order to contain water stress, while it expands in regions such as EAP and SSA, where additional water is projected to be available. HIC and China expand their percentage of production in irrigated areas thanks to the opportunity of investing in the required infrastructure, while LMIC (excluding China) reduce theirs.

Sources of growth in crop production

The crop output obtained in a given period depends on the crop yield and harvested area, as discussed in Section 4.7. Harvested area in turn results from the amount of arable land – i.e. the physical amount of land-used in a given period multiplied by cropping intensity.[110] Yields, arable land, and cropping intensity change over time in response to evolving socio-economic, climate and technological conditions, with each impacting natural resources differently.

For the period of 1961–2007, global contributions to changes in yield, cropping intensity, and arable land were estimated at 77 percent, 9 percent, and 14 percent respectively, with large regional variations (Alexandratos and Bruinsma, 2012). For example, in SSA the contribution of yield increases was estimated at 38 percent, whereas intensification and area expansion made up 31 percent each. Conversely, in SAS production growth was dominated by increased yields (82 percent).

In BAU, projections of growth components are comparable to historical global estimates; the largest proportion of the projected increase in crop output comes from yield increases (62 percent), 14 percent from increases in cropping intensity, and 24 percent from increases in arable land (see Figure 4.16).[111] While yield increases remain the dominant source of production growth, their contribution will decline. In areas where land is more constrained and increases in cropping intensity not limited by the length of the growing period (such as parts of the Mediterranean region and EAP), the contribution of arable land change is projected to decline while yield growth and increased cropping intensity are expected to play a more prominent role.

[109] Two main assumptions regarding water use differentiate TSS from BAU: increased water-use efficiency expands the area that can be irrigated with the same amount of water, but stricter limits on water withdrawal (see Section 3.10) have the opposite effect.

[110] Cropping intensity is the average number of crop harvests obtainable in a given period on the very same plot, as explained in Section 3.9.

[111] The contributions of yield, arable land, and intensification are calculated as explained in the note to Figure 4.16.

Under TSS, more intense use of arable land resulting from higher cropping intensity becomes the most important component of crop output increases (49 percent), whereas the other components contribute relatively less (see Figure 4.16).

Arable land expands more in SSS than in any other scenario. This leads to lower contributions of both yield and cropping intensity in crop output increases.

Figure 4.16 Sources of growth in crop production in 2050, by region and scenario

Note: The contributions of changes in yield, arable area and intensification to changes in crop production were calculated by relating the change in one component to the total change in crop production, while keeping the other two components constant. As the three relative contributions together do not account for the full change in crop production, the residual change was attributed proportionally to each of the components, to obtain a fully consistent breakdown.

Source: FAO Global Perspectives Studies, based on simulations with the FAO GAPS model.

Overall, this section provides evidence that it is possible to move food and agricultural systems towards sustainability by containing the expansion of arable land and reducing water stress, particularly in regions where these resources are already overused. All this can be done while providing enough food for a growing population and improving food security and nutrition conditions (see Section 4.5). However, this implies investing, particularly in LMIC, to enhance water efficiency, implement land conservation practices and develop cropping practices that contribute to improving the quality of soils, increase cropping intensity and help to progressively limit the use of chemicals. Only when these conditions are met can a more efficient use of natural resources be achieved.

4.10 Greenhouse gas emissions

Going forward, it is critical that the agricultural sectors reduce the amount of GHG emissions they emit per unit of output – i.e. that they increase their GHG efficiency (or reduce their GHG intensity). The agricultural sectors currently generate around 20 percent of total global GHG emissions (see Figure 1.15). Changes in crop and livestock production in terms of output volume, composition and technology have implications not only for GHG emissions, but also for agriculture's contribution to economy-wide emissions and mitigation efforts.

Studies conducted to gauge how GHG intensity in agricultural sectors has changed over time (Tubiello *et al.*, 2014) show that from 1961 to 2002 emissions were significantly lower from the dairy and meat industries,[112] but increased by 45 percent for cereals. However, while the overall GHG efficiency of agriculture has substantially improved, increased agricultural output has produced almost unabated emissions from the sector over the last 25 years.[113] The scenarios analysed in this report portray very different GHG dynamics, given their variations in terms of gross agricultural output, composition and emission intensity.

BAU sees limited efforts to reduce GHG emissions (see Section 3.7). Quite significant growth in gross agricultural output (see Section 4.2), which was not adequately compensated for by mitigation efforts, leads to a 20 percent increase in total GHG emissions from 2012 to 2050: from 4.3 to 5.2 gigatonnes of carbon-dioxide equivalent ($GtCO_2eq$) (see Figure 4.17). The bulk of emissions by 2050 originate from LMIC (excluding China), where most of the agricultural output is expected to be generated. These regions are also projected to see the strongest growth in emissions (more than 200 percent in SSA and over 30 percent in LAC), whereas in HIC they will decrease by almost 20 percent (see Table 4.14). More than two-thirds of emissions are generated by the livestock sector (from manure and enteric fermentation), with fertilizers, crop residues and methane emissions from rice contributing to a lesser extent.

112 For instance, the GHG intensity of eggs, rice, pork, milk, and beef decreased by 57 percent, 49 percent, 45 percent, 38 percent, and 27 percent, respectively (Tubiello *et al.* 2014). Despite the progressive increase of GHG emission intensity (GHG per monetary unit), cereals still have lowest among the agricultural items considered.

113 Emissions amount to 4.32 gigatonnes of carbon-dioxide equivalent ($GtCO_2eq$) in the base year. This estimate is consistent with the total for these categories published in FAOSTAT (Tubiello *et al.*, 2013), and thus with FAOSTAT estimates of total emissions from agriculture, which in 2012 were 5.2 $GtCO_2eq$. These estimates do not include emissions related to burning of savannah and crop residues or conversion of peatland. To ensure consistency with FAOSTAT emissions, a global warming potential (GWP) for methane (CH4) of 21 and for nitrous oxide (N2O) of 310 was used. If the GWPof methane is set to 28 as in IPCC AR5, the emissions amount to 5.33 $GtCO_2eq$. The contributions of burning crops and savannahs (0.3 Gt in FAOSTAT for 2012) and cultivation of peatland (0.13 $GtCO_2eq$) are not considered.

In TSS a lower consumption of animal products, particularly in HIC, and reduced GHG intensity (improved GHG efficiency) lead to total emissions being reduced by 17 percent between 2012 and 2050. Despite the expansion of animal herds, specifically in LMIC (excluding China) (see Figure 4.12) more efficient livestock production systems mean emissions from this sector are almost unchanged by 2050. While there is no assumed change in the efficiency of synthetic fertilizer use, it is progressively phased out by 2050, thus eliminating this emissions quotient (see Table 4.15).[114]

Conversely, higher consumption of animal-based products and hardly any mitigation efforts in SSS lead global emissions to rise by 38 percent between 2012 and 2050.

Table 4.14 Agricultural greenhouse gas emissions

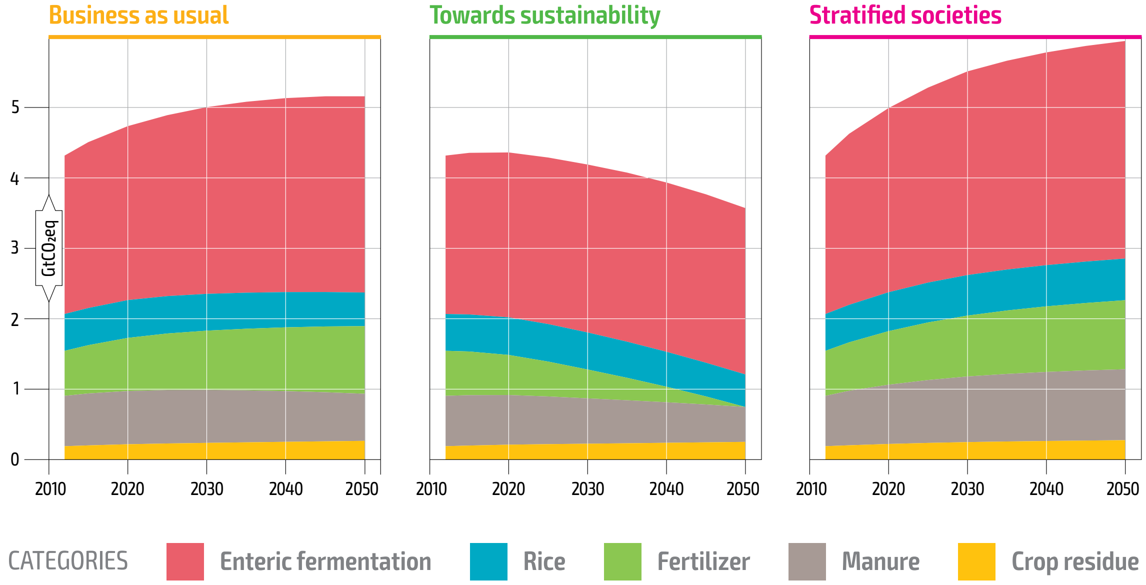
	gigatonnes of carbon-dioxide equivalent							index, 2012 = 100		
	2012	2030			2050			2050		
REGIONS	BASE YEAR	BAU	TSS	SSS	BAU	TSS	SSS	BAU	TSS	SSS
High-income countries	**0.83**	**0.79**	**0.61**	**0.98**	**0.69**	**0.37**	**0.95**	**83**	**45**	**114**
East Asia and Pacific	1.07	1.17	0.97	1.30	1.12	0.72	1.34	105	67	125
– China	0.64	0.71	0.56	0.79	0.67	0.38	0.77	104	59	120
– East Asia and Pacific (excluding China)	0.43	0.46	0.41	0.51	0.45	0.34	0.56	106	79	132
South Asia	0.97	1.12	0.97	1.09	1.10	0.83	1.15	113	85	118
Europe and Central Asia	0.24	0.29	0.23	0.33	0.31	0.19	0.36	132	81	151
Latin America and Caribbean	0.69	0.83	0.72	0.91	0.91	0.65	1.00	132	95	145
Near East and North Africa	0.11	0.13	0.11	0.14	0.14	0.10	0.15	124	84	135
Sub-Saharan Africa	0.41	0.67	0.59	0.77	0.89	0.72	1.01	219	177	248
Low- and middle-income countries	**3.49**	**4.22**	**3.58**	**4.53**	**4.47**	**3.20**	**5.00**	**128**	**92**	**143**
– Low- and middle-income countries (excluding China)	2.84	3.51	3.02	3.75	3.80	2.82	4.23	134	99	149
World	**4.32**	**5.01**	**4.19**	**5.51**	**5.16**	**3.57**	**5.94**	**120**	**83**	**138**

Notes: Values include GHG emissions from livestock and crop production but exclude emissions from burning of savannah and crop residues and conversion of peatland. Note that there are uncertainties associated with these estimates, regarding for example emission intensities and their measurement, the mix of inputs used to achieve a given level of agricultural output, spatial and temporal variations, and so on.

Sources: FAO Global Perspectives Studies, based on simulations with the FAO GAPS model, and emission factors from FAO GLEAM (2017) and FAOSTAT (various years) (see Section 3.7 for details).

[114] Less drastic assumptions regarding the phasing out of synthetic fertilizers would lead to a more moderate reduction of GHG from this source.

Figure 4.17 Projected agricultural greenhouse gas emissions for different scenarios



Notes: Emissions are expressed in gigatonnes (billion metric tonnes) of carbon dioxide equivalent ($GtCO_2eq$). The graph includes GHG emissions from livestock and crop production, but excludes emissions from the burning of the savannah and crop residues, and the conversion of peatlands.

Sources: FAO Global Perspectives Studies, based on simulations with the FAO GAPS model, and emission factors from FAO GLEAM (2017) and FAOSTAT (various years) (see Section 3.7 for details).

Table 4.15 Nitrogen fertilizer consumption

	million tonnes							index, 2012 = 100		
	2012	2030			2050			2050		
REGIONS	BASE YEAR	BAU	TSS	SSS	BAU	TSS	SSS	BAU	TSS	SSS
High-income countries	**23.5**	**29.8**	**13.4**	**33.1**	**32.9**	**0.0**	**37.2**	**140**	**0**	**158**
East Asia and Pacific	34.7	43.6	22.0	44.5	46.2	0.0	48.1	133	0	139
– China	24.0	29.9	15.0	30.9	30.7	0.0	33.1	128	0	138
– East Asia and Pacific (excluding China)	10.7	13.7	7.0	13.5	15.5	0.0	15.0	145	0	140
South Asia	17.4	23.3	11.1	22.5	26.9	0.0	24.8	154	0	142
Europe and Central Asia	9.1	12.2	6.0	12.6	14.1	0.0	14.3	155	0	157
Latin America and Caribbean	8.4	11.8	6.1	11.9	14.9	0.0	14.6	177	0	174
Near East and North Africa	3.2	4.0	1.8	3.9	4.1	0.0	3.9	126	0	120
Sub-Saharan Africa	6.2	10.4	5.4	10.4	15.2	0.0	14.5	244	0	233
Low- and middle-income countries	**79.2**	**105.3**	**52.4**	**105.7**	**121.4**	**0.0**	**120.4**	**153**	**0**	**152**
– Low- and middle-income countries (excluding China)	55.2	75.4	37.4	74.7	90.7	0.0	87.2	164	0	158
World	**102.7**	**135.1**	**65.8**	**138.8**	**154.3**	**0.0**	**157.5**	**150**	**0**	**153**

Note: Fertilizer requirements for individual crops are computed based on fertilizer use in selected countries. See Section 3.7 for details.

Source: FAO Global Perspectives Studies, based on simulations with the FAO GAPS model.

Overall, significant changes in food and agricultural systems are required to move towards sustainability. GHG emissions must be drastically reduced to contain average temperature increases and mitigate other climate change impacts.[115] Change is therefore needed in terms of both demand (to raise consumer awareness on sustainability) and supply (to increase the GHG efficiency of agricultural production processes). This includes switching to low-GHG intensity technologies (FAO, 2018) and/or consuming products that involve lower emissions (such as poultry instead of beef). Making such improvements in the future requires efforts to "internalise environmental externalities" – i.e. to account for environmental costs that are currently not covered and boost investment in resource-efficient technologies. Such mitigation and adaptation efforts could increase agricultural production costs, which could then reflect on consumer prices as highlighted in Section 4.3. Rising food prices could have a knock-on effect on nutrition levels, but should not be of concern as long as income, income-earning opportunities and food distribution move towards increasing equity within and across countries (see Section 4.5).

4.11 Scenario outcomes and Sustainable Development Goals achievements

To identify strategic options for achieving the SDG targets relevant for food and agricultural systems, the outcomes for key individual indicators must be studied not only in isolation as above, but also in comparison with each other. Box 9 shows such a view and the conclusions that can be drawn.

Globally, the largest differences between scenarios are in the PoU. The TSS scenario achieves the best outcomes in this regard and SSS the worst – despite having higher global per capita income, larger agricultural output growth and a lower share of per capita income allocated to food (lower food expenditure share) (Table 4.16). Greater economic growth in SSS compared with the other scenarios fails to help in defeating undernourishment, due to increasing inequalities in income and food distribution within and across countries. On the other hand, TSS achieves a strong reduction in the PoU with fewer land requirements, reduced GHG emissions, and less global GDP growth. This highlights the importance of more equitable income and food distribution for achieving the goals of the 2030 Agenda.

There are marked differences in scenario outcomes across regions (see Box 9). The biggest changes in key indicators among scenarios are projected for countries in SSA. Changing diets and a more than twofold increase in population numbers lead to a significant rise in demand, as a result of which agricultural output in SSA jumps by around 2.5 times in all scenarios: more land is required, the number of livestock rises, and GHG emissions increase sharply. However, these changes are more pronounced under BAU and SSS than TSS, which sees the highest per capita GDP growth. Together with more equitable income distribution, this leads to a sharp reduction in the PoU. On the contrary, in SSA the PoU declines only modestly under BAU and even rises under SSS.

115 The projected scenario-specific GHG emission changes in agriculture are compatible with the maximum emissions that should not be exceeded in order to stay within the specific RCP associated with each scenario, under the assumption that all the other sectors in the economy move with the same order of magnitude (see Table 3.6). Notably, the 20 percent increase under BAU would allow it to stay within RCP 6.0, which implies average temperatures increase by 2100 between 3.1 and 3.7 degrees Celsius. The 42 percent increase in SSS would point towards RCP 8.5, which implies temperature increases above 4 degrees Celsius. The 29 percent reduction in TSS is close to the upper bound of mitigation to stay within RCP 4.5, which implies temperature increases of between 2.3 and 2.9 degrees Celsius. Further efforts would be needed to reduce GHG emissions with respect to those simulated in TSS in order to point towards RCP 2.6 – i.e. to contain average temperature increases by 2100 below or in the vicinity of 2 degrees Celsius.

Table 4.16 Key indicators for the three scenarios in 2030 and 2050

KEY INDICATORS	UNIT	2012	2030			2050			2030 (2012 = 100)			2050 (2012 = 100)		
		BASE YEAR	BAU	TSS	SSS	BAU	TSS	SSS	BAU	TSS	SSS	BAU	TSS	SSS
Prevalence of undernourishment	percent	11	6.7	3.4	11.8	7.6	3.5	12.5	61	31	107	69	32	114
Price index	2012 = 100	100	104	124	109	113	134	136	104	124	109	113	134	136
Per capita GDP	USD (2012)	10 468	14 830	14 830	15 858	16 993	16 993	21 641	142	142	151	162	162	207
Production index	2012 = 100	100	132	122	137	150	140	153	132	122	137	150	140	153
Arable land	million hectares	1 567	1 690	1 594	1 812	1 732	1 653	1 892	108	102	116	111	106	121
Livestock herd size	Livestock units	1 745	2 160	1 995	2 241	2 548	2 203	2 395	124	114	128	146	126	137
Agricultural emissions	$GtCO_2eq$	4.3	5.0	4.2	5.5	5.2	3.6	6.0	116	97	128	119	83	138
Per capita calories	kilocalories	2 779	2 946	2 974	2 809	2 910	2 938	2 805	106	107	101	105	106	101
Yield	tonnes/ hectare	6.2	7.2	6.4	7.0	7.5	7.0	7.5	117	104	113	128	114	121
Food expenditure share	percent	5.3	4.2	4.6	4.0	3.8	4.1	3.6	79	87	76	72	78	68
Population	million	7 098	8 359	8 359	8 359	9 725	9 725	9 725	118	118	118	137	137	137

Notes: PoU refers to the prevalence of undernourishment, LSU is livestock units. Yield is area-weighted for all crops. Note that population is assumed to be equal in all scenarios (Section 3.1). Agricultural emissions are expressed in gigatonnes of carbon-dioxide equivalent ($GtCO_2eq$).

Source: FAO Global Perspectives Studies, based on simulations with the FAO GAPS model.

Scenario outcomes for LMIC (excluding China) generally reveal similar trends as SSA. However, lower population growth in this region means there are fewer changes in agricultural output, land requirements and livestock herd sizes.

Substantial expansion in per capita GDP in China – which is broadly similar across scenarios – leads to a correspondingly lower PoU in all scenarios. Thanks to comparatively restrained demand for animal products in TSS for China, reduced undernourishment can even be achieved with lower GHG emissions over time and almost no additional land requirements.

Smaller differences in outcomes across scenarios are achieved in HIC for several reasons. However, it is notable that under TSS the move towards more balanced diets that are less rich in animal products triggers a reduction in livestock units and GHG emissions. Furthermore, income and food distribution inequalities may well hit HIC under SSS, as indicated by the doubling of the PoU by 2050, although this indicator remains at very low levels.

Overall, the key message from the scenario analysis is that it will not be necessary to increase agricultural production even by 50 percent from 2012 to 2050 in order to meet the SDG targets for ending hunger and achieving food security. These targets could be met with a much lower expansion of agricultural output, as long as production systems become more sustainable while income and food are more equitably distributed across and within countries.

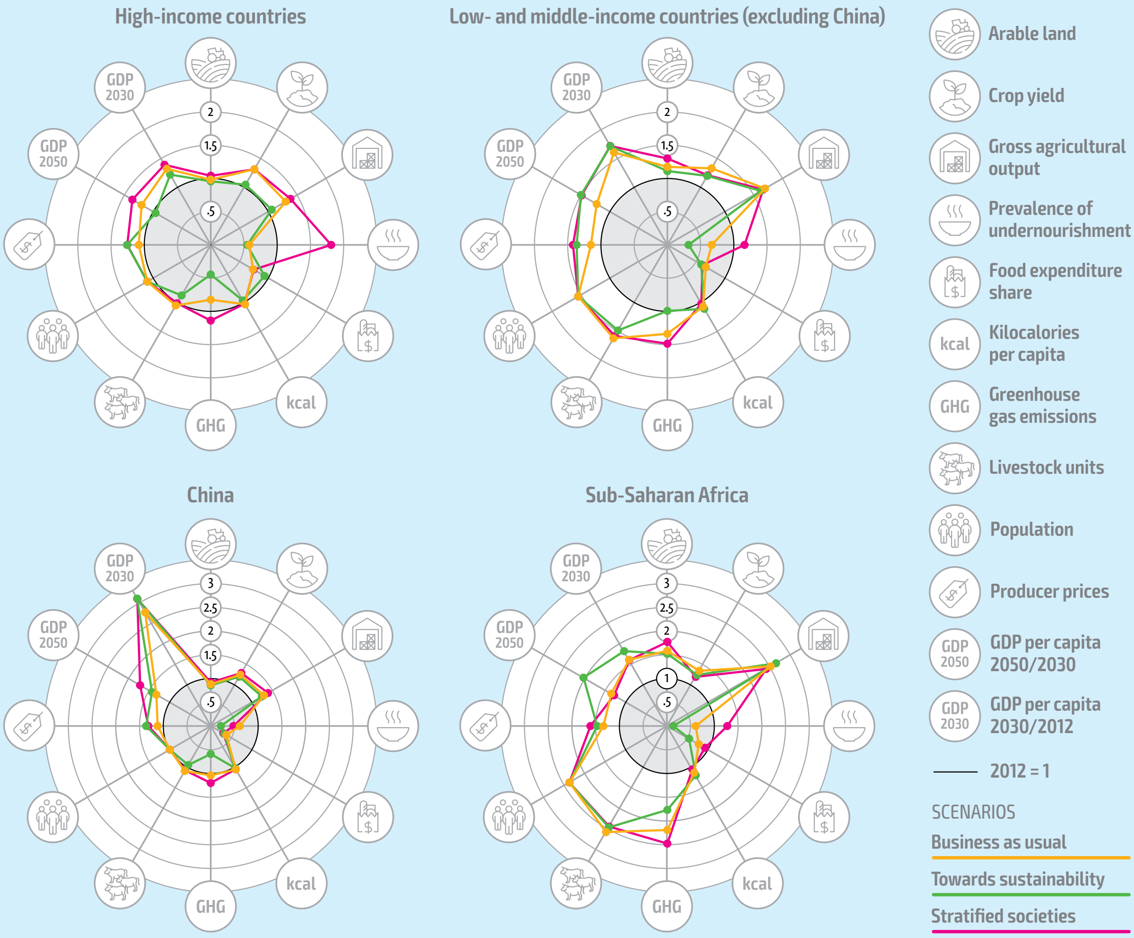
BOX 9 Overview of results for selected regions by scenario

The radar charts below present the main scenario results for selected indicators, by region. Numbers along the axes denote the ratio in the value of the indicator for 2050 relative to the value for 2012 (for example, 2 indicates that the value of the indicator in 2050 is twice the value of 2012). Results outside/inside the shaded circle imply that the value of the indicator for 2050 is above/below the value for 2012.

A clear and consistent result across regions is that in the TSS both undernourishment and GHG emissions shrink significantly compared with 2012. In the SSS the opposite applies, while for BAU significant undernourishment and growing emissions are still notable.

The reduction in GHG emissions in TSS is due in part to the limited expansion of livestock activity. This is the result of more balanced diets in HIC, which in turn contribute to containing the expansion of gross agricultural output and arable land. In this scenario, the drastic reduction in undernourishment is largely due to improved income and food distribution across and within countries. A higher growth rate of per capita income does not necessarily guarantee a reduction in undernourishment.

Selected indicators by region and scenario



Note: To highlight the different pace of economic growth, the change in the per capita GDP indicator is reported for two subsequent periods (2050 compared to 2030, and 2030 compared to 2012).

Source: FAO Global Perspectives Studies, based on simulations with the FAO GAPS model.

5 | Challenges ahead and strategic options

FAO's proposed principles and approaches for a common vision of sustainable food and agriculture comprise universal and equitable access to nutritious food, and management of natural resources that maintains ecosystem functions to support current and future needs. Actors in rural economies are envisioned as able to actively participate in and benefit from economic development and enjoy sufficient income. Furthermore, rural inhabitants are secure and have equitable access to resources, which they utilize efficiently (FAO, 2014).

The overarching question regarding the future of food and agriculture is whether global food and agricultural systems will be able to sustainably and satisfactorily feed humanity by 2050, while accommodating the additional demand of non-food agricultural commodities.

Concerns arise because food and agricultural systems are affected by the following trends, as highlighted in Chapter 1:

1. Population and income growth will continue to drive up food demand and change people's dietary preferences.
2. Persistent poverty, inequality and unemployment will constrain food access and hamper the achievement of food security and nutrition goals.
3. Future agricultural production growth will be constrained by increased scarcity and diminished quality of land and water resources, as well as insufficient investment in sustainable agriculture.
4. Unaddressed climate change will increasingly affect yields and rural livelihoods while agriculture will keep emitting GHGs.

To address the overarching question, three scenarios – BAU, TSS and SSS – were constructed, based on a range of different assumptions regarding the above-mentioned trends.[116]

Analysis of the three scenarios illustrated in Chapter 4 reveals that the answer to the overarching question depends on the following concerns: how consumer preferences related to food will evolve in the future; how much food will be lost or wasted along the food chains; the extent of pressure on agriculture from non-food demand; the capacity of systems to produce more while limiting GHG emissions and conserving land, water and biodiversity; and, last but not least, how agricultural prices – which will contribute to determining all the above-mentioned variables – will move to match supply and demand in a sustainable way.

[116] Scenario-specific assumptions regarding these trends are highlighted in Chapters 2 and 3. Two quantitative economic models provided the relevant projections under the three scenarios, as reported in Chapter 4.

The analytical findings presented in the previous chapter allow to assess the extent to which (and why) each scenario is more or less conducive to sustainable and equitable food and agricultural systems. By making use of *ex ante* evidence produced through scenario analyses, this chapter aims to identify selected strategic options to address the concerns, questions and challenges facing food and agriculture. Strategic options to be implemented through packages of synergetic policy measures and programmatic actions are required to guide food systems along a sustainable and equitable development pathway.

5.1 Trends in food and agriculture and challenges ahead

What can be done to manage food demand and change people's dietary preferences?

KEY MESSAGES

1. **Managing consumer demand through awareness raising and proper regulations can help contain the expansion of agricultural sectors.** Food and non-food agricultural production is expected to rise because of population and income growth. However, the expansion of agricultural sectors can be significantly contained by, for instance, rasing consumer awareness on environmentally sustainable diets, regulating and discouraging food waste, enforcing more efficient food pricing and limiting the use of biofuels.
2. **Demand management through consumer awareness and education is also essential to reduce the "triple burden" of malnutrition.** Consumer awareness and education regarding the nutritional content of food and diet-related diseases are also critical to reduce the "triple burden" of malnutrition that is, undernourishment, micronutrient deficiencies, and overweight and obesity, that often exist within a single country or even community, and to achieve a shift towards generally healthier diets.
3. **Food prices should be "right".** Food prices should reflect the inherent nutritional value of food as well as the full range of costs associated with their production and consumption along the entire food value chain. This includes environmental costs such as biodiversity loss, land degradation, water depletion, GHG emissions, which are often not accounted for. This can help limit the growth of food demand and reduce food losses and waste, while contributing to the preservation of natural resources and the improvement of nutrition.[117] However, as higher food prices may hamper poor people's ability to buy food, targeted and efficient strategies are needed to raise their purchasing power.[118]
4. **Dietary patterns of high-income countries need to become balanced.** While moving towards sustainable food systems, neither restrained expansion of production nor increased food prices would substantially impinge on global food availability – including in low- and middle-income countries – if high-income countries were to consume fewer animal products and food waste and loss were considerably reduced. Raising consumer awareness on this issue could be key. Balanced diets are critical for reducing all types of malnutrition, including undernourishment but also overweight and obesity, often causing non-communicable diseases.

[117] Economists have traditionally regarded unpaid environmental costs as "environmental externalities", which lead to a suboptimal economy-wide outcome. Achieving optimal results in the presence of externalities implies making sure that economic agents face the correct prices for their actions (Varian, 1992).

[118] Legitimate concerns regarding the purchasing power of poor people, as well as possible strategies to increase it, are addressed in the following section.

5. **International trade may help exploit production potential and fill food deficits.** Sustainably expanding the supply of food in countries whose population is expected to increase significantly is essential to ensure adequate food availability. Trade has an important role to play here, and imports may well be needed to fill domestic deficits in case natural resource constraints are an issue. However, strong global and national institutions are needed to coordinate efforts across countries and prevent unfair competition against those countries that adopt more stringent environmental and social regulations.

Despite the fact that each scenario analysed in this report assumes the same demographic patterns, agricultural demand and the corresponding expansion of agricultural output required to satisfy that demand exhibit significantly different dynamics. While under the BAU and SSS scenarios global gross agricultural output from the base year to 2050 is expected to increase by about 50 and 54 percent, respectively, from the base year to 2050, under the TSS scenario the expected increase is only 40 percent (see Figure 4.2).

Food demand is highest under the SSS scenario, which largely explains the higher increase in agricultural output. It is boosted by a significantly larger increase in per capita income compared with the other scenarios – in almost all regions except SSA – as well as by persistent consumer preferences for resource-intensive food items and unabated food loss and waste, particularly in HIC.

The TSS scenario is more sustainable as a set of concurrent changes in food systems helps reduce pressure on agricultural sectors. These include:

- early and significant agricultural price increases (Figure 4.3) due to more limited supply related to environmental constraints that contribute to loweringhelp lower the demand for agricultural goods;
- changing consumer preferences, particularly in HIC, leading to a reduction in the per capita consumption of animal products (Figure 4.5);
- reduced food loss and waste at all levels of the food chains;
- reduced pressure of from non-food agriculturalthe demand for non-food agricultural products, including for animal feed.

It is worth emphasizing that despite reduced agricultural output, satisfactory food availability is ensured in TSS, particularly in LMIC, where each person enjoys more food on average than in the other scenarios (Figure 4.5). This occurs as per capita income grows in many countries, some of which also opt for more balanced diets consisting of less animal products and more nutritious food such as fruits and vegetables – which on a path towards sustainability are likely to result in, *inter alia*, a reduction in the prevalence of obesity, overweight and associated non-communicable diseases. Although relatively more limited, compared with the other two scenarios, the expansion of gross agricultural output under the more sustainable TSS scenario still almost satisfies domestic demand, so that agricultural trade represents only a limited fraction of production and consumption. However, in some instances the self-sufficiency ratio of certain LMIC regions falls below that of the BAU and SSS scenarios and the food and agriculture domestic deficit is compensated by international trade. This is the case for cereals in the NNA and SAS, fruits and vegetables in SAS and SSA, and oilseeds in NNA and EAP (excluding China). Meanwhile, self-sufficiency ratios in other regions move in the opposite direction. The possibility for selected countries to balance out food deficits with imports promotes a more balanced use of natural resources, while helping to meet the demand for food.

These findings from the TSS scenario indicate that containing agricultural expansion to move agricultural sectors towards sustainability, while also increasing food availability, is possible, particularly in the case of LMIC. However, achieving such results rests on the assumption that a set of synergic strategic orientations will be undertaken, including, among others:

- raising consumer awareness regarding healthy diets and food waste, particularly in HIC;
- making prices "right" by ensuring that they reflect all the costs associated with the production and consumption of agricultural products, including environmental costs, so that those costs are charged to resource users;
- reducing feed requirements, for example, through improved livestock management and avoiding excessive meat consumption;
- reducing the pressure from biofuels by implementing other forms of renewable energy;
- safeguarding the development potential of the agricultural sectors, particularly in LMIC while facilitating the international trade in selected food items to compensate for domestic food deficits.

How to address the scarcity and reduced quality of land and water resources in a sustainable manner?

KEY MESSAGES[119]

1. **Sustainable agricultural intensification is key to saving land.** Due to increasing agricultural production and unsustainable practices, the demand for land might exceed the available reserve of very suitable and unprotected land for rainfed crops, as is already the case in specific regions such as the Near East and North Africa, or in selected countries in East Asia and the Pacific. This could entail environmental problems or additional production costs from using lower-quality land and/or building additional infrastructures. As shown by the findings of this report, the sustainable intensification of agricultural sectors can potentially lower the expansion of demand for land while maintaining soil quality.
2. **Avoiding further land degradation and encouraging land rehabilitation helps tackle land constraints.** Although limited, available information on land degradation suggests that current agricultural practices lead to productivity losses that require an increase in the input intensity. Efforts to rehabilitate degraded land and practices that limit degradation are required to maintain the resource base and reduce the use of inputs.

[119] This section draws heavily on work carried out by FAO and its partners to investigate and promote sustainable agricultural practices, as documented in: *Building a common vision for sustainable food and agriculture. Principles and approaches* (FAO, 2014); *Voluntary guidelines for sustainable soil management* (FAO, 2017e); *Save and Grow – A policy maker's guide to the sustainable intensification of smallholder crop production* (FAO, 2011c) and related follow-up publications; *Voluntary guidelines on the responsible governance of tenure of land, fisheries and forestry in the context of national food security* (FAO, 2012); *Strategic work of FAO for sustainable food and agriculture* (FAO, 2017f).

3. **Using water more efficiently is increasingly becoming a must.** Many countries already exploit their water resources at unsustainable rates, thereby jeopardizing the potential for future production. Climate change and population growth may exacerbate water scarcity. Under these conditions, increasing the efficiency of water use is becoming increasingly crucial.
4. **Trading off agricultural yields and sustainability.** The adoption of sustainable agricultural practices might require forgoing certain yield increases, particularly when such increases lead to the overuse of water resources, a reduction in soil fertility, the loss of biodiversity and higher GHG emissions. However, some recovery in yield growth could materialize in the long run, due to a restored natural resource base, or as the result of an improvement in farmers' expertise.
5. **All the above does not come for free: significant investments are needed.** To ensure that sufficient land and water resources are available to meet total demand from agriculture, significant investments are required in the research and development of sustainable technologies and practices, infrastructure and human capital.

A second question regarding the future of food and agricultural systems is whether the increase in gross agricultural output required to ensure adequate food availability can occur within the boundaries of available natural resources, and specifically land and water. Limited information exists regarding the economic costs of expanding arable land in different countries and contexts. However, it is generally recognized that the expansion of arable land, particularly in regions where very suitable land for agriculture is scarce, may have environmental implications that jeopardize ecosystems, protected areas, forests and biodiversity. In addition, expanding agriculture into less suitable land may be technically possible in many instances, but would likely imply lower yields, require the use of additional inputs or necessitate additional investments in infrastructure that would increase production costs.

The three scenarios analysed in this report portray significantly different pictures regarding additional land requirements. Under the BAU and SSS scenarios, land requirements increase from an initial 1 567 million hectares in 2012 to 1 732 million hectares (BAU) and 1 892 million hectares (SSS) by 2050, representing increases of 11 and 21 percent, respectively (Figure 4.13).

Under both the BAU and the SSS scenario, the increase in land requirements is attributed to the above-mentioned expansion of agricultural production, and the limited or lacking crop intensification, which is the average number of crop harvests obtainable in a given period on the very same plot. This applies particularly in SSA and NNA (Figure 4.16). These both imply minimal or utterly ineffective efforts to increase land productivity in a given period. Regarding SSA in particular, all three scenarios suggest that productivity remains well below that of other regions under all three scenarios. This is because, due to the substantially lower historical levels, any projected growth rates of crop yields are not sufficient to lift, for example, cereal or fruit and vegetable productivity into ranges seen for other regions. Indeed, under the BAU and SSS scenarios, crop intensification accounts for only 16 and 10 percent of additional agricultural production, respectively, while the bulk of the increase in production is attributable to increases in yields and the amount of arable land, particularly in SSS. In regions where the availability of land is more limited, and intensification is not restrained by the length of the growing period (such as parts of the Mediterranean region and EAP), yield growth and intensification play a greater role in expanding agricultural production than increases in arable land.

The opposite occurs under the TSS scenario, where almost no additional arable land is required as compared with 2012, while agricultural growth results mainly from crop intensification and moderate yield increases.

It is important to note that achieving sustainable agricultural intensification requires a substantial paradigm shift to reconcile growing human needs with the need to strengthen the resilience and sustainability of landscapes and the biosphere (Rockström *et al.*, 2017). This calls for bold changes in the technological aspects of production systems to improve their ecological efficiency. Long-term strategies, policies and programmes are required to promote, for example:

- improved resource linkages and enhanced nutrient flows in integrated farming systems, such as rice–fish farming and other crop–livestock systems;
- higher-quality feeds and balanced animal diets;
- low-input and precision agriculture;
- innovative land and water conservation techniques, improved biodiversity preservation technologies, enhanced production technologies (such as agroforestry, organic agriculture, agroecology) and integrated pest management;
- the use of information and communication technologies to accelerate the spread and adoption of innovations.

Shifting the currently prevailing production paradigm carries some costs, with two particularly important implications.

First, some productivity gains would have to be given up, particularly in the short to medium term (Figure 4.11), as a consequence of the adoption of more environmentally-friendly techniques. Second, such a paradigm shift requires massively investing in several domains, including in research and development to produce effective and robust results for sustainable agriculture and food production, infrastructure-building, natural resources rehabilitation, human capital and expertise. and the dissemination thereof. All agents in food and agricultural systems would thus need to acquire the necessary know-how, while institutions will need to set up and enforce rules and regulations.

The importance of these actions is widely documented in all FAO work aimed at investigating and promoting sustainable agricultural practices. These investments require additional public funds, which would have to be recovered through general taxes. However, private investments would also be required to replace obsolete capital while transitioning towards sustainable agriculture and food systems. The additional investment will need to be recovered, thus possibly placing upward pressure on food and agricultural prices at least in the initial phases of this transition, as highlighted above under the TSS scenario.

Underpricing food may continue to encourage the overuse of natural resources, overconsumption and food waste, particularly by affluent people, with detrimental effects on the pace of progress towards sustainability. However, concerns that higher prices may hamper the capacity of poorer segments of the population and particularly of those who already suffer from hunger or severe malnutrition to procure sufficient food of satisfactory quality, are legitimate and need to be considered carefully. Poverty is among the main causes of environmental degradation in low-income countries, and sustainability cannot exist without equitability. While adequate social protection mechanisms can certainly provide immediate help for the extreme poor to overcome liquidity constraints and procuring food, programmes such as the UN Poverty–Environment Initiative[120] and projects that promote innovation in family farming need to be strengthened, as they not only help reduce poverty but also contribute to preserving ecosystems and promoting environmentally sustainable economic growth.[121]

Will poverty, inequality and unemployment continue to constrain food access and hamper the achievement of food security and nutrition goals?

KEY MESSAGES

1. **Defeating undernourishment requires reducing poverty and inequalities.** The findings of this report show that much more than "business as usual" will be required to defeat undernourishment. A bold move towards a more equitable income distribution – to be achieved through diverse strategic options, including by ensuring a more equitable access to assets for the poor people, with a focus on poor family farmers – is the most effective way to ensure that the reduction in undernourishment seen in the past years continues uninterrupted in the future.
2. **Environmental sustainability and food security can go hand in hand.** While moving food and agricultural systems towards sustainability drives food prices up and restrains global agricultural output, the per capita food availability in low- and middle-income countries can substantially expand if a more equitable distribution of income within and across countries is pursued.
3. **A more equitable income distribution allows for improved and healthier diets.** The consumption of healthy items, such as fruits and vegetables is likely to increase if income is more equally distributed within and across countries, and particularly low- and middle-income countries. Overall, cereals would remain the most important source of calories.
4. **Moving towards sustainability may help increase farm profitability and/or agricultural employment.** Sustainable agricultural practices can raise farm profitability and/or labour opportunities in agricultural sectors. This would contribute to a more equitable distribution of income, which may in turn be critical to improve food security and nutrition.
5. **Food and agricultural sectors are key, but no longer enough on their own to ensure equitable access to food.** Agricultural sectors continue to be important for employment and income generation in low- and middle-income countries. However, they alone no longer provide enough jobs or income-earning opportunities. On the one hand agriculture and family farming in particular, must be more firmly linked to the broader rural and urban economy. This can be done by developing agro-industries and setting up infrastructure to connect rural areas, small cities and towns. On the other hand, strong institutions supported by efficient fiscal systems, are needed to ensure economy-wide income-earning opportunities, effective social protection, competitive and equitable domestic and international markets for inputs and outputs.

[120] See: www.unpei.org

[121] An example is the FAO project "Farmer Innovation and New Technology Options for Food Production, Income Generation and Combating Desertification in Kenya" (see www.fao.org/in-action/promoting-farmer-innovation-and-ffs-in-kenya/en).

A third question regarding the future of food and agricultural systems is whether they will become more equitable, with access to sufficient and nutritious food for all is increasingly ensured, orif they will move in the opposite direction. This question becomes even more compelling in light of prospective agricultural prices increase particularly under the TSS scenario, which, other things being equal, would make access to food more onerous. The ensuing question is whether trade-offs would emerge between economic, environmental and social sustainability – that is, whether attempting to improve the ecological performance of food systems would imply giving up other desirable objectives, such as universal and permanent food security and improved nutrition.

It is generally recognized that without reducing inequalities in income, access to resources and earning opportunities, it will not be possible to eliminate hunger and extreme poverty (World Bank, 2016). The scenario analysis presented in this report provides insights on the conditions necessary for undernourishment to drop significantly and nutrition to improve, and those which would lead to a deterioration on both fronts. Reading across the scenarios also highlights the importance for food and agricultural sectors to contribute to increasing access to food through equitable access to land and water, credit facilities, improved information, opportunities to increase know-how, job creation, decent wages and diversified earning opportunities for rural people.

Under the BAU scenario, almost 7 percent of the world's population is still undernourished in 2030, compared with 11 percent in 2012 (Figure 4.8). This result confirms the trends already identified in the report *Achieving zero hunger* (FAO, IFAD and WFP, 2015b). Under the BAU scenario, the picture looks even worse in 2050, with undernourishment jumping to almost 8 percent. The limited drop in the percentage of undernourished people in 2050 compared with 2012 leaves the number of undernourished almost unchanged up to 2050 (Figure 4.9). An even worse situation unfolds under the SSS scenario, where the PoU climbs to more than 12 percent by 2050, leaving almost one billion people undernourished.

The TSS scenario portrays a completely different picture: the percentage of undernourished people drops to well below 4 percent of the world population, and their absolute number decreases to fewer than 400 million. Following this path towards sustainability, the average apparent per capita dietary composition also moves towards less meat consumption, specifically in HIC (compared with the other scenarios) which is associated with relatively higher consumption of fruits and vegetables in LMIC compared with HIC (see Figure 4.6).

It follows that a more sustainable pathway, characterized by reduced food availability and agricultural price increases, would not have a negative effect upon the performance of food systems in terms of food security and nutrition. In other words, there are no apparent trade-offs between environmental and social sustainability. There are two complementary reasons why the TSS scenario outperforms the other two in terms of food security and nutrition:

- One reason is the increased purchasing power in LMIC, resulting from a more equitable income distribution across countries (Figure 3.6). TSS is the only scenario that shows a positive trend towards per capita income convergence between LMIC and HIC,[122] allowing consumers in LMIC to buy more food. As a result, people in LMIC take in more per capita kilocalories than under the BAU scenario, and almost

[122] Under the BAU and SSS scenarios, LMIC and SSA in particular, are far from catching up with HIC in terms of per capita income, as the share of their per capita income in 2050 is still about 10 percent of HIC. China is an exception as in all scenarios it shows a positive trend towards convergence with HIC, as already observed since 1980.

the same amount as under the SSS scenario. The effect is particularly strong in SSA, where the per capita income is markedly higher under the TSS scenario than under the other two scenarios.

- The other reason is the more equitable food distribution within countries, achieved by means of a more equitable distribution of income across the different layers of societies, particularly in LMIC.

Income is more equitably distributed in TSS as compared with the BAU scenario, under the assumption that investments are oriented towards "pro-poor" growth. This implies that earning opportunities are available across all layers of society, basic services are universally accessible, and effective income redistribution mechanisms are at work. Under the TSS scenario, unskilled labour wages in LMIC are projected to be comparatively higher than in under the BAU scenario including in agriculture; in many instances, they are also higher than under the SSS scenario (Figure 4.4, green lines).

Moving food and agricultural systems towards sustainability may result in higher wages in agriculture or in the creation of additional employment – or both, depending on the system. For example, "conservation agriculture" could increase labour productivity, particularly where the supply of rural labour is relatively scarce, although in many instances, this would entail a more intensified use of herbicides and fungicides (Derpsch *et al.*, 2010; Kassam *et al.*, 2009; FAO, 2001); this type of agriculture must be adapted to local conditions (Pannel, Llewellyn and Corbeels, 2014). Meanwhile, "organic agriculture" practices can help to absorb labour, particularly where rural labour supply is abundant (Nemes, 2009; Herren *et al.*, 2011; Muller *et al.*, 2017).

Improving the income distribution within and across countries is imperative if food security and nutrition objectives are to be achieved while also ensuring the environmental sustainability of food systems. This is challenging in a world where inequalities remain pervasive, between rural and urban areas, regions, ethnic groups, and men and women. Moreover, the evidence indicates that "the rich are getting richer" (World Bank, 2016), while the rising trends in undernourishment highlighted in *The State of Food Security and Nutrition in the World 2018* (FAO, IFAD, UNICEF, WFP and WHO, 2018) are a clear indication that the poor may be becoming poorer. In this context, LMIC look highly unlikely to catch up with HIC for several decades (FAO, 2017a). However, agricultural sectors and food systems in general have a fundamental role to play in addressing this challenge, and some strategic options are available to promote equitable and pro-poor growth, including, for example:

- stepping up public spending on research and development and enabling a better environment for private research into innovative sustainable agricultural technologies, particularly those suitable to family farmers;
- ensuring family farmers' access to innovative technologies through measures such as specific credit lines, which may help shoulder the initial adoption costs, incentives and advisory services to motivate and support the learning phases, and other institutional arrangements, such as the creation of communities of practice to share information, exploit economies of scale, procure equipment in bulk at fair prices, or participate in dedicated insurance schemes for risk management;
- improving coordination along value chains and ensuring that the weaker segments in the chain reap the benefits of the integration of agricultural sectors into wider markets;

- protecting asset ownership and control, including through effective institutional arrangements and transparent land markets, particularly for those segments of the population driven out of agriculture by economic transformations and urbanization, with a view to preventing the dispossession of essential capital;
- building and/or reinforcing institutions that ensure the competitiveness of markets for agricultural inputs and outputs, prevent undue concentration, regulate oligopolies and oligopsonies, and prevent rent seeking behaviour that diverts income away from farmers;
- promoting investment in agricultural sectors only if it is compliant with the principles for responsible investment in agriculture and food systems, to ensure that it contributes to sustainable and inclusive economic development, the eradication of hunger and poverty, access to safe and nutritious food, equality and empowerment at all levels, resilience and the reduction of disaster risks (CFS, 2014).

Despite its key role, it is increasingly clear that agriculture alone is no longer enough to significantly improve equity and support pro-poor growth. The ongoing wider process of economic transformation has led in many instances to fewer people being engaged in agriculture, and available analysis signals that this trend may continue. This may lead to further urbanization and international migration, particularly if decently remunerated jobs and alternative earning opportunities are not generated in rural areas, off-farm and outside of agriculture. Permanently reducing poverty requires actions that cut across rural and urban areas, and, by and large, across countries and regions. This would require, for example:

- providing broad and gender-balanced access to good quality health services, sanitation and education, as well as to professional training and retraining, especially for marginal farmers prone to leaving agriculture, to allow people to benefit from technical progress and economic transformations, while reducing poverty;
- promoting economic diversification into rural non-farm income-generating activities by developing industrial (sector-specific) policies, protecting infant industries and implementing measures to favour private businesses, particularly small- and medium-sized enterprises and create jobs (FAO, 2017g);
- promoting the development of agro-industries and setting up the territorial infrastructure needed to interconnect rural areas, small cities and towns, so that rural populations can benefit from structural transformation and urbanization;
- supporting economy-wide job creation through the promotion of equitable innovative processes, and ensuring decent job remuneration and working conditions through the use of enforceable laws and regulations;
- implementing adequate social protection mechanisms to provide immediate relief for undernourished, food-insecure and extremely poor people and help overcome households' liquidity constraints, thus enabling individuals and communities to engage in more profitable but riskier income- and employment-generating activities (FAO, IFAD and WFP, 2015b);
- increasing the savings and investment potential of those without it, especially the poor through, for example, inclusive financing;
- facilitating the access to production factors such as land, water, credit, technical assistance and infrastructure, among others, with a focus on the poorest people.

All these measures require appropriate funding from both public and private sources. Official development assistance (ODA) and foreign direct investment (FDI), as well as other forms of funding that are increasingly available through various partnerships, may be required to support transformative processes that lead economic systems towards more sustainability, particularly in low-income countries (FAO, 2017a). However, significant additional funding may be generated by improving international and national governance and reinforcing institutions at all levels, including:

- setting up more equitable and effective fiscal systems to exploit the "fiscal space" that many countries, including some in the LMIC group, possess to fund public policies and orient development processes towards equitability and sustainability;
- significantly reducing illicit financial outflows,[123] which probably exceed ODA and FDI and strip resources from LMIC that could otherwise be used to finance much-needed public services and development policies (OECD, 2014). As illicit financial flows largely affect SSA (AfDB, 2013) (the region most prone to hunger) and such flows affect food and agricultural sectors as well (UNECA, 2014), tackling them may not only benefit public funds and citizens' incomes, but also have immediate and direct impacts on agricultural development and food security.

Given these considerations, it appears that achieving an equitable income distribution across and within countries – which would contribute considerably towards SDG2 (ending hunger, achieving food security and improved nutrition and promoting sustainable agriculture) – requires full political commitment, innovative thinking and drastic changes to the structure and relationship between labour and capital, agriculture and non-agricultural sectors, and LMIC and HIC.

A final remark regarding undernourishment: even under the TSS scenario, which is based on a decisively more equitable income distribution than the other scenarios, a combination of factors including population growth, price increases and climate change – albeit moderate – result in a rebound in the number of undernourished people after 2030. This suggests that progressive commitments may be required to not only achieve, but also maintain food security achievements in the long run.

[123] See the SDG target 16.4: "By 2030, significantly reduce illicit financial and arms flows, strengthen the recovery and return of stolen assets and combat all forms of organized crime" and indicator 16.4.1: "Total value of inward and outward illicit financial flows (in current United States dollars)."

How will climate change affect agriculture and rural livelihoods, and can agriculture help reduce GHG emissions?

KEY MESSAGES

1. **Climate change will incrementally affect all the agricultural sectors.** Climate change already has negative effects on crop yields, livestock production and fisheries, particularly in low- and middle- income countries. Such impacts are likely to become even stronger later in this century.
2. **If left unaddressed, climate change will exacerbate poverty and inequalities.** Unaddressed climate change, which is associated, inter alia, with unsustainable agricultural practices, is likely to lead to more land and water use, disproportionately affecting poor people and exacerbating inequalities within and between countries. This carries negative implications for both food availability and food access.
3. **Climate change impacts go well beyond crop yields.** Climate change also affects soil quality, fish habitats and stocks, the biodiversity of landscapes, and the epidemiology and antimicrobial resistance of pests and diseases. There are great uncertainties about the combined effects of these impacts.
4. **Agricultural sectors can only reduce their GHG emissions through more investment.** Agricultural sectors can adapt to climate change and lower their GHG emissions while producing enough food for all. However, for this to be possible, substantial investments must be made to develop and implement more resource-saving and climate-friendly technologies.
5. **Efforts in agricultural sectors are not enough – drastic economy-wide GHG reductions are needed.** Although agricultural sectors have a significant potential for climate change mitigation through the adoption of better practices such as land conservation, increasing livestock efficiency, afforestation and reforestation, efforts in agriculture alone are not enough. Boosting energy-use efficiency and reducing GHG emissions per unit of energy must happen on an economy-wide basis.

A fourth concern regarding the future of food and agricultural systems is whether the sector – which will be increasingly affected by climate change – can substantially contribute to reducing global GHG emissions while producing enough food for all.

Agricultural sectors will be affected by climate change to varying degrees depending on the economy-wide amount of GHGs emitted in coming decades. The existing knowledge of the relationships between climate change and agricultural performance is relatively limited. However, it is well known that climate change will affect crop yields as well as other ecological and social aspects, including biodiversity, soil quality, animal and plant resilience to diseases, and poverty and inequalities across and within countries. These factors could trigger migration flows and conflicts, with negative consequences of an unforeseeable magnitude for the well-being of billions of people (IPCC, 2014a).

Under the BAU scenario, climate change will negatively affect crop yields worldwide due to growing GHG emissions. The same holds true for the SSS scenario, where GHG emissions expand as economic systems grow. Meanwhile, GHG emissions decrease under the TSS scenario as a result of substantial investments that bring about more sustainable production and consumption patterns and ensure that the impact of climate change on crop yields is less severe than under the other scenarios (Figure 3.9).

It is well recognized that agricultural sectors are not only affected by climate change, to which they need to adapt; they also contribute substantially to it. Under the BAU and SSS scenarios, for example, GHG emissions from agricultural sectors increase by 24 and 54 percent, respectively, while the TSS scenario sees a substantial reduction of 39 percent in emissions (Figure 4.17).

The notable reduction in GHG emissions by agricultural sectors under the TSS scenario is the joint result of three concurring factors:

- a reduced expansion in gross agricultural output compared with the other scenarios;
- a different composition of agricultural output, with a more limited expansion in livestock, and particularly of large and small ruminants, which significantly contribute to GHG emissions;
- efficiency gains in both crop and animal production processes as a result of reducing land and input use per unit of output.

The first two aspects pertain to changes in consumer habits and preferences, as discussed above. The third aspect relates to the way production processes are organized and managed.

The wide range across countries and regions of emission intensities, which are the amount of GHG emissions per unit of output, suggests that there is a potential to lower GHG emissions from food and agricultural sectors. This implies examining the overall impacts of the food and agricultural systems at large, which include food and feed demand, food loss and waste, other uses of agricultural outputs (fibres, biofuels, etc.), water usage, as well as the system's effects on soil health, ecosystem services, biodiversity and agriculture–forest trade-offs and/or synergies, including soil carbon storage, afforestation and reforestation.

Agriculture, land use, land-use changes and forests are among the most referenced sectors in intended nationally determined contributions (INDCs) as domains for GHG emission reductions that countries submitted ahead of the 2015 United Nations Climate Change Conference (COP21) (FAO, 2017h). Options for significantly reducing GHG emissions exist also for fisheries, for instance in capture, by using more efficient engines, improving vessel shapes or simply by reducing the mean speed of vessels, as well as in aquaculture, by using renewable energy sources, and improving feed conversion rates (Barange *et al.*, 2018). However, all these aspects need to be further mainstreamed to allow for the effective implementation of INDCs and to achieve further results in GHG reduction.

Furthermore, it is apparent that, although the agricultural sectors have significant potential to contribute to overall GHG emission reductions, the burden of this challenge has to be borne by the economy at large. This implies, for example, achieving economy-wide improvements in the efficiency of energy use – that is, the energy use per unit of output, as well as the GHG emissions efficiency per unit of energy.

5.2 Concluding remarks

"Business as usual" is no longer an option if the targets set by the 2030 Agenda for Sustainable Development – and specifically those directly concerning food and agriculture – are to be met. The high-input, resource-intensive farming systems that have caused massive deforestation, water scarcity, soil depletion, the loss of biodiversity, antimicrobial resistance of pests and diseases and high levels of GHG emissions cannot guarantee the sustainability of food and agricultural systems. Moreover, a future of increasing inequalities, exacerbated climate change effects, uncontrolled migration, increasing conflicts, extreme poverty and undernourishment, as outlined in one of the scenarios of this study, is highly undesirable.

Innovative systems are needed to increase productivity without compromising the natural resource base. Technological improvements resulting in a drastic reduction in agricultural GHG emissions would help to address climate change and counteract the intensification of natural hazards, which affect all ecosystems and every aspect of human life (FAO, 2017a). These are the salient features of the "towards sustainability" scenario developed and analysed in this report to reflect a future with desirable outcomes.

However, this scenario is far from being an easy path without hurdles: there are no "silver bullets" and society must be prepared to address certain trade-offs. The conclusions of this report provide solid evidence to corroborate the assertion that "fundamental changes in the way societies consume and produce are indispensable for achieving global sustainable development" (UN, 2012).

To permanently and universally achieve the SDGs and guide food systems and socio-economic systems in general along an economically, socially and environmentally sustainable path, a global transformative process that goes well beyond the divide between "developed" and "developing" countries is required. Where the conventional "development" wisdom once focused mainly on addressing the needs of low-income countries, sustainable development looks at the universal challenge – and collective responsibility – of addressing the needs of all countries. All socio-economic and environmental systems require substantial investments along the path towards sustainability to overhaul obsolete capital stock, research and develop new solutions, and implement innovative technologies adapted to different contexts and actors. These aspects are all at the heart of the SDGs.

The investments required to move food and agricultural systems towards sustainability are by nature riskier than in other sectors, and require a better ex ante risk assessment and guarantees to ensure that projects are sustainable. Moreover, these investments will only materialize if both private and public funding becomes available to:

- research and develop innovative sustainable technologies for primary production and processing;
- replace obsolete capital to improve efficiency in land and water use;
- reduce GHG emissions along the entire food and agriculture value chains;
- build market and logistical infrastructure to reduce food losses and improve value chain efficiency;
- support the implementation of social protection programmes and increase their coverage, especially in rural areas;
- reinforce institutions, including those promoting responsible investments in agriculture and food systems.

Making this funding available requires sacrificing certain present – not necessarily essential – needs in order to reap future benefits. Such sacrifices should be borne by richer countries and by the better-off segments of society, which can reasonably afford them. As such, a brighter future is prepared for the next generations and for those who already suffer from the negative effects of unsustainable development.

The findings of this report are subject to uncertainties regarding the interaction between various production, consumption and biophysical processes occurring across different sectors and regions. Moreover, as data on many aspects are insufficient or inconsistent, it was necessary to identify, merge and harmonize a myriad of datasets from different domains.

To avoid looking into the future with the same lenses used to observe the past, and to overcome data gaps, this report was based on the ideas, positions and contributions of a broad array of actors and constituencies, including other international organizations, national governments, non-governmental and civil society organizations, and academia. It builds heavily upon the multidisciplinary knowledge of FAO and its development partners, which in many instances represent the best and most up-to-date information available worldwide in fields such as animal production technologies and related GHG emissions, climate change scenarios, agricultural commodity production and use, and global economic data, to mention but a few.

Despite its difficulties and limitations, this report contributes to the debate on the future of food and agriculture and its sustainable development patterns. Much more remains to be done to better understand how socio-economic and environmental systems may evolve in the future, and comprehend the possible future pathways of food and agricultural systems. Nonetheless, this report constitutes a significant step forward in this direction. For the first time does a report not only provide a globally comprehensive and consistent foresight exercise on food and agricultural systems based on three alternative scenarios – which catalyses such a large amount of multidisciplinary expertise – but it does so by examining the challenges to food security and nutrition in all their complexity and within the context of the wider economy, taking into account future climate change.

This report advocates for more sustainable food and agriculture systems based on sound quantitative evidence. The absence of such evidence would make any calls for increased sustainability much less convincing and, ultimately, largely ineffective.

Hopefully, the findings of this report will be of use to everyone interested in long-term foresight assessments of global food and agricultural systems, including decision-makers and analysts in governments, international organizations, civil society organizations, the private sector, and academic and research institutions.

Decision makers, the international community, academia and civil society are invited to consider this report not as the end point of an analytical endeavor, but rather as the starting point for a dialogue on strategic policy choices and processes aimed at shaping sustainable development patterns at country, regional and global levels. It is in this perspective that this report should be regarded as a contribution towards achieving both the United Nations' Sustainable Development Goals and FAO's vision of a world with sustainably produced, nutritious and accessible food for all.

Annexes

Annex I
A comparative review of selected foresight exercises

This annex summarizes a selection of forward-looking exercises that helped "set the scene" for the scenarios of this foresight exercise.[124] Here, we briefly review two broad exercises that provide the reference framework for many recent forward-looking exercises, namely the Representative Concentration Pathways (van Vuuren *et al.*, 2011), and the Shared Socio-economic Pathways (O'Neill *et al.*, 2017). Further summarized publications are:

- *World Agriculture Towards 2030/2050* (Alexandratos and Bruinsma, 2012);
- *Alternative Futures for Global Food and Agriculture* (OECD, 2016);
- *Securing Livelihoods for All* (OECD, 2015);
- *Towards a High-Impact Demand-Driven Research Agenda for IFAD* (IFAD, 2015);
- *Scenarios of land use and food security in 2050. Agrimonde-Terra foresight: Land use and food security in 2050* (Mora, 2016);
- *Exploring future changes in land use and land condition and the impacts on food, water, climate change and biodiversity: Scenarios for the UNCCD Global Land Outlook* (van der Esch *et al.*, 2017);
- *Challenges of Global Agriculture in a Climate Change Context by 2050* (van Meijl *et al.*, 2017);
- *Global Food Security 2030 - Assessing Trends in View of Guiding Future EU Policies* (Maggio, van Criekinge and Malingreau, 2015).

[124] A comprehensive review of forward-looking exercises is beyond the scope of this annex. Le Mouël and Forslund (2017) provide a review of 25 scenario studies and a synthesis of their main responses on how to feed the world up to 2050.

Representative Concentration and Shared Socio-economic Pathways

Representative Concentration Pathways[125]

The so-called Representative Concentration Pathways (RCPs) provide alternative patterns of GHG concentration in the atmosphere and of expected average temperature changes (van Vuuren *et al.*, 2011). The RCPs were produced by the integrated assessment modelling teams, used by climate modelling teams and considered in the Fifth Assessment Report of the Intergovernmental Panel for Climate Change (IPCC). There are four RCPs comprising emissions pathways starting from an identical base year (2000) – that is for radiative forcing of 8.5, 6, 4.5, and 2.6 in watt per square metre (W/m^2) – and concentrations of GHGs are given for the RCPs up to 2100.

Each concentration pathway was quantified by a different research group using a different climate model, based on different assumptions regarding the key socio-economic scenarios. This implies that the socio-economic assumptions of the RCPs do not constitute a homogenous set, namely the highest emission scenario (RCP 8.5) does not necessarily combine with the highest population or income growth in all regions when compared against the other three RCPs.

The RCP 2.6 concentration pathway is a *"peak"* scenario, displaying very low GHG concentration levels; its radiative forcing level first reaches a value around 3.1 W/m^2 mid-century, and returns to 2.6 W/m^2 by 2100. In order to follow this pathway and to reduce emissions substantially from their current level it requires: declining fossil fuel usage; moderating population level at around 9 billion by the year 2100; increasing bioenergy production; intensifying animal husbandry; reducing methane emissions by 40 percent compared to the base year (2000); controlling CO_2 emissions so they stay at current levels until 2020, and then gradually decline and become negative in 2100, with CO_2 concentrations peaking around 2060 and declining thereafter to around 400 ppm by 2100.

RCP 4.5 is a *"stabilization"* scenario where total GHG emissions are stabilized before 2100 by applying a range of technologies and strategies for reducing GHG emissions. The scenario is consistent with lower energy intensity, strong reforestation programmes, decreases of croplands and grasslands due to yield increases and dietary changes, stringent climate policies, stable methane emissions, and CO_2 emissions increasing only slightly before decline commences around 2040 with CO_2 concentrations at around 570 ppm by 2100.

RCP 6.0 is also a *"stabilization"* scenario, where total GHG emissions are stabilized after 2100 at 750 ppm CO_2. The scenario is consistent with the adoption of a wide range of technologies and strategies for limiting GHG emissions. The future is still reliant to a large extent on fossil fuels, intermediate energy intensity, an increasing use of croplands and a declining use of grasslands, as well as almost stable methane emissions. The CO_2 emissions peak in 2060 at 75 percent above current levels, then decline to 25 percent above today's rates.

RCP 8.5 is representative for scenarios leading to high GHG concentration levels and is characterized by significantly increasing GHG emissions, with GHG emissions three times those of current levels and CO_2 emissions at 1250 ppm by 2100. This scenario is compatible with high and increasing methane emissions; an increased use of croplands and grasslands, driven by a significant population increase to 12 billion by 2100; a lower

125 http://sedac.ipcc-data.org/ddc/ar5_scenario_process/RCPs.html

rate of technology development than all other RCPs; heavy reliance on fossil fuels; high energy intensity; and no implementation of policies mitigating climate change.

The scenarios designed for this foresight exercise, notably – BAU, TSS and SSS – are characterized by various levels of economy-wide GHG emissions and impacts of climate change, as well as by different contributions by the agricultural sector, corresponding to RCP 6.0, RCP 4.5, and RCP 8.5.

Shared Socio-economic Pathways

The Shared Socio-economic Pathways (SSPs) (O'Neill *et al.* 2017) have been developed by the integrated assessment modelling teams in parallel to the RCPs and replaced the so-called Special Report on Emission Scenarios. The SSP scenarios have been developed along two axes directly linked to climate change challenges: to challenges for adapting to climate change and to challenges for mitigating climate change. In detail, they include five narratives for alternative futures based on "reference assumptions" related to key socio-economic variables:

SSP1: Sustainability – taking the green road. The world shifts towards a more sustainable path of inclusive development and respect for environmental boundaries. International governance improves with effective cooperation at all levels and sectors. Low population, high education and health investments accelerate demographic transition. There is a shift from a focus on economic growth to human well-being. Further positive developments include reductions in inequality, improved resource efficiency, low energy and resource use, and consumption that is oriented towards low material growth and low intensity.

SSP2: Middle of the road. Social, economic, and technological trends proceed along historical patterns. Development and income growth proceed unevenly. There is slow progress on reaching sustainable development goals. Technological developments proceed without breakthrough. Environmental systems experience degradation. Fossil-fuel dependency decreases slowly with no reluctance to use unconventional fossil resources. The population remains at moderate levels. Income inequality persists or improves slowly.

SSP3: Regional rivalry – a rocky road. There is growing interest in regional identity, and concerns about competitiveness and security push countries to increasingly focus on domestic or regional issues. Weak global institutions are ineffective at addressing environmental concerns. Low population growth occurs in industrialized countries, while developing countries experience high population growth. Policies are oriented towards security, with trade barriers erected. Energy and food security is achieved within own regions, and more authoritarian forms of government evolve. Countries experience slow economic development, material-intensive consumption, and inequalities persist/worsen. Strong environmental degradation occurs globally, with countries placing low priority on international cooperation.

SSP4: Inequality – a road divided. Highly unequal investments in human capital, combined with increasing disparities in economic opportunity and political power lead to increasing inequalities and stratification both across and within countries. Economic growth is moderate, low-income countries lag behind, and a gap develops between internationally-connected societies and low-income societies. Power becomes concentrated in a small political and business elite, and social cohesion degrades. Technology development is high in high-tech economies, but low otherwise. The energy sector diversifies in the face of uncertain supply, including uncertain fossil fuel markets. Environmental policies focus on local issues in middle- and high-income areas.

SSP5: Rapid growth – taking the highway. Driven by the economic success of industrialized and emerging economies, this world places increasing faith in competitive markets, innovation, and participatory societies to produce rapid technological progress and development of human capital as the path to sustainable development. The global economy experiences rapid growth. However, population growth is low, with high mobility. Strong investments are made in health, education, and institutions to enhance human and social capital. There is further exploitation of abundant fossil fuel resources and the adoption of resource- and energy-intensive lifestyles around the world. Local environmental impacts are addressed, but there is little effort put towards global issues.

The SSP scenarios can be considered as building blocks that provide the starting point to other long-term projections.

The patterns of socio-economic systems reflected in the scenarios designed for this foresight exercise, which describe alternative global socio-economic futures, borrow several elements from the SSP scenarios, such as selected assumptions on economic growth, technologies and the use of natural resources. However, there is no one-to-one correspondence. For instance, the BAU scenario is not based on SSP2: "middle of the road". In the "challenges space" for this foresight exercise, BAU contains some elements of SSP3, especially regarding innovation, unmanaged urbanization and low environmental and land and water conservation policies.

Food and agriculture-specific forward-looking exercises

World Agriculture Towards 2030/2050. The 2012 Revision (Alexandratos and Bruinsma, 2012)

This publication analyses a single long-term scenario that reflects a common plausible future state of agriculture, with a focus on the use and availability of natural resources in different regions. It builds upon FAOSTAT food and commodity balance sheets, other data sources and expert judgement. This foresight exercise is based on selected drivers, such as per capita income and population, also used in the study analysed. However, the "what if" approach adopted in this foresight exercise required a shift away from the "single scenario" approach of Alexandratos and Bruinsma (2012), towards a "multiple scenario" approach. This is the reason why other drivers and scenario elements such as climate change and income inequality across alternative scenarios are unique to this foresight exercise.

Alternative Futures for Global Food and Agriculture (OECD, 2016)

The OECD and non-Member ministry participants discussed how the global food system can feed 9 billion people without destroying sensitive ecosystems and/or social cohesion. In this work the three key trends that frame the challenges facing food and agriculture are: growing and shifting food demand, constraints upon natural resources, and agricultural productivity uncertainties resulting from climate change. Three scenarios have been designed: the *sustainability scenario*; the *scenario of globalization*; and the *scenario of separate growth*.

The *sustainability scenario* is similar to SSP1 and RCP 2.6 regarding assumptions on world population, urbanization, temperature increases, and effective energy consumption. This scenario is grounded on the rapidly developing mindset of consumers, citizens and policy-makers towards sustainable production and the consideration of one's environmental and social footprint when making everyday decisions on consumption and production. Environmentally-friendly technologies are developed and shared easily, and natural resources are reserved. Agricultural productivity gains are realized by mainly reducing overall inputs. Focus is given to connecting cities and rural areas, resulting in an increased importance of peri-urban supply chains.

The *scenario of globalization* is driven by a revival of multilateralism, in which – despite a general commitment to increase carbon efficiencies – economic growth keeps on increasing GHG emissions. There is rapid urbanization, and income and wealth inequalities between countries and individuals brighten. Consumption growth in food and energy is very high, leading to water scarcity and land losses. Unequal access to resources is widely spread across countries and climate change affects all countries.

The *scenario of separate growth* envisions a world of sovereignty and self-sufficiency ambitions, which involves reduced global governance structures. This scenario is characterized by a strong focus of individual regions on contributing to economic growth, whereby inequalities increase both across and within regions and countries. The agricultural system is highly input intensive and is based on high-productivity, large-scale and non-environmentally-friendly production systems. In this scenario there are biodiversity losses and GHG emissions rise significantly.

Each of the three scenarios in OECD (2016) is loosely linked to one of the SSPs, while the narratives for climate change are directly linked to a specific RCP.

Securing Livelihoods for All (OECD, 2015)

To explore the policy options and possibilities for building inclusiveness and resilience for future livelihoods, the OECD developed five scenario storylines that look forward to 2030 – three are crisis scenarios, while two are more positive. All scenarios are possible, based on current trends (e.g. ageing high-income countries, unemployment enhancement, financial crises and climatic changes). In the *first three scenarios*, most people fail to adapt rapidly enough and find it difficult to secure their livelihoods. About a billion people fall into poverty, whereby inequality increases more quickly than expected. Social tensions and disruptions increase due to widening protests against governments. *Scenario 4* takes a different perspective, in which technology contributes to job creation and brings solutions to cope with environmental challenges. Green productivity continues to increase. Plant fertilizers match local soil conditions and technologies such as hydroponic cultures, satellite and drone monitoring take over. There is a high demand for skilled and educated workers. *Scenario 5* explores a world in which unemployment encourages people to value social well-being over economic growth, and to develop creative ways of making a living. The application of technology increases in both low- and high-income countries alike. Societies evolve towards new ways of living and working, with each individual and community being key actors of change.

The focus on the linkages between technology and socio-economic aspects and their different impacts on poverty reduction and sustainable agriculture development contributed to some extent to inspire the scenario narratives of this foresight exercise.

Towards a High-Impact Demand-Driven Research Agenda for IFAD (IFAD, 2015)

To identify major components of future policy and investment priorities, IFAD used a scenario approach with two criteria on economic growth and institutional development to categorize countries. In low-capacity countries, support should provide for the creation of farm jobs, better social protection, rural-urban linkages, the enhancement of nutrition, and a demand for healthy foods. In these countries governments should empower and secure family farmer access to natural resources and provide for sufficient rural services. In high-capacity countries, investment should be designed to enforce regulations on environmental sustainability, develop human capital in rural areas, minimize the risk of malnutrition and obesity, and revitalize private investments.

Although the distinction between low and high regarding economic and governance aspects may be somewhat artificial, this report has borrowed the need to consider various institutional support and investment policies in the narratives of the scenarios.

Scenarios of land use and food security in 2050. Agrimonde-Terra foresight: Land use and food security in 2050 (Mora, 2016)

The Agrimonde-Terra foresight project explores pathways towards sustainably feeding 9 billion people by 2050. The study highlights the complex array of interactions between food security, land and its use, and environmental impacts from human activities. Five land-use scenarios were developed, which assume the same population growth and combine external drivers and their impacts on five dimensions of land-use and four dimensions of food and nutrition security.

The first three scenarios ("Metropolization", "Regionalization" and "Households") are based on current completion trends identified in most world regions. For example, the potential cultivable land area will not continue increasing by 2100 but will rather remain constant because of the moderate level of urban growth. Further, soil degradation and urbanization will reduce farmlands, and small farmers may find it difficult to keep their land. Cooperatives will be major actors in land-use. Under the "land-use for food quality and healthy nutrition" scenario (fourth scenario), climate change will stabilise, and many countries will restore soil fertility and avoid land degradation through organic methods. Farmland yield potential will increase, enhancing food and nutritional diversity for healthier diets by 2050, while limiting the growth of agricultural land and deforestation will require greater diversification in cropping and livestock systems. In the "Communities" scenario (fifth scenario), arable land areas increase in higher latitudes, but decrease in the tropics, reinforcing the interdependency between different regions of the world; the use of land prevails over ownership. In all scenarios, international trade will play a key role in ensuring world food availability up to 2050 and in various regions.

As the Agrimonde-Terra foresight study does, this foresight exercise assumes the same population growth in all three scenarios so as to focus on how different production systems can affect the availability of natural resources and more specifically land-uses. This foresight exercise explores the long-term dynamics of "land-use and food security" as identified in the Agrimonde-Terra foresight study in formulating the three scenarios (BAU, TSS and SSS). For instance, the TSS scenario combines sustainable development with food security, while the SSS scenario includes land-use expansion together with high GHG emissions.

Exploring future changes in land use and land condition and the impacts on food, water, climate change and biodiversity: Scenarios for the UNCCD Global Land Outlook (van der Esch *et al.*, 2017)

This study aims to explore how various demands on land are expected to change under alternative future developments by 2050, how they will affect the challenges facing global sustainability ambitions, and the extent to which land degradation may exacerbate these challenges. Three SSPs scenarios (SSP1, SSP2 and SSP3) reveal the scope of potential future changes in land-use up to 2050.

The projections for land-use by humans in 2050 (food and feed crops, pasture, bioenergy, built-up areas) differ widely among the three SSPs. For example, SSP1 foresees a net decrease in land-use due to a reduction in cropland and pasture. However, SSP2 suggests a moderate increase in land-use of 4 million km^2, while SSP3 points to the largest increase of about 8 million km^2. The three scenarios foresee a 25 percent to 75 percent increase in the demand for and production of agricultural products and timber until 2050. Similar to this foresight exercise, the projections for future change in land-use in the UNCCD Global Land Outlook vary significantly across regions.

Challenges of Global Agriculture in a Climate Change Context by 2050 (van Meijl *et al.*, 2017)

The study by van Meijl *et al.* (2017) assesses the impact of climate change on the agricultural sector by 2050, as well as the economic consequences of stringent global emission mitigation efforts under different socio-economic and representative GHG concentration pathways. This report is a step forward in exploring the scenario space of the impact of future climate change scenarios on the agricultural sector. The overall trends of the 12 scenarios are very similar and the few 'outliers' can be well explained by structural model characteristics or different scenario implementation choices. Results of the study are relatively consistent across Shared Socio-economic Pathways (SSP1, SSP2 and SSP3) and climate scenarios (RCP 2.6 and RCP 6.0 with and without mitigation policies in place), despite the fact of having models with some significant structural differences. Global agricultural production is lowest in SSP1 and highest in SSP3. The impact of climate change on agricultural production in 2050 is negative but relatively small at the aggregated global level. Emission mitigation measures (i.e. carbon pricing) have a negative impact on primary agricultural production for all SSPs across all models.

Results from van Meijl *et al.* (2017) have been compared with quantitative projection findings of this foresight exercise.

Global Food Security 2030 - Assessing Trends in View of Guiding Future EU Policies (Maggio, van Criekinge and Malingreau, 2015)

The Global Food Security 2030 report provides a quite “rosy” vision of the future of food and agriculture, with a significant reduction in the relative number of undernourished people and food security guaranteed for 8–9 billion people. This vision may materialize on a sustainable basis if the following occurs: 1) the significant transformation of agriculture production systems (especially through investments, research and capacity building); 2) maintenance of an adequate enabling environment in rural areas (namely rural development); 3) a food system where production and consumption are balanced between local, regional and global levels (via trade and integrated markets); and 4) a largely demand-driven food system where responsible consumer behaviour shapes sustainable objectives. The "vision" portrayed in Maggio, van Criekinge and Malingreau (2015) contributed to inspire the scenario narrative and identify selected strategic options for the TSS scenario.

Overall remarks

The studies reviewed here all suggest that agricultural demand may continue to grow, driven by population growth, urbanization and increasing per capita incomes. In the case where low to medium economic growth is associated with a set of driving forces towards increased sustainability, the food and nutrition evolution is associated with a change in lifestyle and the deceleration in the rise of calorie consumption – involving diets with limited increase in daily calorie intake together with a reduction of the meat consumed and of the food lost at retail and household levels. There is also a shared vision that agricultural systems must face increased competition for natural resource use, while also facing the threats of soil degradation, water shortages, biodiversity losses, and climate change. Table A 1.1 summarizes the main features of the scenarios in the discussed foresight studies.

Most studies highlight that, expanding cropland area globally contributes to further deforestation, which in turn leads to increasing GHG emissions and decreasing biodiversity. To sustainably feed the world by 2050, prominence has to be given to the development of alternative farming systems that are less detrimental to the environment while maintaining their yield performance. Convergence across studies emerges on the fact that, without greater efforts to combat climate change and mitigate its negative effects, economic growth will likely increase GHG emissions and hence negatively affect the productive capacity of the agricultural sector, particularly in low-income countries.

Table A 1.1 Overview of reviewed foresight studies

STUDY	SCENARIOS				
Representative Concentration Pathways	+2.6 W/m^2 peak (2060) CO_2 concentration, declining to 400 ppm CO_2 by 2100	+ 4.5 W/m^2 Stabilization by 2100 at 570 ppm CO_2	+ 6.0 W/m^2 Stabilization beyond 2100 at 750 ppm CO_2	+ 8.5 W/m^2 Increasing CO_2 concentration (1 250 ppm by 2100)	
Shared Socio-economic Pathways	SSP1: Sustainability: taking the green road	SSP2: Middle of the road ("moderate" of everything)	SSP3: regional rivalry (resurgent nationalism), a rocky road	SSP4: Inequality across and within countries, a road divided	SSP5: Fossil-fuel-based development, taking the highway
Alexandratos and Bruinsma, 2012	Single scenario, no climate change, constant agricultural prices				
OECD, 2016	Sustainability: Greening, environmental and socially focused	Globalization: Economic growth-focused	Separate growth: Sovereignty and self-sufficiency-focused		
OECD, 2015	"Automated North" (inequality increases, south is slower)	Droughts and unemployment in the south (migrations, inequality)	Global financial crash (protectionism, fragmentation, government failure, inequality)	Regenerative economies (sustainable energy, jobs, virtuous transformation)	Creative societies (technology, unemployment, social experiment)
IFAD, 2015	Low institutional capacity and high-growth pattern	High institutional capacity and high growth	Moderate institutional development with any growth	Very low institutional capacity	
Mora, 2016	Land used for food quality and healthy nutrition (RCP 2.6)	Land used for regional food systems (RCP 4.5)	Uneven land-use driven by massive urbanization (RCP 8.5)	Fragmented world and land as commons for rural communities	
van der Esch *et al.*, 2017	Net land-use: decrease. Agriculture and timber land demand: increase of 25 percent (SSP1)	Net land-use: 4 million km^2. Agriculture and timber land demand: increase of 50 percent (SSP2)	Net land-use: 8 million km^2. Agriculture and timber land demand: increase of 75 percent (SSP3)		
van Meijl *et al.*, 2017	RCP 2.6, SSPs 1,2,3 Three scenarios of ambitious mitigation to stabilize global warming at 2 °C	RCP 2.6 without mitigation to climate change, SSPs 1,2,3	RCP 6.0, SSPs 1,2,3 Three scenarios: with medium climate change mitigation efforts (without CO_2 fertilization)	RCP 6.0 without mitigation to climate change; SSPs 1, 2, 3	
Maggio, van Criekinge and Malingreau, 2015	Single scenario "desirable vision" to 2030, to be realized				

Sources: FAO Global Perspectives Studies, based on cited studies.

Annex II
Detailed assumptions for scenario narratives

The tables in this annex present assumptions for the scenario narratives regarding macroeconomic, social and technical drivers (Table A 2.1), the food and agricultural sectors (Table A 2.2), and food- and agriculture-specific policies (Table A 2.3).

Table A 2.1 Macroeconomic, social and technical drivers by scenario

GROUP/VARIABLE	BAU	TSS	SSS	NOTES
DEMOGRAPHICS				
Population projections	Medium variant of UN 2015 population projections. Growth is high in Asia (until 2050) and Africa, and low elsewhere.	As in BAU.	As in BAU.	Same population projections across scenarios helps focus on key dynamics of the food and agricultural sectors.
Fertility	Medium variant.	As in BAU.	As in BAU.	
Mortality	Medium variant.	As in BAU.	As in BAU.	
International migrations	Medium levels.	Lower than BAU.	Higher than BAU.	
Urbanization level	Medium-high.	Low to medium.	High.	In SSS, clustered areas for elites. Slums emerge in many countries, including HIC.
Urbanization management	Medium.	High.	Low and poorly managed.	In SSS, mostly to protected areas for elites.
ECONOMY				
Economic growth	Moderate (SSP3).	Same total gross world product as in BAU, but more distributed across countries as in SSP1.	High (SSP4), but "immiserizing growth" mechanisms are at work.	SSPs' per capita GDP growth rates are kept as a reference to ease comparisons with other studies.

GROUP/VARIABLE	BAU	TSS	SSS	NOTES
ECONOMY (continued)				
Income inequality within countries	Current trends of modest convergence are maintained. SDG10 is barely achieved through fiscal policies and public spending.	Inequality reduction achievements exceed SDG10 targets.	SDG10 targets are not achieved, as within-country income distribution follows diverging patterns.	Only indirectly modelled through wage differentials across sectors and food distribution. SDG10: Reductions of inequality within and among countries.
Income inequality across countries	Current trends of modest convergence (based on SSP3).	Inequality reduction achievements exceed SDG10 targets (proportions of per capita income as in SSP1).	Higher than BAU from 2050 onward (based on SSP4). SDG10 targets are not achieved, even by 2080.	Global Gini index base year: 0.62 (0.66 without China). In FAT 2, the global Gini index stays above 0.55 until 2080 as in SSP3. In TSS it drops to 0.35.
Domestic savings	Current trends apply.	Increase, to fund investment in innovative technologies.	Saving potential of poor countries shrinks.	In TSS, the elasticity of "non-food" allocation is increased in FAO GAPS to reflect increasing savings.
Public investment	Modest, along current trends.	Focused on R&D that stimulates technical progress on sustainable and pro-poor practices.	Limited, flowing rather on non-sustainable practices, like fossil fuels and favouring elites.	In TSS, the redistributive role of the public sector increases, while in SSS it progressively shrinks.
International trade	More bilateral trade agreements in place; tariff barriers are modest; non-tariff barriers gain some importance.	Both tariff and non-tariff barriers are lower than in BAU.	Both tariff and non-tariff barriers are higher than in BAU, creating more fragmentation.	Fragmentation across countries in SSS may not prevent increased trade of luxury goods, to the benefit of elites.
Foreign investment	Medium and along the north-south axis.	Higher than BAU in low-income countries, with positive impacts on local incomes.	Higher than BAU in low-income countries with little impact on local incomes.	
Wage levels	Modest reductions in wage differentials across sectors but increased differences between bottom and top wages.	Wage differentials are lowering across countries and sectors.	High wage differences across countries and sectors.	
Employment	Medium to high unemployment, particularly in high population growth countries.	Low unemployment.	High unemployment, dual labour market.	
HUMAN DEVELOPMENT				
Education	By 2030, countries barely achieve SDG4 targets. High population growth countries struggle to maintain them.	Universal primary and secondary education and all the other SDG4 targets are permanently achieved.	SDG4 targets are not achieved, even after 2030. Education levels are highly stratified between income groups and countries.	SDG4: Ensure inclusive and quality education for all and promote lifelong learning.
Access to health facilities	By 2030, LIC barely achieve SDG3 targets and struggle to maintain them afterwards.	Universal access to healthcare services, medicines and vaccines, and other SDG3 targets are permanently achieved.	SDG3 targets are not achieved. Access to healthcare is skewed. In HIC, poor people do not have access to quality health services.	SDG3: Ensure healthy lives and promote well-being for all, and at all ages.

GROUP/VARIABLE	BAU	TSS	SSS	NOTES
HUMAN DEVELOPMENT (cont.)				
Access to water sanitation	By 2030, LMIC barely achieve SDG6 targets and struggle to maintain them afterwards.	Universal access to drinking water and sanitation and the other SDG6 targets are permanently achieved.	LIC do not achieve SDG6. HIC struggle to maintain SDG6 achievements.	SDG6: Ensure access to water and sanitation for all.
Gender equality	Many forms of discrimination against women and girls are permanently ended but labour market discriminations may persist in many countries.	All forms of discrimination against women and girls are ended and other SDG5 targets permanently achieved.	Gender discrimination is exacerbated, particularly in labour markets, due to slack enforcement of regulations and lowering of education.	SDG5: Achieve gender equality and empower all women and girls.
Social cohesion	Persisting inequalities jeopardize social cohesion. SDG16 targets are barely achieved and maintained, and global governance is weak.	Social cohesion is maintained through equitable access to basic services and strong institutions. SDG16 targets are achieved and maintained.	Social cohesion is progressively hampered by increasing inequalities, skewed access to information (including "big data") and justice. SDG16 targets are far from being achieved even in the long run.	SDG16: Promote just, peaceful and inclusive societies: … Promote the rule of law, equal access to justice for all … Ensure public access to information and protect fundamental freedoms.
WELFARE AND LIFESTYLE				
Food security and nutrition	Moderate food security improvements occur, but "zero hunger" and "no malnutrition" are not achieved in either 2030 or 2050.	The SDG2 target "zero hunger" is achieved by 2030 and maintained afterwards, with substantial progress in malnutrition.	Reverse trends in hunger reduction and malnutrition occur, particularly in countries with high population growth.	SDG2: End hunger, achieve food security and improved nutrition, and promote sustainable agriculture.
Extreme poverty and poverty	Current trends of moderate extreme poverty reduction are maintained. Other targets not universally achieved.	SDG1 extreme poverty and poverty targets achieved by 2030. Other targets mostly achieved thanks to pro-poor development.	Reverse trends in extreme poverty and poverty reduction. Poverty also increasing in HIC.	SDG1: End poverty in all forms. Targets: zero extreme poverty, halve the share of poor, set up universal social protection and resilience programmes.
Evolution of diets	Current trends of moderate convergence towards the consumption of more nutritious food maintained.	Balanced, healthy and environmentally sustainable diets are mostly universally adopted.	Diets worsen for most people due to lower purchasing power and lessened consumer awareness. Elites consume high-quality luxury foods.	
Focus of consumer preferences	The current mix of material items and services is maintained. Limited willingness to pay for environmental services.	High willingness to pay for immaterial goods, social and environmental services.	Dichotomous preferences across and within societies. Focus on basic needs for large majority of people. Luxury goods for elites.	Narratives of consumer preferences are based on SSPs.

GROUP/VARIABLE	BAU	TSS	SSS	NOTES
INTERNATIONAL GOVERNANCE				
International institutions	SDG16 partially achieved. Illicit international flows and bribes continue but institutions enforce some standards and regulations.	SDG16 targets mostly achieved through better governance. No illicit financial flows leave LMIC towards HIC and fiscal heavens.	SDG16 not achieved. Illicit financial flows expand. Bribes distort decision-making, thus favouring elites. Arms lobbies fuel conflicts.	SDG16: Promote just, peaceful and inclusive societies: Enforce the rule of law at all levels, significantly reduce illicit financial and arms flows, bribery and corruption.
International cooperation	SDG17 partially achieved. Official Development Assistance (ODA) continues at current rates. LMIC foreign debt levels remain stable.	ODA first expands then decreases, as it becomes no longer required. Foreign debt of LMIC decreases. LMIC international trade is pro-poor.	ODA drastically declines. Fiscal system weakens. Foreign debt of LMIC increases. SDG17 targets are not achieved.	SDG17: Revitalize the global partnership for sustainable development (finance, technology, trade, capacity development macro stability).
Conflicts	Continuation of current trends: conflicts for energy and other natural resource control continue.	Reduced national and international conflicts.	Conflicts for energy and other natural resource control intensify but international elites prevent global collapse.	
NATURAL RESOURCES AND CLIMATE				
Land	Agricultural land expands at limited rates to complement limited yield increases. Land degradation only partially handled.	No additional land converted into agricultural uses. Land degradation stopped through sustainable practices. SDG target 15.3 achieved.	New agricultural land is used to compensate for increasing land degradation and to satisfy additional demand.	SDG15, Target 15.3: By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land-degradation-neutral world.
Water	Water efficiency improves but no major technical changes occur. More water-stressed countries emerge.	Water efficiency significantly improves thanks to investment. Limited climate change reduces extreme droughts.	Water is unsustainably used. Little investment in water efficiency. Climate change exacerbates constraints.	
Forests	Deforestation continues at current rates.	No additional deforestation. Investment in reforestation.	Further deforestation.	
Metals and other minerals	Continues at current rates.	Extraction rates decline as recycling becomes the prevailing form of raw material supply.	Continues at current rates.	
Climate change	Average temperature increases by 3–4 °C by the end of century.	Average temperature increases less than 2 °C by the end of century.	Average temperature increases by 4–5 °C by the end of century.	
Overall GHG emissions	Emissions follow RCP 6.0 (or 8.5).	Emissions follow RCP 4.5 (or 2.6).	Emissions follow RCP 8.5.	
Biodiversity	Current loss rates prevail, also in the future.	Conservation practices (e.g. eco-agriculture, agroforestry) reduce the loss of biodiversity.	Current loss rates prevail, also in the future.	

GROUP/VARIABLE	BAU	TSS	SSS	NOTES
TECHNOLOGY				
Development/ Innovation	Medium and along current trends and unequal between countries and sectors.	Production shifts towards innovative and sustainable processes thanks to more investment.	Innovation focuses more on labour saving than on sustainability.	
International-domestic technology transfer	Modest and along north-south axis.	LMIC benefit from HIC technology while they contribute to new discoveries through partnerships.	Asymmetric. International elites keep the control of know-how. Rent-seeking behaviour prevails.	
Energy sources	Fossil fuels remain the main energy source in upcoming decades, but renewables slowly emerge.	Greater than 50 percent renewable before 2050, and 100 percent after 2050, thanks to huge investments in technologies.	The current energy mix prevails until 2080.	
Energy intensity	Current trends in increased energy efficiency continue.	Lower energy intensity in all sectors thanks to investment in R&D and implementation of new technologies.	Energy efficiency is not of great concern. Current efficiency levels are maintained.	
Energy infrastructure	Mostly centralized, with limited decentralized production.	Decentralized and gridded.	Centralized.	
Transport infrastructure	Current trends prevail: Mixed roads, rail, sea, air routes.	Mostly rail and other low-impact means. No need for heavy intercontinental shipments.	Highly energy intensive (roads, air). Shipments from LMIC to HIC increase.	
Information, communications infrastructure	Institutions rule ICT but struggle to avoid rent-seeking in "big data" generation/ management. Poor people have limited access to relevant info.	ICT allow all people to improve production processes, consumption awareness, and civil-society building.	Most people access irrelevant information only. Elites exploit ICT by controlling "big data", shaping preferences and selective know-how access.	

Source: FAO Global Perspectives Studies.

Table A 2.2 Food and agricultural sector features by scenario

GROUP/VARIABLE	BAU	TSS	SSS	NOTES
Prevailing production systems	Mixed. High value-added small farms and processors for high-quality food coexist with large scale, high-input agriculture. Irrigation and intensive livestock increase to the extent possible.	Low-input precision agriculture, agroforestry intercropping, conservation, climate-smart ecological agriculture fit in "circular" economies. Animal welfare and biodiversity is promoted.	Segmented agriculture and food systems: a) many marginal producers for subsistence in LMIC; b) big corporations for mass, low-quality food; c) small-medium farms both in HIC and LMIC for luxury food for elites.	
Land intensity (quantity of land per unit of output)	Along current trends: The quantity of land per unit of output decreases as long as crop and animal yields increase.	The quantity of land per unit of output is stable at base-year levels to preserve soil quality and restore degraded/ eroded land.	The quantity of land per unit of output decreases for commercial agriculture and remains stable for family/marginal farmers.	Under TSS, "sustainable crop and livestock intensification" may also occur, leading to less land per unit of output.
Water intensity (quantity of water per unit of output)	Water intensity moderately decreases.	Water intensity substantially decreases as investments for water efficiency materialize.	Water intensity is stable.	
GHG emissions intensity (emissions per unit of output)	Along current trends both for crops and animal production.	Sharp decrease thanks to investment in R&D, capital replacement and GHG soil storage.	Intensive use of chemicals and land use changes maintain high unit levels of GHG emissions.	
Energy intensity (energy per unit of output)	Modest improvements.	Substantial improvements thanks to R&D and technical innovation in the first decades.	No substantial improvements.	
Agricultural prices relative to non-agricultural ones	Agricultural prices globally show limited increases to reflect pressure on demand and limited resources.	Agricultural prices globally increase moderately to reflect pressure on demand and the adoption of sustainable practices.	Agricultural prices globally increase significantly due to loss of productivity associated with resource degradation.	
Agents' concentration	Current concentration trends continue, both upstream (input supply to farmers) and downstream (monopsonies, oligopsonies).	Possible concentration does not result in rent-seeking behaviour thanks to institutions governing the sector.	Higher than in FAT 2 and dominated by multinational agrobusiness. Stratified: many small marginal agents and relatively few large ones.	In SSS, agriculture inputs are relatively more expensive and price gaps between producers and consumers widen due to rent-seeking behaviour of agents. In BAU, this occurs to a lesser extent.
Innovations	Modest, due to limited investments in R&D and limited focus on GHG emissions.	High, as technologies and products shift towards sustainability. This includes precision agriculture, IPC, and applied robotics.	Limited, due to cheap labour available. Focused on luxury products. No innovations for GHG emissions.	IPM: Integrated Pest Management

GROUP/VARIABLE	BAU	TSS	SSS	NOTES
Asset ownership and capital control in agriculture and food processing	Mixed. Commercial farms, processing firms concentrated but small- and medium-scale farmers in high value-added niches control their capital.	Diffused. Farmers and employees control capital either directly or indirectly, and receive related remuneration.	Mostly concentrated in the hands of corporations.	Under TSS, capital control may take the form of participation in capital ownership through cooperatives or company stocks.
Resilience to shocks	Moderate, due to limited diversification, limited adoption of conservation practices and insufficient investment to address antimicrobial resistance.	Increased by multiple cropping, integrated pest management and disease control, reduced climate change, increased land quality.	Very limited for marginal farmers, moderate for commercial farms for mass consumption, high for luxury goods.	
Crop diversification	Limited, worsening.	High, to reduce risks and increase resilience.	Low for mass production, as monoculture prevails.	
Potential yield expansion	Increases of yields along AT 2050 trends, but variably affected by climate change depending on latitude and crop.	Limited, due to the adoption of sustainable practices to preserve soils, protect biodiversity and support crop diversification.	Limited, as land progressively degrades and climate change negatively hits, particularly at low latitudes.	
Potential land expansion	Low to moderate expansion of agricultural areas. Moderate restrictions in the use of land.	No expansion. Strict regulations on the use of land for agriculture; e.g. REDD+ in place.	Agricultural land significantly expands to compensate for progressive land degradation.	UN REDD: Programme for Reducing Emissions from Deforestation and Forest Degradation. REDD+: Nationally-led processes for REDD.
Input use	Continuation of current regulations for consumer protection. Selected countries apply low-input tech. Lobbies promote large use of herbicides.	More restrained use (quantity and type e.g. regulations on nitrate uses or mix of fertilizer nutrients), favouring precision and/or organic agriculture.	Relaxed regulations on quantity and types of inputs and residues in food. Abused herbicides, hormones, antibiotics and other chemicals for mass production.	
Food processing	Continuation of current trends towards more processed food in LMIC and more fresh food in HIC. Lobbies hinder information rights of consumers, but civil society is active.	Low GHG emission food systems are favoured and fresh food consumption is promoted. Consumers get info. on origin, content, quality, sustainability of processed food.	Elites consume lightly processed and/or fresh food. No regulations for labelling, origin, content apply to heavily-processed food for mass consumption.	In TSS, trade-offs between quality of food and GHG emissions from processing, refrigeration and transport are addressed by considering economies of scale and scope.

GROUP/VARIABLE	BAU	TSS	SSS	NOTES
Food loss and waste	Continuation of current trends. Food loss and waste is only partially reduced through selected programmes in LMIC and consumer campaigns in HIC.	Regulatory frameworks, R&D and investment for improved storage and processing, and consumer awareness drastically reduce food loss and waste.	Marginal farmers keep suffering from crop losses, also fuelled by extreme climatic events. Elites increasingly waste food. Masses are thoughtless and continue wasting food.	
Potential for GHG sequestration	Limited, as uncertainty regarding future economic incentives limits R&D and the adoption of suitable practices.	High, due to suitable crop technologies, reforestation, afforestation. Economic incentives are in place.	Not exploited due to the continued adoption of conventional agricultural techniques with high positive net GHG emissions.	
Land degradation	Continues at current trend levels as innovative technologies for land conservation are only partially adopted due to weak incentives and environmental regulations.	Stopped by regulations and incentives that promote the adoption of land conservation practices (e.g. storage of organic matter, erosion and salinization control).	Commercial monoculture for mass production boosts land degradation. No regulatory frameworks for the internalization of environmental externalities.	See land intensity above.
Pests and diseases	Continuation of current trends of increasing spread and antimicrobial resistance. Average long-term yields are negatively affected by occurrence.	R&D to focus on fighting against them.	Boosted by climate change, international trade and AMR. Increased use of drugs, particularly against them, and so more pests and diseases that threaten yields.	
Extreme weather events	Recent increasing trends apply as climate change materializes. Limited adoption of adaptation technologies. Average long-term crop yields are negatively affected.	Moderate and infrequent as long as climate change is mitigated through reduced GHG emissions and agricultural adaptation technologies are adopted.	Extreme weather events substantially increase in frequency and severity as GHG emissions boost climate change. The livelihood of marginal farmers is deeply affected.	
Water availability	Along current trends, albeit restricted so as not to exhaust water resources. Climate change shifts rainfall across regions.	Strict regulations ensuring groundwater and avoiding salinization of water basins. Limited shifts of rainfall across regions thanks to mitigated climate change.	Loose regulations, so water resources almost exhausted and salinized. Climate change substantially shifts rainfall across regions. Irrigation water becomes increasingly expensive.	

Source: FAO Global Perspectives Studies.

Table A 2.3 Food- and agriculture-specific policies by scenario

DOMAIN	BAU	TSS	SSS
Input-water subsidies	Chemical inputs implicitly or explicitly subsidized. Fossil fuels subsidized, including in HIC. Suboptimal water subsidies.	Limited, constrained by environmental objectives. Temporary, targeted to progressively lower inequalities and/or to promote selected agricultural practises.	Increasingly disconnected from environmental objectives and favouring inequalities among family farmers and large commercial farms.
Land titling institutions and policies	Mixed across countries. Ineffective in selected LMIC.	Land ownership is increasingly ensured through titling.	Proper mechanisms to ensure titling is not maintained.
Land-use regulations	Mixed across countries. Generally low or mostly not enforced.	Regulations imposing rather strict restrictions in the use of land for agriculture.	Regulations imposing rather loose restrictions in the use of land for agriculture.
Food quality-safety controls	Moderate to high in HIC. LMIC struggle due to lack of investment.	Ensured through proper institutions in both HIC and LMIC.	High for elites, low for mass consumption.
Public investment in rural infrastructure	Increasingly limited by budgetary cuts.	High, also through involvement of local administrations and communities.	The public sector progressively withdraws. Large private investors build own infrastructures.
Public R&D in agriculture	Increasingly limited by budgetary cuts.	Enhanced, aimed to identify and implement locally adapted sustainable agricultural practices.	Policies rather ignoring it.
Extension services	Increasingly limited by budgetary cuts.	More extension services, specifically focused on family farmers are increasingly funded and implemented.	Public extension services progressively fade. Private extension services biased towards monoculture.
Plant-animal protection regulations and research	Increasingly limited by budgetary cuts.	Significant R&D to identify sustainable forms of plant and animal protection.	R&D not particularly geared towards promoting protection.
Climate change adaptation policies	Mixed across countries. Generally limited in LMIC.	Significant public support to achieve adaptation through investment in human capital, credit facilities, infrastructure.	No specific policies and low adaptation, particularly of family farmers in LMIC.
Climate change mitigation policies	Nationally Determined Contributions (NDCs) barely implemented by large countries. Livestock emissions not regulated.	High public investment and strong regulations to achieve improved agricultural practices. NDCs effective and mostly implemented.	Large countries withdraw from international agreements or do not implement their NDCs. Agriculture emissions dramatically increase.

Source: FAO Global Perspectives Studies.

Annex III
Quantitative model features and data

Basic structure and data in FAO GAPS

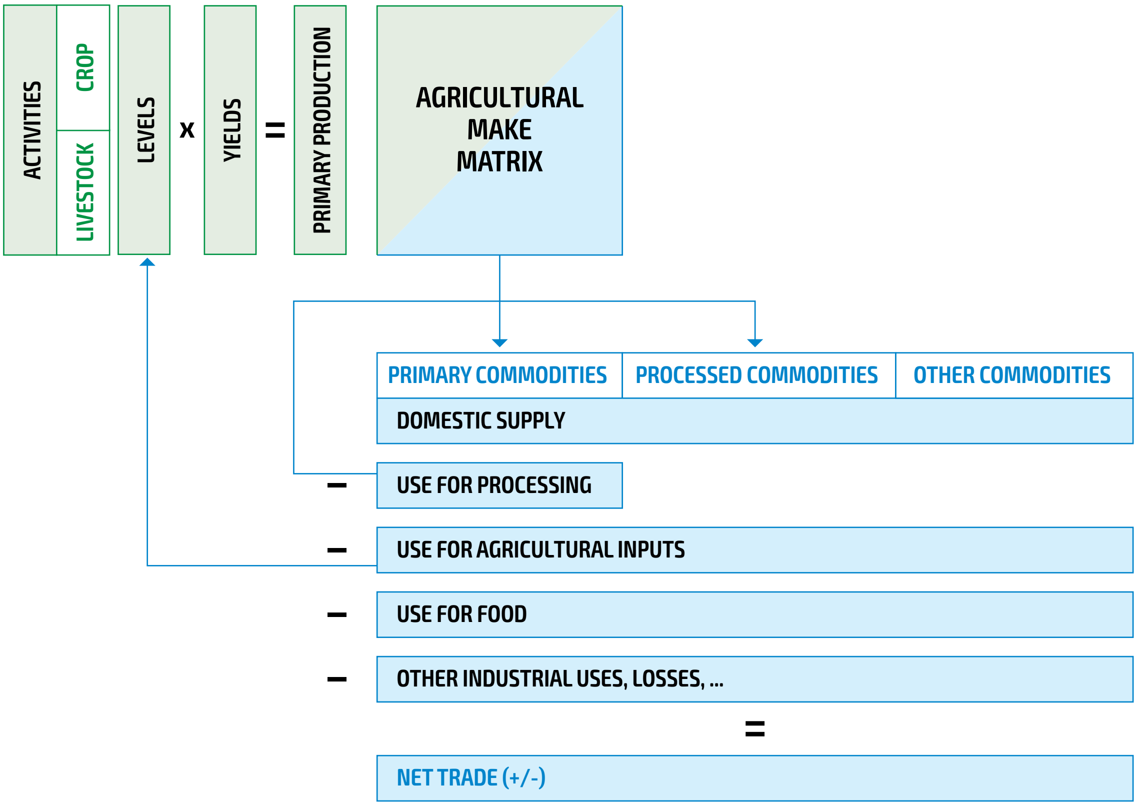
The FAO Global Agriculture Perspectives System (GAPS) is a partial market equilibrium model for primary equivalents of agricultural commodities and selected processed food commodities. It is designed to accommodate datasets from a variety of FAOSTAT domains, most importantly the production and food-balances domains (Table A 3.2). A crucial feature is the distinction of primary production by activities and the supply of marketed agricultural commodities, which permits the combined usage of FAOSTAT production and food-balance datasets. The simplified activity/commodity structure for one country is sketched in Figure A 3.1. Agricultural activities refer to all items in the FAOSTAT production domain that have an entry for either harvested area in the case of crops or animal heads in case of livestock production. The "Levels" of each activity are measured accordingly in either hectares or heads. Physical output per hectare or head ("Yield") refers to the corresponding raw product or "Primary product". In most cases, the primary product is equivalent to the marketed commodity. An example of this is cereals, for which each unit of raw product translates into one unit of marketed supply. In contrast, primary production of groundnuts refers to "groundnuts in shell", whereas they enter the commodity markets in "shelled equivalents", in which case one unit of primary output translates into e.g. 0.7 units of market supply. More complicated cases are those of palm fruit and cotton. For instance the activity "Cotton production" produces "Raw cotton" as primary output, which is ginned into seeds and fibres and supplied to agricultural product markets. In this case, one raw product translates into two marketed commodities (see Table A 3.1). This translation of primary products into marketed commodities takes place within the "Agricultural make matrix", which consists of the appropriate processing coefficients.

Domestic agricultural commodity supply may then either completely or partly enter further processing steps – sugar cane and beet are processed into sugar, or oilseeds are milled into vegetable oil and oilcake, which gives the "Processed supply" in Figure A 3.1. A more detailed overview on the linkages between agricultural activities and processed commodities is given in Table A 3.1 for some selected cases with a multi-output structure.

The designation of a commodity as either primary agriculture or processed is largely based on the UN International Standard Industrial Classification of All Economic Activities (ISIC Rev.4) (UN, 2008). Cotton ginning, for example, is listed as post-harvest crop activity belonging to "Section A: Agriculture, forestry and fishing", while the manufacture of vegetable oils and meals of oilseeds belongs to "Section C: Manufacturing". In the case of oil palms, the designation of the related products as either primary or processed is not as straightforward: FAOSTAT considers palm oil (coming from the pulp) and palm kernels to be primary products, whereas ISIC defines palm oil as manufactured output. For pragmatic reasons, palm oil and kernels are here treated as primary products, following FAOSTAT, and the production of palm kernel oil takes place in the manufacturing sector according to ISIC Rev.4.

The item "Other supply" refers to commodities which are part of the FAOSTAT food balance sheet and hence play at least an important role in human food consumption, but are not covered within the agricultural activity structure. An example here is fish production, which enters the model as exogenous supply.

Figure A 3.1 Activity and commodity structure in FAO GAPS for a single country



Source: FAO Global Perspectives Studies.

Primary, processed, and other commodities can then be used as agricultural inputs (seed and feed uses), for human food consumption, or for other (non-food) industrial purposes. Losses on markets are also deducted at this stage. The difference between domestic supply and domestic uses gives the net-trade position of the individual country on a particular commodity market. As a partial equilibrium model, the FAO GAPS model imposes clearance of all markets at global scale, forcing the sum of country-level net-trade positions to be zero (Figure A 3.2). This restriction forces the model to find a global reference price for all commodities that balances supply and demand across all countries. Altogether, FAO GAPS represents the supply and demand of 66 agro-food commodities in 154 countries and country groups. The commodities list includes 45 primary and 21 processed commodities (Table A 3.3, centre and right columns).

The agricultural activities in FAO GAPS (see Table A 3.3, left column) distinguish 36 crops and 6 animal species. These 42 activities are split further into production systems – crop production can be either irrigated or rainfed. The definitions of animal production systems follow the categories of the FAO Global Livestock Environmental Assessment Model (FAO GLEAM): for cattle, buffaloes, sheep, and goats, up to six production systems can be modelled; and production of pigs and poultry may take place in up to three systems.

Table A 3.1 Activity/commodity structure for processed commodities

AGRICULTURAL ACTIVITY	PRIMARY PRODUCT	PRIMARY COMMODITY	PROCESSED COMMODITY
STANDARD CASE			
Growing of oilseeds	Oilseeds	Oilseeds	Oilseed oil
			Oilseed cake
SPECIAL CASE			
Growing of groundnuts	Groundnuts (in shell)	Groundnuts (shelled)	Groundnut oil
			Groundnut cake
Growing of raw cotton	Raw cotton	Cotton fibre	
		Cottonseed	Cottonseed oil
			Cottonseed cake
Growing of oil palm fruit	Oil palm fruit	Palm fruit oil	
		Palm kernels	Palm kernel oil
			Palm kernel cake
Growing of sugar beet	Sugar beet	Sugar beet	Processed sugar
Growing of sugar cane	Sugar cane	Sugar cane	
Growing of paddy rice	Paddy rice	Paddy rice	Milled rice

Source: FAO Global Perspectives Studies.

Figure A 3.2 Multi-country trade equilibrium in FAO GAPS

NET TRADE (+/-) BY COMMODITY FROM COUNTRY A

+

NET TRADE (+/-) BY COMMODITY FROM COUNTRY B

+

• • •

+

NET TRADE (+/-) BY COMMODITY FROM COUNTRY Z

=

GLOBAL NET TRADE = 0

Source: FAO Global Perspectives Studies.

FAO GAPS is calibrated to a base year dataset, which is built around the 2011–2013 three-year average of FAOSTAT Food Balance Sheets and production statistics. In addition, datasets on live animals, agricultural producer prices, trade, etc., have been incorporated. The relevant FAOSTAT domains are reported in Table A 3.2. Further datasets used for the construction of the base year included parts of the FAO GLEAM database and the FAO-IIASA GAEZ v4 database. The use of heterogeneous datasets with different classifications for crops or countries, as well as different updating frequencies, meant it was necessary to apply a balancing routine to ensure completeness and consistency of the model database.

FAO GAPS runs on a set of structural parameters, which cannot always be taken from the database. Examples are: price and income elasticities of food demand; land demand; crop yield shifters which reflect scenario- and country-specific assumptions regarding the impacts of climate change, as derived by the FAO-IIASA GAEZ v4; scenario-specific assumptions regarding the impacts of technical progress on crop and livestock systems; feed requirements; and output shares by animal system, based on FAO GLEAM.

Table A 3.2 FAOSTAT data used to calibrate FAO GAPS

FAOSTAT DOMAINS (CODE)	FAOSTAT DATASETS (ELEMENTS) RETRIEVED
Production: Crops (QC)	Area harvested (ha), Yield (hg/ha), Production Quantity (tonnes)
Production: Live Animals (QA)	Stocks (in heads)
Production: Livestock Primary (QL)	Producing animals (heads), Slaughtered animals (heads), Yield (hg/head), Production Quantity (tonnes)
Production: Value of Agricultural Production (QV)	Gross Production Value (current million USD and constant 2004–2006 million USD)
Trade: Crops and livestock products (TP)	Import Quantity (tonnes), Import Value (current 1 000 USD) Export Quantity (tonnes), Export Value (current 1 000 USD)
Food balances: Commodity Balances – Crops Primary Equivalent (BC) Commodity Balances – Livestock Primary Equivalent (BL)	Production Quantity (tonnes), Import Quantity (tonnes) Stock Variation (tonnes), Export Quantity (tonnes) Feed (tonnes), Seed (tonnes), Waste (tonnes) Processed (tonnes), Food (tonnes) Other uses (tonnes)
Food balances: Food Balance Sheets (FBS)	Food supply quantity (kg/capita/year) Food supply (kcal/capita/day) Protein supply quantity (g/capita/day) Fat supply quantity (g/capita/day)
Prices: Producer Prices – Annual	Producer Price (current USD/tonnes)
Inputs: Land	Area (1 000 ha)

Source: FAO Global Perspectives Studies.

Table A 3.3 Activities and commodities in FAO GAPS

CATEGORY	CODE	DESCRIPTION
AGRICULTURAL ACTIVITIES		
CROP	A_WHEA	Growing of wheat
	A_MAIZ	Growing of grain maize
	A_BARL	Growing of barley
	A_MILL	Growing of millet
	A_SORG	Growing of sorghum
	A_XCER	Growing of other cereals
	A_PARI	Growing of paddy rice
	A_POTA	Growing of potatoes
	A_SWPY	Growing of sweet potato and yams
	A_CASS	Growing of cassava
	A_XRNT	Growing of other roots and tubers
	A_SUGB	Growing of sugar beet
	A_SUGC	Growing of sugar cane
	A_PULS	Growing of dried pulses
	A_XVEG	Growing of other vegetables
	A_PLAN	Growing of plantains
	A_BANA	Growing of bananas
	A_CITR	Growing of citrus fruit
	A_XFRU	Growing of other fruit
	A_RAPS	Growing of rape and mustardseed
	A_SOYB	Growing of soybeans
	A_GRND	Growing of groundnuts
	A_SUNF	Growing of sunflower seed
	A_SESA	Growing of sesame seed
	A_CCNT	Growing of coconuts
	A_XOLT	Growing of other oilseeds
	A_PALM	Growing of oil palm fruit
	A_OLIV	Growing of olives
	A_COCO	Growing of cocoa beans
	A_COFF	Growing of coffee, green
	A_TEAS	Growing of tea
	A_TOBA	Growing of tobacco
	A_COTT	Growing of raw cotton
	A_XFIB	Growing of other fibre crops
	A_RUBB	Growing of natural rubber
	A_XCRO	Growing of other crops

CATEGORY	CODE	DESCRIPTION
AGRICULTURAL ACTIVITIES		
LIVESTOCK	A_CATL	Raising of cattle
	A_BUFF	Raising of buffaloes
	A_SHEP	Raising of sheep
	A_GOAT	Raising of goats
	A_PIGS	Raising of pigs
	A_PLTY	Raising of poultry

CATEGORY	CODE	DESCRIPTION
PRIMARY COMMODITIES		
CROP	C_WHEA	Wheat
	C_MAIZ	Grain maize
	C_BARL	Barley
	C_MILL	Millet
	C_SORG	Sorghum
	C_XCER	Other cereals
	C_PARI	Paddy rice
	C_POTA	Potatoes
	C_SWPY	Sweet potato and yams
	C_CASS	Cassava
	C_XRNT	Other roots and tubers
	C_SUGB	Sugar beet
	C_SUGC	Sugar cane
	C_PULS	Dried pulses
	C_XVEG	Vegetables
	C_PLAN	Plantains
	C_BANA	Bananas
	C_CITR	Citrus fruit
	C_XFRU	Other fruit
	C_RAPS	Rapeseed and mustard seed
	C_SOYB	Soybeans
	C_GRND	Groundnuts

CATEGORY	CODE	DESCRIPTION
PRIMARY COMMODITIES		
CROP	C_SUNF	Sunflower seed
	C_SESA	Sesame seed
	C_CCNT	Coconuts
	C_XOLT	Other oilseeds
	C_PALO	Palm fruit oil
	C_PALK	Palm kernels
	C_OLIV	Olives
	C_COCO	Cocoa beans
	C_COFF	Coffee, green
	C_TEAS	Tea
	C_TOBA	Tobacco
	C_COTF	Cotton fibre
	C_COTS	Cotton seed
	C_XFIB	Other fibre crops
	C_RUBB	Natural rubber
	C_XCRO	Other crops
ANIMAL	C_BEEF	Beef and veal
	C_SGMT	Sheep and goat meat
	C_PORK	Pigmeat
	C_PLTY	Poultry meat
	C_RMLK	Raw milk
	C_EGGS	Eggs

CATEGORY	CODE	DESCRIPTION
OTHER COMMODITIES		
PROCESSED	C_MIRI	Milled rice
	C_SUGA	Processed sugar
	C_RAPO	Rapeseed oil
	C_RAPC	Rapeseed cake
	C_SOYO	Soya oil
	C_SOYC	Soya cake
	C_GRDO	Groundnut oil
	C_GRDC	Groundnut cake
	C_SUNO	Sunflower seed oil
	C_SUNC	Sunflower seed cake
	C_SESO	Sesame seed oil
	C_SESC	Semame seed cake
	C_CCNO	Coconuts oil
	C_CCNC	Copra cake
	C_XOLO	Oilcrops, nes, oil
	C_XOLC	Oilcrops, nes, cake
	C_PAKO	Palm kernel oil
	C_PAKC	Palm kernel cake
	C_OLIO	Olive oil
	C_COTO	Cottonseed oil
	C_COTC	Cottonseed cake
FISH	C_FISH	Fish

Note: Vegetables excludes mellons.

Source: FAO Global Perspectives Studies.

Table A 3.4 Countries in FAO GAPS regions

High-income		East Asia and Pacific (excluding China)	Europe and Central Asia	Latin America and Caribbean	Near East and North Africa	South Asia	Sub-Saharan Africa	
Australia	Lithuania	Cambodia	Albania	Argentina	Algeria	Afghanistan	Angola	Mali
Austria	Netherlands	Democratic People's Republic of Korea	Armenia	Bolivia (Plurinational State of)	Egypt	Bangladesh	Benin	Mauritania
Belgium	New Zealand	Indonesia	Azerbaijan	Brazil	Iran (Islamic Republic of)	India	Botswana	Mauritius
Canada	Norway	Lao People's Democratic Republic	Belarus	Colombia	Iraq	Nepal	Burkina Faso	Mozambique
Chile	Poland	Malaysia	Bosnia and Herzegovina	Costa Rica	Jordan	Pakistan	Burundi	Namibia
China, Hong Kong SAR	Portugal	Mongolia	Bulgaria	Cuba	Lebanon	Rest of South Asia	Cameroon	Niger
Taiwan Province of China	Republic of Korea	Myanmar	Georgia	Dominican Republic	Libya	Sri Lanka	Central African Republic	Nigeria
Croatia	Rest of European Union	Papua New Guinea	Kazakhstan	Ecuador	Morocco		Chad	Rest of sub-Saharan Africa
Czechia	Rest of high-income countries	Philippines	Kyrgyzstan	El Salvador	Rest of Near East and North Africa		Congo	Rwanda
Denmark	Saudi Arabia	Rest of East Asia and Pacific	Republic of Moldova	Guatemala	Syrian Arab Republic		Côte d'Ivoire	Senegal
Estonia	Slovakia	Thailand	Rest of Europe and Central Asia	Guyana	Tunisia		Democratic Republic of the Congo	Sierra Leone
Finland	Spain	Viet Nam	Romania	Haiti	Yemen		Eritrea	Somalia
France	Sweden		Russian Federation	Honduras			Ethiopia	South Africa
Germany	Trinidad and Tobago		Serbia	Jamaica			Gabon	South Sudan
Greece	United Kingdom		Tajikistan	Mexico			Gambia	Sudan
Hungary	United States of America		Turkey	Nicaragua			Ghana	Swaziland
Ireland	Uruguay		Turkmenistan	Panama			Guinea	Togo
Israel			Ukraine	Paraguay			Kenya	Uganda
Italy			Uzbekistan	Peru			Lesotho	United Republic of Tanzania
Japan				Rest of Latin America and Caribbean			Liberia	Zambia
Latvia				Suriname			Madagascar	Zimbabwe
				Venezuela (Bolivarian Republic of)			Malawi	

Note: The designation of a country to a group followed the World Bank Country Groups of July 2016, downloaded on 2 August 2016 from http://databank.worldbank.org/data/download/site-content/CLASS.xls. China refers to mainland only.

Source: FAO Global Perspectives Studies.

Food demand in FAO GAPS

Demand theory, which is based on consumer's optimizing behaviour under budget restrictions, suggests that necessary and sufficient conditions for theoretical consistency require demand to satisfy the following properties:

- adding-up (i.e. expenditure shares of all commodities add up to one);
- homogeneity (i.e. if all prices and income increase by the same factor, there should be no change in consumption);
- symmetry (i.e. the substitution effects between commodities are symmetric); and
- negativity (i.e. if the price of one commodity increases and utility is held constant, demand for this commodity should decline).

These properties are reflected in restrictions on the price and income demand elasticities.

In long-term projections, consumer behaviour may change over time and so the variations of price and income elasticities are crucial. An empirical regularity – also known as Engel's law – suggests that as income increases, the share of expenditure allocated to food consumption declines. Furthermore, income changes may well provoke a change in dietary preferences. In this respect, a second empirical regularity, the so-called "Bennett's law", suggests that an income increase stimulates substitution away from carbohydrates (e.g. staple food) towards proteins (e.g. animal-based food). Further, empirical regularities that are discussed frequently in demand theory suggest that not only do income elasticities vary with the level of income, but price elasticities (own- and cross-price) may also vary with the level of income/development and may decline when income per capita increases.

Calibration of base-year elasticities

Data issues related to the definitions of countries in time series data – some countries that exist now declared independence only in the last few years – as well as the scarcity of price data for some commodities and the incompatibility of sources from which prices can be derived (e.g. statistics on gross output value, trade statistics, international comparison programmes on expenditure and statistics on national accounts) made the estimation of a demand system suitable to inform long-term elasticities for the 66 agro-food commodities in the 154 countries/regions of FAO GAPS impossible.

FAO GAPS thus adopted a "synthetic" approach to inform the base-year price and income food demand elasticities. FAO GAPS borrowed from the model IMPACT v3.0 (Robinson *et al.*, 2015) and from USDA ERS work on food consumption patterns (e.g. Muhammad *et al.*, 2017) uncalibrated income and Marshallian price (own and cross-price). Food prices whenever needed were adjusted based on food expenditure data from World Bank's International Comparison Programme (World Bank, 2015) so as to allow the calculation of expenditure for each of the FAO GAPS commodities.

The initial uncalibrated elasticities were calibrated to base-year consumption expenditures while imposing the microeconomic restrictions listed above. Because some of the 66 agro-food commodities had very small shares in overall food expenditures in some countries, they were grouped in ten food bundles as shown in Table A 3.5. A one-stage budget allocation process is assumed – as shown in Figure A 3.3 – which allocates GDP per capita to each of the food bundles and to other non-food consumption (see equation (6)). The latter is calculated as a residual and it has been cross-checked with data from the International Comparison programme (World Bank, 2015).

Table A 3.5 Food bundles in FAO GAPS

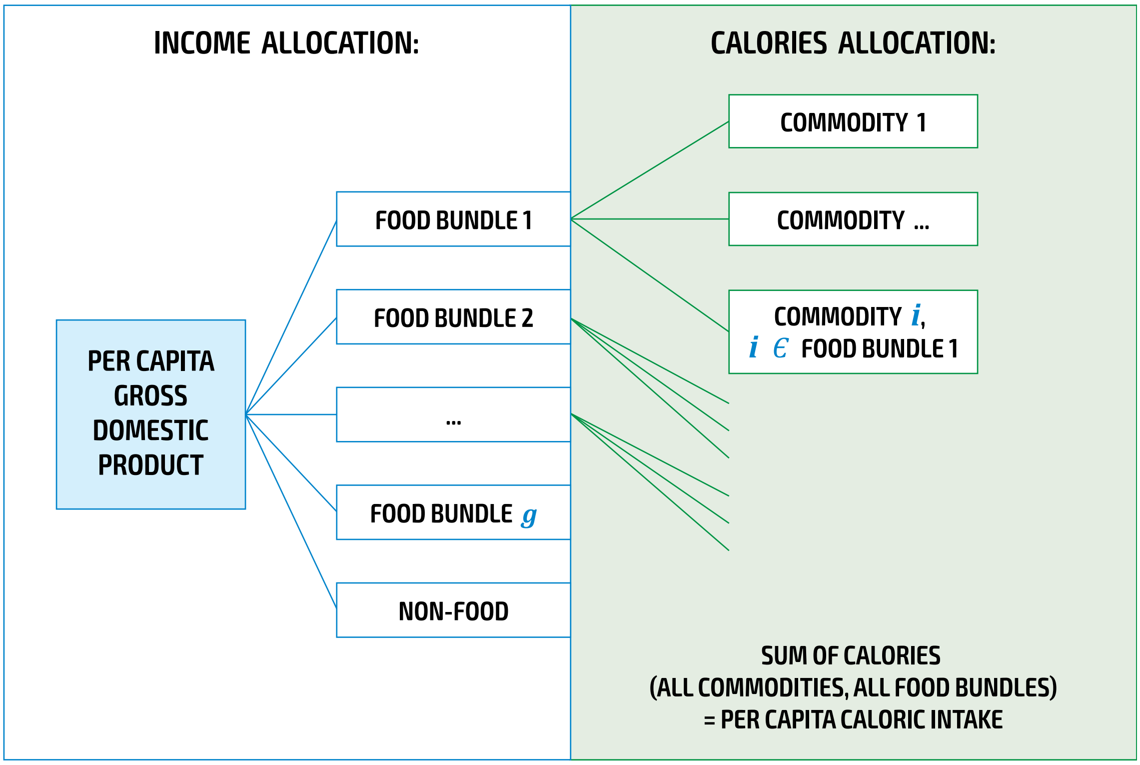
FOOD BUNDLE	LONG DESCRIPTION	FAO GAPS COMMODITY	
CERE	Cereals	C_MAIZ C_MIRI C_WHEA	
CERD	Cereals that are mostly consumed domestically	C_BARL C_MILL C_SORG C_XCER	
STAR	Starchy crops	C_CASS C_PLAN C_POTA C_SWPY C_XRNT	
PROT	Protein crops	C_CCNT C_GRND C_PALK C_PULS C_RAPS	C_SESA C_SOYB C_SUNF C_XOLT
FRVG	Fruit and vegetables	C_BANA C_CITR C_OLIV C_XFRU C_XVEG	
XCRP	Other crops and derived processed commodities	C_COCO C_COFF C_SUGA C_SUGB	C_SUGC C_TEAS C_XCRO
VOIL	Vegetable oils	C_CCNO C_COTO C_GRDO C_OLIO C_PAKO C_PALO	C_RAPO C_SESO C_SOYO C_SUNO C_XOLO
MEAT	Meat and fish	C_BEEF C_FISH C_PLTY C_PORK C_SGMT	
MEGG	Dairy (in raw milk equivalent) and eggs	C_EGGS C_RMLK	
XFOD	Other food	C_XFOC	

Note: The long description of the FAO GAPS commodities is available in Table A 3.3.

Source: FAO Global Perspectives Studies.

Once income is allocated to the ten food bundles, the consumer decides on the cost-efficient combination of commodities within each group, depending on country-specific preferences (Figure A 3.3). The procedure ensures that theoretically desirable properties of food consumption and budget allocation are maintained at the level of the food groups and the high degree of diversity of consumed commodities across countries is reflected in the model simulations while avoiding computational problems arising from small expenditure shares in some cases. The quantities consumed are then used to calculate the total calorie intake per person.

Figure A 3.3 Budget and calorie allocation process in FAO GAPS



Source: FAO Global Perspectives Studies.

In general, the calibration procedure is implemented by minimizing the squared differences between initial and calibrated elasticities subject to restrictions derived from microeconomic consumer theory. These properties have been imposed as shown in equations (1) to (3):[126]

- Homogeneity of degree zero for every good g: $\sum_{gg} \varepsilon_{g,gg} + \eta_g = 0$ (1)
- Adding up for all the goods: $\sum_g w_g \eta_g = 1$ (2)
- Symmetry andnegative semidefiniteness of the Hicksian substitution matrix was imposed using a Cholesky decomposition with negativity constraints on appropriate elements of the decomposed matrices.

126 The calibration routine is repeated for each of the FAO GAPS countries. Hereafter and in order to ease the readability of the algebraic functions the index ***r*** (which denotes regions/countries) is omitted. Each of the variables however is meant to be region/country specific. In all equations the index ***t*** denotes the current simulation period.

- The Hicksian substitution terms are reflected in the Hicksian price elasticities, whereby the Slutsky equation allows conversion of the Hicksian (compensated) price elasticities into Marshallian (uncompensated) elasticities:

$$\varepsilon_{g,gg} = \hat{\varepsilon}_{g,gg} - w_{gg}\ \eta_g \tag{3}$$

With:

g,gg: commodities arranged in food bundles – including non-food (gg is the alias of g)

ε: Marshallian price elasticities

$\hat{\varepsilon}$: Hicksian price elasticities

η: income elasticities

w: share of expenditure for a specific commodity over total income

Dynamic update of elasticities

FAO GAPS is used to simulate the long-term evolution of supply and demand and so, following the considerations of Section 1, food demand elasticities (income and price elasticities) should vary to reflect income and expenditure changes. In this respect, FAO GAPS updates the elasticities in each of the simulation periods using the previous period's results on income, food demand and hence share of food and non-food expenditure in income (with the latter derived always as a residual).

Income demand elasticities are assumed to follow an exponential curve as depicted by equation (4), following Strauss and Thomas (1990) and in-house empirical work following Bodirsky *et al.* (2015).

$$\eta_{g,t} = \frac{a_g}{y_{t-1}^{\gamma_g}} + \beta_g \tag{4}$$

With:

a_g : base-year calibration parameter

γ_g : calorie expenditure elasticity taken from Subramanian and Deaton (1996)

β_g : constant that allows convergence between countries (or not) and facilitates assumptions on dietary patterns and preferences

y : income per capita

Especially for the BAU scenario, which assumes that behavioural patterns of the past regarding food availability are continued in the projections, an arch elasticity of the past behaviour is used to inform the parameter β_g .

Following Alston, Chalfant and Piggot (2002) and by keeping the Hicksian substitution terms $\partial h_g / \partial p_{gg}$ fixed over time, the Hicksian price elasticities are updated as in equation (5).

$$\hat{\varepsilon}_{g,gg} = \frac{\partial h_g}{\partial p_{gg}} \frac{p_{gg}}{q_g} \tag{5}$$

With:

q: quantity

p: price

$h\ (p,utility)$: Hicksian demand function

In the next step, by using the Slutsky equation (see equation (3)), the Marshallian price elasticities are updated. Doing so implies that in each simulation period the elasticity matrix used respects properties implied by microeconomic consumer theory.

Food demand functions in FAO GAPS

Demand for a food bundle CD_g in region r at time t is the product of total population (Pop) and per capita demand (equation (6) – the regional index was dropped here to improve readability). The latter is a function of per capita income Y and prices of the food bundles PC_g, with income and price elasticities determined by the routines described in the preceding sections. The factor a_g is the base-year calibration factor, whereas the factor $\lambda_{g,t}$ is a time-varying shifter which permits the calibration of the FAO GAPS model to projections on food demand. In this foresight exercise it is set equal to 1.

$$CD_{g,t} = Pop_t\, a_g\, \lambda_{g,t}\, Y_t^{\eta_{g,t}} \prod_{gg} PC_{gg,t}^{\varepsilon_{g,gg,t}} \tag{6}$$

The per capita income enters equation (6) as an index calculated by dividing the per capita GDP in year t with the per capita GDP of the base year. It is hence the change of per capita income that stimulates food demand rather than the absolute level of the income. Similarly to per capita income, consumer prices per region and commodity enter equation (6) as an index which equals 1 for the base year.

A one-nest Constant Elasticity of Substitution (CES) structure is used to allocate consumption of a food bundle g to the individual FAO GAPS commodities denoted by i (equation (7)):

$$CD_{i,t} = a_i\, CD_{g,t} \left(\frac{PC_{g,t}}{\lambda_{i,t} PC_{i,t}} \right)^{\sigma} \forall i \in g \tag{7}$$

With:

a_i : base-year shifter of commodity i within group g

$\lambda_{ii,t}$: time-varying shifter for commodity i within group g

$PC_{i,t}$: market equilibrium price of commodity i within group g

σ: substitution elasticity

Finally, the price of the food bundle is given by the CES dual-price expression as in equation (8):

$$PC_{g,t} = \left[\sum_{\iota \epsilon g} a_i \left(\frac{PC_{i,t}}{\lambda_{i,t}} \right)^{1-\sigma} \right]^{1/_{1-\sigma}} \quad (8)$$

Minimum dietary requirements and "within-country" food distribution

To derive food security indicators, this foresight exercise relies on a dedicated module developed for the FAO GAPS model, which enables the calculation of the prevalence of undernourishment, and the number of undernourished.

First, the projected per capita food demand in each of the scenarios, measured in tonnes per person and per year, is expressed in per capita caloric availability. The conversion is provided by equation (9), where the parameter φ converts annual per capita consumption $CPC_{i,t} = \frac{CD_{it}}{Pop}$ into an average daily caloric intake and is derived from FAOSTAT's

Food Balance Sheets (average of years 2011–2013). Annual per capita consumption comprises commodities included in the FAO GAPS model (index i as used in the previous section) as well as other food commodities which were assumed as exogenously given, like certain processed food. For this reason, the index it includes endogenously modelled (i) and exogenously determined commodities.

The average daily energy supply, DES, in each region r at time t refers to the total annual food intake (equation 10).

$$CAL_{r,it,t} = \varphi_{r,it,t} CPC_{r,it,t} \quad (9)$$

$$DES_{r,t} = \sum_{it} CAL_{r,it,t} \quad (10)$$

The percentage of undernourished is calculated based on three parameters: the daily energy consumption (DEC), the minimum dietary energy requirement ($MDER$) and an estimate of the standard deviation of the underlying distribution of caloric intake by the national population (or equivalently, the coefficient of variation). The DEC is derived from the DES, accounting for food losses and waste at the household level.

Equation (11) converts the estimate of the coefficient of variation of the log-normal distribution CV to the standard deviation of the log-normal distribution. Equation (12) measures the percentage of the population estimated to be under the $MDER$ threshold, where the function $SNCDF$ is the cumulative distribution function for the standard normal distribution. The number of undernourished is simply the product of P^0 with the size of the population (equation 13).

$$\sigma^{u}_{r,t} = \sqrt{\log\left(CV^{2}_{r,t} + 1\right)} \quad (11)$$

$$P^{0}_{r,t} = SNCDF\left(\frac{\log\left(\frac{MDER_{r,t}}{DEC_{r,t}}\right)}{\sigma^{u}_{r,t}} + 0.5\sigma^{u}_{r,t}\right) \quad (12)$$

$$Under_{r,t} = P^{0}_{r,t}\, Pop_{r,t} \quad (13)$$

The latter is taken from FAO, IFAD, UNICEF, WFP and WHO (2017) and is assumed to remain at the 2012 level under the BAU scenario, to be half of it under the TSS scenario and to be twice as high under the SSS scenario.

The ***MDER*** for 2012 is taken over FAO, IFAD, UNICEF, WFP and WHO (2017), whereby for the projection period it is adjusted to account for demographic changes (sex and age) and corresponds to the population assumptions underlying the BAU, TSS and SSS scenarios (see also Figure 3.7).

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