Agriculture and Food Systems to 2050: A Synthesis: Global Trends, Challenges and Opportunities

Chapter · January 2019

DOI: 10.1142/9789813278356_0001

3 authors:

Rachid Serraj
Mohammed VI Polytechnic University

Lakshmi Krishnan
Food and Agriculture Organization of the United Nations

Prabhu L. Pingali
Cornell University

World Scientific Series in Grand Public Policy Challenges of the 21st Century

Rachid Serraj • Prabhu Pingali *editors*

Agriculture & Food Systems to 2050

Global Trends, Challenges and Opportunities

CGIAR Independent Science and Partnership Council

World Scientific

Chapter 1

Agriculture and Food Systems to 2050: A Synthesis

Rachid Serraj, Lakshmi Krishnan, and Prabhu Pingali

1.1 Introduction

Over the next 30 years, the global agri-food system will confront an unprecedented confluence of pressures, facing the so-termed "perfect storm" (Foresight, 2011). Whereas the Green Revolution focused on increasing food security and agricultural productivity, in the coming years questions will center on access to food, nutrition, and the sustainability of agroecological systems (Pingali, 2012). This change implies a need for a paradigm shift to address tensions related to food availability, diet quality, and resource efficiency.

On the demand side, the global population is projected to increase from nearly 7 billion today to 8 billion by 2030 and more than 9 billion by 2050. This growth—accompanied by rising prosperity, changing dietary patterns in emerging economies, and increased demand for a more varied, high-quality diet requiring additional resources for production—will exert pressure on the food system. Parallel demographic changes—such as the migration of youth into urban areas in response to low agricultural productivity—will in turn affect agricultural productivity through labor and wage effects. On the supply side, the availability and productivity of water, energy, and land vary enormously between regions and production systems, and competition for all three resources will intensify, even as the combined effects of climate change will become increasingly obvious. Agriculture makes use of 70% of water withdrawn from aquifers, lakes, and streams. By 2050, water withdrawals for agricultural irrigation are projected to increase further compared to 2006. This projection masks regional- and country-level variations in availability and existing water stress (FAO, 2011). For instance, groundwater withdrawals are already reported to exceed rates of natural replenishment in key cereal-producing regions across high-, middle-, and low-income countries. The largest increases in withdrawal levels are projected to occur in Southeast Asia (19%) and Southern America (53%), with a modest increase (22 km^3) in absolute terms for Sub-Saharan Africa, representing a 21% increase (FAO, 2011). Excessive nitrogen use, particularly in agriculture and livestock activities, affects both food production on land and freshwater and inland fisheries. At the same time, some projections suggest that fertilizer use may have to double to meet the demand for food by 2050 (Malingreau *et al.,* 2012). There are questions about whether sufficient nutrients (in the form of fertilizers) essential to plant growth will be available to meet this demand. Among other issues, phosphorus is a finite resource, nitrogen transformation is energy-intensive, and potassium reserves could be sensitive to geopolitical developments—two-thirds of potassium production comes from Belarus, Canada, and Russia (Malingreau *et al.,* 2012).

The complex relationship known as the water-food-energy nexus implies that any solution for one parameter of the nexus must equally consider the other parameters (Hoff, 2011). Climate change adds to this complexity. The need to reduce greenhouse gas emissions is already an imperative (IPCC, 2014), and even after emissions peak, the emphasis on aggressive mitigation actions and adaptation—including in the agri-food sector—to a changing climate will predominate. The transition away from traditional biomass (e.g., agricultural residues, animal waste, charcoal, wood) in developing countries will not only need to consider the significant growth in local demand; countries will need to rapidly transition to low-carbon energy while balancing the demand for land to produce (liquid) biofuels with the need to ensure an adequate food supply and water availability and management, in the context of global warming.

The post-2015 agenda has set new, complex, and more interconnected challenges, such as eradicating poverty, ending hunger, achieving food and nutrition security, halting biodiversity loss, sustainably managing water resources, and protecting and restoring terrestrial ecosystems. Between 1981 and 2015, the percentage of the world's population living in absolute poverty declined by a factor of four—from 44% in 1981 to less than 10% in 2015—and the rate of reduction has been accelerating (Roser and Ortiz-Ospina, 2017). Recognizing this and the fact that 767 million people still live on less than US$1.90 a day (primarily in Sub-Saharan Africa and South Asia), Sustainable Development Goal 1 proposes an end to poverty by 2030. Globalization of markets and the concentration of the food and agricultural sector have occurred at a rapid pace and are likely to continue over the next decades. This interconnectedness implies that economic shocks or altered geopolitical dynamics could have significant consequences, although inter-connectedness can also reduce the effects of economic shocks through trade and remittances (Anderson, this volume). As the international community attempts to deliver on the 2030 Agenda for Sustainable Development, fragility, conflict, and violence (FCV) are on the rise (OECD, 2016). According to the World Bank (2018), 2 billion people now live in countries where development outcomes are affected by FCV. The share of the extreme poor living in conflict-affected situations is expected to rise from 17% of the global total today to almost 50% by 2030. Conflicts are contributing to forced displacement and massive migration; they currently drive 80% of all humanitarian needs while reducing GDP growth by 2 percentage points a year on average (World Bank, 2018). Although the world made significant progress on many targets of the Millennium Development Goals (MDGs), the implementation of Agenda 2030 and achievement of SDGs and sustainable development beyond will be much harder to accomplish, particularly under more extreme climates in many parts of the world.

Any of these pressures described (or drivers of change) would represent a substantial challenge to food and nutrition security. Together, they encompass a major and complex threat that requires a strategic reappraisal of how global agri-food systems are designed and managed (Foresight, 2011), and the positioning of research to address these challenges. We need to do things differently than in the past, not only to address the pressing problems of today but to identify potential threats, opportunities, and appropriate strategies for tomorrow. Strategic foresight is needed to navigate times of change, uncertainty, and disruption. Horizon scanning, early identification of key trends and weak signals of change, and an understanding how the future may evolve and what responses are needed now and into the future are critically important in making strategic decisions that optimize the organizational performance of research-for-development (R4D) institutions dealing with these development challenges.

A number of studies have discussed the future of food security, agriculture, and sustainable development in the recent years. Maggio *et al.* (this volume) provide an overview of these foresight studies and summarize the key drivers and megatrends. The analysis shows a growing interest in foresight work on food and nutrition security and highlights issues that merit further investigation and attention. Using a systemic approach to the future, the authors analyze 14 megatrends, considering social, technological, economic, environmental, and political forces of change and potential disruptions, and examining their implications for the future of food systems, poverty reduction, and sustainability. The analysis shows that 6 out of the 14 megatrends have been well addressed as key drivers of food systems and food security. These 6 are climate change and environmental degradation; worsening resource scarcity and growing consumerism; accelerating technological change and hyperconnectivity; the changing nature of work; shifting health challenges due to changing diets; and demography transitions and urbanization. However, a second group of megatrends—potential game changers—are still currently not adequately addressed in agri-food systems analyses. These include rising income inequality; improved education and literacy; the increasing significance of migration; and the expanding influence of countries in the East and South. This second group of megatrends may require further attention in foresight work on food and nutrition security (Maggio *et al.,* this volume).

The Independent Science and Partnership Council (ISPC) of CGIAR initiated a foresight assessment, through an international workshop in 2017, to explore the pressures—threats as well as opportunities—on the global agri-food system between now and 2050 (Figure 1.1). The overarching objective was to first help understand the context by analyzing global trends and anticipating change in order to enable better planning and construction of pathways from the present to the future. Subsequently, the aim was to focus on the right questions and problems and identify a wider range of opportunities and options for agricultural research for development (AR4D); in order to enable prioritization and inform strategy and decision making in the CGIAR. This book presents the outcome of the assessment, including the thematic chapters that form the core of the book (Table A1.1 summarizes the chapters, highlighting the main findings and conclusions). It contextualizes the role of international agricultural research in addressing the complex challenges posed by Agenda 2030 and beyond, and identifies the decisions that CGIAR donors, scientific leaders, and policy makers must take today, and in the years ahead, to ensure that a global population rising to 9 billion or more, combined with their rising incomes and changing diets, can be fed sustainably and equitably.

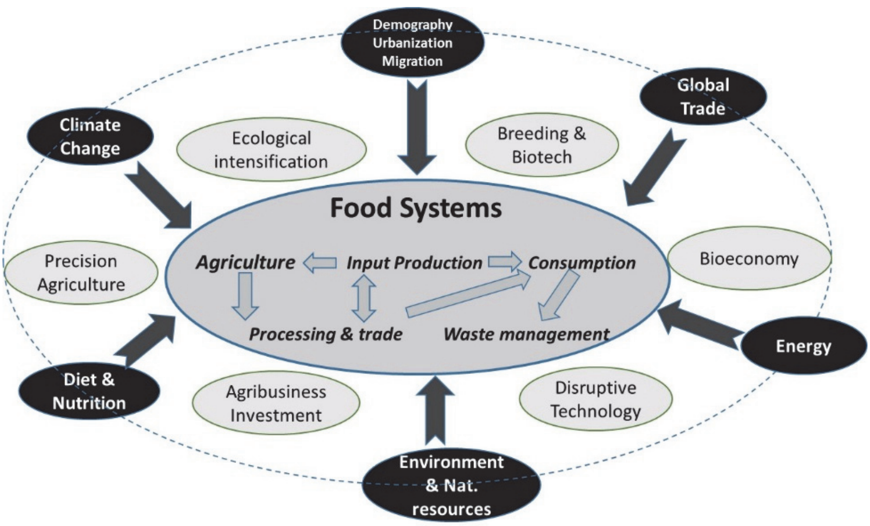

Fig. 1.1. Key drivers or threats (dark ovals) and opportunities (light ovals) of agri-food systems.

While there have been several other foresight initiatives, our effort provides a sharp focus on the future prospects for developing-country agriculture and food systems, the consequences for the rural poor, and the implications for international agricultural research for development.

The chapters in this book describe how the future may look with regard to the “grand challenges,” global trends, and likely disruptions to food and nutrition security, and to an extent, they reflect on how the world is prepared to address them for reaching the SDGs and beyond. We did not undertake a scenario analysis but rather analyzed the consequences of global trends on the future of developing-country agriculture and food systems. Wherever relevant, we juxtaposed alternative visions or trends and compared their likely consequences.

The ISPC assessment has identified key challenges for the future, including the following:

- shifting the focus from food security to nutrition security and from agricultural production to sustainable agri-food systems, diet quality, and diversity;
- addressing the fact that producing enough food globally does not necessarily ensure equitable global access to food and progress toward food and nutrition security for all;
- enhancing the quantity, quality, and diversity of agri-food systems to balance future demand and supply, to ensure that food supplies remain affordable and stable, and to protect the poor and most vulnerable from the risk of volatility, both social and environmental; and
- managing the contribution of agri-food systems to the mitigation of climate change; preparing for and adapting to the effects of climate change on agri-food systems; and maintaining biodiversity, natural resources, and ecosystem services while feeding the world.

The last two challenges recognize that food production already dominates 40% of the world’s land surface and 70% of freshwater use and has a major impact on all of Earth’s ecosystems. In recognizing the need for urgent action to address these future challenges, policy makers should not lose sight of existing major weaknesses in the food system. If we are to anticipate and manage major stresses to the food system, it will be vital to address these challenges pragmatically while promoting economic and ecosystem resilience to shocks and future uncertainties.

This chapter synthesizes the dominant drivers of agriculture and food system change, with a particular emphasis on smallholder agriculture and the food and nutrition security of the poor in developing countries. It also provides an assessment of new science and technology opportunities and policy options for a more sustainable and resilient food system.

1.2 Urbanization, Demographic Transitions, and the Transformation of Smallholder Farming

The world's population is projected to increase by more than 1 billion people by 2030, reaching 8.6 billion, and to climb to 9.8 billion in 2050 (UN, 2017). A substantial shift in the proportion of the world's population in urban (versus rural) areas has already occurred—by 2008, 50% of the population already lived in urban areas. By 2040, more than half of the population on the African continent will live in urban areas (UN, 2015). Hazell (this volume) states that by 2050, 82.4% of the world's urban population will be based in less-developed regions. He notes that rapid urbanization and rising incomes in many developing countries are leading to more diverse national diets, characterized by increased per capita demand for livestock products, horticultural products, and processed and precooked foods and by reduced per capita demand for traditional food staples. For instance, by 2050, per capita meat consumption in developing countries is projected to increase from 28 to 42 kg (an increase of 50% from 2005–07), and in developed countries from 82 to 91 kg (Alexandratos and Bruinsma, 2012). Urban areas also consume a disproportionate amount of the food produced and sold—in a study of Bangladesh, Indonesia, Nepal, and Vietnam, urban areas accounted for 38% of the population but 53% of consumption (Reardon *et al.,* 2014); similarly, in eastern and southern Africa, 26% of the population is urban, and they consume 48% of food (Dolislager *et al.,* 2015).

The movement of population from rural to urban areas is a consequence of economic growth and structural transformation that is historical, observed across the developed world over the past several centuries and occurring now in emerging economies (Hazell, this volume). However, rapid migration to urban areas is also taking place in poor countries, particularly in Sub-Saharan Africa, driven primarily by the poor state of the agricultural sector and the rising urban-rural wage gap. This trend is particularly pronounced for youth, primarily in Africa (Arslan *et al*., this volume). Such an urbanization trend can in turn usher in the modernization of the agricultural sector, particularly for smallholders. Remittances from migrants have been found to increase household investment in agriculture and stimulate agricultural productivity (Böhme, 2015; Taylor *et al*., 2003), in addition to investments in nonfarm enterprises. However, the evidence is not unequivocal (Quisumbing and McNiven, 2010; Castelhano *et al.,* 2016), and investments may depend on a number of factors, including smallholder access to markets and resource endowments. Environmental degradation and climate change impacts have also contributed to migration out of rural areas, particularly in the least-developed countries. Some projections suggest an increase of 0.8–1.2% in climate migrants' share of the global population, with just over 143 million people (2.8% of the regional population) forced to move within countries in Sub-Saharan Africa, South Asia, and Latin America by 2050 (Rigaud *et al.,* 2018) to escape the impacts, albeit slow-evolving, of climate change. Conflicts and political unrest are other well-recognized drivers of migration and can affect demographic trends and migration patterns (Arslan *et al*., this volume).

The other dimension to urbanization is the physical expansion of urban areas: between 1970 and 2000, the global urban land area increased by 58,000 km^2, with the highest rates of expansion occurring in China, India and across Africa, and the largest change in area occurring in North America. By 2030, "built-up areas" are expected to triple in size to 1.2 million km^2 (Seto *et al.,* 2011). While cropland area makes up 12% of the world's ice-free land cover, and urban areas make up only 3%—indicating that physical expansion of urban areas will have minimal impact on agricultural land use—there are likely to be regional variations and significant implications for urbanization's ecological footprint. In countries where urban population growth is high and agriculture is the main economic activity, because built-up areas are growing faster than urban populations, cropland loss is likely to be acute. In countries like China, India, Turkey, the United States, and Vietnam, urban expansion has occurred on prime agricultural land—such a trend has implications for cropland productivity and yield gaps (Seto and Ramankutty, 2016; Seto *et al.*, 2011). However, as urban populations rise, we should also expect cities to grow vertically (with higher buildings) and thereby slow expansion into agricultural lands. In addition to land, there will be competing demands for water (or energy) between urban and rural areas, and urbanization is projected to have negative impacts on protected ecosystems through direct and indirect effects (such as fragmentation, edge effects, and species composition) (Seto *et al.,* 2012).

Economic growth, structural transformation, and rapid urbanization can represent new growth opportunities for the rural poor. As agricultural systems increasingly focus on meeting the needs of cities, there will be a shift from agriculture as a way of life toward agriculture as a business. Smallholder farmers can benefit from the new growth opportunities by becoming integrated into agri-business value chains that provision the cities on a commercial basis. In general, small farms will play a diminishing role in feeding urban populations with food staples, but many will be successful in producing some high-value and labor-intensive products such as livestock or horticulture products for urban markets. It is medium- and large-sized farms that are expected to meet urban and agri-food industry needs, including for food staples (Hazell, this volume). The changes in dietary preferences and composition related to urbanization, economic growth, and rising incomes will affect the entirety of the food system, from production to transport to storage and distribution and finally waste management.

These transformation trends also present potential obstacles that threaten to exclude many small farms (Masters *et al.*, 2013). The challenges facing small farms will be compounded in much of Africa and South Asia by continuing rural population growth and the further subdivision of landholdings. Despite these challenges, small farms are unlikely to diminish much in numbers by 2030 even as they shrink in size. A few smallholder farms will succeed as full-time commercial farmers, while others will either diversify extensively into nonfarm sources of income or continue subsistence modes of production, particularly in more remote and less-favored areas (Masters *et al*., 2013). There is also a risk, in the absence of supportive investments and policies, that transition and subsistence farmers who are unable to transform and become integrated into commercial value chains or exit farming will be left behind and may be forced to move to marginal lands or be jobless and food insecure in cities (Hazell, this volume).

Greater global trade integration and more open emerging economies will increase the need to enhance the competitiveness of domestic agriculture systems. International trade can ease supply shocks and increase the resilience of food systems, but there can be systemic risks, as the financial and food price crises of 2008 illustrated, with particular implications for developing countries and poor households. Anderson (this volume) documents the current extent of trade in farm products and of barriers to trade, summarizes projections of trade under various assumptions to 2050, and makes the case for further opening up to trade by suggesting ways to increase the openness of emerging economies. There are prospects for stronger WTO disciplines not only on farm import tariffs and nontariff trade measures but also on domestic support policies, for freeing up farm trade with bilateral and regional preferential free trade agreements, and especially for unilateral market liberalization. For instance, the increased liberalization of markets might come about as more efficient instruments to assist food-insecure households—such as conditional targeted income supplements—become administratively feasible even in low-income countries.

However, if current trade integration trends slow down or are reversed, then we should anticipate increased vulnerabilities for developing-country food systems and food security, particularly in those countries that are net importers of food. The pressure to enhance and stabilize domestic food supplies could stimulate agricultural productivity growth, but could also lead to long-term environmental degradation. Climate change impacts, discussed in the next section, will also be exacerbated if trade integration trends are reversed.

1.3 Climate Change and Agri-Food Systems

Agri-food systems are facing increased risks owing to progressive climate change that manifests itself as more frequent, severe extreme weather events—heat waves, droughts, and floods (IPCC, 2013). Often without warning, weather-related shocks can have catastrophic and reverberating impacts on the increasingly exposed global food system—through production, processing, distribution, retail, disposal, and waste. Simultaneously, crops and livestock will respond to higher minimum and maximum temperatures, variations in precipitation, increased atmospheric CO_2, changes in pest and disease population dynamics, soil salinization due to sea-level rise, and other climate change-related effects. The resultant impacts—long-term or temporary, widespread or geographically contained—on yield and productivity could be beneficial or detrimental depending on the agroecological system and will require various adaptation and resilience mechanisms ranging from genetic and agronomic practices and irrigation infrastructure to alterations of planting seasons and significant changes in land-use allocation.

It is now becoming evident that climatic changes will affect elements of agricultural value chains beyond the farm, including storage facilities, processing plants, and transportation. For example, sea-level rise may disrupt trading ports, or extreme weather events may affect transportation of agricultural commodities. Ruane and Rosenzweig (this volume) provide an overview of climate trends and extreme events affecting agriculture, projected risks from future agro-climatic changes, and the nature of differing impacts among regions and farming systems. They offer a transdisciplinary foresight framework based on the Agricultural Model Intercomparison and Improvement Project (AgMIP) (Rosenzweig *et al.*, 2013) and Coordinated Global and Regional Assessments (CGRA), which incorporates biophysical and socioeconomic assessments across spatial scales while also seeking to integrate nutrition and food security metrics (Rosenzweig *et al.,* 2016).

Most of these studies focus primarily on four major crops (maize, wheat, rice, and soybeans), which together account for about 43% of global dietary calories (Ruane and Rosenzweig, this volume). This reflects the focus of the scientific literature but falls short of the meeting diverse needs of agricultural sector planners. Priority areas for continuing foresight development include the creation of models for more crop species (notably perennials, fruits and vegetables, oil crops, and tropical cereals) and plantation crops (such as coffee, tea, cacao, and wine grapes, where yield quality may be more important than yield quantity). Tools capable of simulating more complex systems would also allow testing of creative interventions for intercropping, crop rotations, mixed crop-livestock systems, and aquaculture.

Climate change impacts on agriculture must be understood in the context of the intertwined systems that affect food security and agricultural trade, including biological, socioeconomic, and political processes. Ruane and Rosenzweig (this volume) illustrate how the current and future state of these intertwined systems dictate the extent of vulnerability to physical climate risks, which for agriculture in any given location are determined by a combination of societal pathways; mean climate change variables (e.g., temperature, precipitation, sunlight, winds, relative humidity); extent to which extreme climate events alter their magnitude, frequency, duration, and geographic extent; and the patterns of local agro-climate exposure. In addition to the biological impact of changing climate conditions on farms, future agricultural production will be affected by economic and policy incentives across a wide variety of stakeholders and actors, both locally and interacting through global markets (Valdivia *et al.*, 2015). Anderson (this volume) argues that since climate change is expected to constrain global food production via larger and more-frequent extreme weather events, this can be a strong incentive for countries to be open to international food markets to allow trade to buffer seasonal fluctuations in each country's domestic production and to reduce the volatility of international food prices. Climate-induced changes in regional production may affect trade balances and alter the flow of goods (Ruane and Rosenzweig, this volume).

A holistic approach is needed to create a long-term research portfolio and a development strategy for dealing with climate shocks and for building climate-resilient food systems that take into account the complexity of the food-water-energy nexus. This would include an understanding of the disruptive effect of climate-induced shifts in agroecological zones and production systems on livelihoods of the rural poor. Impacts of mean climate change and extreme climate events (such as droughts and floods) on the nutritional status of the poor would also be an important area for further investigation.

Other remaining research gaps on climate change interactions include the linkages between climate change and internal migration, rural transformation, and global trade (Arslan *et al*., this volume; Anderson, this volume). Given the projections that climate change will alter seasonal weather patterns and hence increase the risk for rural incomes dependent on agriculture, seasonal and temporary migration within and between countries can be expected to play an increasingly important role in the future. Many countries, however, continue to deter internal migration through direct and indirect policies. Seasonal migration and its implications for rural, peri-urban, and urban livelihoods under the projected demographic and climatic pressures require further attention.

The agricultural sector is vulnerable to weather and climate hazards but is also a major contributor to the greenhouse gas emissions and land use changes that drive climate change. Agriculture, forestry, and land use change account for just under a quarter of total greenhouse gas emissions (Smith *et al*., 2014), which implies a substantial role for agricultural systems in overall societal mitigation and efforts toward sustainability. Rising demand for livestock products can exacerbate greenhouse gas emissions. On the other hand, diversification out of staple grains—especially wetland rice systems—more efficient input use practices, and shifts to diets with a lower emissions footprint can help reduce greenhouse gas emissions.

Renewable energy provides another important entry point to mitigation. Skeer and Leme (this volume) demonstrate that keeping global warming to well below 2° C., as the Paris climate agreement requires, will be a big challenge that requires dramatic reductions in carbon emissions and nearly complete decarbonization of the energy system. Scaling up renewable energy supplies, including bioenergy, is essential, but dedicated use of land for bioenergy production could compete with land cropped for food or increase carbon emissions through deforestation. However, there is scope for producing additional bioenergy by closing the gap between projected and potential crop yields, using more of the agricultural residues currently available, making land available for bioenergy crops by restoring degraded lands and sustainably intensifying pasture land used for livestock production, and reducing waste and losses in the food chain.

These themes come together in an analysis of the bioeconomy and the effect of its development on agri-food systems (Birner and Pray, this volume). In recent years, the bioeconomy concept has been embedded more explicitly into the ideas of sustainable development and the green economy. The forecasting framework—linking the development of the bioeconomy to food system impacts—classifies all items consumed by humans into three categories (food, energy, and materials) and then by sources (bio-based resources, bio-based renewable sources, and nonrenewable sources). The framework is in some senses a simplified version of the economic system, wherein all processes involved in the production, conversion, and consumption of materials and energy, as well as trade, are captured.

Changes in population size as well as consumer behavior are the two most significant demand-side factors influencing the competition for biomass as food and as energy and material, threatening food security. While the use of biomass for energy and bio-materials (such as chemicals, plastics, and lubricants) constituted only 3% of crop production in 2015, this share is expected to grow—e.g., depending on biofuel policies, biofuels may account for nearly one-fifth of global land use change over the 2006–2035 period. In the medium term, there are likely to be trade-offs between bioenergy production and food security, and the magnitude of this effect will depend both on the evolution of second-generation biofuels and on energy efficiency–related innovations. The forestry sector also plays a significant role in supplying biomass for bioenergy and bio-based materials (Birner and Pray, this volume). The availability of fossil fuels and their price relative to that of biomass, and the availability of renewable energy technologies, are factors that will exert or ease pressures on the supply side (Skeer and Leme, this volume). The rationale for the bioeconomy model is to reduce the environmental effects of the economic system, in particular greenhouse gas (GHG) emissions, climate policies and the environmental decisions that influence outcomes. At the same time, the model helps identify those uses of biomass that have considerable GHG emissions reduction potential—implying that preference should be given to non-bio-based renewable energy sources (solar and wind) over conversion of staple crops to bioenergy.

1.4 Food Systems for Better Nutrition and Health

Substantial progress was made between 1990 and 2012 in addressing hunger and undernutrition—rates of hunger decreased from 18.6% to 11.8% globally, and the percentage of children stunted fell from 39.6% to 23.8% (Global Panel, 2016). However, the global R&D and policy community is faced with the tremendous challenge of responding to rising nutrition and dietary dilemmas. The 2017 *Global Nutrition Report* shows that 88% of countries for which data are available face either two or three forms of malnutrition (childhood stunting, anemia in women of reproductive age, and incidence of obesity/overweight in adult women). While the number of chronically or acutely undernourished children under five years old has fallen in many countries, recent statistics show that global progress to reduce these forms of malnutrition (stunting and wasting) is not keeping pace (Development Initiatives, 2017). Minimum dietary diversity standards needed for growth are met by fewer than one-third of all young infants across 60 low- and middle-income countries (Global Panel, 2016), and each year more than 3.1 million child deaths are attributed to poor nutrition (Abraham and Pingali, 2017). At this rate, the global nutrition targets, including SDG target 2.2 to end all forms of malnutrition by 2030, will not be met. The number of individuals going to bed hungry increased from 777 million in 2015 to 815 million in 2017, and the number of women with anemia has increased since 2012. More than 2 billion people are micronutrient deficient—a systematic review found that fewer than half of adolescent girls and young women in low- and middle-income countries meet their micronutrient needs (Global Panel, 2016).

While undernutrition continues to be an important priority, the rise of obesity and noncommunicable diseases (NCDs) in the developing world needs urgent and concurrent attention (Meenakshi and Webb, this volume). The number of children and adults who are overweight and obese continues to increase in every region, particularly in low- and middle-income countries. For instance, in Sub-Saharan Africa, the growth rate for obese or overweight men now exceeds that for underweight, and in South Asia, the prevalence of obesity/overweight and underweight is the same among women (Global Panel, 2016). The probability of meeting the global targets related to stopping the rise in obesity and diabetes by 2025 is less than 1%. NCDs associated with overnutrition are also on the increase, with little capacity in public health systems as yet to deal with them (Meenakshi and Webb, this volume). Globally, overweight and obesity cost an estimated US$2 trillion per year, and 68% of all deaths are caused by NCDs, of which three of the four most common are diet-related—namely cardiovascular diseases, cancers, and diabetes (World Bank, 2017).

The Global Panel on Agriculture and Food Systems for Nutrition recently concluded that most global burden of disease risk factors are linked to diet. It is clear that there is an increasing convergence toward the negative aspects of Western diets, which are highly processed and contain high amounts of sugar, salt, trans fats, and oils, as well as processed meats (Meenakshi and Webb, this volume). Actionable priorities identified by the Global Panel's report for addressing the nutritional crisis include focusing systemwide policies on diet quality; ensuring that food-based dietary guidelines inform policy decisions to reshape food systems (not only consumer focus); making fruits, vegetables, pulses, nuts, and seeds affordable, safe, and more available in markets globally and year-round; ensuring that policy support for animal source foods are pragmatically evidence-based rather than driven by ideology; and refocusing agricultural research investments globally to support healthy diets and good nutrition (Global Panel, 2016). This may also imply moving the predominant focus of international agricultural R&D away from the big three staple grains—rice, wheat, and maize—and toward promoting a nutrition-sensitive food system that can help address both ends of the nutrition problem (Pingali and Aiyar, this volume).

Urbanization, rising incomes, and economic development are all drivers of dietary quality. On the one hand, there is greater diversification of national diets with increased per capita demand for animal source foods and horticultural products and reduced per capita demand for traditional food staples (Hazell, this volume; Seto and Ramankutty, 2016). On the other hand, these trends can negatively influence diet quality by altering the composition of foods consumed toward greater fat, sugar, and salt content. The demand for precooked and processed foods is higher in urban areas and for households with women engaged in rural off-farm employment, with little difference across income levels (Pingali, 2006; Reardon *et al.,* 2014). Globally, more food is consumed outside the home in more urbanized societies (Seto and Ramankutty, 2016). Even among the rural poor and nonpoor, food purchases constitute a significant proportion of total food consumption. Besides diet quality issues, managing food safety will become critical as these trends amplify in the low- and middle-income countries. The challenge is to find ways to enhance the positive links between, say, urbanization and diet quality while concurrently addressing challenges such as food safety, nutrient quality, and affordability (Global Panel, 2016). Similarly, structural changes in the rural environment pose challenges and opportunities for the design of food and nutrition policies. In Asia, factors such as a systematic decline in women's rural labor force participation rates, a lack of progress in reducing adult anemia, increasing scarcity of freshwater, poor food safety, and high rates of postharvest loss will increasingly influence both under- and overnutrition (Meenakshi and Webb, this volume).

"Food systems thinking" can help identify points of intervention across the whole food system that can help alleviate malnutrition and better understand the synergies and trade-offs between strategic goals related to food, nutrition, and the environment (Ingram and Zurek, this volume). While primary production is often the focus of food security considerations, post-farmgate activities (processing, packaging, transporting, marketing, consuming, and disposing of food and food-related items) are also important for household food security and individual nutrition outcomes (Abraham and Pingali, 2017). Similarly, addressing poor sanitation and high-disease-risk environments and increasing access to clean water can help address issues of food safety and human health, even as balancing water use for domestic and agricultural sectors is anticipated to be increasingly difficult (Meenakshi and Webb, this volume). The food systems approach allows food chain activities to be linked to their social, economic, and environmental context and to contribute to addressing the root causes of malnutrition in all its forms (Gustafson *et al*., 2016; Tomich *et al*., 2018).

Advances in genomics and molecular biology targeted toward enhancing the nutritive value of crops, particularly the less commonly researched crops (Langridge, this volume), as well as innovations in agronomy (Tittonell, this volume), food processing, and the use of modern communication technologies for enhancing consumer demand are some of the options that ought to be examined. Research could also draw on advances in food technology being developed by advanced-country public and private systems (Crouch, this volume). Van der Duin and den Hartog (this volume) discuss potential applications of disruptive technologies and innovations such as synthetic biology, food design, and protein transition (see section 1.6 of this chapter). The World Economic Forum identifies food-sensing technologies such as radio-frequency identification tags, genetic markers, and hyperspectral imaging combined with mobile phones as having the potential to significantly influence diets and behaviors by providing nutritional and environmental information (such as on safety and freshness) to consumers (WEF, 2018).

1.5 Sustainable and Resilient Farming Systems

By 2050, world average per capita food consumption is projected to be around 3,000 kcal/person/per day, with Sub-Saharan Africa and South Asia experiencing a substantial increase compared with 2005/07 (Le Mouël and Forslund, 2017). Global food production (net of biomass used for biofuels) would need to increase by 70% to feed 9 billion people by 2050 (FAO/IFAD/UNICEF/WFP/WHO, 2017). Yet food production per capita in the least-favored regions of the world, bypassed by the Green Revolution (e.g., Sub-Saharan Africa), remains at the same level as in the 1960s. The doubling of global crop yields experienced between 1960s and late 1990s was paralleled by a sevenfold increase in nitrogen fertilizer use, a tripling of phosphorus use, and the doubling of irrigation water (Tilman *et al*., 2002). Tittonell (this volume) concludes that if food production needs to increase by an extra 70% over the next 40 years, as some scenarios seem to suggest, then such an increase cannot be fueled by further inputs of N, P, and water—at least not at the same rates as experienced over the past decades. New forms of agricultural intensification are needed to produce more food where it is most needed and to make use of the natural functionalities that ecosystems offer in order to reduce the need for and increase the efficiency of external inputs (Tittonell, this volume). Although recent experiences with using agroecological principles to design resource use–efficient agriculture present some promising avenues (e.g., in Sub-Saharan Africa), important challenges, such as approaches to scaling, remain unresolved (Tomich *et al.,* 2011). In market-based systems, sustainability labeling and certifications for agricultural commodities play an increasingly important role in promoting sustainable resource use (Birner and Pray, this volume).

Agronomy is making significant progress in bridging yield gaps, though debates on several topics and concepts (e.g., conservation agriculture, system of rice intensification) are ongoing and must be resolved to ensure future improvement in the sustainability of agricultural productivity (Giller *et al.,* 2017; Verhagen *et al.,* 2017). There has been progress in building scientific consensus about methods, data requirements and sources, and models for yield gap analysis, as well as about how to use yield gap analysis to evaluate food security and constraints to increased crop production at different spatial scales (van Ittersum and Cassman, 2013). More transparent, scientifically robust, and reproducible methods will enhance the agronomic relevance and impact of yield gap assessments. Improved understanding of hydrological and biogeochemical cycles, such as N and P cycles, will help further improve the management of soil nutrient balance and water and nutrient use efficiency. However, the scaling challenge applies here as well—recent efforts to scale up an integrated soil-crop system management (ISSM) program in China demonstrate the degree to which this task requires more than the development of scientifically credible and evidence-based technologies. Beyond demonstrating the role that science can play in increasing productivity and reducing environmental damage, the program underlined the extent of the research network (1,200 scientists, 65,000 local officials, 140,000 industry representatives, and 21 million farmers) needed both for scaling up and for providing scientists with access to essential data (Cui *et al.,* 2018).

Agriculturally marginal dryland environments continue to pose major challenges for sustainably increasing agricultural productivity and resilience. Globally, drylands represent about 40% of the land area and host about 35% of world population in nearly 100 countries (ISPC, 2015). About half of dryland inhabitants are poor, depend on a highly variable natural resource base for their livelihoods, and are constrained by socioeconomic conditions that are worse than in other areas of the world (Safriel and Adeel, 2005). The inherent water scarcity in drylands is exacerbated by frequent droughts, land degradation, and desertification. Looking toward 2030 and beyond, climate change is expected to worsen the plight of the dryland farmers. Similarly, climate change will exacerbate salinity intrusion in coastal areas. Finding better solutions for drought, salinity, and abiotic stresses should be a priority for research for development (ISPC, 2015).

Modern science and technology, in association with “big data” tools, GIS, and remote sensing, can contribute significantly to sustainable intensification and maximization of the use of inputs in smallholder farming systems (Huang and Brown, this volume). Distributed ledger technologies such as blockchain, which enable secure information storage and retrieval for transactions, can the efficiency of agricultural supply chains in many ways, such as by improving food safety through increased traceability and reducing deforestation by enabling origin tracing (WEF, 2018). Precision agriculture can be a part of the response to changing climatic conditions and the increasing costs of agricultural inputs, which are reducing farm profitability globally. While the commercial agricultural sector in developing countries, through variable application and yield monitoring using GPS systems, has adopted precision agriculture technologies, the enabling environment—in the form of mobile internet, portable plant sensors, and small unmanned aerial vehicles—is considered sufficiently well developed in Asia, Africa, and South America to implement these technologies in high-value production systems as well (Huang and Brown, this volume). The challenge is that transformative innovations and modern tools for making agricultural systems more efficient and sustainable, such as precision agriculture, are often not designed for smallholder use. Adaptation to smaller scales is a major challenge for research and technology design targeted to smallholder farmers in developing countries.

The massive improvement in communications networks, for instance in India, presents an opportunity to digitize information and bridge the gap between farmers and value-chain actors by reducing costs and inefficiencies (Huang and Brown, this volume; Crouch, this volume). Similarly, while energy use in agriculture accounts for less than 4% of global energy use, it has been growing faster in Sub-Saharan Africa. Improved access to energy, particularly renewable energy, can have important effects on costs and efficiencies along the agri-food value chain from irrigation to postharvest practices (e.g., drying) to food processing (Skeer and Leme, this volume).

1.6 New Science and Technology for Managing Systemic Complexity and Trade-offs

The complexity of the global grand challenges described in the sections above require new science and synergistic interventions involving many types of expertise across biological, physical, and social disciplines. To ensure the long-term sustainability of agri-food systems, it will become more and more crucial to preserve natural resources and environmental health, including water, soil nutrients, and biodiversity, while paying attention to the biogeochemical flows, terrestrial degradation, and land-use productivity (Van der Elst and Williams, this volume). The concept of planetary boundaries has proved useful as a framework for supporting global sustainability and monitoring the fundamental characteristics of a healthy, sustainable natural environment (Rockström *et al*., 2009). Agriculture has led to the transgression of two planetary boundaries—i.e., biosphere integrity and biogeochemical flows—which are already at high risk (Campbell *et al*., 2017; Ripple *et al*., 2017). Scientists are increasingly coming together to solve the grand challenges of food, energy, water, climate change, and environmental sustainability. Interand transdisciplinary research is considered increasingly essential by scientists, policy makers, and funders (GRC, 2017; *Nature*, 2015; ISPC, 2017). Innovation is often the result of dynamic interactions among a diverse range of actors within complex systems that are interdependent, nonlinear, and collaborative (Katz, 2016).

Breakthroughs in biotechnology and genetic improvement are expected to address the challenge of increasing productivity and accelerating the rates of genetic gain in breeding by, among other things, making efficient use of genetic resources; accessing genomic regions and generating novel variation through gene editing, mutagenesis, and genetic engineering; and exploiting heterosis through hybrid technology (Langridge, this volume). This area also requires crosscutting technologies for data management, mechanization, high-throughput precise phenotyping, and close integration with agronomic practices and socioeconomic analyses of the factors involved in successful technology adoption by farmers, consumers, and governments. For instance, new crop varieties must be delivered to farmers as part of a set of products that includes optimal production methods and considers the entire farming system (Langridge, this volume). Innovations in biotechnologies, information and communication technologies (ICTs), big data, smart- and precision-farming technologies, and technologies for enhancing food quality and safety and reducing waste would fall into this category, as well as labor-saving, digital agriculture systems and mobile technologies (Huang and Brown, this volume).

Technologies and innovations such as synthetic biology, food design, and the protein transition may play a key role in addressing challenges arising in agri-food systems (van der Duin and den Hartog, this volume). The prospects for disruptive innovations with potential applications for developing countries are most likely to come from the private sector (Crouch, this volume). Examples of disruptive food innovations include private sector investments in food substitutes (insect protein), plant-based meat substitutes, and "clean meat" as well as public sector investments through the U.S. Department of Defense (DOD) in areas ranging from artificial intelligence to miniature sensors and novel materials. Technologies being developed by the DOD's Defense Advanced Research Projects Agency (DARPA) or through the U.S.

National Aeronautics and Space Administration (NASA) Advanced Food Technologies Project, such as ready-to-eat meals with extended shelf life for the military (e.g., food for Mars missions), could have significant spin-off benefits for the target population in developing countries. Advances made by the agri-food industry and the pharmaceutical industry in nutrient-rich foods targeted to the commercial food sector could have similar spin-off benefits. A variety of promising transformational innovations are focusing on reducing postharvest losses in food packaging, processing, storage, and transport (GKI, 2017). Technology also has a role to play in increasing the sustainability of agriculture and mitigating its adverse impacts on aforementioned planetary boundaries. For instance, smart irrigation systems using sensor technologies could help manage and reduce agricultural water use; organic and inorganic nanomaterials (metal oxides, polymer and carbon nanotubes) can help absorb contaminants in soil and increase soil remediation capacity; and integration of artificial intelligence tools, cloud computing, and on-farm sensors could facilitate decision making and improve on-farm efficiencies (Fraceto *et al.*, 2016; Small, 2017). While water issues—such as groundwater depletion and competing demands for water between agricultural, domestic, and industrial sectors—are projected to intensify in the future, leading to an 18% reduction in availability of freshwater for agriculture, changes in consumption patterns and innovative policies could enable transitions that ensure that ecosystems remain within boundaries to meet future demand for food, energy, water, and materials (van der Elst and Williams, this volume).

Food systems, agriculture, nutrition, and environmental sustainability are all important components of the 2030 Development Agenda. The link between the SDGs and the agri-food sector, particularly smallholder farming, is clear: while SDG2 explicitly illustrates this link (end hunger, achieve food security and improved nutrition, and promote sustainable agriculture), farm development and growth are also central to the success of eight other goals, related to ending poverty, gender discrimination, inequality, environmental degradation, and climate change, and promoting healthy lives (Abraham and Pingali, 2017). Recent work on the trade-offs between the SDGs stresses the complexity of integrating individual, often competing or conflicting, goals and targets and ways to minimize the negative impacts of trade-offs (Machingura and Lally, 2017).

On the policy side, a new integrated approach is needed at the intersection of food, agriculture, climate, and health. Food, agricultural, and nutrition policies should address priorities for increased production diversity to meet rising demand for dietary diversity and to increase people's access to nutritious food and thereby reduce malnutrition (including reversing rising obesity rates)—and do so in ways that enhance biodiversity and climate change mitigation and adaptation. The use of modern technologies and policies to enhance the competitiveness of smallholder agriculture systems and the design of effective aggregation models for linking small farms to agri-business value chains will continue to be major areas of applied research (Pingali and Aiyar, this volume).

1.7 Conclusions

The perfect storm of global threats and challenges faced by the world's agri-food system also offer opportunities for future food and agricultural systems to positively contribute to rural prosperity, improved nutrition, and environmental sustainability, including enhanced management of climate threats. The overarching question that this book seeks to address is how agricultural research and policy ought to re-orient themselves to confront those challenges and opportunities.

Positive futures can be driven by demand-side factors, such as the rising urban demand for food diversity, or driven by technology, such as the increasing role of ICTs and other disruptive innovations in, say, precision agriculture. Since agri-food systems are intricately linked to and interact with ecosystems and natural resources, these changes also have implications for trends in those areas (related, e.g., to freshwater, land, and marine ecosystems). Rapid urbanization, income growth, and the consequent rising demand for food, in terms of both quantity and diversity, provide a new growth opportunity for the agricultural sector in developing countries. Increasing urban demand for high-value agricultural products such as fruits, vegetables, meat, eggs, and milk creates opportunities for small farms to diversify production and realize better income by participating in value chains. With that change comes a shift from agriculture as a way of life to agriculture as a business for smallholder farmers in developing countries. However, smallholders' ability to participate in agricultural markets is determined by transaction costs or the cost of accessing goods and services and making exchanges. Meeting the quality and safety standards demanded by modern agri-food value chains also adds to small farm marketing costs. These costs could limit the ability of smallholders to effectively participate in markets, hindering commercialization.

Increased global trade integration and the openness of emerging economies will increase the need to enhance the competitiveness of small farms in developing countries. Significant research is needed on boosting competitiveness and reducing transaction costs in smallholder agriculture systems. Crop-breeding technologies that can enhance yields or reduce yield variability could lead to lower production costs per ton of crop output and thereby enhance competitiveness. However, major scientific advances in our understanding of the genes controlling disease resistance and tolerance to environmental stresses have generally failed to find delivery through genetic modification (GM). Yet, although the predictions of diverse products resulting from large investments in GM have been largely unrealized, the technology has advanced our understanding of gene structure and function. There is now optimism about the use of gene editing as a route to deliver advances in gene discovery; this means that issues related to regulatory requirements and consumer acceptance of this technology will need to be resolved. Innovations for enhancing input use efficiencies, such as ICTs, labor-saving and mobile technologies, and smart- and precision-farming technologies, could also lead to unit cost reduction. Similarly, improved access to markets might enable farmers to sell surpluses at a higher price and influence their cropping choices. Effective aggregation models for linking small farms to agri-business value chains will continue to be a major area of applied research. Technologies for enhancing food quality and safety and reducing waste could also improve farmers' market integration, especially for products targeted to the urban food value chains. Disruptive technological breakthroughs are most likely to arise in agricultural resource use efficiency, such as energy and water and in post-harvest operations for enhancing shelf life, quality and safety.

The global R&D and policy community is faced with the unprecedented challenge of responding to escalating nutrition and dietary dilemmas in the developing world. While malnutrition continues to be an important priority, the rise of obesity and NCDs in developing countries needs urgent and concurrent attention. Moving away from the current, almost predominant, focus on the big three staple grains—rice, wheat, and maize—and toward a nutrition-sensitive food system can help address both ends of the nutrition problem. Advances in genomics and molecular biology could help create healthier food systems by enhancing the nutritive value of crops, particularly less commonly researched crops such as millets. International R&D could also draw on advances in food technology being developed by public and private research systems in advanced economies. Advances by the agri-food and pharmaceutical industries in nutrient-rich foods targeted to the commercial food sector could have similar spin-off benefits. Recent advances in cellular agriculture, such as "clean meat," could have long-term health and environmental benefits, although it could be decades before such novel foods are generally available in our food systems.

The challenge for policy makers—and thus for research to inform those decisions—is to balance investments and policies supporting the increased productivity of staple crops with investments and policies that improve the productivity of or returns to higher-value products (including livestock products). Food systems thinking—i.e., looking at the food system as a whole—can help identify synergies and trade-offs between various goals (poverty, nutrition, environment) and indicate leverage points for policies and interventions.

In terms of promoting climate-resilient food systems, there has been significant modeling work on the implications of the projected shifts in mean climate and climate extremes on agriculture, but it has again concentrated on the big staples (rice, wheat, maize, and soybeans). Little is known of the adverse impacts of climate change on the crops and resources that have been traditionally important to the poor, such as millets, roots, and tubers, and crops of emerging significance, such as fruits and vegetables, livestock, and fish. A holistic strategy is needed to formulate a long-term research portfolio and a development plan for dealing with climate shocks and for building a climate-resilient food system that takes into account the complexity of the food-water-energy nexus. Many agricultural "best practices" (such as reduced tillage) are also best practices for sustainable management of carbon, nitrogen, and water stocks—helping raise production and building resilience against climate variability in addition to mitigating (or even reversing) greenhouse gas fluxes into the atmosphere. Understanding the disruptive effect of shifts in agroecological zones and production systems due to climate change on livelihoods of the rural poor as well as their *ex ante* and *ex post* coping strategies on- and off-farm (e.g., changes in land use allocations, migration) requires further investigation. More study is also needed on the impacts of mean climate change and extreme climate events (such as droughts and floods) on the nutritional status of the poor. Finally, climate mitigation can come from a reduction in the intensity of emissions from agriculture (emissions per ton of harvested product) or from a reduction in demand for high-emission products and toward dietary pathways with a lower emissions footprint. Investments in consumer behavior change could over the long term lead to a more climate-resilient food system.

In addition to making positive contributions to climate mitigation, sustainable intensification of food systems has direct impacts on agricultural resources and the natural resource base. Modern science and technology with big-data tools such as GIS, remote sensing, and precision agriculture have the potential to contribute significantly to sustainable intensification. Improved understanding of hydrological and biogeochemical cycles, such as N and P cycles, could help to improve soil nutrient balance and water and nutrient use efficiency. Transformative innovations and modern tools, however, are often not designed for smallholder use; adaptation to smaller scales is a major challenge for research and technology design targeted to developing-country agriculture. Advances in renewable energy sources, such as solar and biofuels, could contribute to more efficient energy use and a more sustainable resource base. Emerging bioeconomy paradigms and practices, such as the reuse of bio-waste, could help reduce current trade-offs in land resource use between food and energy.

The locus of scientific research and innovation is rapidly moving from public sector laboratories and universities to multinational bioscience companies. This trend is likely to continue into the future, and this holds true for disruptive innovations with potential applications to developing countries as well. The international agriculture research system, CGIAR, may need to increasingly focus on its comparative advantage in areas of market failure, where private sector investments are limited. The continued amalgamation of the bioscience companies and the food industry can transform power relations in ways that could hamper access to technology for the poor. It is important to understand the conditions under which CGIAR could play an essential role as a conduit for technology access, adaptation, and delivery to poor, smallholder agricultural systems.

Finally, as already stated, food and agricultural policy needs to become more holistic, operating at the nexus between productivity, environment, and human health. In-depth analysis and monitoring of trends in food supply, demand, availability, input consumption, waste, and recycling must be weighed in the context of planetary boundaries. This agri-food systems approach could provide a policy framework for driving future sustainability by relieving pressure on stressed systems, leading to an increased focus on environmental care and reduced footprints, and making progress toward achievement of the SDGs. Such an integrated food policy will help promote sustainable intensification while ensuring nutrition security as incomes rise and diets further diversify in emerging economies. The health implications of food policies must also be explicitly considered, specifically with regard to the rising trends in obesity and noncommunicable diseases. Climate mitigation through carbon sequestration programs, such as plantation agriculture and recycling of agricultural wastes, can become income growth opportunities for smallholders. Finally, as economies grow, investments in rural human capital are essential to help people transition out of agriculture. Particularly important are investments targeted toward rural youth, whose capacity may be often underutilized.

Table A1.1. Summary of chapters.

Authors	Title	Main conclusions
2. Albino Maggio, Fabiana Scapolo, Tine van Criekinge, and Rachid Serraj	Global drivers and megatrends in agri-food systems	• 14 megatrends are shaping the future, including some trends that are "usual suspects" (4), trends recognized as important but not addressed properly (3), game changers (3), and trends to be taken into account in systemic analysis (4).
3. Aslihan Arslan, Eva-Maria Egger, and Paul Winters	Migration, demography, and agri-food systems	• Expected demographic trends (until 2050) translate into expected increases in rural-urban migration rates in low- and lower-middle-income countries (primarily in Africa); this trend is even more pronounced for youth migration. • Higher projected migration rates are correlated with lower levels of income, low commercialization of agricultural production, low specialization, and slow agricultural productivity growth, suggesting that rural-urban migration is part of the rural transformation process. • Policies should consider gender differences in mobility and access to resources; evidence suggests that young women are at a particular disadvantage. • There are research gaps on the implications of rural transformation and agri-food value chains on internal migration, especially in Africa and Asia; on linkages between climate change and internal migration; and on seasonal migration and its implications for rural, peri-urban, and urban livelihoods under the projected demographic and climatic pressures.

Table A1.1. (*continued*).

4. Peter B. R. Hazell	Urbanization, agriculture, and smallholder farming	• By 2050, 82.4% of the world's urban population will be based in less-developed regions; urbanization is leading to more diverse national diets, with increased per capita demand for livestock and horticultural products and processed and precooked foods, and reduced per capita demand for traditional food staples. • Urbanization and the changing nature of the agri-food system offer new opportunities for those small farms that can successfully link to value chains on a commercial basis, but also present obstacles that threaten to exclude many other small farms. • Small farms will play a diminishing role in feeding urban populations with food staples, but many will be successful in producing some high-value and labor-intensive products for urban markets. • Assistance programs for small farms, including agricultural research, will need to be better targeted to meet the changing needs of different types of farm households as their livelihood strategies diverge.
5. Alex C. Ruane and Cynthia Rosenzweig	Climate change impacts on agriculture	• Climate change and related shifts in the distribution of extreme events are increasingly clear and pose sizable challenges for food production and stability. • Ability to understand the diversity of climate responses is limited by the complexity associated with differences in latitudes, agroecological zones, and agricultural systems ($G \times E \times M$) interactions. • Advances in modeling (AgMIP; CGRA) allow integrated assessment frameworks to systematically evaluate vulnerability, feedback loops, and unintended consequences within complex food systems; this also helps stakeholders and policymakers identify and prioritize adaptation strategies.

Table A1.1. (*continued*).

6. Kristel Van der Elst and Alex Wlliams.	Environment and natural resources (Land, Water & Ecosystems)	• The business-as-usual trajectory of environment and natural resources management as well as alternative scenarios to 2050 have are key policy implications for strategic decision making and governance. Present and future environmental health is discussed with a particular focus on biodiversity, biogeochemical flows, marine health, terrestrial degradation, and land-use productivity. • There is a risk of emergence of a water-scarcity-dominated regime, where extreme regional water pressures—induced by human activities and climate change—compromise the freshwater reserves essential for life and economic stability, such as water for drinking, sanitation, and food production. • Climate change, fragmented and lost habitat, overfishing, coastal pollution, and the invasive species rate of spread are among the highest risk factors for continued biodiversity losses. • Key threats and opportunities, if capitalized upon, can provide a high-level policy framework to drive significant sustainability improvements, which can secure the future of natural resources and the environment, mainly by relieving pressure on stressed systems, and advance progress toward meeting specific SDGs.
7. J. V. Meenakshi and Patrick Webb	Food systems, diets, and nutrition	• The relationship between agriculture and nutrition has long been recognized. While high-quality diets are critical and agriculture plays a key role, investments in agriculture will need to interface with investments in roads, water systems, education, disease control, disaster management, and poverty reduction. • For overall sustainability, policies and incentive structures for farmers (to influence crop choice) will need to consider inherent trade-offs (nutrition, yields, yields defined in terms of nutrition water productivity, etc.). Data to inform nutrition and health policy are sparse and require investment.

Table A1.1. (*continued*).

		• Food supply and access are twin pillars of a high-quality diet and will need to be managed in the context of persistent shocks/threats (climate change, emerging pests and diseases of crops and livestock, etc.). • Anemia as a health issue requires urgent attention—half of the anemia burden can be attributed to poor-quality diets, and changing diets takes time. Developing countries, traditionally set up to focus on malnutrition and maternal/child health, will also need to address noncommunicable diseases. • Dietary quality requires investments in market and transportation infrastructure to ensure year-round access to nutrient-rich foods, make high-value foods more accessible to consumers, etc.
8. Peter Langridge	Innovation in breeding and biotechnology	• Biotechnology already makes a significant contribution to crop and animal improvement, and the agricultural biotechnology industry is expected to reach almost $55 billion by 2022. • Innovations in crop improvement expected to accelerate genetic gain in breeding include more efficient use of genetic resources; accessing of genomic regions and generation of novel variation through mutagenesis, gene editing, and genetic engineering; and exploitation of heterosis through hybrids and apomixes. • Investment in technology development alone is not sufficient; strong support for breeding programs is needed to optimize their strategies and use of the diverse array of technological options. • New varieties must be delivered to farmers as part of a package that includes optimal production methods and looks at the entire farming system.

Table A1.1. (*continued*).

9. Yanbo Huang and Molly E. Brown	Advancing to the next generation of precision agriculture	• Novel technologies and innovations such as unmanned aerial vehicles, big data, artificial intelligence, and automation have been developed for diverse applications in precision agriculture. • The new generation of precision agriculture will be characterized by high-performance cloud/mobile computing, intensive big data analysis, artificial intelligent perception, and real-time control and automation. • Precision agriculture applications relevant for smallholders include inexpensive online massive data, real-time monitoring, optimization and control, use of mobile devices, and social media applications. • Various information and communication technologies and digital agriculture systems applications can transform knowledge of farming systems and provide powerful tools for engaging smallholders, by improving information accessibility, ensuring institutional credibility, and stimulating their ability to improve agricultural productivity.
10. Patrick van der Duin and Silke den Hartog	Disruptive futures: Prospects for breakthrough technologies	• The potential disruptiveness of a technology depends not only on its technical performance, but also on how and the extent to which it addresses societal issues and Grand Societal Challenges (GSCs). • Bioinformatics, smart farming, synthetic biology, food design, and the protein transition often play a role in addressing the GSCs; the connection is less well-recognized for vertical agriculture, aquaculture, and conservation technology. • The future of the agro-food sector will be disruptive, shaped by new technologies in new contexts; many technologies can achieve a combination of economic, social, and environmental objectives, but the most important question in the future will concern how society will deal with new technological possibilities? • Technological trends, GSCs, and scenarios are instruments that provide an important basis for further study, policy studies, innovation, and public debate.

Table A1.1. (*continued*).

11. Jonathon Crouch	Investor perspectives on future priorities	• Mapping capital flows to African agriculture highlights the critical need for addressing the “missing middle” to enable scaling up of agribusiness investment across the region. • Investor perspectives on agribusiness investment help explain the key constraints to investor appetite in the sector, at different points along agri-food value chains, and at different investment sizes. • Building inclusive agribusinesses can help achieve development impact at scale based on an ecosystem approach that facilitates the sharing of value capture across all components of the value chain, from the perspective of impact investment in small and medium-sized enterprises as well as opportunities in value chains dominated by multinational corporations. • Promising commercial opportunities in agricultural development are presented from an agritech venture capitalist’s perspective, with particular focus on three of the most important factors for commercial agricultural development over the coming decades in Africa, where new technologies may have greatest impact: water, protein, and data.
12. Marie-Hélène Schwoob, Peter Timmer, Martin Andersson, and Sébastien Treyer	Agricultural transformation pathways toward the SDGs	• The dynamics of past development processes show a heterogeneity of systems and pathways, and a heterogeneity of such systems’ ability to address challenges such as preserving natural resources or closing the gap between the living levels of the agricultural and non-agricultural labor force. • Analysis must start at the country level to establish priorities and test options and pathways in the long term that are coherent with the specific conditions of each location. Multiple tools, approaches, and methodologies are being developed by projects that aim at building shared visions of the future and commonly agreed pathways in participatory ways. • More research is needed on the sociopolitical roadblocks to transformation. The role of local stakeholders in implementing actions must be taken into account.

Table A1.1. (*continued*).

13. Pablo Tittonell	Ecological intensification of agriculture	• Three major reasons for current productivity gaps in Sub-Saharan Africa are as follows: (1) inadequate models of agricultural development coupled with increasing population densities in rural areas have led to severe degradation of the natural resource base; (2) poor farmers in the poorer regions do not have access to, cannot afford, or are unwilling to adopt modern agricultural technologies; and (3) technologies were not developed to fit the reality of smallholder systems in these contexts and hence are ineffective at increasing crop and livestock productivity. • The increase in food production needed over the next decades cannot be fueled by further inputs of N, P, and water—at least not at the same rate as in the past 50 years. • New forms of agroecological intensification are needed to produce more food where it is needed and to make use of natural ecosystem functions to reduce the need for and increase the efficiency of external inputs. Promising avenues are explored based on recent experiences in Sub-Saharan Africa in which agroecological principles are used to design restorative and resource-use-efficient agriculture.
14. Jeffrey Skeer and Rodrigo Leme	Renewable energy in the energy future	• Keeping global warming to an increase less than 2° C. will require dramatic reductions in carbon emissions and nearly complete decarbonization of the energy system, implying the substitution of substantially carbon-free renewable energy sources for carbon-bearing energy vectors. • Renewable energy—including bioenergy—will play a growing role in the global energy mix. • There is substantial potential to produce additional bioenergy by closing the gap between projected and potential crop yields, making land available for bioenergy crops through restoration of degraded land and sustainable intensification of pastureland used for livestock production, and reducing waste and losses in the food chain. • The chapter summarizes trends in energy use in agriculture (e.g., irrigation, fertilizer production, processing) and examines the conditions and policy environment to assist the energy transition.

Table A1.1. (*continued*).

15. Regina Birner and Carl Pray	Bioeconomy	• The forecasting framework on the development of the bioeconomy highlights various demand-side and supply-side factors influencing the competition between biomass for food and biomass for energy and materials. • While the agriculture sector is currently the largest component of the bioeconomy in terms of both biomass share and employment and turnover, the bioenergy and biomaterials share could grow significantly in the coming decades depending on factors such as biofuel policy. • The driving forces of the bioeconomy on the supply side include the perceived scarcity and price of fossil fuels; the need for climate change mitigation; biotechnology innovations (agriculture, marine and freshwater, insects); efforts to improve the sustainability of the economic system, in particular by linking to the circular economy concept; and innovations in bio-based resources. • Changes in population and income levels, with associated changes in consumption patterns and increased demand for food, energy, and materials, are important demand-side factors. • International agricultural research must play a major role in reducing the competition between the use of biomass for the bioeconomy and food security, by increasing crop productivity, creating novel ways of managing inputs, and using by-products of outputs. The rise of the bioeconomy calls for specific attention to three food/biofuel crops: corn, sorghum, and cassava. Increasing their productivity and use of residues and stalks in industrial products has implications for food security, energy, and smallholder farmer income.

Table A1.1. (*continued*).

16. John Ingram and Monika Zurek	Food systems approaches for the future	• A shift was made from a focus solely on food production to one that also incorporates food consumption, retail, and policy. Food systems approaches integrate multiple activities, actors, and motivations; multiple environments and drivers; and multiple outcomes of food systems activities. Hence the approach allows food chain activities to be linked to their social, economic, and environmental context. • Food systems "thinking" can identify and address root causes of malnutrition; establish connections with other systems (e.g., energy, infrastructure, information); and analyze synergies and trade-offs of interventions (between food and nutrition security, environment, and other societal goals). • Besides providing a framework to structure the debate around a highly complex issue, food systems thinking allows for an integrated assessment that can focus on impacts and leverage points in different domains of the food system.
17. Kym Anderson	Global trade futures	• As climate change becomes more damaging to food production, there is more reason for countries to be open to international food markets and allow trade to buffer seasonal fluctuations in each country's domestic production and to reduce the volatility of global food prices. • Prospects for freeing up farm trade with bilateral and regional preferential free trade agreements, for stronger WTO disciplines not only on farm import tariffs and nontariff trade measures but also on domestic support policies, and especially for unilateral market liberalization through more efficient instruments to assist the most food-insecure households, such as conditional targeted income supplements, become administratively feasible even in low-income countries. • Trade opening should be considered among the food policy options of national governments seeking to reduce income inequality, poverty, malnutrition and hunger; to boost diet diversity and food safety; and to raise food quality.

Table A1.1. (*continued*).

18. Prabhu Pingali and Anaka Aiyar	Food, agriculture, and nutrition policy: Looking ahead to 2050	• To address the multiple challenges it faces, the global food system requires an alternative paradigm where the main goal of policymakers is to ensure better health and well-being of all stakeholders (individuals, biodiversity, firms, governments). • A first policy priority is to reorient away from sector-specific goals and toward integration of sectoral priorities into a more climate-sensitive food system and to consider spillover impacts across sectors. • A second policy priority involves changing the focus of the scientific community from designing strategies to increase calorie production to strategies that improve access to nutrition.

References

Abraham, M., and Pingali, P. L. (2017). Transforming smallholder agriculture to achieve the SDGs. In Riesgo, L., Gomez-Y-Paloma, S., and Louhichi, K., eds., *The role of small farms in food and nutrition security*. New York: Springer.

Alexandratos, N., and Bruinsma, J. (2012). *World agriculture towards 2030/2050: The 2012 revision*. Rome: Food and Agriculture Organization of the United Nations.

Böhme, M. H. (2015). Does migration raise agricultural investment? An empirical analysis for rural Mexico. *Agr. Econ*., 46(2), pp. 211–225.

Campbell, B. M., Beare, D. J., Bennett, E. M., Hall-Spencer, J. M., Ingram, J. S. I., Jaramillo, F., Ortiz, R., *et al*. (2017). Agriculture production as a major driver of the earth system exceeding planetary boundaries. *Ecol. Soc*., 22(4), p. 8. https://doi.org/10.5751/ES-09595-220408.

Castelhano, M., Lawell, C.-Y. C. L, Sumner, D. A., and Taylor, J. E. (2016). *Migration, remittances, and productive investment in rural Mexico*. Working paper. University of California at Davis.

Cui, Z., Zhang, H., Chen, X., Zhang, C., Ma, W., Huang, C., *et al*. (2018). Pursuing sustainable productivity with millions of smallholder farmers. *Nature*, 555, p. 363.

Delgado, L., Schuster, M., and Torero, M. (2017). *The reality of food losses: A new measurement methodology*. IFPRI Discussion Paper 1686. Washington, DC: International Food Policy Research Institute (IFPRI).

Development Initiatives. (2017). *Global nutrition report 2017: Nourishing the SDGs*. Bristol, UK.Dolislager, M. D., Tschirley, D., and Reardon, T. (2015). Consumption patterns in eastern and southern Africa. Report to the U.S. Agency for International Development (USAID). East Lansing, MI: Michigan State University, Innovation Lab for Food Security Policy.

FAO (Food and Agriculture Organization of the United Nations). (2011). The state of the world's land and water resources for food and agriculture (SOLAW): Managing systems at risk. Rome: FAO, and London: Earthscan.

FAO, IFAD, UNICEF, WFP, and WHO (Food and Agriculture Organization of the United Nations, International Fund for Agricultural Development, United Nations Children's Fund, World Food Programme, and World Health Organization). (2017). *The state of food security and nutrition in the world 2017: Building resilience for peace and food security*. Rome: FAO.

Foresight. (2011). *The future of food and farming*. Final Project Report. London: Government Office for Science.

Fraceto, L. F., Grillo, R., de Medeiros, G. A., Scognamiglio, V., Rea, G., and Bartolucci, C. (2016). Nanotechnology in agriculture: Which innovation potential does it have? *Frontiers Environ. Sci*., 4, p. 20. doi:10.3389/fenvs.2016.00020.

Giller, K. E., Andersson, J. A., Sumberg, J., and Thompson, J. (2017). A golden age for agronomy? In Sumberg, J., ed., *Agronomy for development: The politics of knowledge in agricultural research*, pp. 150–160. London: Taylor and Francis.

GKI (Global Knowledge Initiative). (2017). Innovating the future of food systems: A global scan for the innovations needed to transform food systems in emerging markets by 2035. Washington, DC.

Global Panel. (2016). *Food systems and diets: Facing the challenges of the 21st century*. London: Global Panel on Agriculture and Food Systems for Nutrition.

GRC (Global Research Council). (2017). *Statement of principles on interdisciplinarity*. https://www.jsps.go.jp/english/egrc/data/5th/Statement_of_Principles_on_Interdisciplinarity_FINAL.pdf.

Gustafson, D., Gutman, A., Leet, W., Drewnowski, A., Fanzo, J. and Ingram, J. (2016). Seven food system metrics of sustainable nutrition security. *Sustainability*, 8 (3), p. 196.

Hoff, H. (2011). Understanding the nexus. Background paper for the conference "The Water, Energy and Food Security Nexus," Bonn, November 16–18. Stockholm: Stockholm Environment Institute.

IPCC (Intergovernmental Panel on Climate Change). (2013). Summary for policymakers. In Stocker, T. F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S. K., Boschung, J., Nauels, A., *et al*., eds., *Climate change 2013: The physical science basis*. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press.

IPCC. (2014). Summary for policymakers. In Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Farahani, E., Kadner, S., Seyboth, K., Adler, A., *et al*., eds., *Climate change 2014: Mitigation of climate change*. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press.

ISPC (Independent Science and Partnership Council). (2015). Background paper for FC13 session on dryland systems. Fund Council, 13th meeting, Bogor, Indonesia, April 28–29.

ISPC. (2017). Quality of research for development in the CGIAR context. Brief No. 62. Rome.

Katz, J. S. (2016). What is a complex innovation system? *PLoS One*, 11(6), e0156150. https://doi.org/10.1371/journal.pone.0156150.

Le Mouël, C., and Forslund, A. (2017). How can we feed the world in 2050? A review of the responses from global scenario studies. *Eur. Rev. Agr. Econ*., 44(4), pp. 541–591.

Machingura, F., and Lally, S. (2017). *The Sustainable Development Goals and their trade-offs*. ODI Development Progress: Case Study Report. London: Overseas Development Institute.

Malingreau, J. P., Eva, H., and Maggio, A. (2012). *NPK: Will there be enough plant nutrients to feed a world of 9 billion in 2050?* Brussels: European Commission Joint Research Centre.

Masters, W. A., Djurfeldt, A. A., De Haan, C., Hazell, P. Jayne, T., Jirström, M., and Reardon, T. (2013). Urbanization and farm size in Asia and Africa: Implications for food security and agricultural research. *Global Food Security*, 2(3), pp. 156–165. https://doi.org/10.1016/j.gfs.2013.07.002.

Nature Editors. (2015). Mind meld: Interdisciplinary science must break down barriers between fields to build common ground. *Nature*, 525(7569), pp. 289–290.

OECD (Organisation for Economic Co-operation and Development). (2016). *States of fragility 2016: Understanding violence*. Paris. http://dx.doi.org/10.1787/9789264267213-en.

Pingali, P., (2006). Westernization of Asian diets and the transformation of food systems: Implications for research and policy. *Food Policy*, 32(3), pp. 281–298.

Pingali, P. L. (2012). Green Revolution: Impacts, limits, and the path ahead. *PNAS*, 109, pp. 12302–12308.

Quisumbing, A. R., and McNiven, S. (2010). Moving forward, looking back: The impact of migration and remittances on assets, consumption, and credit constraints in the rural Philippines. *J. Devel. Stud.*, 46(1), pp. 91–113.

Reardon, T., Tschirley, D., Dolislager, M., Snyder, J., Hu, C., and White, S. (2014). *Urbanization, diet change, and transformation of food supply chains in Asia*. Report for the U.S. Agency for International Development (USAID). Project of the Global Center for Food System Innovation and the Food Security Policy Innovation Lab, Michigan State University, East Lansing, MI.

Rigaud, K. K., de Sherbinin, A., Jones, B., Bergmann, J., Clement, V., Ober, K., Schewe, J., *et al*. (2018). *Groundswell: Preparing for internal climate migration*. Washington, DC: World Bank.

Ripple, W. J., Wolf, C., Newsome, T. M., Galetti, M., Alamgir, M., Crist, E., Mahmoud, M. I., and Laurance, W. F. (2017). World scientists' warning to humanity: A second notice. *BioScience*, 67(12), pp. 1026–1028. https://doi.org/10.1093/biosci/bix125.

Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin, III, F. S., Lambin, E., Lenton, T. M., *et al*. (2009). Planetary boundaries: Exploring the safe operating space for humanity. *Ecol. Soc*., 14(2), p. 32.

Rosenzweig, C., Jones, J. W., Hatfield, J. L., Ruane, A. C., Boote, K. J., Thorburn, P., Antle, J. M., *et al*. (2013). The Agricultural Model Intercomparison and Improvement Project (AgMIP): Protocols and pilot studies. *Agric. Forest Meteorol*., 170, pp. 166–182. doi:10.1016/j.agrformet.2012.09.011.

Rosenzweig, C., Antle, J., and Elliott, J. (2016). Assessing impacts of climate change on food security worldwide. *Eos*, 97(8), p. 11. doi:10.1029/2016EO047387.

Roser, M., and Ortiz-Ospina, E. (2017). Global extreme poverty. Our World in Data, March 27. https://ourworldindata.org/extreme-poverty.

Safriel, U., and Adeel, Z. (2005). *Dryland systems*. In *Millennium ecosystem assessment*, Chapter 22. Washington, DC: World Resources Institute and Island Press.

Seto, K. C., Fragkias, M., Güneralp, B., and Reilly, M. K. (2011). A meta-analysis of global urban land expansion. *PLoS One*, 6, e23777.

Seto, K. C., Güneralp, B., and Hutyra, L. R. (2012). Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. *PNAS*, 109, pp. 16083–16088.

Seto, K. C., and Ramankutty, N. (2016). Hidden linkages between urbanization and food systems. *Science*, 352(6288), pp. 943–945.

Small, B. (2017). Digital technology and agriculture: Foresight for rural enterprises and rural lives in New Zealand. *J. Agr. Environ. Sci.*, 6(2), pp. 54–77. doi:10.15640/jaes.v6n2a7.

Smith, P., Bustamante, M., Ahammad, H., Clark, H., Dong, H., Elsiddig, E. A., Haberl, H., *et al*. (2014). Agriculture, forestry and other land use (AFOLU). In Edenhofer, O., Pichs-Madruga, R., Sokona, T., Farahani, E., Kadner, S., Seyboth, K., Adler, A., *et al*., eds., *Climate change 2014: Mitigation of climate change*. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press.

Taylor, J. E., Rozelle, S., and de Brauw, A. (2003). Migration and incomes in source communities: A new economics of migration perspective from China. *Econ. Dev. Cultur. Change*, 52(1), pp. 75–101.

Tilman, D., Cassman, K. G., Matson, P. A., Naylor, R., and Polasky, S. (2002). Agricultural sustainability and intensive production practices. *Nature*, 418, 671–677.

Tomich, T. P., Brodt, S., Ferris, H., Galt, R., Horwath, W. R., Kebreab, E., and Yang, L. (2011). Agroecology: A review from a global-change perspective. *Ann. Rev. Environ. Resourc*., 36, pp. 193–222.

Tomich, T. P., Lidder, P., Coley, M., Gollin, D., Meinzen-Dick, R., Webb, P., and Carberry, P. (2018). Food and agricultural innovation pathways for prosperity. *Agr. Syst*., in press. https://doi.org/10.1016/j.agsy.2018.01.002.

UN (United Nations). (2015). *World urbanization prospects: The 2014 revision*. New York: United Nations, Department of Economic and Social Affairs, Population Division.

UN. (2017). *World population prospects: The 2017 revision: Key findings and advance tables*. Working Paper No. ESA/P/WP/248. New York: United Nations, Department of Economic and Social Affairs, Population Division. https://esa.un.org/unpd/wpp/Publications/Files/WPP2017_KeyFindings.pdf.

Valdivia, R. O., Antle, J. M., Rosenzweig, C., Ruane, A. C., Vervoot, J., Ashfaq, M., Hathie, I., *et al*. (2015). Representative agricultural pathways and scenarios for regional integrated assessment of climate change impacts, vulnerability, and adaptation. In Rosenzweig, C., and Hillel, D., eds., *Handbook of climate change and agroecosystems: The Agricultural Model Intercomparison and Improvement Project (AgMIP) integrated crop and economic assessments*, Part 1, pp. 101–156.

ICP Series on Climate Change Impacts, Adaptation, and Mitigation, Vol. 3. London: Imperial College Press.

van Ittersum, M. K., and Cassman, K. (2013). Yield gap analysis: Rationale, methods and applications: Introduction to the Special Issue. *Field Crops Res*., 143, pp. 1–3.

Verhagen, J., Blom, G., van Beek, C, and Verzandvoort, S. (2017). *Approaches aiming at sustainable agricultural production*. Wageningen Research Report WPR-677. Wageningen, Netherlands: Wageningen Research Foundation. http://dx.doi.org/10.18174/416937

WEF (World Economic Forum). (2018). Innovation with a purpose: The role of technology innovation in accelerating food systems transformation. Geneva.

World Bank. (2017). *An overview of links between obesity and food systems; Implications for the Agricultural GP agenda*. Washington, DC: World Bank, Agricultural Global Practice. http://www.gainhealth.org/wp-content/uploads/2017/07/Final-Overweight-Obesity-Report.pdf.

World Bank. (2018). *Fragility, conflict, and violence*. Washington, DC. http://www.worldbank.org/en/topic/fragilityconflictviolence/overview.

WWF (World Wide Fund for Nature). (2016). *Living planet report 2016: Risk and resilience in a new era*. Gland, Switzerland: WWF International.