[NINE]

Global Food Demand Projections

A Review

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SINCE THE 1960S, the world population has increased from about three billion to more than seven billion people.[1] At the same time, although inequality remains large, global average gross domestic product (GDP) per capita worldwide has increased almost threefold from around US$3,700 per capita to more than US$10,000 per capita measured in constant 2010 dollars.[2] Most of the growth can be attributed to the emerging economies such as China and India, but notable progress has also occurred in African countries. Population and income growth have led to an increasing demand for food. At least until the end of the past century, modernization of farming systems, technological change, and increase in trade ensured that food supply kept pace with the increasing demand for food, illustrated by the trend in decreasing food prices.[3] Nonetheless, the food price spikes in 2007–8 indicated that the balance between food demand and food supply is becoming fragile.

The latest population projections show that the world population will reach 9.8 billion in 2050 and 11.2 billion in 2100, resulting in an increase in the demand for food. At the same time, climate change is expected to have negative effects on agricultural yields, and crops such as maize and sugar are increasingly used for the production of biofuels, putting additional pressure on the food demand-and-supply equation. An important question that arises is what this all means for future food demand. Will food consumption continue to grow in the future? And by how much would the production of food need to increase in order to satisfy food demand?

The aim of our study is to review and compare existing scenarios of world food demand up to 2050. These explorative scenarios present trends on contrasting but plausible developments of food demand in the future and, hence, provide information on the required increase in the food production that is necessary to feed the world population by 2050. This latter issue is a key question for policy makers and scientists. In general, it requires an assessment of the earth's capacity to produce sufficient food and/or an analysis of population dynamics and diets. Note that our analysis does not cover the question, By how much *should* food demand and production change in the future to feed the world population? This normative question requires different types of scenario studies that we do not cover in our review.

Drivers of (Future) Food Demand

The global demand for food, now and in the future, is strongly influenced by several key driving forces. The most obvious factor is population growth. A second important determinant of global food consumption constitutes the changes in dietary patterns. In particular, lower- and middle-income countries are experiencing a rapid "nutrition transition"[4,5,6] from a traditional diet of grains rich in fiber toward a "Western diet" that is high in saturated fats (especially from animal products), sugar, and processed foods.[7,8,9] The most important drivers of the nutrient transition are economic growth, urbanization, technical change, and culture.[10] In this section, we first discuss the three main drivers of global food demand and reflect on how their development may affect the change in food demand in the future. Factors like culture, beliefs and religion also play a very important role in determining diet. These are, however, very idiosyncratic factors that often differ from country to country and are therefore very difficult to incorporate into global food demand projections. For this reason, we do not discuss them here.

Population Growth

According to the medium variant in the United Nations World Population Projections (figure 9.1), the global population will increase from 7.4 billion in 2015 to 9.8 billion in 2050. If we assume that average global food consumption remains constant at 2,897 kcal/cap/day,[11] a simple back-of-the-envelope calculation reveals that total food demand (measured as food availability) will increase by 32%. If we also consider the low and high variants of the population projections, the demand for food will increase by between 19% and 47% over the coming four decades.

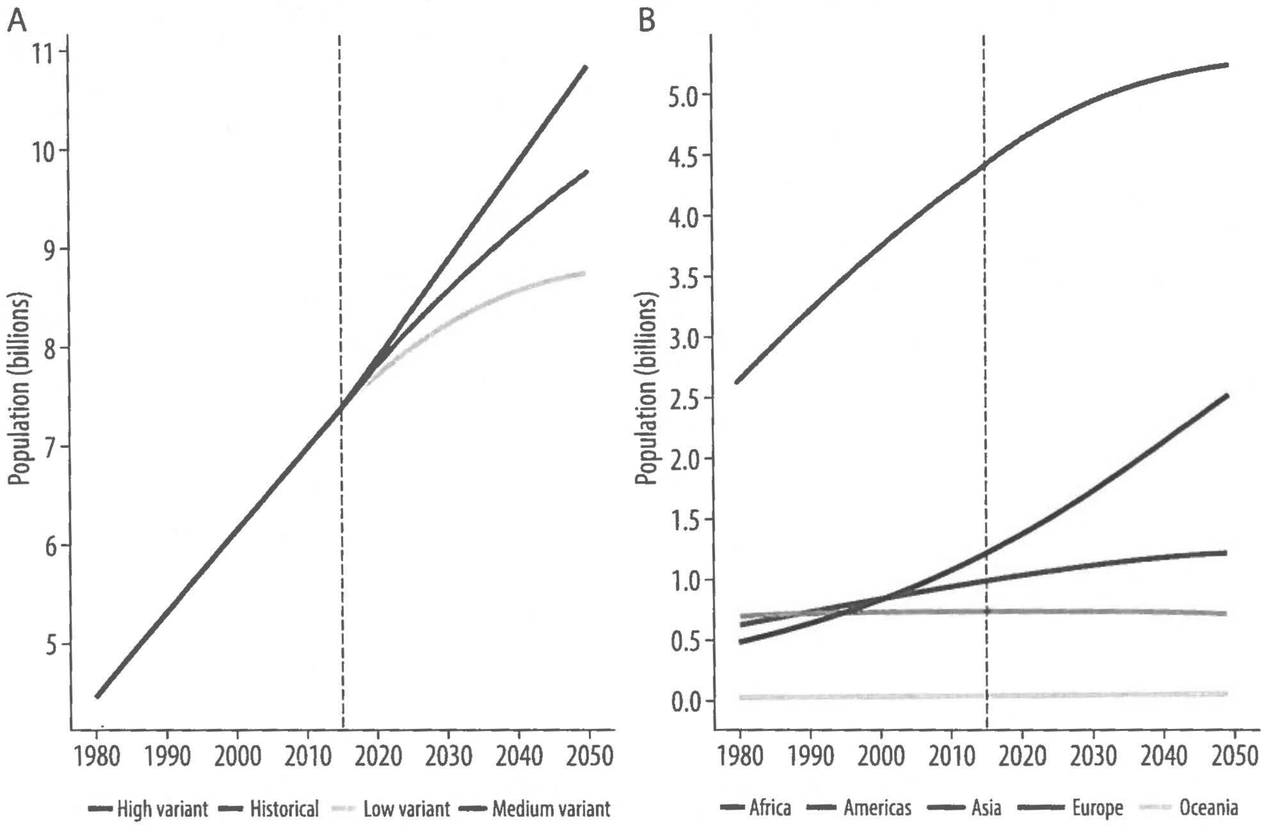

Figure 9.1. UN Population Projections. (A) High, medium, and low world population projections; (B) Medium world population projections by region.

Source: Data from "2017 Revision of World Population Prospects," United Nations Department of Economic and Social Affairs, 2018, https://population.un.org/wpp/.

FOOD AVAILABILITY AS PROXY FOR FOOD DEMAND

There are several sources of information that can be used to make international comparisons of the demand for food. Probably the most accurate sources are household budget surveys and individual dietary surveys, which provide detailed information on the consumption pattern at the individual and household level. Unfortunately, this type of information is difficult to compare across countries due to differences in methodology, definitions, and country coverage. For this reason, all global analyses of (future) food demand, including those in this chapter, use food availability from the FAOSTAT Food and Balance Sheets as an indicator of food consumption.

See John Kearney, "Food Consumption Trends and Drivers," *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences* 365, no. 1554 (September 2010): 2793–2807, and Sophie Hawkesworth et al., "Feeding the World Healthily: The Challenge of Measuring the Effects of Agriculture on Health," *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences* 365, no. 1554 (September 2010): 3083–97.

Most of the population growth will occur in Africa, where the total population is expected to more than double from 1.2 to 2.5 billion over the period 2015–50. At the same time, with 2,597 kcal/cap/day, Africa is also the region with the lowest average food consumption. Hence, the combination of rapid population growth and the expected nutrient transition toward diets that are higher in energy content will have a disproportional effect on total global food demand. The impact on other regions will be much smaller because of lower projected population growth and higher average food consumption levels.

The FAOSTAT Food and Balance Sheets (FBS) provide country-level annual breakdowns of the food that is available for human consumption. Food availability is calculated as total food produced in and imported into the country, minus exports of food, minus food used for other purposes (e.g., livestock feed, seed use, and losses along the supply chain), divided by population size. All food items are expressed in "primary commodity equivalent" (the amount of primary commodity input that would be required to produce a given amount of derived product output). This means that, for example, quantities of bread are expressed as wheat equivalents, using a product-specific technical coefficient, and then added to other wheat (equivalent) availability measures. Food availability is expressed in terms of both quantity and raw energy equivalent (kcal/cap/day), which can easily be aggregated and compared across countries.

The FBS Food availability indicator has to be regarded as a proxy for the actual food that is consumed. Comparison with household budget surveys has shown that it tends to overestimate actual food consumption. The main reason for this is that the availability indicator does not account for food waste and food fed to animals at the household and retail levels.[12,13]

Economic Development and Income Change

Income change is one of the main drivers of food demand and diet shifts. Two well-known empirical relationships describe distinct aspects of the connection between income and food demand. The first is Engel's law, named after the German statistician Ernst Engel (1821–96), which states that the proportion of food expenditure to total expenditure declines as income increases.[14] The second law is Bennett's law, named after M. K. Bennett,[15] who presented a pioneering study in which the diet composition of 40 countries is related to per capita income for the period 1934–39. Bennett's law shows that as people become wealthier, the share of starchy staples (e.g., cereals, potatoes, and plantain) in the diet will decrease, while the share of animal-related products, sugars, fruits, and vegetables will increase. The main explanation for this observation is that consumers tend to improve the variety of their diet as soon as they can afford it. As we discuss later, the empirical relationships described by Engels's and Bennett's laws are a key for the modeling of future food demand.

Bennett's law is illustrated by plotting the share of meat consumption in the diet against economic development at the country level (figure 9.2). The figure clearly shows a positive relationship between meat consumption and income per capita. In most developing countries, in particular those located in Africa and Asia, the share of meat consump-

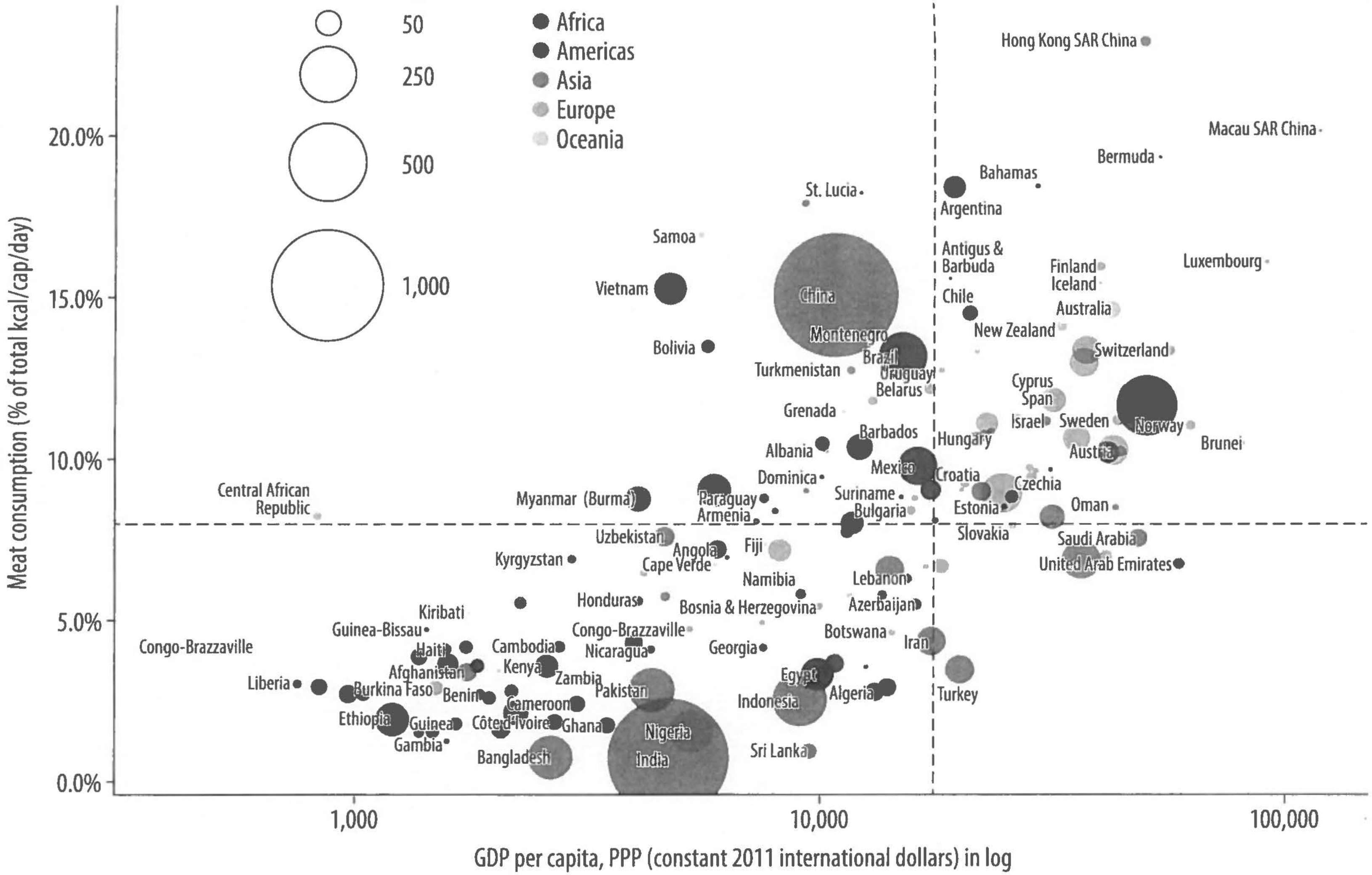

Figure 9.2. Meat Consumption and GDP per Capita, 2010-2015. Meat consumption includes bovine, mutton on goat, pig, poultry, and other meat groups.

Notes: Values are averages for the period 2010-15. The dashed lines indicate global averages, and the size of the circles measure population size. PPP = purchasing power parity. *Source:* Data on meat consumption: "FAOSTAT," Food and Agriculture Organization, http://www.fao.org/faostat/en/. Data on GDP per capita and population data: "World Development Indicators," World Bank, 2018, https://datacatalog.worldbank.org/dataset/world-development-indicators.

tion in the total diet is below the world average of 8%, while countries with a high income per capita exhibit a meat consumption of up to 23%. Bennett's law has important implications for the projection of future food demand. The OECD long-term global growth prospects expect that GDP per capita in the poorest economies will more than quadruple in the period from 2011 to 2060.[16] Combining these projections implies a dramatic increase in meat consumption for many African and Asian countries.

Urbanization

Apart from changes in income and population growth, urbanization, defined as the proportion of the urban residents in the total population, is considered a key driver of future food demand. Although urbanization is strongly linked to and interacts with economic development, it also has an independent effect on the pattern and structure of diets.[17] Several studies show a clear difference in food consumption patterns between urban and rural populations.[18] Overall, the diet of urban residents is characterized by consumption of superior grains (e.g., rice and wheat instead of corn and millet), foods higher in fat, more animal products, more sugar, and more processed food that is often prepared outside the home. This is illustrated by comparing the diets of households in urban and rural areas in Vietnam (figure 9.3).

There are various causes that explain this finding.[19] First, work done by urban residents is mainly sedentary and therefore requires less calorie-rich food than more physical demanding activities, which are often related to agriculture in rural areas. Second, food availability and income differ between urban and rural areas. In rural areas, most consumers are farm households that produce most of their own food, which means that the diet is often restricted to a relatively small number of crops that are regionally produced (e.g., starchy roots and tubers). This pattern contrasts with urban areas, where households generally do not grow their own food and have access to a broader selection of food products. The rapid increase in the number of supermarkets in African, Latin American, and Asian cities,[20] as well as the spread of "fast-food" res-

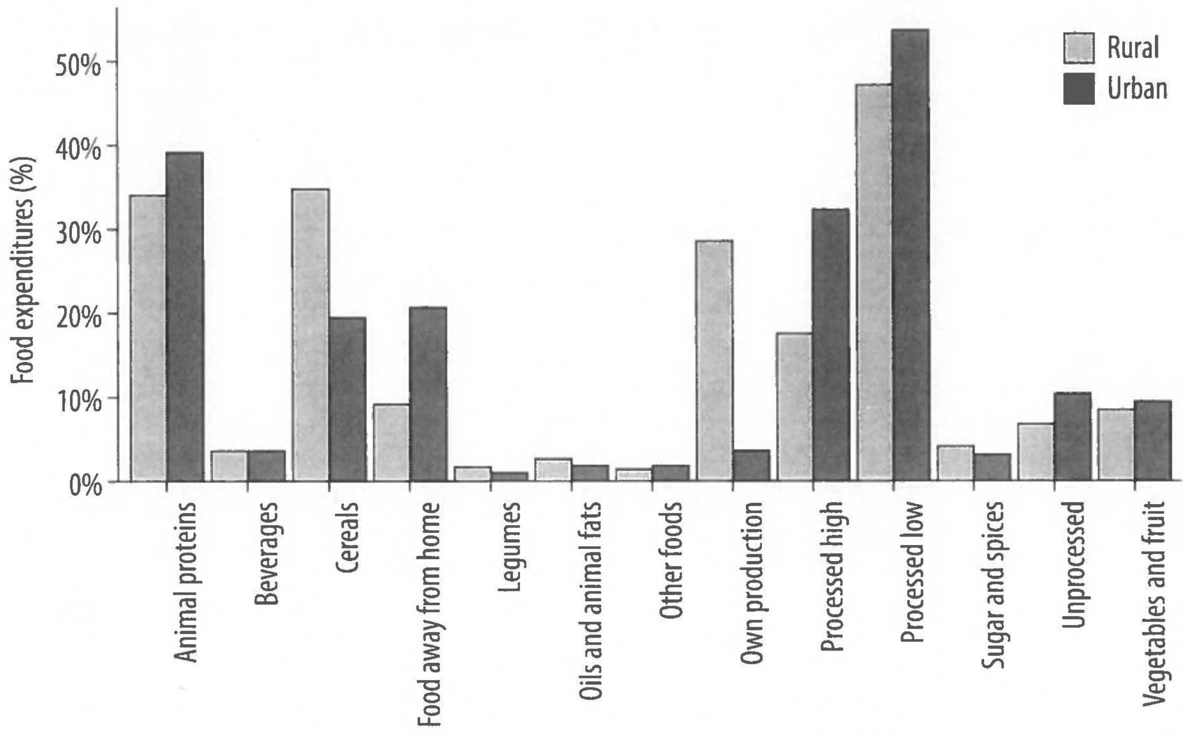

Figure 9.3. Comparison in Diets between Urban and Rural Areas in Vietnam.
Source: Data from Thomas Reardon, David Tschirley, Michael Dolislager, Jason Snyder, Chaoran Hu, and Stephanie White, "Urbanization, Diet Change, and Transformation of Food Supply Chains in Asia," Michigan State University, May 2014.

taurants, has made it easier for urban residents to purchase preprocessed products and "Western-style" food. Finally, urbanization is associated with greater participation of women in the workforce. The increased opportunity costs of time for women in combination with higher wages has shifted demand toward more processed foods with shorter preparation times and away from traditional food products.[21]

By far most of future population growth depicted in figure 9.1 will take place in urban areas. The urban population of the world has grown rapidly from 751 million in 1950 to 4 billion in 2015. According to the 2018 Revision of World Urbanization Prospects of the United Nations, the overall growth of the world population would add more than 2.5 billion people to urban areas by 2050.[22] A large part of this growth will take place in populous developing countries, such as China, India, and Nigeria and will therefore have a dramatic impact on the growth in global food demand.

The Prevailing View: Food Demand Will Increase by 70% (or 60%) in 2050

If one searched the Internet for an answer to the question, By how much will global food demand increase by 2050?, there is a large chance one would find 70%. This figure, which was downscaled to 60% in a revision,[23] has been (and still is) frequently cited in the media. It is evident that this figure (hereafter referred to as the 70% figure) has had considerable impact on the political, public, and scientific debate about global hunger, food price trends, and the capacity of the planet to feed the global population. In this section, we briefly describe its origins, summarize the methodology that was used to derive the figure, and outline several reasons why the 70% figure should be interpreted with care.

Its Origins: The Food and Agriculture Organization "World Agriculture: Towards" Studies

The 70% figure was first reported in a Food and Agriculture Organization (FAO) briefing paper that was released on 23 September 2009, as part of the High-Level Expert Forum on "How to Feed the World in 2050." The paper stated that, "in order to feed this larger, more urban and richer population, food production (net of food used for biofuels) must increase by 70 percent."[24] It is part of a series of FAO reports that assesses future world agriculture and food, the "World Agriculture: Towards . . ." (or FAO WAT) studies (figure 9.4).[25]

The basis of the 70% figure is the fourth report in the series, titled "World agriculture: Towards 2030/2050 Interim Report." Using UN global projections for population growth and FAO historical statistics on global diet change, agricultural production, and crop and livestock yield, the report presents a baseline scenario on future development of agricultural production and world food demand and supply until 2050. One of the main findings is that global agricultural production will need to increase by 87% between the base year 1999/2001 and 2050.[26,27,28] The 70% figure is essentially based on the analysis presented in the 2006 report with a minor update in terms of data and, most importantly, a

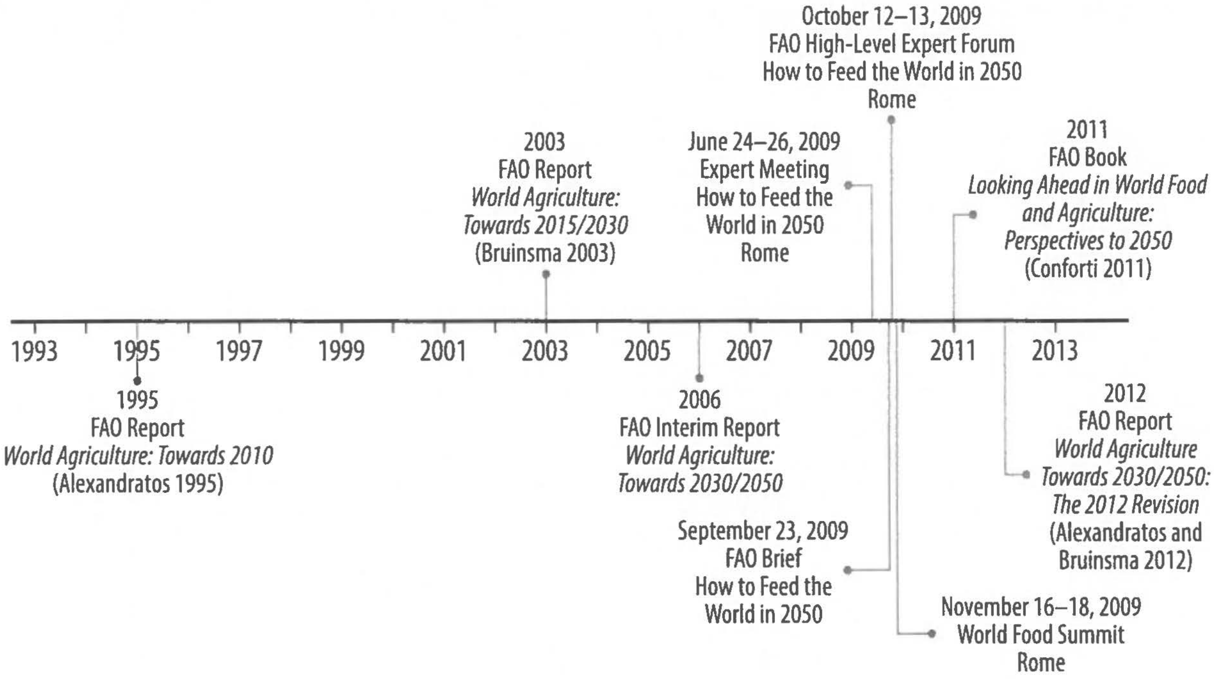

Figure 9.4. Timeline of FAO WAT (Related) Reports and Events.

Notes: The figure does not depict the *World Agriculture: Toward 2000* study, published in 1988. *Source:* Adapted from Harald Grethe, Assa Dembélé, and Nuray Duman. *How to Feed the World's Growing Billions: Understanding FAO World Food Projections and Their Implications* (Berlin: Heinrich-Böll-Stiftung, 2011).

more recent base year of 2005/7. The shorter projection period (44 years versus 50 years) is the main reason for the lower estimate of the required increase in world agricultural production.

Methodology

The 70% figure (and subsequent 60% revision) reflects an increase in value terms using constant 1989/91 international dollar prices: "The figures we use refer to the aggregate volume of demand and production of the crop and livestock sectors. They are obtained by multiplying physical quantities of demand or production times price for each commodity and summing up over all commodities (each commodity is valued at the same average international price in all countries in all years)."[29]

It is based on a single baseline scenario that describes trends in agricultural production and food demand and supply for a range of commodities and major regions. The scenario represents the "most likely" future change in world agriculture and food,[30] and does not explicitly refer to what is "required to feed the projected world population or to meet some other normative target."[31] For this reason, hunger is not completely eliminated in the FAO projections, and 4% of the developing countries' populations is still undernourished in 2050. The basis of the projections is the FAO Supply-Utilization Accounts (SUAs), which are part of an accounting framework that annually harmonizes the sources and uses of agricultural commodities. The first step is the preparation of food demand projections by commodity and country using Engel demand functions and exogenous assumptions on population and GDP per capita growth. The results are then "inspected by the commodity and nutrition specialists and adjusted taking into account any relevant knowledge and information, in particular the historical evolution of per caput demand and the nutritional patterns in the country examined."[32] In subsequent steps, food supply is projected and demand and supply are reconciled, which involves "several rounds of iterations and adjustments in consultation with specialists."[33]

The projections for future food demand rely on the 2002 UN medium population projections and (extrapolated) World Bank GDP growth projections as key inputs. World population is assumed to increase by around 40% between 2005/7 and 2050, reaching 8.8 billion in 2050. GDP per capita is assumed to increase by 2.1% in 2030 and by 2.7% in 2050. Although GDP per capita and population growth are the main drivers of the 70% projection, the FAO WAT methodology also incorporates other drivers of the demand for food and other agricultural products, including changes in income distribution (through the GDP projections), sociocultural factors (by means of country specific adjustments), food loss and waste, and the demand for biofuels. However, the reports present only very limited and often not specific information on how these factors have affected the food demand projections.[34]

The revised 60% figure is presented by Alexandratos and Bruinsma,[35] who apply the same basic methodology and reference year (2005/7) but use updated information on agricultural statistics and projections for population and GDP per capita growth. The main reason for the lower estimate is not a change in the food demand projections for 2050 but higher values for 2005/7 world production in comparison to the provisional figures that were used in the 2009 FAO briefing paper. They also indicate that the baseline scenario should be regarded as a "limited biofuels" scenario, as projections for biofuel demand apply only to the medium term.

Why the FAO WAT Results Must Be Interpreted with Care

For a number of reasons, the 70% (and 60%) increase in food demand should be interpreted with care.[36] First, the reference year that is used to calculate the 70% figure (2005/7) is more than 10 years old. As total agricultural production has increased since 2005/7, the actual increase estimated when using the present as the base year for the projection will be surely lower. Second, FAO uses a price-weighted index to measure aggregate food demand and production. A price-based index will grow faster than an index that uses calorie content as weights when there is a shift in the diet from low-priced staples toward higher-value products (e.g., processed foods and animal products).[37] Interestingly, the FAO WAT reports also present projections for the global change in kcal/cap/day, which makes it possible to calculate a calorie-based index of food demand that can be compared to other projections (see the next section). Third, the FAO WAT studies are largely based on expert knowledge (with limited documentation), which makes it very difficult to validate the assumptions and methodology.[38] Fourth, the FAO WAT projections do not take into account climate change, which is not realistic in view of the current evidence on the (mostly) negative impact of climate change on agricultural production.[39] Finally, and most importantly, the FAO WAT studies present only one baseline scenario. While the studies claim to represent the "most likely" future, there are, in fact, many other plausible futures and hence projections of food demand. Alternative projections of future population growth and income change will result in different food demand trajectories. It can hence be argued that assessing only one scenario is potentially misleading as it suggests only a limited degree of uncertainty.

Review of Recent Scenario-Based Food Demand Projections

As described earlier, global food demand depends on the complex interaction of several drivers whose future trajectory is far from clear. This means that future food demand is subject to a high level of uncertainty and might consequently diverge from the historical trend. A common approach to deal with high levels of complexity and uncertainty is the use of scenario analysis, which envisages several contrasting futures. A scenario is defined as a "plausible and often simplified description of how the future may develop, based on a coherent and internally consistent set of assumptions about key driving forces (e.g., rate of technology change, prices) and relationships."[40] To ensure consistency, scenario analysis often combines the development of storylines, which present the key features of potential future worlds (e.g., rate of technical change, population growth, and economic development), with quantitative modeling in order to assess the structural relationship between drivers and scenario outputs (e.g., agricultural production, food demand and supply, and number of people at risk of hunger).[41] Scenario analyses have been frequently used to asses major global issues, such as climate change,[42] ecosystem change,[43] and environmental and sustainability challenges.[44] They emerged only recently as a tool to assess global food security.[45]

In this section, we summarize the results of a systematic literature review to evaluate all major and recent global food demand scenario exercises.[46] Among the 61 that are included in the review, 23 use the "Shared Socio-economic Pathways (SSPs)" to quantify global food demand and supply.[47] In this section, we start by providing background information on the SSPs, followed by a brief description on the quantitative modeling approaches that have been used to quantify global food demand in a scenario setting. In the next two parts, we show the bandwidth of total food and commodity demand projections under different SSPs and provide an illustration of regional level results.

Shared Socioeconomic Pathways

The Shared Socio-economic Pathways (SSPs) are a recently developed scenario framework, prepared by the climate change research community in order to assess the impact of climate change.[48,49] They consist of two elements: narratives that describe five alternative but potential future socioeconomic developments[50] and a database with projections for key driving forces, in particular population and GDP growth.[51,52] The SSPs can be combined with assumptions on climate outcomes, the so-called representative concentration pathways (RCPs), to derive a matrix that reflects an elaborate scenario framework to assess the impact of climate change and its mitigation under a variety of socioeconomic conditions, such as the degree of inequality within and between societies, types of technology development, economic development, consumption patterns, and international integration or fragmentation between nations and regions.[53]

The five SSPs represent a variety of often contrasting worlds that are intended to span a wide range of plausible futures (table 9.1). They include a world with sustainable growth and equality (SSP1); a "middle-of-the-road" world in which future trends are comparable to historical patterns (SSP2); a fragmented world, characterized by nationalism and regional conflict (SSP3); a world with persistent and growing global inequality (SSP4); and a world dominated by rapid fossil-fueled economic growth (SSP5).

Methodologies to Assess Future Food Demand

As described earlier, the FAO WAT studies heavily rely on expert opinion to prepare the food demand projections. This approach is not very transparent and therefore difficult to validate and replicate. The systematic literature review by Van Dijk et al. shows that most recent studies use quantitative modeling approaches to assess future food demand. In these approaches, the structural relationship between drivers and the demand for food (following Engel's and Bennett's laws) is made explicit and analyzed in a consistent framework. Most of the studies that were

Table 9.1. Summary of SSP Narratives

SSP1	Sustainability	The world shifts gradually, but pervasively, toward a more sustainable path, emphasizing more inclusive development that respects perceived environmental boundaries. Management of the global commons slowly improves, educational and health investments accelerate the demographic transition, and the emphasis on economic growth shifts toward a broader emphasis on human well-being. Driven by an increasing commitment to achieving development goals, inequality is reduced both across and within countries. Consumption is oriented toward low material growth and lower resource and energy intensity.
SSP2	Middle of the Road	The world follows a path in which social, economic, and technological trends do not shift markedly from historical patterns. Development and income growth proceeds unevenly, with some countries making relatively good progress while others fall short of expectations. Global and national institutions work toward but make slow progress in achieving sustainable development goals. Environmental systems experience degradation, although there are some improvements and overall the intensity of resource and energy use declines. Global population growth is moderate and levels off in the second half of the century. Income inequality persists or improves only slowly and challenges to reducing vulnerability to societal and environmental changes remain
SSP3	Regional Rivalry	A resurgent nationalism, concerns about competitiveness and security, and regional conflicts push countries to increasingly focus on domestic or, at most, regional issues. Policies shift over time to become increasingly oriented toward national and regional security issues. Countries focus on achieving energy and food security goals within their own regions at the expense of broader-based development. Investments in education and technological development decline. Economic development is slow, consumption is material-intensive, and inequalities persist or worsen over time. Population growth is low in industrialized and high in developing countries. A low international priority for addressing environmental concerns leads to strong environmental degradation in some regions
SSP4	Inequality	Highly unequal investments in human capital, combined with increasing disparities in economic opportunity and political power, lead to increasing inequalities and stratification both across and within countries. Over time, a gap widens between an internationally-connected society that contributes to knowledge- and capital-intensive sectors of the global economy, and a fragmented collection of lower-income, poorly educated societies that work in a labor intensive, low-tech economy. Social cohesion degrades and conflict and unrest become increasingly common. Technology development is high in the high-tech economy and sectors. The globally connected energy sector diversifies, with investments in both carbon-intensive fuels like coal and unconventional oil, but also low-carbon energy sources. Environmental policies focus on local issues around middle and high income areas
SSP5	Fossil-fueled Development	This world places increasing faith in competitive markets, innovation and participatory societies to produce rapid technological progress and development of human capital as the path to sustainable development. Global markets are increasingly integrated. There are also strong investments in health, education, and institutions to enhance human and social capital. At the same time, the push for economic and social development is coupled with the exploitation of abundant fossil fuel resources and the adoption of resource and energy intensive lifestyles around the world. All these factors lead to rapid growth of the global economy, while global population peaks and declines in the 21st century. Local environmental problems like air pollution are successfully managed. There is faith in the ability to effectively manage social and ecological systems, including by geo-engineering if necessary.

Source: Keywan Riahi, Detlef P. van Vuuren, Elmar Kriegler, Jae Edmonds, Brian C. O'Neill, Shinichiro Fujimori, Nico Bauer, et al. "The Shared Socioeconomic Pathways and Their Energy, Land Use, and Greenhouse Gas Emissions Implications: An Overview," *Global Environmental Change: Human and Policy Dimensions* 42 (January 1, 2017): 153-68, doi://doi.org/10.1016/j.gloenvcha.2016.05.009.

published after 2013 combine modeling with the SSP scenario framework in order to account for the large uncertainty in socioeconomic drivers and climate change.[54]

Taking a step back from the SSP scenarios, studies on future food demand can be divided into three broad approaches (figure 9.5).[55] The most popular is the use of global simulation models. Out of the 58 studies that assessed future food demand, 49 used a global simulation model. Two types of models have mostly been used for the modeling of the food system: partial equilibrium (PE) models and computable general equilibrium (CGE) models.[56] Both PE and CGE models are economic simulation models in which trade, price development, and the clearing of markets are key in determining global food demand and supply. The main difference is that PE models cover only the agriculture and food sector, whereas CGE models represent the total economy, including agriculture, energy, and manufacturing, but with less detail.

A second approach, which was used by eight studies included in the systematic literature review, comprises statistical extrapolation in order to project food demand.[57] In this approach, calorie consumption per capita per day (total or per major food group) is regressed on explanatory

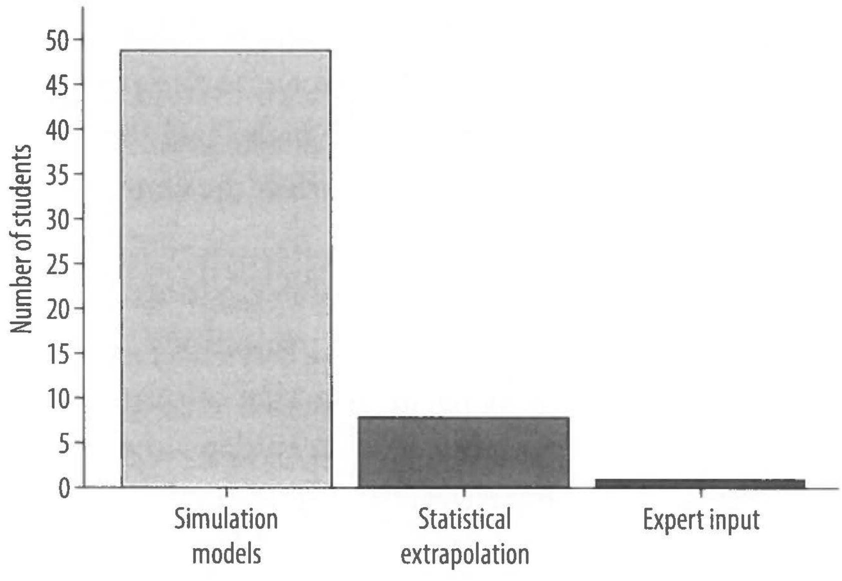

Figure 9.5. Frequency of Approaches Used to Assess Future Food Demand.

Notes: The figure shows the results of 58 studies published between 2004 and 2018. *Source:* Data from Michiel van Dijk et al., "Systematic Review of Global Food Security Projections," Presentation, 3rd International Conference on Global Food Security, December 2017.

factors, in most cases GDP per capita. The estimated relationship is subsequently combined with income per capita and population scenarios to extrapolate total food demand into the future. Godfray and Robinson compare the strengths and weaknesses of simulation models and statistical extrapolation. The advantage of simulation models is that they explicitly capture the underlying dynamics that determine food demand, including the impact of food supply and prices. The statistical approaches do not capture this effect and therefore might generate biased results—for example, if prices change dramatically in the future. A drawback of the simulation models is that they require a large amount of information, which is often not easily available. This may affect their performance when used in scenario analysis to project future trends.[58] The final category is made up by the FAO WAT study, which mainly relies on expert opinion to generate food demand projections.

SSP-Based Global Food Demand Projections

In this section, we use the global food demand projections from the studies identified by the systematic literature review to calculate by how much global food production needs to be increased to fulfill demand in 2050 under different but plausible futures as described by the five SSPs. As such, they provide an alternative for the 60/70% figure presented in the FAO WAT and take into account the high level of uncertainty in socioeconomic drivers that is expected to affect the change in the future food demand.

For 5 out of the aforementioned 58 studies, we are able to extract comparable information on food demand projections. To calculate the increase in food demand, we start by extracting information on global food demand projections expressed in kcal/cap/day—the preferred measure of aggregate food demand as opposed to the price-weighted figure presented in the FAO WAT—for each of the five SSPs. Next, we multiply these values with the population growth projections, which differ between SSPs, to obtain the total global food demand in kcal. Finally, the increase in food demand in 2050 is calculated relative to 2010, the base year for most of the model studies.

There are three steps for the SSPs as well as the FAO WAT projection (figure 9.6). If we use the information on kcal/cap/day development up to 2050 in Alexandratos and Bruinsma's article and use 2010 (instead of 2005/7) as a base year, food demand is projected to increase by 44% if one assumes no climate change. This figure is similar to that of Hunter et al.,[59] who also present an update of Alexandratos and Bruinsma's article but limit their analysis to total cereal consumption and a base year of 2014. If we assume no climate change, food demand in SSP3, the scenario with the highest population growth but the lowest kcal/cap/day consumption, increases with on average 51% in 2050. In contrast, under SSP1, which describes a sustainable future with relative low population growth and medium calorie consumption per capita, and again with no climate change, food demand expands on average 37%. Food demand projections for SSP2, SSP4, and SSP5 are in between those of SSP1 and SSP3, which represent the most extreme scenarios.

Apart from the average SSP projections (in bold), figure 9.6b–c also depicts all individual scenario projections, which show much larger bandwidth, in particular for the kcal/cap/day projections. The wide range in results is caused by a combination of factors. Several studies assess future food demand under a range of climate change scenarios (i.e., RCPs combined with SSPs), which (often negatively) affect food consumption.[60] Other factors that contribute to the variety in scenario results include differences in model design and reporting.[61]

Global Demand Projections at the Food Group Level

The previous section reviewed global projections on total demand of food, adding together a broad range of food items that among others include animal-based products, fruits and vegetables, and cereals. Due to the high level of aggregation, such projections do not provide insights into the different patterns of dietary change, which, in addition to population growth, are one of the main reasons why total food demand projections differ between the SSPs.

The future dietary pattern will have a large influence on global health. At present, unhealthy diets, characterized by high consumption of red

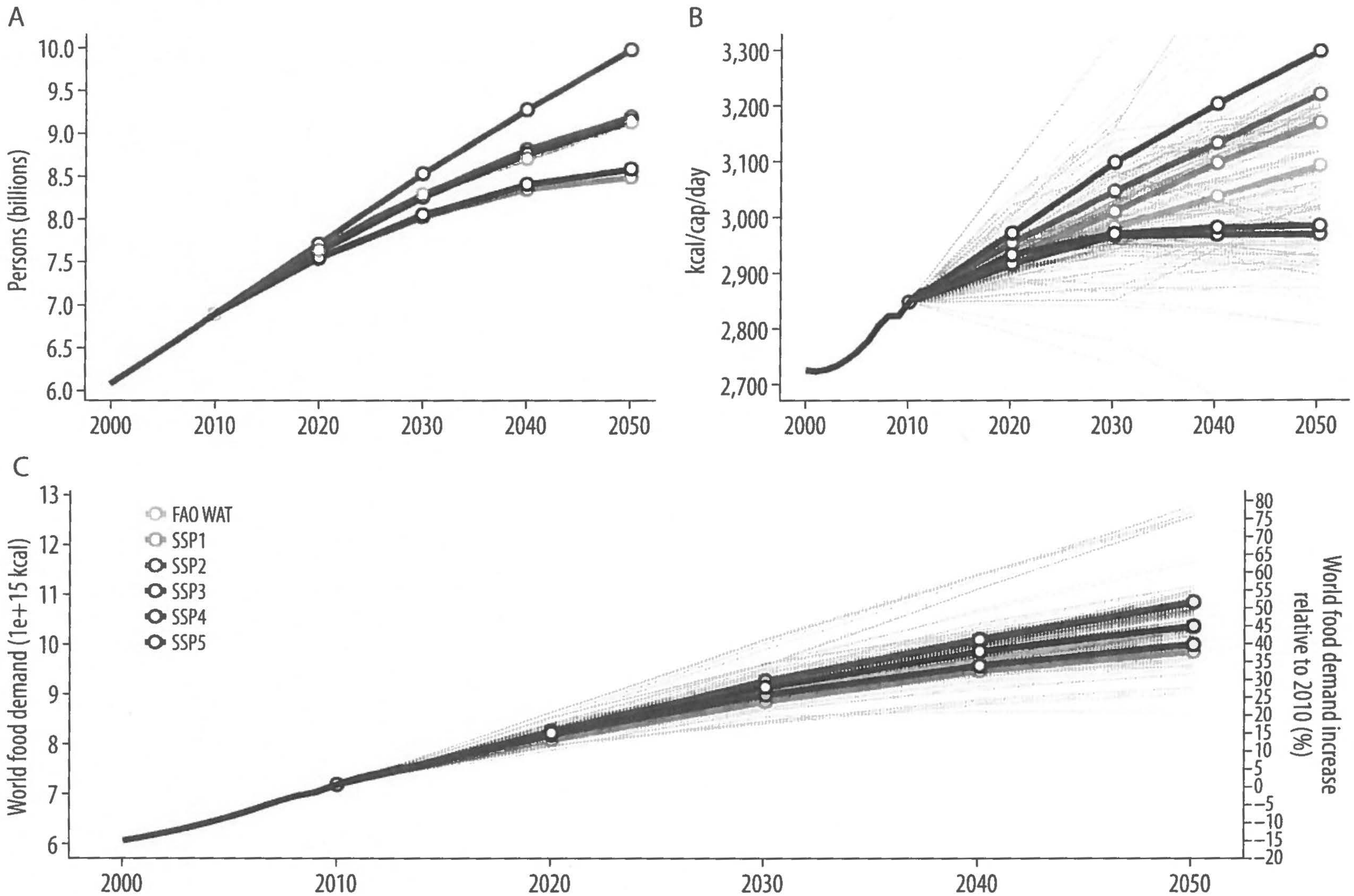

Figure 9.6. Population, Change in Diets, and Food Demand up to 2050. (A) SSP global population projections; (B) Average global food demand in kcal/cap/day; and (C) Total food demand in kcal (left axis) and percent increase relative to 2010 (right axis).

Notes: The solid black line illustrates the historical trend. The other solid lines show the average of the no climate change SSP baseline scenarios. The thin dashed lines show variations of the SSP scenarios under different climate change scenarios. Total number of scenarios is 211. *Source:* Data from Michiel van Dijk et al., "Systematic Review of Global Food Security Projections," Presentation, 3rd International Conference on Global Food Security, December 2017.

and processed meat and low consumption of fruits and vegetables, are already responsible for the greatest health burden worldwide.[62] The situation is expected to get worse in the future if the observed nutrient transition toward Western diets continues, resulting in an increase in nutrient-related noncommunicable diseases (NR-NCDs) that are associated with overweight and obesity.[63] The change in diets will also have a large influence on climate change. A growing demand for meat can be expected to push the expansion of the livestock sector, which makes up for the largest share of agricultural greenhouse gas emissions.[64] A recent study assessed the health and climate impact of a shift toward "sustainable" diets and found that the transition toward more plant-based diets could reduce global mortality by 6–10% and food-related greenhouse gas emissions by 29–70% in 2050.[65]

Reviewing the projections for future demand for meat and other food groups would have been interesting. Unfortunately, only a few of the studies, for which results are presented in figure 9.5, present detailed information on the shifts in diet. In most cases, the results are not comparable due to differences in the composition of food groups and cover only a subset of the SSPs. One recent study presents changes in the composition of the diet for the world and China for three SSPs between 2010 and 2050 (figure 9.7).

Differences in diet trends between the three scenarios are clearly revealed in figure 9.7. In SSP1, as a consequence of a move toward a more sustainable lifestyle and a shift toward lower meat consumption, the share of meat in the diet decreases by around 19%. At the same time, the consumption of fruits and vegetables increases by more than 100%. SSP5, which is characterized by high growth and resource-intensive lifestyles, shows the opposite trend. Meat consumption increases by 69–74%, while fruit and vegetable consumption decreases by 5%. The SSP2 scenario shows a pattern that lies between the change in diets projected by SSP1 and SSP2 (32–37% increase in meat and 19% increase in fruits and vegetables consumption). The pattern for China is similar, but the increase in meat consumption is much larger in SSP5 as a consequence of a change in diets induced by income growth, which illustrates important differences across regions.

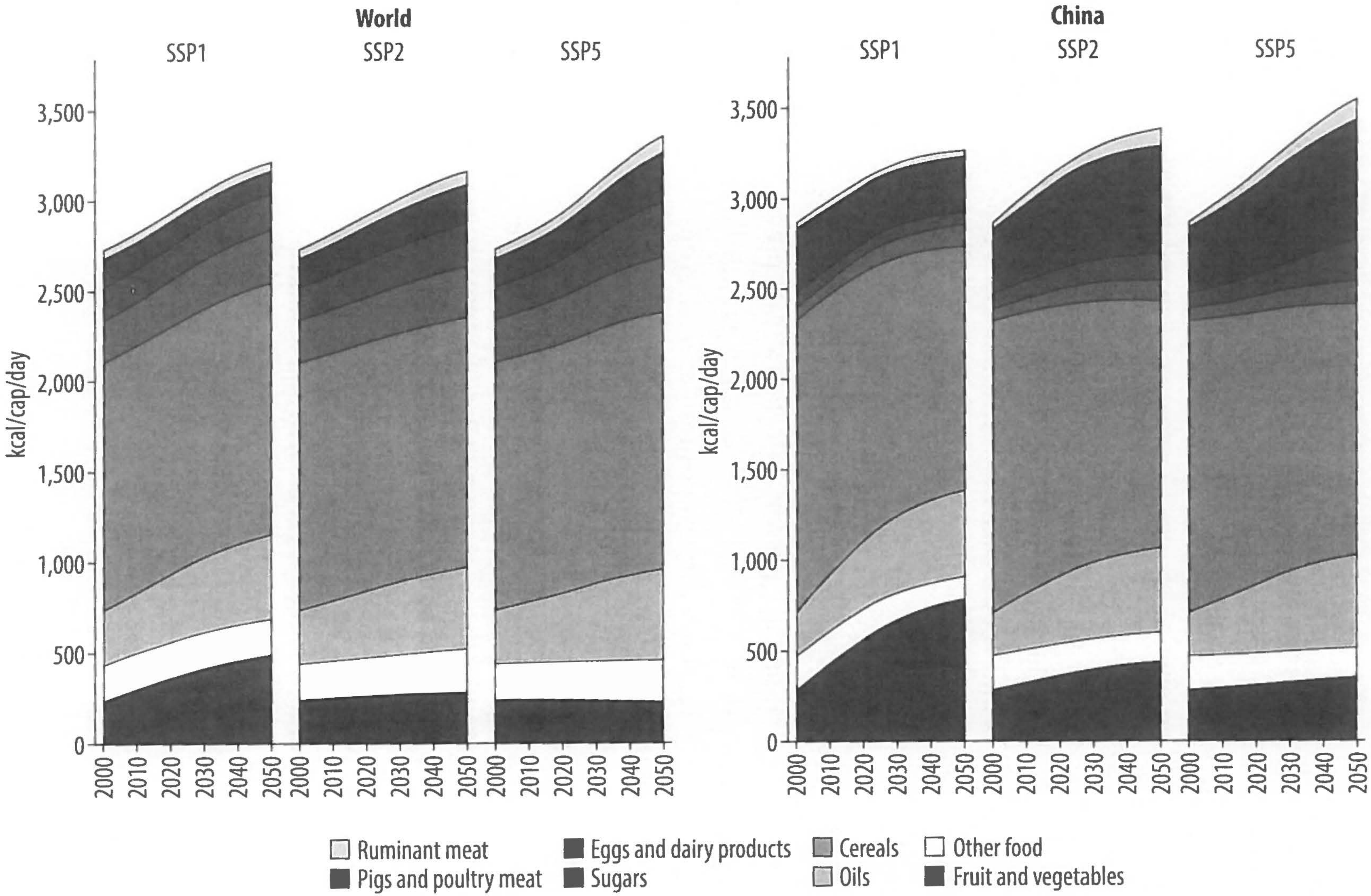

Figure 9.7. SSP Diet Projections for the World and China.

Source: Unpublished data from Oliver Fricko, Petr Havlik, Joeri Rogelj, Zbigniew Klimont, Mykola Gusti, Nils Johnson, Peter Kolp, et al. "The Marker Quantification of the Shared Socioeconomic Pathway 2: A Middle-of-the-Road Scenario for the 21st Century," *Global Environmental Change: Human and Policy Dimensions* 42 (2017): 251-67.

Discussion and Conclusion

The most cited figure on future global food demand originates from an FAO study that projects that food production needs to be increased by 70% (later downscaled to 60%) to fulfill demand in 2050. However, we have shown that this figure is not a satisfactory indicator of future global food demand. Unlike the FAO 70% figure, which presents only a single baseline projection of the "most likely" future, recent studies explore multiple plausible futures using a combination of scenario narratives and model simulations. Many studies use the Shared Socioeconomic Pathways (SSPs), which are the main scenarios used in climate change research, to capture the high level of uncertainty in socioeconomic factors (e.g., technical change, income development, and population growth) that drive future trends in global food demand. Comparing a large number of food demand projections from a systematic literature review in Van Dijk et al., we find an average increase in future food demand between 37% and 51%, under the assumption of no climate change, which is much lower than the 60–70% suggested by the FAO study. The main reasons for the difference are (1) the use of simulation models that account for feedback effects to project future food demand (as opposed to expert opinion), (2) the adoption of a more recent base year as reference (2010 instead of 2005/7), and (3) the use of a raw energy equivalent measure (i.e., kcal/cap/day instead of a price-weighted index) to measure food demand.

Despite the improvements in methodology, the 37–51% range still needs to be interpreted with care as it represents the range only in average SSP projections. The real uncertainty in food demand projections is expected to be much larger as the individual scenario projections show a much wider bandwidth. The large spread can be attributed to a combination of factors, including the impact of climate change and other policy assumptions, differences in model design, and differences in the reporting of results. A meta-analysis that statistically compares the results of all scenarios is required to determine the confidence interval of global food demand projections.

Change: Human and Policy Dimensions 42 (2017): 251-67.

Naturally, the latest SSP-based studies also have their limitations.[66] Many studies model a limited number of socioeconomic drivers and focus predominantly on future projections of food availability, which is only one of the three dimensions of food security.[67] Designing more complex global food futures studies requires the creation of new indicators and the reliable collection and analysis of accurate data. For example, future studies need to better account for the impact of food loss and waste (see chapter 12 for more on this topic). Already there is considerable effort to create global databases for food and nutrient consumption,[68,69] which are used by the latest studies to quantify the impact of healthy and sustainable diets on climate change and the environment.[70]

REFERENCES

1. "2017 Revision of World Population Prospects," United Nations Department of Economic and Social Affairs, 2018, https://population.un.org/wpp/.

2. "World Development Indicators," World Bank, 2018, https://datacatalog.worldbank.org/dataset/world-development-indicators.

3. Uris Lantz C. Baldos and Thomas W. Hertel, "Debunking the 'New Normal': Why World Food Prices Are Expected to Resume Their Long Run Downward Trend," *Global Food Security* 8 (March 2016): 27–38, http://dx.doi.org/10.1016/j.gfs.2016.03.002.

4. Barry M. Popkin, "Nutritional Patterns and Transitions," *Population and Development Review* 19, no. 1 (March 1993): 138–57.

5. Adam Drewnowski and Barry M. Popkin, "The Nutrition Transition: New Trends in the Global Diet," *Nutrition Reviews* 55, no. 2 (February 1997): 31–43.

6. Barry M. Popkin, "The Nutrition Transition: An Overview of World Patterns of Change," *Nutrition Reviews* 62, no. suppl. 2 (July 2004): S140–43.

7. Barry M. Popkin, "The Shift in Stages of the Nutrition Transition in the Developing World Differs from Past Experiences!," *Public Health Nutrition* 5, no. 1A (February 2002): 205–14.

8. Barry M. Popkin, "The Nutrition Transition in the Developing World," *Development Policy Review: The Journal of the Overseas Development Institute* 21, nos. 5–6 (September 2003): 581–97.

9. The nutrition transition model offers a much broader framework than what is presented here. It describes and explains changes in global dietary patterns, their health effects and nutritional outcomes, and how they are affected by economic, social, and demographic factors.

10. Popkin, "The Nutrition Transition in the Developing World."

11. "Food Security Statistics," Food and Agriculture Organization, 2018, http://www.fao.org/economic/ess/ess-fs/en/.

12. John Kearney, "Food Consumption Trends and Drivers," *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences* 365, no. 1554 (September 2010): 2793–2807.

13. Sophie Hawkesworth et al., "Feeding the World Healthily: The Challenge of Measuring the Effects of Agriculture on Health," *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences* 365, no. 1554 (September 2010): 3083–97.

14. C. Peter Timmer et al., *Food Policy Analysis* (Baltimore: Johns Hopkins University Press, 1983).

15. See M. K. Bennett, *The World's Food* (New York: Harper & Brothers, 1954).

16. Åsa Johansson et al., "Looking to 2060: Long-Term Global Growth Prospects," OECD Economic Policy Papers, No. 3 (Paris: OECD Publishing, 2012), https://doi.org/10.1787/5k8zxpjsggfo-en.

17. Barry M. Popkin, "Urbanization, Lifestyle Changes and the Nutrition Transition," *World Development* 27, no. 11 (November 1999): 1905–16.

18. See Anita Regmi and John Dyck, "Effects of Urbanization on Global Food Demand," in *Changing Structure of Global Food Consumption and Trade*, ed. Anita Regmi (Washington, DC: ERS-USDA, 2001), 23–30, and Popkin, "Urbanization."

19. Regmi and Dyck, "Effects of Urbanization."

20. Thomas Reardon et al., "The Rise of Supermarkets in Africa, Asia, and Latin America," *American Journal of Agricultural Economics* 85, no. 5 (December 2003): 1140–46.

21. Thomas Reardon et al., "Urbanization, Diet Change, and Transformation of Food Supply Chains in Asia" (Michigan State University, May 2014), http://www.fao.org/fileadmin/templates/ags/docs/MUFN/DOCUMENTS/MUS_Reardon_2014.pdf.

22. "2018 Revision of World Urbanization Prospects," United Nations Department of Economic and Social Affairs, 2018, https://population.un.org/wup/.

23. Nikos Alexandratos and Jelle Bruinsma, "World Agriculture towards 2030/2050: The 2012 Revision," ESA Working Paper (Rome, 2012), doi:10.1016/S0264-8377(03)00047-4.

24. FAO, "How to Feed the World in 2050" (Rome: High-Level Expert Forum; Food and Agricultural Organisation, 2009).

25. See Nikos Alexandratos, ed., *World Agriculture: Toward 2000* (London: Belhaven Press, 1988); Nikos Alexandratos, ed., *World Agriculture: Toward 2010* (Chichester, UK: John Wiley & Sons, 1995); Jelle Bruinsma, ed., *World Agriculture: Towards 2015/2030; An FAO Perspective* (London: Earthscan, 2003); FAO, "World Agriculture: Towards 2030/2050 Interim Report" (Rome: Food; Agriculture Organization of the United Nations, 2006); FAO, "How to Feed the World"; Jelle Bruinsma, "The Resource Outlook to 2050: By How Much Do Land, Water and Crop Yields Need to Increase by 2050," in *Expert Meeting on How to Feed the World in 2050* (Rome: Food and Agriculture

Organization, 2009); and Alexandratos and Bruinsma, "World Agriculture towards 2030/2050."

26. Estimation by Harald Grethe, Assa Dembélé, and Nuray Duman, *How to Feed the World's Growing Billions: Understanding FAO World Food Projections and Their Implications* (Berlin: Heinrich-Böll-Stiftung, 2011).

27. FAO, "World Agriculture: Towards 2030/2050."

28. Note that the FAO 2006 report, the Bruinsma 2009 paper, and the Alexandratos and Bruinsma 2012 paper refer to an increase in world "agricultural" production, whereas the FAO 2009 report refers to "food production (net of food used for biofuels)." Both refer to the same aggregate.

29. FAO, "World Agriculture: Towards 2030/2050."

30. Bruinsma, *World Agriculture: Towards 2015/2030.*

31. Alexandratos and Bruinsma, "World Agriculture towards 2030/2050."

32. Alexandratos, *World Agriculture: Toward 2010.*

33. Alexandratos and Bruinsma, "World Agriculture towards 2030/2050."

34. Grethe, Dembélé, and Duman, *How to Feed the World's Growing Billions.*

35. Alexandratos and Bruinsma, "World Agriculture towards 2030/2050."

36. See also Mitchell C. Hunter et al., "Agriculture in 2050: Recalibrating Targets for Sustainable Intensification," *Bioscience* 67, no. 4 (April 2017): 386–91.

37. FAO, "World Agriculture: Towards 2030/2050.

38. Grethe, Dembélé, and Duman, *How to Feed the World's Growing Billions.*

39. Cynthia Rosenzweig et al., "Assessing Agricultural Risks of Climate Change in the 21st Century in a Global Gridded Crop Model Intercomparison," *Proceedings of the National Academy of Sciences of the United States of America* 111, no. 9 (March 2014): 3268–73.

40. Millennium Ecosystem Assessment, *Ecosystems and Human Well-Being: Our Human Planet,* vol. 2, *Scenarios* (Washington, DC: Island Press, 2005).

41. Joseph Alcamo, "The SAS Approach: Combining Qualitative and Quantitative Knowledge in Environmental Scenarios," in *Developments in Integrated Environmental Assessment*, ed. Joseph Alcamo (Amsterdam: Elsevier, 2008): 123–50.

42. Nebojsa Nakicenovic et al., *Special Report on Emissions Scenarios (SRES), A Special Report of Working Group III of the Intergovernmental Panel on Climate Change* (Cambridge: Cambridge University Press, 2000).

43. Millennium Ecosystem Assessment, *Ecosystems.*

44. United Nations Environment Programme, *GEO-4 Global Environment Outlook: Environment for Development* (Valetta: Progress Press, 2007).

45. International Assessment of Agricultural Knowledge, Science and Technology for Development, *Agriculture at a Crossroad, Global Report* (Washington, DC: Island Press, 2009).

46. See Michiel van Dijk et al., "Systematic Review of Global Food Security Projections," Presentation, 3rd International Conference on Global Food Security, December 2017.

47. Tomoko Hasegawa et al., "Scenarios for the Risk of Hunger in the Twenty-First Century Using Shared Socioeconomic Pathways," *Environmental Research Letters* 10, no. 1 (January 2015): 014010.

48. Elmar Kriegler et al., "The Need for and Use of Socio-economic Scenarios for Climate Change Analysis: A New Approach Based on Shared Socio-economic Pathways," *Global Environmental Change: Human and Policy Dimensions* 22, no. 4 (October 2012): 807–22.

49. Keywan Riahi et al., "The Shared Socioeconomic Pathways and Their Energy, Land Use, and Greenhouse Gas Emissions Implications: An Overview," *Global Environmental Change: Human and Policy Dimensions* 42 (January 2017): 153–68.

50. Brian C. O'Neill et al., "The Roads Ahead: Narratives for Shared Socioeconomic Pathways Describing World Futures in the 21st Century," *Global Environmental Change: Human and Policy Dimensions* 42 (January 2017): 169–80.

51. Samir KC and Wolfgang Lutz, "The Human Core of the Shared Socioeconomic Pathways: Population Scenarios by Age, Sex and Level of Education for All Countries to 2100," *Global Environmental Change: Human and Policy Dimensions* 42 (January 2017): 181–92.

52. Rob Dellink et al., "Long-Term Economic Growth Projections in the Shared Socioeconomic Pathways," *Global Environmental Change: Human and Policy Dimensions* 42 (January 2017): 200–214.

53. Detlef P. van Vuuren et al., "A New Scenario Framework for Climate Change Research: Scenario Matrix Architecture," *Climatic Change* 122, no. 3 (February 2014): 373–86.

54. Van Dijk et al., "Systematic Review."

55. H. Charles, J. Godfray, and Sherman Robinson, "Contrasting Approaches to Projecting Long-Run Global Food Security," *Oxford Review of Economic Policy* 31, no. 1 (March 2015): 26–44.

56. Hugo Valin et al., "The Future of Food Demand: Understanding Differences in Global Economic Models," *Agricultural Economics* 45, no. 1 (January 2014): 51–67.

57. See David Tilman et al., "Global Food Demand and the Sustainable Intensification of Agriculture," *Proceedings of the National Academy of Sciences of the United States of America* 108, no. 50 (December 2011): 20260–64; Benjamin Leon Bodirsky et al., "Global Food Demand Scenarios for the 21st Century," *PloS One* 10, no. 11 (November 2015): e0139201; David L. Bijl et al., "A Physically-Based Model of Long-Term Food Demand," *Global Environmental Change: Human and Policy Dimensions* 45 (July 2017): 47–62; and Christophe Gouel and Houssein Guimbard, "Nutrition Transition and the Structure of Global Food Demand," *American Journal of Agricultural Economics* 101, no. 2 (March 2019): 383–403.

58. Godfray and Robinson, "Contrasting Approaches."

59. Hunter et al., "Agriculture in 2050."

60. See, for example, Alexander Popp et al., "Land-Use Futures in the Shared Socio-economic Pathways," *Global Environmental Change: Human and Policy Dimensions* 42 (January 2017): 331–45.

61. Michiel van Dijk and Gerdien W. Meijerink, "A Review of Global Food Security Scenario and Assessment Studies: Results, Gaps and Research Priorities," *Global Food Security* 3, nos. 3–4 (November 2014): 227–38.

62. GBD 2013 Risk Factors Collaborators et al., "Global, Regional, and National Comparative Risk Assessment of 79 Behavioural, Environmental and Occupational, and Metabolic Risks or Clusters of Risks in 188 Countries, 1990–2013: A Systematic Analysis for the Global Burden of Disease Study 2013," *Lancet* 386, no. 10010 (December 2015): 2287–2323.

63. Barry M. Popkin, "Global Nutrition Dynamics: The World Is Shifting Rapidly toward a Diet Linked with Noncommunicable Diseases," *American Journal of Clinical Nutrition* 84, no. 2 (2006): 289–98.

64. Sonja J. Vermeulen, Bruce M. Campbell, and John S. I. Ingram, "Climate Change and Food Systems," *Annual Review of Environment and Resources* 37, no. 1 (November 2012): 195–222.

65. Marco Springmann et al., "Analysis and Valuation of the Health and Climate Change Cobenefits of Dietary Change," *Proceedings of the National Academy of Sciences of the United States of America* 113, no. 15 (April 2016): 4146–51.

66. Van Dijk et al., "Systematic Review."

67. FAO, *Rome Declaration on World Food Security and World Food Summit Plan of Action* (Rome: FAO, 1996).

68. Shahab Khatibzadeh et al., "A Global Database of Food and Nutrient Consumption," *Bulletin of the World Health Organization* 94, no. 12 (December 2016): 931–34.

69. Matthew R. Smith et al., "Global Expanded Nutrient Supply (GENuS) Model: A New Method for Estimating the Global Dietary Supply of Nutrients," *PloS One* 11, no. 1 (January 2016): e0146976.

70. See Marco Springmann et al., "Global and Regional Health Effects of Future Food Production under Climate Change: A Modelling Study," *Lancet* 387, no. 10031 (May 2016): 1937–46; Marco Springmann et al., "Options for Keeping the Food System within Environmental Limits," *Nature* 562, no. 7728 (October 2018): 519–25; and Walter Willett et al., "Food in the Anthropocene: The EAT-Lancet Commission on Healthy Diets from Sustainable Food Systems," *Lancet* 393, no. 10170 (February 2019): 447–92.