Food and Agriculture Systems Foresight Study: Implications for Gender, Poverty, and Nutrition

Erin Lentz

April 2020

Author:
Erin Lentz, Associate Professor of Public Affairs at LBJ School of Public Affairs at The University of Texas at Austin

Acknowledgments

Thank you to Chris Barrett, Amy Beaudreault, Suneetha Kadiyala, Allison Smith, Lesley Torrance, Monika Zurek, and attendees at the ISDC online workshop on April 20-22, 2020, for lively and valuable discussions and helpful comments on this topic. All errors are my own.

Citation
Lentz, E. (2020). *Food and Agriculture Systems Foresight Study: Implications for Gender, Poverty, and Nutrition*. Rome: CGIAR Independent Science for Development Council (ISDC).

Table of Contents

Executive Summary

The agricultural and food system (AFS) will face substantial change in the next 20 to 30 years; numerous forces such as demographic waves, technological change, disease, climate change, and economic and political shifts will change what is grown by whom, how it reaches consumers, and which foods are consumed by whom. This review evaluates studies that explore the prospective effects of these changes with regard to three One CGIAR impact areas: gender, poverty, and nutrition (GPN).

Climate change and depletion of natural resources will have adverse consequences for gender equality, poverty reduction, and nutrition: rural producers can expect greater production volatility, consumers can expect increased prices, nutritious foods are likely to be more expensive, the nutrient quality of foods will deteriorate owing to climate change (Myers et al. 2014), and women and girls are likely absorb a disproportionate share of these adverse consequences (HLPE 2017).

Numerous foresight studies propose technological and/or sustainable agricultural management interventions to support a transformation of the AFS; few, however, systematically consider well-established barriers to adoption. Without explicit discussion of pathways to adopting new technologies and management practices, there is a significant risk that such innovations will fail to deliver the expected changes in the AFS.

With notable exceptions, analyses related to GPN are generally missing from current AFS foresight work. As a result, we have a poor understanding of the net effects of AFS transformations on GPN. Instead, studies often focus on intermediate outcomes, such as prices or crop production. There is a need to systematically map out possible relationships between intermediate outcomes and GPN outcomes to support analysis of the net effects of AFS transformations and to identify possible tradeoffs.

When GPN outcomes are incorporated, strong assumptions about the efficacy of global or regional governance and leadership appear to be required for achieving positive GPN outcomes (HLPE 2017, 2019; FOLU 2019; Rawe et al. 2019; Willett et al. 2019; WRI 2019). To achieve positive transformation of the AFS requires coordination across seemingly disparate aspects of the AFS to ensure that, as Rawe et al. (2019) point out, efforts are not at cross-purposes. In reality, however, leaders may not fully understand the complex implications of policy decisions (HLPE 2019) and may not coordinate. Making tradeoffs visible can help policymakers better balance them within the AFS.

Other findings include the following:

- **Gender**: Gender outcomes are least discussed across the foresight work. Gender-transformative work will require engaging not only with women but also with men, as well as changing norms and removing structural and institutional inequalities (Quisumbing et al. 2019). Few foresight studies consider how gender shapes the behaviors and barriers faced by men or how to engage men and boys as partners in gender-transformative AFS practices.

- **Poverty:** Changes in food prices and GDP have differential effects based on the AFS role and poverty status of a given actor. Foresight studies do not consistently identify both consumers and producers as people at risk of poverty or point out that a particular trend may differentially impact

consumers and producers. Few studies discuss the role of other AFS actors (e.g., processors, transporters, and day laborers).

- **Nutrition:** Approaches to expand production and consumption of healthier, high-quality foods are needed. Several foresight studies chart pathways to expand the supply of affordable, healthy foods, ensure those foods reach consumers, and encourage their consumption. These diets converge on low consumption of animal-based products and increased consumption of fruits, vegetables, and pulses. Changes require systemwide interventions and policy guidance.

- **Nutrition:** Shifts in consumer preferences are happening, but the direction and magnitude of these changes are currently ambiguous. There is substantial disagreement about whether more people will adopt Western diets (e.g., high in animal-source foods and low in fruits and vegetables) or whether people can be convinced to eat more diverse, healthier diets.

- **GPN:** Other transformations in the AFS may help or hinder improvements in nutrition (and other One CGIAR outcomes). For example, increases in income may increase demand for unhealthy diets or enable impoverished individuals to afford healthier foods. Increases in inequality could have the opposite effect. Policies that guide consumer choice could ensure healthier outcomes.

Foresight studies agree that it will be challenging to transform the agri-food system into one that is sustainable, healthy, and just. Much of the foresight work that promotes socioeconomic changes to improve the AFS in ways that prioritize GPN outcomes relies heavily on the assumption that global coordination of policies and regulations is possible. However, history to date has shown that efforts to coordinate globally have had mixed success; that is, relying on transformative global governance to lead AFS change may be a risky strategy. At the same time, other foresight work considers the role of technology and improved management techniques in our future AFS. The paths for these innovations appear more certain and path dependent than the socioeconomic changes. Yet innovation-led studies pay less attention to barriers to equitable adoption and nutritional outcomes. The history of development has amply demonstrated the difficulties of equitable implementation of new technological innovations. While the barriers are not considered directly in most of these scenarios, this history suggests that there will be a range of challenges in implementing and facilitating the adoption of new and potentially game-changing technologies in ways that do not exacerbate existing social and economic inequalities.

CGIAR has a long track record of addressing the challenge of transforming the AFS and is well positioned to continue to do so. To inform both policy-led and innovation-led pathways, CGIAR can pursue a multitrack strategy through the following: (1) using systems thinking to incorporate gender, poverty, and nutrition into the design and implementation of CGIAR-led and -supported innovations, (2) supporting and advocating for the mainstreaming of GPN into the work of others, (3) integrating fit-for-purpose, regularly updated foresight work into decision-making, and (4) while acknowledging that global coordination may or may not be an achievable future outcome, providing policymakers with multisectoral and multilevel tools and analyses that systematically identify the net effects of AFS changes on GPN outcomes and the tradeoffs across One CGIAR impact areas.

Introduction

Agricultural and food systems in the next 20 to 30 years will face substantial change. Numerous forces such as demographic waves, technological change, disease, climate change, and economic and political shifts will change what is grown by whom, how it reaches consumers, and what is consumed by whom. If current trends continue, malnutrition is expected to increase, poverty will likely worsen for some individuals, and some populations will face increased vulnerability (FAO 2018a; WEF 2017; Willett et al. 2019). At the same time, the agri-food system (AFS) can be harnessed to decrease poverty, improve nutrition, and improve gender equality, among other positive outcomes. The objective of this document is to synthesize existing agriculture and food foresight studies. It conducts an analysis to identify common and rare themes across three foresight methods: (1) anticipated trends and drivers impacting agricultural and food systems, (2) variations in agricultural and food system scenarios, and (3) visions for future agricultural and food systems. This review evaluates the prospective effects with regard to three One CGIAR impact areas: gender,[1] poverty, and nutrition. For the purpose of this study, the desired impacts are improved gender equality (equity), decreased poverty, and reduced malnutrition in all its forms, with special attention to efforts to enhance diet quality (in contrast to primarily expanding caloric availability).

To understand how One CGIAR outcomes may be impacted in the future, this review uses a systems approach to understand the different pathways through which gender, poverty, and nutrition may be impacted. There are numerous definitions and examples of AFS (HLPE 2017; FAO 2018a; Zurek et al. 2018; Rosenzweig et al. 2020).[2] Here I use a general definition of food and agricultural systems: integrated, multi-scalar entities that include drivers, activities, actors, and outcomes. Drivers are macro-level factors that both directly and indirectly influence the food system and can include climate and climate variability, policy environments (including trade), and cultures and norms. Drivers can be categorized into societal, technological, economic, environmental, political, and demographic (STEEP-D) trends. Actors include producers, processors, traders, consumers, and others involved in the AFS. Activities include trade, production, storage, postharvest handling, etc. The outcomes map to the One CGIAR impact areas.

A systems approach to analysis recognizes that food both contributes to and is impacted by climate change (Rosenzweig et al. 2020). Using a systems approach also highlights agricultural production linkages to food consumption, processing, land use, waste disposal, storage, and other activities. These activities, in turn, are influenced by STEEP-D trends and by local institutional environments, local support systems, and local norms. A systems perspective can support transparent conversations about tradeoffs and synergies by bringing environmental and societal goals into conversation with food system actors and activities (Zurek et al. 2018; Ingram and Zurek 2019) and can help practitioners, researchers, and policymakers avoid siloed thinking (NAS 2019; WEF 2017). Sustainable Development Goal (SDG) 2, which aims to end hunger, achieve food security and improved nutrition, and promote sustainable agriculture, takes a systems perspective by linking agriculture and consumption. A systems approach also shows that agri-food systems impact other SDGs such as ending poverty, gender discrimination, inequality, environmental degradation, and climate change, and promoting healthy lives (Serraj et al. 2019).

[1] The One CGIAR impact area is "gender, youth, and social inclusion." This study focuses on gender. However, most of the reviewed foresight studies do not explicitly consider any of the three.

[2] See Annex A for representations of AFS.

Foresight Methodologies

Wiebe et al. (2018) describe foresight as "the act of thinking about the future to guide decisions today." (p. 546). While there are several foresight methodologies, the AFS foresight work in this review can be typologized into three main methodologies: megatrend analysis (what is driving us toward a specific future?); scenario planning (what are likely future worlds?); and visioning and backcasting (how can we reach a certain world?). Wilkinson (2017) details the differences. A megatrends analysis describes how an "observable phenomenon" is expected to change over a specific time period (in both direction and magnitude: linear, volatile, exponential, etc.) (Wilkinson 2017, p. 17). Emerging megatrends can often be categorized as social, technological, economic, environmental, political, or demographic shifts (STEEP-D). Scenario planning results in "a set of plausible stories of the future" (Wilkinson 2017, p. 14). Scenarios show how changes to select trends create different futures. The number of scenarios generally ranges between two and six, with each scenario describing both what the future holds and how it may come about. The foresight method of visioning and backcasting starts with a preferred (i.e., normative) future world or future state and then describes pathways useful for attaining that future (Wiebe et al. 2018; Wilkinson 2017).[3] Foresight work can draw on qualitative and/or quantitative techniques and can involve participation of stakeholders or not. Zurek et al. (2018) point out that engaging qualitative and quantitative research communities and supporting participation of stakeholders is vital in efforts to achieve a shared understanding of the current and future AFS (p. 10).

Approach

The criteria for selecting foresight studies for inclusion were based on studies listed in the terms of reference (see Annex C).[4] I included additional studies that focused on global or low-income-country food and agricultural foresight (Willett et al. 2019; FAO 2018a; Future Today Institute 2020) or had a strong poverty, gender, or nutrition lens as related to the future AFS (Quisumbing et al. 2019 on gender in Africa; Willett et al. 2019 on nutrition). In general, most foresight reports tend to have a dominant theme such as the future role of technology and science; the future role of markets (and governance); or the role of policy at subnational, national, and global levels.

In what follows, I review AFS studies by foresight methodology. Within each methodology, I identify key findings and areas of consensus and divergence; examine possible implications of the findings for gender, poverty, and nutrition (GPN); and describe gaps and limitations. I then identify themes related to gender, poverty, and nutrition. I identify findings relevant to CGIAR, including its role in evaluating technologies and innovations for GPN outcomes, analyzing how different drivers and/or intermediate outcomes influence GPN outcomes, and priority setting.

Megatrends

I describe megatrends (drivers), their influence on the AFS, and their impacts GPN outcomes. Table 1 is a summary of the reviewed trends. The trends are divided into relatively common and less common trends,

[3] See Annex B for Wilkinson's graphical representation of these differences (2017).

[4] There are numerous foresight studies. For example, Wiebe et al. (2018) identified 3,161 articles in SCOPUS, published in 2013–2017, that included the keywords "uncertainty," "scenario," and "future" (p. 549). It is beyond the scope of this review to systematically identify or review the full set of these articles.

which are then sorted into STEEP-D categories. The table includes a simple characterization of the megatrends' influence on each CGIAR impact area. For each impact area, does the megatrend present challenges (C), opportunities (O), or a mix of the two (M), or is it uncertain (U)? The One CGIAR impact areas of GPN are not consistently incorporated into these analyses; when consensus is lacking or cannot be easily identified, they are marked as uncertain (U). The One CGIAR impact area of poverty is split between reductions in poverty for people earning income through the AFS (farmers, processors, traders, transporters, etc.) and for consumers, to reflect that there may be different pathways of impact. For example, lower prices will help impoverished consumers; how they influence small producers' incomes depends on why prices change. In what follows, I synthesize some of the main megatrends, less common megatrends, and their impact on GPN.

Major Megatrends and Their Impacts on Gender, Poverty, and Nutrition

The megatrends of climate change and depletion of natural resources are regularly incorporated into megatrend analyses with a consistent direction of change. These drivers all increase pressure on the AFS, primarily by either increasing demand for food or decreasing yields or productivity. There is general agreement that these pressures are unidirectional and often gradual. There is also agreement that such trends will have adverse consequences for GPN: rural producers can expect greater production volatility, consumers can expect increased prices, nutritious foods are likely to be more expensive, the nutrient quality of foods will deteriorate owing to climate change (Myers et al. 2014), and women and girls are likely to absorb a disproportionate share of these adverse consequences (HLPE 2017).

Two other common trends are population growth and migration, both of which will increase urbanization and likely increase the global middle class. Both trends are likely to increase demand for processed convenience foods, potentially increasing prices, harming poor consumers, and increasing the cost of healthy diets (Maggio et al. 2019). Overnutrition is likely to increase (Willett et al. 2019). The impacts of those two trends on poor farmers and other income earners in the AFS and their impacts on gender are less clear. While foresight analyses argue that migration will increase, the gender dimension of migration is often neglected (e.g., WEF 2017; Willett et al. 2019). Currently, more men migrate than women (HLPE 2017; Arslan et al. 2019; Huyer et al. 2019), and migrants are generally younger, leaving women and older people in rural areas (Arslan et al. 2019). The overall implication of this demographic shift is uncertain for rural poverty and women. If people migrate to better urban jobs, rural areas may benefit from remittances and/or increased urban demand for food (Arslan et al. 2019). A greater share of men migrating may open up income-earning opportunities for women in the AFS, particularly as demand for food increases. However, these opportunities may be undermined by gendered barriers to accessing credit, extension, and information (Quisumbing et al. 2019). At the same time, gendered rural-to-urban migration may increase women's on-farm work; as populations age and younger people migrate, women may also face increasing time pressure as they care for both aging relatives and young children. In addition to reducing time available for remunerative activities, women's time poverty may increase demand for convenience foods, with adverse nutritional consequences (Meenakshi and Webb 2019).

The impacts of technological trends on GPN are ambiguous. For example, artificial intelligence (AI), synthetic biology, and a suite of other technologies that can decrease the unpredictability and risk of production could decrease prices and, if used to support the growth of healthier foods, could increase nutrition (Future Today Institute 2020). However, whether technological change will increase incomes equally across the AFS is uncertain. Most technologically focused megatrend studies do not discuss requirements to ensure technology adoption by smallholder farmers or by small actors in the AFS. Yet

technology adoption depends on multiple factors including scale neutrality (e.g., technologies captured in the seed, drought-tolerant varietals, or nitrogen-fixing cereals); accessibility across AFS actors; appropriateness to social and ecological context; policies and extension to support equitable adoption; and intellectual property regimes (WEF 2018; Hazell 2019; Langridge 2019; Future Today Institute 2020). When technology is not scale neutral, it can contribute to increased inequality between large and small farmers (Hazell 2019). For example, precision agriculture may improve yields and decrease prices in industrial agriculture but is likely to remain too expensive for most small farmers (Huang and Brown 2019). New technologies may not be accessible to some farmers or may not be suitable for some environmental or social contexts, and this situation can impact non-adopting farmers indirectly through prices and can increase disparities between farms in favored versus less favored areas. Without access to extension, credit services, and information, farmers may be unable to adopt new technology or unable to continue using it. Intellectual property rights can create barriers to adoption, particularly in low-income countries (Graff and Hamdan-Livramento 2019).

Technologies with more consistently positive outcomes for poverty include clean and renewable energy and logistics and supply chain innovations, in part because of their scale neutrality (GKI and Rockefeller 2017; WEF 2018). See Table 1 for details on specific technologies such as cold storage and first-mile processing. These can improve efficiency and market access for smallholders, supporting increased and/or more sustainable agricultural production and positive outcomes for poverty and/or nutrition.

Gender is generally overlooked in reports focused on technological innovations (e.g., NAS 2019; ReThinkX 2019). Rawe et al. (2019) point out that women are often not "recognized as 'farmers,' so services and technologies are not designed to meet their needs" (p. 23). In addition to the barriers to adoption listed above, gender-equitable technologies must also consider whether a particular technology results in labor savings, particularly for women; whether it is designed with different body types in mind (e.g., smaller plows that women can easily maneuver); whether it is accessible to women (and other marginalized groups), who may have lower levels of formal education and less formal access to land; and whether training, credit, extension, and other wraparound services are available, accessible, and targeted to women (Rawe et al. 2019; Huyer et al. 2019).

Shifts in consumer preferences are happening, but the direction and magnitude of these changes are currently ambiguous. In particular, there is substantial disagreement about consumer preferences regarding animal-source foods and whether more people will adopt Western diets that are high in animal-source foods and low in fruits and vegetables. Some studies assume consumers will increase consumption of livestock products (NAS 2019; Maggio et al. 2019) and Western diets (Meenashki and Webb 2019; Hazell 2019); others argue that consumers are willing to adapt to consuming lab-based foods and animal products grown using precision biology (RethinkX 2019). Some visioning studies propose policies to nudge or strongly encourage consumers to eat less meat (e.g., Willett et al. 2019).

A reason for the lack of consensus about trends in consumer preferences is that studies often have significantly different assumptions about what else will happen in the AFS that may or may not contribute to changing consumer preferences. First, there is disagreement over how transformative synthetic biology will be in the AFS. Several studies argue that synthetic biology could improve food safety, change the way food is produced, and have nutritional benefits (ReThinkX 2019; Future Today Institute 2019). RethinkX (2019) argues that synthetic biology will disrupt the AFS, with plant-based foods replacing animal-source foods and leading to decreased livestock production. The Future Today Institute (2020) identifies meat replacement as just one aspect of innovations in synthetic biology, but it does not discuss changes in consumer demand. Other analyses describe technologies that could support livestock production in its

current form (e.g., bio-tattoos) but do not expect systemic changes to livestock production (see NAS 2019). Second, other studies focus on non-technology drivers that may shift consumer preferences. Willett et al. (2019) argue for changes to the policy and regulatory environment to shape consumer demand. Maggio et al. (2019) argue that income growth and increased urbanization will increase adoption of Western diets. HLPE (2017) argues that culture informs eating patterns and that a cultural perspective can help explain consumer choices (p. 78). They also note that within some cultures women tend to decide what to eat. Thus, expected changes in consumer demand turn on whether the studies assume synthetic technology will be a disruptor, on whether policies and regulations that encourage healthy eating will do so, and on the roles of income, urbanization, and culture, among other things.

Less Common Megatrends and Their Impacts on Gender, Poverty, and Nutrition

Several less-discussed social, political, and economic trends could also influence the AFS (see Table 1). As with the megatrend of shifting consumer preferences, differences in projected outcomes often turn on starting assumptions, and there is less agreement on the magnitude or direction of change. Geopolitical dynamics could result in increasing nationalist and isolationist tendencies, which could harm food security and nutrition in low-income or net-food-importing countries (WEF 2017). Changes in political and economic drivers, including increases in conflict and crises, could both disrupt local AFS and put further pressure on AFS, particularly in places with high rates of internal displacement or mass migration (HLPE 2017). However, leadership on trade, agricultural, nutritional, and food policies that support a sustainable, healthy AFS could be transformative, as could effective use of multi-stakeholder partnerships to prioritize the needs of marginalized groups (HLPE 2017, 2018). The net result of geopolitical dynamics and political and economic drivers is uncertain.

HLPE (2017) argues that gender relationships and norms are among the most significant drivers of food environments and diets. While a goal in itself, supporting women's empowerment could improve nutritional outcomes (HLPE 2017). HLPE proposes the following to improve nutritional outcomes, "(i) increasing household income under women's control to improve overall household well-being (health, nutrition, literacy and happiness); (ii) ensuring women's access to markets and economic and financial resources; and (iii) increasing women's status by changing gender roles through developing agency (women's skills and self-worth), challenging power relationships and modifying laws and norms that limit women's choices" (HLPE 2017, p. 79). HLPE does not classify expanding women's empowerment as a single megatrend. Rather, they argue that sociocultural drivers, including women's empowerment, play an important role in shaping agri-food systems and the women's futures.

Other less-analyzed trends are likely to have adverse impacts on AFS and GPN outcomes by disproportionately harming impoverished individuals, hindering improvements in nutrition, and exacerbating gender inequality. Human disease, inadequate water and sanitation, declines in public funding for agricultural research, failure to address shortages of key fertilizer ingredients (either through changing production systems or changing inputs), agricultural pests and diseases, and pandemics have the potential to devastate the AFS (Maggio et al. 2019; NAS 2019).

Gaps and Limitations

Trends in isolation can be misleading. For example, the shift in consumer preferences away from animal-source foods may be more transformative for the AFS and for human nutrition if policy changes to discourage meat consumption are paired with an expansion of synthetic biology. At the same time, if

more people enter the middle class and strongly associate middle-class lifestyles with eating more meat, the overall impact of synthetic biology on livestock, without policy and behavior change, may be muted.

Scenarios

Scenarios can show how different assumptions about megatrends and drivers create new worlds and impact outcomes in the AFS. For each set of the reviewed scenarios, Table 2 gives information on geographic coverage, period covered by the scenario, main drivers and axes, implications of the scenario for the world and the AFS, and implications for GPN.

The scenarios are sorted into three categories. Most of the scenario-based AFS foresight work takes the Shared Socioeconomic Pathways (SSPs) as the departure point for understanding what the agri-food system looks like in each world. The SSPs were developed as alternative socioeconomic development pathways to help users better understand and prepare for climate change and its impacts (O'Neill et al. 2014). The SSPs do not embed efforts address climate change or support adaptation, and they can thus be adapted by users to show different scenarios under which mitigating and/or adapting to climate change is easier or harder (O'Neill 2014, p. 390). The first set of scenarios begins with the SSP Business as Usual (SSP2) as a baseline and then evaluates the impact of more aggressive assumptions about drivers on the AFS (FAO 2018a; Hasegawa et al. 2018; FOLU 2019; Willett et al. 2019). The second set includes studies that do not use (or do not reference using) SSPs as their baseline (WEF 2017; WRI 2019). The third set of scenarios adapts the set of SSPs to regional specifications (Palazzo et al. 2014; Vervoort et al. 2014; Mason D'Croz et al. 2016; Palazzo et al. 2017). The line between scenario and visioning foresight work can blur. Both WRI (2019) and Willet et al. (2019) discuss several worlds, and then describe the pathways leading to the preferred scenario outcomes.

Across scenarios, there is general agreement on the need to (sustainably) increase food production, decrease GHG emissions, and address natural resource and land degradation. Many scenarios (e.g., work by the CGIAR Research Program on Climate Change, Agriculture and Food Security, such as Palazzo et al. 2014; Vervoort et al. 2016; Mason-D'Croz et al. 2016 Palazzo et al. 2017; Hasegawa et al. 2018) focus on production outcomes, food prices, and caloric availability as model outcomes rather than on poverty, nutrient quality, and healthy diets, which make the GPN impacts uncertain. A general finding among scenarios that incorporate a political economy axis (e.g., institutional capacity or regional coordination) is that worlds with more proactive governance tend to have much better outcomes in terms of food security, growth, and natural resources and land use.

Overview of the SSPs

The SSPs start with two axes: socioeconomic challenges for mitigation and socioeconomic challenges for adaptation. Four combinations of the axes plus a "middle" result in the five archetypal scenarios based on the SSPs (O'Neill et al. 2014; Riahi et al. 2017). The SSPs make assumptions about major socioeconomic STEEP-D drivers, including population, education, urbanization, and economic development. These drivers then inform energy use, land use, and environmental outcomes. Table 3 is a brief overview of the SSP scenarios, their axes, and socioeconomic drivers and provides an overview of each SSP world. Storyline descriptions of SSP scenarios (drawing from O'Neill et al. 2014 and Riahi et al. 2017) are as follows:

- *Green Worlds (SSP1)* faces low adaptation and mitigation challenges. Population growth will slow, education will increase, and urbanization could reach 92 percent. Economic development will be equitable. Renewable energy will increase, land use will be sustainable, and agricultural productivity will be high. Further, diets will be healthy.

- *Business As Usual (SSP2)* is considered to face intermediate adaption and mitigation challenges, including modest extensification for agriculture, slightly lower rates of urbanization, and improvements to education comparable to SSP1.

- *Fragmentation / Regional Rivalry (SSP3)* is driven by high adaptation and high mitigation challenges. High economic growth in some regions increases emissions. Interregional inequality increases, and trade flows decline. Population growth is highest, education levels are stagnant or declining, urbanization is stable, heavy reliance on fossil fuels continues, and land extensification and land pressure increase owing to lack of yield increases and limited environmental protection. Under SSP3, many people are vulnerable to climate change and have low adaptive capacity.

- *Unequal Worlds (SSP4)* has high adaptation and low mitigation challenges. Across scenarios, regional inequality is the highest in this world, leaving some regions economically isolated with high vulnerability and low adaptive capacity. Education levels are stagnant, and land use for agriculture expands modestly. Although there is increased use of renewable energy, it is out of reach for many low-income-country households, who instead rely on biomass.

- *Economy Leads / Fossil Fuels Development* (SSP5) has high economic development and increasing human capital. This results in rapid development and economic convergence, with slower population growth and high rates of urbanization. Climate policies are absent, fossil fuels meet high demands for energy, and there is a modest expansion of land used for agriculture.

The macroeconomic implications of these SSPs suggest that SSP3 and SSP4 will have regions with high rates of poverty and slow or stagnant increases in education. Scenarios SSP1, SSP2, and SSP5 will have high levels of education, which can increase human capabilities. Equal access to and participation in education can support gender equality (Rawe et al. 2019). Sustainable production is prioritized in SSP1, with a focus on healthy diets. Investments in health are also made in SSP5, although it is unclear whether such investments are related to nutrition.

Impacts of Changing Drivers on SSP2 Business As Usual

Several scenarios begin with SSP2 as a baseline and then examine how changing assumptions yield new worlds. Across these SSP2 scenarios, the outcomes considered vary. FAO (2018a) and Hasegawa et al. (2018) focus on price effects; how these price effects influence nutrition and poverty outcomes is discussed in broad terms. In contrast, both FOLU (2019) and Willett et al. (2019) assume the world will converge toward a healthy diet and focus primarily on planetary health outcomes and, in the case of FOLU, land use and rural economic development outcomes.

FAO finds that more proactive assumptions relative to Business As Usual will have positive AFS outcomes; not addressing AFS challenges will harm the AFS. FAO's proactive Toward Sustainability Scenario (2018a) assumes, among other things, that consumer preferences change toward increased consumption of healthier foods, full costing of food is instituted, gender imbalances in access to opportunities are

addressed, sustainability of the AFS increases, and climate change slows. Findings using these assumptions show decreases in obesity (owing to changes in preferences and to true costing of food), decreased poverty (owing to expansion of social protection), and improved gender equality (owing to proactive gender-equitable policies). Second, in contrast, the Stratified Societies Scenario assumes that challenges in the AFS are left unaddressed or ignored. Income inequalities increase, production of animal products increases, and food waste worsens. Sustainable agricultural practices are not adopted, and as a result climate change worsens and natural resources are depleted. Severe impacts include greater gender imbalances, worsening poverty, and increases in all forms of malnutrition. The FAO finds that demographic trends such as population growth assumptions have a substantial impact on the scenario results (FAO 2018a, p. 25). Sub-Saharan African is expected to fare worst under this scenario. The Toward Sustainability Scenario requires these assumptions to happen in concert and assumes that global governance can induce these changes.

FOLU (2019) starts with SSP2 and then models a Better Futures Scenario. Like FAO (2018a), it makes strong assumptions about governance. The Better Futures Scenario requires sustained political commitment, an ability to address the current inefficiencies and misallocation of resources, and an increased pace of change for the positive trends. This scenario identifies 10 drivers that address inefficiencies within the AFS. Outcomes are generally positive and consistent with the more aggressive (and positive) assumptions relative to the baseline of SSP2. For example, FOLU argues that compared with Business As Usual, the Better Futures Scenario shows transitions to healthier diets, improved nutrition, and greater food security. Well-paying jobs will be available in rural areas, with rural incomes growing twice as fast as under Business As Usual. FOLU also argues that gender will need to be mainstreamed into efforts to transform the AFS, given pervasive inequalities.

Rather than using food prices or food security as an outcome, Willett et al. (2019) change assumptions about dietary choices (e.g., adoption of a reference diet with little animal-source food and high consumption of pulses and other plant-based foods) and then assess the impacts of these diets on environmental outcomes. The authors start with SSP2 and evaluate a range of values for each of three drivers of the AFS: production, food waste, and diet. Willett et al. (2019) ultimately focus on five strategies to achieve a Great Food Transformation, which would support a worldwide ability to eat the healthy reference diet and stay within planetary boundaries (see visioning section below). In their description of how to achieve a Great Food Transformation, the authors make several arguments about how to support positive nutritional outcomes, decrease poverty, and promote gender equality. Among other things, they assert that prices should reflect true costs and that policy interventions should improve rural infrastructure, expand equitable access to economic resources for women, create social protection programs, and expand knowledge about healthy diets. Willett et al. (2019) use scenario results to propose pathways to achieving a Great Food Transformation (described below in visioning). The authors argue that their assumptions about the values for each driver are “feasible with existing technologies but have not been widely implemented” (p. 471).

Food prices increase in several SSP2-based global scenarios. Achieving improved land management, sustainable agricultural production, and greenhouse gas emission reductions puts more pressure on agriculture, causing food prices to rise. FAO (2018a) finds that food prices increase across all three of its scenarios. Prices increase least in Business As Usual and fastest under Toward Sustainability, resulting from the transition toward prices that reflect the true costs of food. Prices level out, however, owing to adoption of sustainable production practices and decreases in food waste. Under the Stratified Societies Scenario, prices rise later but faster, as upper limits on conventional approaches and resource degradation are reached. FAO (2018a) recognizes that the impact of price increases on nutrition depends on which

food prices increase. In their Stratified Societies Scenario, the prices of healthier foods are expected to be higher than in other scenarios, contributing to overconsumption. Hasegawa et al. (2018) also find that food prices will increase but focus instead on staple foods. They start with SSP2 as a benchmark and examine the impacts of climate mitigation efforts such as carbon taxes on the costs of agricultural production and food prices. A consistent finding is that "mitigation policies linearly increase food prices and expenditure, decrease food availability, and increase the risk of hunger" (Hasegawa et al. 2018, p. 701). They find that mitigation efforts are responsible for 50 percent of estimated food price increases under SSP2.

There are several challenges with using food prices as an outcome. First, the net effects of price changes differ across AFS actors. Price increases will likely harm poor consumers but may or may not harm other AFS actors. If staples are Giffen goods, increases in staple prices could actually increase consumption of those staples, decreasing dietary quality and increasing malnutrition. Second, price changes will likely not occur in a vacuum. If policies to nudge consumer preferences are successful, adverse impacts of prices changes on nutritional outcomes could be mitigated. Finally, some work (e.g., Palazzo et al. 2014; Hasegawa et al. 2018) looks at price changes for "food," meaning staples. Yet relative prices of different foods will change if, for example, polyculture techniques are widely adopted or if postharvest losses in horticulture decrease. Decreasing the relative prices of fruits and vegetables could support adoption of healthier diets. Willett et al. (2019) argue that the full costing of food could support improved nutritional outcomes by changing the relative prices of foods. We need a better understanding of how the interactions of prices, economic growth, climate change mitigation policies, and changes in inequality, among other things, may combine to improve or worsen GPN outcomes.

When price increases are an outcome, scenario studies argue that additional policies need to be included to ensure that the poorest and most marginalized are not harmed. Hasegawa et al. (2018) suggest that while climate change mitigation policies involve tradeoffs, other policies may be win-win. For example, the transfer of resource-efficient production technologies could support economic development and cut emissions (p. 701). Whether such technologies will be accessible to impoverished actors in the AFS or whether there will be gender-based barriers to their adoption are not discussed. The authors also warn of regional variation, with undernourishment increasing in sub-Saharan Africa and Asia.

Non-SSP Scenarios with Innovative Drivers: Global Coordination, Breakthrough Technologies, Market Connectivity, and Food Demand

A few studies do not use (or do not reference using) SSPs as their baseline, although the challenges within the AFS remain the same, as do many of the drivers and assumptions.

Consistent with FOLU (2019), FAO (2018a), and Willett et al. (2019), WRI (2019) also uses scenarios to advocate for stronger global coordination. It is the most technology-forward scenario-based foresight study. Using its own model, GlobAgri-WRR, WRI identifies 22 menu items that increase in terms of ambition, coordination, political will, and technology. It also advocates for investments to support breakthrough technologies. WRI seeks to address challenges of food supply, agricultural land area, and greenhouse gas emissions; it also seeks to alleviate poverty, protect freshwater, and empower women farmers. Its three scenarios are additive, increasing the intensity of adoption of each of the menu items. Its most aggressive scenario, Breakthrough Technologies, assumes dramatic improvements in the performance and costs of technologies, although the authors include only technologies they believe have "genuine grounds for optimism." The authors identify four menu items as particularly important: boost

agricultural productivity, shift diets away from ruminant meat, reduce food loss and waste, and restore peatlands and reforest liberated agricultural land (p. 431).

GlobiAgri-WRR does not include feedback from economic changes in its models. Like Hasegawa et al. (2018), it has difficulty identifying the net effect of the bundle of 22 interventions on GPN outcomes (WRI 2019, p. 30). A stated goal is alleviating poverty and empowering women farmers, but its focus is on whether and how to meet the challenges of food gaps, land use, and GHG emissions. All three models show the food gap is met—albeit through different approaches—and there are no discernable variations in nutritional outcomes. Questions of whether households will adjust their diets across worlds are not addressed.

WEF (2017) presents four possible scenarios, which vary by two axes: degree of market connectivity and type of demand for food. WEF's focus on market connectivity and the role of trade is unique among scenarios. Demand for food includes assumptions about the nature of the future demand for food and agricultural products: resource intensive versus resource efficient. Market connectivity includes assumptions about the openness of trade, trust in and resilience of commodity markets, and inclusivity of technological innovations. Within market connectivity, WEF incorporates assumptions about access to technologies (i.e., whether intellectual property barriers will limit technological adoption), a consideration that is also rare in foresight work (although see Graff and Hamdan-Livramento 2019). It also shows how changes in food demand will influence malnutrition.

The WEF axis that matters most for smallholder farmers and most for addressing malnutrition is whether resources are efficiently or intensively used (on the demand for food axis). Greater connectivity is more beneficial for GPN outcomes when added on top of resource-efficient use. In WEF 1, a world with low connectivity and resource-intensive consumption, greater instability, and conflict will harm women, increase poverty, and result in increased consumption of low-nutrient, high-calorie diets. In WEF 2, a world of resource-intensive consumption and high connectivity, small farmers may be left behind while consumers have low food costs, leading to overnutrition. Small farmers do best in WEF 3 and 4, which both have resource-efficient consumption; the low market connectivity in WEF 4 may leave some farmers unable to access beneficial technologies. Overall, diets are also most nutritious under WEF 3 and 4, reflecting a shift in focus away from calories and toward technologically "new" foods and decreased cost of healthier diets. In WEF 3 some consumers in countries unable to meet self-sufficiency will face hunger owing to increased resource disparities. GKI and Rockefeller (2017) used the WEF (2017) scenarios to point out that certain interventions will have greater impacts on certain of the four WEF worlds whereas other interventions transcend worlds. The authors argue that two questions are relevant for all four worlds: (1) how might we engineer production systems impervious to crop failure and spoilage? and (2) how might we create closed-loop agricultural systems?

Regional Scenarios Building off of the SSPs

CGIAR's Climate Change, Agriculture, and Food Security (CCAFS) team worked with regional stakeholders to adapt the SSPs to region-specific scenarios to 2050. Regional specifications include choice of axes and regionally specific assumptions about Palazzo per capita, crop and livestock yields, and production costs. Every regional scenario includes at least one regional political economy–focused axis. Several regions focused on governance and institution capacity (East Africa, West Africa, South Asia, Andes, Central America). Regions also considered the degree of regional economic integration, regional market regulation, and collaboration (East Africa, Southeast Asia, Andes). Other axes focus on land use, consumer

preferences, water resources, and human capital, among other things. The outcomes primarily discussed are yield gaps (with some attention to land extensification) and food security (Palazzo et al. 2014).

Consistent across the regional scenarios, more proactive governance improves food security outcomes. In the West African scenarios, food security is most improved with the scenario that is most closely aligned with SSP1, where sustainability is combined with high economic growth. The scenario with the worst food security outcomes is similar to SSP3 and results from a lack of proactive action and weak and unstable governments. In East Africa, the scenario with highly effective and proactive governments and high regional integration has the best food security outcomes (again, similar to SSP1), while the scenario with self-interested governments and high regional integration results in extractive outcomes with instability and food insecurity. In South Asia, in one world (SSP3 – Jugaad), the combination of low human capital, low governance and institutional capabilities, low transfer of and availability of science and technology, low political stability, a dominant agricultural sector, high population growth, and high urbanization results in increases in poverty and rising food insecurity. In some regions, food insecurity rates are lower and are less sensitive to changes across worlds. In the regional scenarios for the Andes and Central America, food security increases over the time period for all scenarios.

Consistent with other scenarios, weak regional collaboration paired with resource degradation, unregulated markets, and unbalanced investment yields the most inequality and highest likelihood of increased hunger in Southeast Asia (Buffalo Buffalo world). However, in contrast to the other regions, the Southeast Asia scenario does not examine food security as an explicit outcome. Rather, the scenario describes changes in agricultural production and income. Incomes generally increase. Overall, how the combination of increases in income and inequality impacts food security remains unclear (Mason D'Croz et al. 2016, p. 267).

Across scenarios, the focus is on yields of staple crops, growth in GDP, and staple food prices. Nutritional outcomes are uncertain. Decreases in food prices might benefit hungry consumers but could also lead to overnutrition, depending on how consumer preferences change. Similarly, growth in GDP could increase demand for livestock products (the South Asian, Andean, and Central American scenarios make this assumption). If increases in GDP are paired with increases in inequality, overnutrition could increase as more people adopt Western diets. Gender, like nutrition, is not explicitly discussed in the CCAFS scenarios, although increases in food insecurity are likely to hinder nutrition and have gender-differentiated intrahousehold impacts.

Themes, Gaps, and Limitations in Scenarios

Several global scenarios identify sub-Saharan Africa's AFS to be at greatest risk (FAO 2018a; WRI 2019; Willet et al. 2019). Regional scenarios (Palazzo et al. 2014) concur, showing East and West Africa most sensitive to deteriorating conditions in the AFS and likely to experience food insecurity. Future work on the specific challenges within sub-Saharan Africa could be valuable.

The reliance on SSPs may be limiting. While they offer a consistent departure point for understanding the influence of socioeconomic drivers on the AFS, given the dominance of the SSPs there is a decreased possibility of radically different findings about the AFS. Scenarios starting with SSP2 Business As Usual as a baseline assume that SSP2 is the right departure point. As a result, we know less about how food prices may contribute to more or less poverty across other scenarios; those with high rates of urbanization—for

example, SSP1, SSP4, and SSP5—may have particularly high rates of poverty owing to price increases, particularly if other sorts of poverty alleviation measures are not in place.

GPN outcomes are not regularly incorporated into the scenarios. When they are, strong assumptions about the efficacy of global or regional governance appear to be the dominant drivers in achieving positive GPN outcomes. Worlds with coordinated global governance tend to consider the importance of decreasing the cost of healthy foods (e.g., horticultural products) relative to unhealthy foods (e.g., diets high in staples and livestock products), as well as the importance of social protection and low-inequality growth to protect impoverished individuals.

A challenge for drawing cross-scenario comparisons is that which drivers are taken as given or fixed varies. When scenarios incorporate changes to the GPN outcomes of interest (e.g., assuming diets shift toward healthier food as in Willet et al. 2019 or assuming that there is coordinated agreement on the need to promote the empowerment of women farmers as in FOLU 2019), the GPN outcomes are, perhaps not surprisingly, generally positive. The visioning work, described below, has a stronger focus on healthy diets and gender within the AFS (Willett et al. 2019; HLPE 2017).

All scenarios have limitations. Most of the incorporated megatrends are assumed to be gradual rather than shocks or acute one-off events that could ripple through the global economy. Human diseases and pandemics (e.g., COVID-19) and agricultural pests and diseases (e.g., the current desert locust infestation in East Africa) are not included in either visioning or scenarios. Scenario building does not include unseen technologies and often cannot pick up feedbacks (Hasegawa et al. 2018). The scenarios reviewed exclude a few megatrends that could be pertinent for understanding GPN outcomes. One megatrend that is inconsistently incorporated into scenarios is inadequate water and sanitation (Maggio et al. 2019). While it is intuitive that water scarcity could adversely impact GPN, the linkages between access to water, sanitation, and water infrastructure and GPN are not commonly discussed in the results (Palazzo et al. 2014; WRI 2019; FAO 2018b). Indirect impacts of climate change on gender, poverty, and nutrition are not incorporated. For example, increased temperature could cause heat stress, harming health, which could lead to greater poverty. Emerging research (Myers et al. 2014) indicates that climate change may decrease the nutrient content of some foods. These concerns may be secondary; however, incorporating them may allow for a richer understanding of the impacts of AFS transformations on GPN.

Visioning and Backcasting

Visioning studies provide responses to *a* future rather than providing foresight into *possible or plausible* futures. Several reports propose specific visions of the future, such as “sustainably feed 10 billion people in 2050” or “meet the SDGs, sustainably.” After declaring the need to meet these goals, the reports propose pathways that can help us to arrive at that future. The pathways are often composed of bundles of technologies and/or policies. The visioning studies are a departure from the megatrends analyses and scenario analyses in that they often explicitly include the objectives of poverty alleviation, improved nutrition and health outcomes, and/or gender equality in their desired world. After briefly describing visions of the future, I split pathways by common themes, including environmentally driven pathways to sustainable agriculture and conservation, technology-driven pathways, policy-led and integrated pathways, and the roles of markets and true costing. I then discuss gaps and limitations.

Visions of the Future

Nearly all visioning studies assume that a similar set of megatrends is driving the need for changes to the AFS. The megatrends include (1) climate change, (2) decreasing natural resources, environmental degradation, and increasing demand for agricultural land, and (3) increased demand for food and shifting preferences. Thus, the perceived need for the future AFS generally is to identify pathways to *sustainably* increase *healthy* food production.

As a result, the visions for what the future global food system in 2050 (or, less commonly, in 2030) ought to look like are similar, although the weight that each vision puts on different aspects varies (see Table 4). These different areas of emphasis also inform the proposed pathways. For example, WEF (2018) and FOLU (2019) explicitly incorporate inclusivity. WRI (2019) includes both addressing water challenges and empowering women farmers. Quisumbing et al. (2019) argue that achieving inclusive agricultural growth requires attention to gender (the study's focus is only until 2025). NAS (2019) aims to "to achieve efficiency, resilience, and sustainability of the agrifood system" (p. 29), with less focus on gender, poverty, and nutrition.

What Types of Innovation Are Required?

The proposed pathways are often a mix of approaches, such as sustainable agriculture techniques, natural resource conservation, technologies, markets, businesses, nudges in consumer choice, government coordination, and regulations. Each study weighs the transformative value of various pathway components differently and tends to propose dominant components. The weights that authors put on each approach reflect authors' implicit and explicit assumptions about what is required to achieve a sustainable, healthy food system. For example, GKI and Rockefeller (2017), WEF (2018), and Hansen et al. (2019) recognize the need for supportive policies but focus on technology to drive change in the AFS. A few studies focus more narrowly on "scientific breakthroughs" and do not consider issues of technological access, adoption, or regulation (NAS 2019).

Environmentally Driven Pathways to Support Sustainable Agriculture and Conservation

Many studies envision farmers moving toward more sustainable farming techniques. Such techniques could mitigate the current contributions of the AFS to environmental degradation and climate change and make farming less reliant on unsustainable inputs and land extensification. The proposed farming approaches include ecological intensification, which result in nutrition-sensitive landscapes (Titonell 2019); efforts to improve soils, including conservation agriculture and low-till agriculture (WRI 2019); agroecological and other transformative approaches (HLPE 2019); a shift toward a bioeconomy (Birner and Pray 2019); redesigned agricultural systems that take an integrated approach to improving environmental and socioeconomic outcomes (Schwoob et al. 2019); and an integrated climate-sensitive AFS that includes nutrition foods (Pingali and Aiyar 2019). These techniques generally prioritize growing a greater diversity of products, which can benefit nutrition (Pingali and Aiyar 2019; Titonell 2019). HLPE (2019) argues for a two-pronged strategy including both transformative (e.g., organic, permaculture, and agroforeststry) and incremental (e.g., nutrition-sensitive and climate-smart) shifts in agricultural production systems. Which techniques are adopted and by whom could vary across sizes and types of production systems and ecological contexts. Such changes could decrease the yield volatility small farmers experience and potentially increase access to nutritious foods (Tittonell 2019; Pingali and Aiyar 2019; HLPE 2019). However, productivity per unit of land may not increase (HLPE 2019).

The labor requirements for such holistic agricultural approaches are generally, although not always, higher than other agricultural techniques, which may hinder gender equity (HLPE 2019). Improving soil and water management, if done with low-barrier technologies (e.g., water harvesting), could save women and their families time and physical effort (WRI 2019). However, as WRI (2019) notes, many soil-improving and soil-conserving techniques require increased inputs, increased labor, or both, which have limited their adoption to date. Access to land may also constrain adoption of holistic agricultural approaches by small farmers such as formalization of land sales and rental markets and support for farmers transitioning out of farming (WRI 2019). A further limiting factor is women's lack of formal land rights and loss of usufruct land rights, particularly in sub-Saharan Africa (HLPE 2019; WRI 2019).

Technology-Driven Pathways

Many of the technology-driven visions do not address how and whether these technologies are accessible to and useful for women, smallholders, and other AFS actors. Questions about scale neutrality; governance regimes (e.g., intellectual property); the presence of complementary infrastructure, extension, and credit services; the costs and risks of adoption; user acceptance; whether the technologies are labor saving; and whether technologies need to be tailored to specific locations may ultimately determine whether technologies are adopted and useful (Langridge 2019; Hazell 2019).

Yet examples of low adoption rates of technologies in AFS are commonplace. Tittonell (2019) examines the opportunity for ecological intensification to decrease the smallholder productivity gap in sub-Saharan Africa, arguing that many modern agricultural technologies "were not developed to fit the reality of smallholder systems" in sub-Saharan Africa and that this failure contributes to their low adoption rates and smallholders' continued low relative productivity (p. 466). Similarly, the role of gender in agronomic, market, and consumption decisions influences the likelihood of adoption of technologies (e.g., biofortification) that may support nutrition (Quisumbing et al. 2019). Training men on planting and women on nutrition may be less effective than outreach strategies that target both men and women (Doss and Quisumbing 2019). When technologies increase income or marketing opportunities for certain agricultural products, women may also lose decision-making power over them (GKI and Rockefeller 2017; Quisumbing et al. 2019).

Several technologies are scale neutral or small scale and poised to offer potential benefits to smallholders, other AFS actors, and/or consumers and therefore may face lower barriers to adoption. Scale-neutral innovations include farmgate packaging and processing technologies such as mobile precooling and packhouses; dehydration and cooling technologies such as solar driers, solar cooling, and evaporative cooling; cooperative processing and packaging and near-farm mobile processing; and storage and transport technologies such as storage crates and micro cold transport (GKI and Rockefeller 2017; Hansen et al. 2019). Improved and institutionalized data collection, improved traceability, farmer connectivity to markets through information technology, and market brokerage services could be made accessible to small actors in the AFS (GKI and Rockefeller 2017; HLPE 2017; Hansen et al. 2019). Huyer et al. (2019) warn that there are considerable gender gaps in digital agricultural services and mobile finance. Renewable energy can support farmgate packaging and processing as well as cold storage transportation along the AFS, including for the last mile (GKI and Rockefeller 2017; Skeer and Leme in S&P 2019). Innovations in life sciences such as biodegradable coatings (with food safety regulations) and microbiomes and microbes for soil could reduce food waste and postharvest losses (PHL). In sum, these technologies could increase efficiency across the AFS and provide opportunities for farmers to earn premiums on their products or to decrease PHL. They also will likely expand the availability of nutritious foods and decrease food waste

along the AFS. Several of these also support increasing production of safer, healthier foods, benefiting nutrition.

Other technologies have the potential to be transformative for the AFS but may be less accessible to smaller actors. Biosensors and food-sensing technologies could decrease PHL and increase productivity (WEF 2018; NAS 2019). They, along with blockchain technologies, could also support traceability, transparency, and safety in the AFS (WEF 2018). Synthetic biology, including gene editing, and microbiome technology could increase crop yields, increase resilience to stress and disease, and even increase nutrient availability (WEF 2018; NAS 2019). WEF (2018) notes that gene-editing and microbiome technologies could have substantial benefits for famers but that intellectual property issues must be resolved. Data science and artificial intelligence can support improvements in and hasten research on crop breeding (NAS 2019) and aid in pricing of insurance (WEF 2018). WEF (2018) argues that while biological-based crop protection could save costs, decrease input use, and increase food safety, the technology needs to be tailored for specific locations, potentially limiting its uptake in low-income countries. Similarly, precision agriculture, nutrigenics, and food-sensing technologies are likelier to be adopted in Western agri-food systems first (WEF 2018; Huang and Brown 2019). Questions about consumer acceptance of biological-based crop production, biotechnology for plant-based meat alternatives, synthetic biology, and gene editing remain (WEF 2018; HLPE 2019; FOLU 2019; Serraj et al. 2019).

HLPE (2019) is more cautious about the role of technology in the AFS, arguing that there are several unresolved debates about transformative technologies and management techniques in agriculture, including: farm sizes, modern biotechnology, digital technologies, synthetic fertilizers, the role of biofortification, and biodiversity. Such calls for more cautious approaches to technology are often part of pathways that prioritize strong governance and leadership.

Policy-Led and Integrated Approaches

Several visioning exercises propose radical transformations of the AFS. These studies tend to argue that the AFS faces several externalities and governance failures that cannot be addressed through technology or markets alone and therefore require holistic approaches that combine technology, sustainable environmental approaches, and market-led changes, with a focus on the primacy of effective global and local policies and regulations. The line between scenarios and visioning work can blur; both WRI (2019) and Willet et al. (2019), in their scenario work, argue for the need for strong policy leadership and improved global governance, which is then reflected in their scenario assumptions.

HLPE (2017, 2018, 2019), Rawe et al. (2019), and Willett et al. (2019) advocate for strong leadership from government and for policies and regulations integrated with science and technology. In its 2019 study, HLPE warns that markets have little incentive to address systemic externalities associated with agricultural production and processing. The authors write, “Government policy, regulation and moves towards true pricing aim at internalizing all ecological and social effects of production in the price of food, enabling markets to function in ways that would foster transitions towards SFSs [sustainable food systems]” (p. 18). Rawe et al. (2019) argue that tradeoffs within the food system demand participation and action from policymakers in multiple sectors and across global, regional, national, and local levels. They warn, “Without effective policy coordination, there could be actors working at cross purposes, elite capture, and entrenchment of poverty and inequality” (p. 11). Some aspects of the global AFS particularly require multilevel coordination in policymaking, with strong global governance. For example, three studies (WRI 2019 FOLU 2019; HLPE 2019) detail how business as usual regarding oceans and ocean-based foods are unsustainable and will remain so without coordinated governance.

In holistic approaches to transforming the AFS, it can be difficult to understand how the various pieces of the pathways interact, and what the ultimate impacts will be on gender, poverty, and nutrition. In one example, Willett et al. (2019) advocate for a bundled approach to achieving a Great Food Transformation. They argue for a global reorientation of priorities toward healthy diets and away from an AFS focused on producing calories. Sustainable intensification, technologies, conservation, poverty alleviation efforts, changing consumer demand, and the true costing of food (among others) will support this goal. Yet Hirvonen et al. (2020) assessed the cost of the reference diet proposed by Willett et al. (2019), finding that without a combination of higher incomes, lower prices, and nutritional assistance, the reference diet's cost will exceed household per capita income for an estimated 1.58 billion people. Further, HLPE (2017) argues for the need to better understand how consumers make food choices; it is uncertain what sorts of nudges are needed and how effective they will be in changing consumer choice. Thus, while the Great Food Transformation seeks to improve nutrition, it will not succeed without greater attention to poverty.

Similarly, WRI (2019) argues for a holistic approach to building a sustainable and healthy food system that will also empower women (among other outcomes); it offers 22 menu items that can support this transformation. Yet the menu items, either alone or in combination, may support or hinder a specific GPN goal. For example, WRI proposes to expand access to reproductive healthcare and to pursue soil and water management techniques. While reproductive healthcare will support women, conservation agriculture techniques with high labor requirements that are not accompanied by changing norms may disproportionately increase women's work burden. The net effect of these and the other menu items on gender equality is hard to discern. In general, identifying the net effects of holistic, cross-sectoral combinations of interventions on gender, poverty, and nutrition is challenging because the interventions interact in multiple ways. Thus, there is a need for coordination across seemingly disparate aspects of the AFS to ensure that, as Rawe et al. (2019) point out, efforts are not at cross-purposes.

Even addressing single issues within the food system may need interventions that draw on coordinated efforts (HLPE 2019). For example, reducing food waste may require an integrated pathway combining regulation, markets, technologies, and communication. Rawe et al. (2019) lay out a variety of policy-based approaches, including nudges, regulation, and information campaigns. Technologies to reduce waste include increasing shelf life of food through cooling and proximate processing (GKI and Rockefeller 2017; Hansen 2019). Willett et al. (2019) argue that because women are heavily involved in postharvest processing in low-income countries, food waste solutions should be accessible to and informed by women producers.

Markets and Full Costing

Several studies raise the issue of full or true costing (see FAO 2018a; WEF 2018; FOLU 2019; HLPE 2019; Willet et al. 2019) and the role of agricultural subsidies (WRI 2019 Anderson in S&P 2019) in their scenarios or visioning. FOLU (2019), for example, argues that incentives in the AFS must change in order to better incentivize businesses to pursue strategies aligned with healthier and sustainable food systems and that people need to be "paid fairly to produce the right food the right way" (p. 17). HLPE (2019) also advocates for true costing, arguing that governments need to address market inefficiencies: "There are many externalities associated with production, processing and distribution of food that are not priced and . . . agri-food input and retail sector often works against addressing these externalities" (p. 18). FAO (2018a) argues that true costs will reduce overconsumption in high-income countries. Full costing of labor and full

income measures that incorporate leisure (Quisumbing et al. 2019) might change the relative payoffs to particular strategies and could make visible the work that women do within the AFS.

Accomplishing such market transformations would require sustained policy efforts (HLPE 2019). Full costing is likely beneficial for smallholders within the AFS, but it is likely to lead to increases in consumer prices, which could make the cost of healthy diets quite high (FAO 2018a; HLPE 2019). Several studies argue that tackling food waste, creating nutrition-sensitive social protection programming, incorporating consumer subsidies, and/or providing nutritionally sensitive social protection (see FAO 2018a) will dampen the impacts of price increases on poor households. Such a bundled approach would require coordinated, high-level policy.

Gaps and Limitations

First, visioning exercises show us pathways to idealized futures and often include little discussion of whether the assumptions are plausible. For example, it is often assumed that technologies beneficial to the AFS will be adopted, but there are often numerous barriers to technology adoption. It is also often assumed that it is possible to achieve effective, coordinated global policy. Second, there is little discussion of how different innovations within a study interact with one another or whether tradeoffs across impact areas will be necessary. The interactions of drivers could increase or decrease the likelihood that these visions are achievable. For example, moving to fully costing food may make some regenerative agricultural practices look much more appealing.

GPN Themes across AFS Foresight Studies

Given the environmental and demographic trends facing the AFS, it is not surprising that most foresight studies warn that the future, without radical transformations, will be challenging for impoverished individuals, for gender equality, and for addressing the triple burden of malnutrition. Across studies, there is general agreement that overnutrition will rise under the Business As Usual case. Undernutrition may increase as well, particularly in South Asia and sub-Saharan Africa. Yet there is ample opportunity to better incorporate a GPN-focused perspective into the agri-food system.

Gender

Among GPN, gender is the outcome least discussed across the foresight work. In studies that do consider gender, authors argue that prioritizing gender equality is essential for the successful transformation of the AFS (HLPE 2017; FOLU 2019; HLPE 2019; Quisumbing et al. 2019; Rawe et al. 2019). Quisumbing et al. (2019) argue that a gender-transformative food system requires a combination of four elements of gender equality: “increasing access to control over productive resources, investing in women’s leadership, addressing gender and social norms, and removing structural and institutional barriers” (p. 211). Quisumbing et al. note that the latter two are least considered in the AFS but most important. Indeed, few studies include the structural and institutional barriers women face when adopting new technologies or assess whether social norms, if left unaddressed, combined with new technologies and new agricultural management techniques, will create more work for women, potentially resulting in increased gender inequality (e.g., Tittonell 2019; Skeer and Leme 2019; WEF 2018; NAS 2019).

Understanding unintended consequences is particularly important for supporting marginalized populations and addressing social exclusion within the AFS. For example, if innovations require additional labor requirements, gender-based time poverty may worsen or may contribute to gender-based productivity gaps (Simelton and Kawarazuka 2019). Similarly, aging populations may increase the time burden for (often female) caregivers and increase demand for convenience foods, potentially at the expense of health (Meenakshi and Webb 2019). Gender norms and gendered inequalities often shape what roles are available to men and women within agricultural value chains; considering women as either only farmers or only consumers risks overlooking opportunities to support transformations within the AFS so that women can be fully engaged in small and medium enterprises, trading, transportation, and other parts of the AFS (Quisumbing et al. 2019). These issues are also relevant for reducing poverty in the AFS. In general, an intersectional approach to understanding how gender interacts with other categories such as age, status, poverty, and ethnicity will better support the most marginalized (Huyer et al. 2019).

Finally, gender-transformative work will require engaging not only with women but also with men (HLPE 2019; Quisumbing et al. 2019). Yet few foresight studies consider how gender shapes the behaviors and barriers faced by men or how to engage men and boys as partners in gender-transformative AFS practices. "Changing norms and expectations through community dialogue, engaging men and boys, influencing traditional leaders, and using male champions for gender equality, alongside traditional agriculture interventions, can create transformative change that allows women to benefit from agriculture without having to 'fix' women" (Quisumbing et al. 2019, p. 211).

Poverty

Several themes emerge around poverty. Poverty-related outcomes are presented in terms of food security (e.g., Palazzo et al. 2014), food prices (Hasegawa et al. 2018), or GDP, sometimes adjusted for inequality (Palazzo et al. 2014). Among foresight studies that consider poverty, poverty outcomes are evaluated for either consumers or producers but rarely both. The impacts of food price increases differ based on whether an individual is a consumer, producer, or other AFS actor. Similarly, different sectors of the economy may experience different rates of growth: if GDP increases primarily in urban areas, urban consumers may benefit while rural producers are left behind. Across the studies, there is very little discussion of the different roles and experiences of actors in the AFS throughout value chains (e.g., processors, traders, transporters). Further, few foresight studies advocating for the adoption of sustainable agricultural techniques discuss labor requirements (HLPE 2019); more attention to labor as an input in the AFS could help researchers understand the potential challenges to adoption and potential for poverty alleviation.

Nutrition

Nutrition-focused foresight studies argue for a shift from production of staples (or staples and livestock) to greater access to and production of diverse diets. Several foresight studies take a systems approach to addressing malnutrition by charting pathways that expand the supply of affordable, healthy foods, ensure those foods reach consumers, and encourage consumers to eat them. These diets converge on low consumption of animal-based products and increased consumption of fruits, vegetables, and pulses. How to shift consumer demand toward more diverse diets remains an area of debate. Suggestions include mixtures of policy nudges, changes to pricing, decreased waste, improved storage, expansion of nutrition-sensitive agriculture, and adoption of speed-breeding techniques.

In other studies, production of calories (or calories and livestock) is the primary focus, with less attention to dietary quality and the role of horticultural products (e.g., Palazzo et al. 2014; NAS 2019). When studies focus on one aspect of the triple burden (e.g., expanding access to AI to increase yields), there is a risk that such technologies, if pursued in isolation, could adversely impact other forms of malnutrition (e.g., increased overnutrition due to the cheap and expanding availability of staples).

Authors argue not only that a systems approach to addressing malnutrition is needed, but also that other transformations in the AFS may hinder improvements in nutrition. For example, increases in income may increase demand for unhealthy diets; reductions in greenhouse gas emissions may increase prices, making healthy food unaffordable for key populations. Questions of consumer acceptance of biological-based crop production, biotechnology for plant-based meat alternatives, synthetic biology, and gene editing remain (WEF 2018; HLPE 2019; FOLU 2019; Serraj et al. 2019), as do questions about what roles livestock production can play in the future AFS. Further, the impact of prices on nutritional outcomes is complicated because prices interact with consumer behaviors, cultural norms, and choices (HLPE 2017) and because price increases may help some AFS actors while harming others.

Summary of Gaps and Recommendations for Future Foresight Work

Integrating fit-for-purpose, regularly updated foresight work into decision-making could support coherent decision-making across divisions and levels. Yet much of the foresight work reviewed here is designed with other goals in mind. Addressing the following gaps (drawn from the megatrends, scenarios, and visioning studies above) could help the ISDC and CGIAR develop future foresight studies that are designed to assess outcomes for the One CGIAR impact areas and that incorporate analyses of possible CGIAR interventions and innovations.

First, biotic pressures on the AFS and resulting from climate change were not commonly included in the reviewed foresight studies and are rarely linked to GPN outcomes. Human disease, heat stress on labor productivity, the physiology of plants and nutrients, inadequate water and sanitation, shortages of key fertilizer ingredients (either through changing production systems or changing inputs), agricultural pests and diseases, and pandemics have the potential to devastate the AFS (Myers et al. 2014; Maggio et al. 2019; NAS 2019). These concerns may be secondary; however, incorporating them may allow for a richer understanding of the impacts of AFS transformations on One CGIAR outcomes.

Second, most of the incorporated megatrends are assumed to be gradual rather than shocks or acute one-off events (e.g., pandemics) that could ripple through the global economy or regional agri-food systems (e.g., desert locusts in East Africa). Some disruptive technologies (e.g., artificial intelligence or synthetic biology) seem poised to change the AFS in high-income countries. Some authors identify such technologies as relevant primarily for high-income countries, yet they will likely spill over either directly or indirectly into low- and middle-income countries. For example, synthetic biology could decrease demand for livestock in the United States, leading to decreased demand for staple crops used for livestock feed and potentially depressing global staple food prices. How technologies spill over is less well understood.

Third, there are several challenges with using food prices as an outcome, and greater clarity is needed about the impact of prices on GPN and about how prices interact within the food system. The net effects of price changes will differ: across AFS actors, by whether “food” means staples or a diverse and nutritious diet, by changes in relative prices of different foods, by other changes within the AFS, and by whether

there is a movement toward the full or true cost of food. We need a better understanding of how prices, economic growth, climate change mitigation policies, and changes in inequality, among other things, may interact to improve or worsen GPN outcomes. Defining outcomes that match the One CGIAR impact areas will also increase the value of foresight work.

Finally, particularly in the visioning work, foresight studies make strong assumptions about possible pathways to desired futures. Two commonly made assumptions are that there are no or few barriers to adopting new technologies and management practices and that multilevel coordination with strong global governance will occur. The pathways detailed may not be realistic when these assumptions do not hold. Clarifying the impact of these assumptions on envisioned pathways and identifying ways to support these assumptions (e.g., CGIAR may choose to focus on identifying and resolving barriers to innovation adoption) may make such pathways more achievable.

Discussion: Opportunities for CGIAR

Based on the megatrends, scenarios, and visioning, several themes relevant to the research of CGIAR emerge. First, most of the studies show that to support healthy diets, the AFS needs to move away from increasing cereal yields and focus on expanding production of horticultural crops. Second, while there is some disagreement on the mix of changing agricultural management practices and changing agricultural technologies, there is agreement that the AFS needs transformations in both. If designed with small AFS actors in mind, innovations such as supply-chain logistics and packaging can be pro-poor, support increased access to nutritious foods, and decrease food waste. Third, based on CCAFS scenarios (see Palazzo et al. 2014), the greatest food security needs (a rough proxy for poverty) will remain in sub-Saharan Africa, and possibly South Asia. Additional themes are discussed in greater detail below.

Evaluating Technologies' and Innovations' Possible Impacts on GPN

Analyses related to gender, poverty, and nutrition are generally missing from current AFS foresight work. There are notable exceptions, including CGIAR-led work (e.g., Huyer et al. 2019; Quisumbing et al. 2019). CGIAR is well positioned to support the mainstreaming of GPN concerns throughout the AFS and the use of a systems approach to better understand and incorporate the complexity of the AFS in its analysis (Ingram and Zurek 2019).

What does mainstreaming GPN into the AFS look like? A critical role for CGIAR could be in developing methods and approaches to identify if and when GPN outcomes will be furthered by innovations, technologies, and management techniques. In other words, by situating innovation pathways within the broader AFS, CGIAR will be able to identify and address barriers to adoption, to uptake, and to impact. By using a systems approach, CGIAR will also be able to speak to possible tradeoffs and synergies within the system.

Numerous foresight studies propose technological interventions to support a transformation of the AFS; few, however, systematically consider well-established barriers to adoption. Consumer acceptance, the regulatory environment, economies of scale, access to credit and other supportive infrastructure, adaptation to regional social and environmental needs, and labor requirements are some of the considerations that may determine the uptake of new technologies (WEF 2017; NAS 2019; Hazell 2019; HLPE 2019; Quisumbing et al. 2019; Tittonell 2019). Some foresight authors are more critical of technology-led innovation in agriculture, citing concerns that technology is treated as a straightforward

mechanism for change and arguing instead for development of inclusive and participatory innovations (HLPE 2019). Careful, participatory analysis of barriers to adoption that takes a gendered, pro-poor, and nutrition-focused lens could help alleviate these concerns.

Clarifying Interactions and Tradeoffs

There is a need for better tools to systematically and explicitly map the relationships between intermediate outcomes (such as prices) and GPN outcomes as well as the tradeoffs across different impact areas. Such a mapping will aid in the analysis of the net effects of AFS transformations on GPN. This is needed for two related reasons.

First, foresight studies show that, if left on its current path, the agri-food system will face serious challenges, likely contribute to adverse nutritional outcomes, and hinder efforts to decrease poverty and gender inequality. However, we have a poorer understanding of the net effects of efforts to *transform* the AFS on GPN. Many studies do not focus on GPN or draw uncertain conclusions about GPN based on intermediate outcomes such as prices and crop production. These intermediate outcomes may interact with other drivers, or multiple drivers may interact with each other in ways that necessitate tradeoffs across outcomes. These interactions are left unspecified because realistic assumptions are hard to identify (e.g., WRI 2019). However, such interactions could offset or compound impacts on GPN outcomes. Further, in the reviewed studies that prioritize GPN, it is often difficult to identify the net effect of the bundle of interventions on gender, poverty, and nutrition.

Second, well-informed leadership will be critical for transformation of the AFS. HLPE (2017) argues that the quality of leadership is what matters most for AFS transformation (see also FOLU 2019; HLPE 2019; Rawe et al. 2019; Willett et al. 2019; WRI 2019). A multisectoral and multilevel coordinated approach to policymaking is required to address inevitable tradeoffs and to harmonize policies and incentives (Rawe et al. 2019). However, leaders may not fully understand the complex implications of policy decisions for impoverished individuals, for inequality, or for other outcomes (HLPE 2017; Rawe et al. 2019). CGIAR can support effective, coordinated leadership by making tradeoffs visible to policymakers, by using its convening power for effective conversations about such tradeoffs, and by incorporating the perspectives of multiple stakeholders to inform decisions regarding tradeoffs (HLPE 2018).

Research Prioritization, Synergies, and Sequencing

CGIAR has an opportunity to support the achievement of the One CGIAR outcomes but faces inevitable questions regarding research prioritization, synergies, tradeoffs, and unintended consequences. One approach to prioritizing interventions is to score them by value to society, as measured by One CGIAR goals. How to evaluate such interventions was a focal area for the CGIAR Big Lift Workshop in February 2020. In this workshop, Fuglie and Wiebe proposed three approaches (scoring model, parity model, benefits-costs model) to prioritization. Establishing the value of interventions to society requires costing information, an acknowledged challenge. Also important is understanding whether this lack of costing information causes biases in priority setting. While the undervaluing of environment is well recognized, other costs related to gender, poverty, and nutrition are less recognized. Chomitz (2020) of the Global Innovation Fund identifies tradeoffs between the size of impact and the number of people impacted. GKI and Rockefeller (2017) propose a set of criteria against which to benchmark possible interventions; these include affordability, usability, scalability, smallholder benefits, postharvest loss reduction potential, and

sustainability, energy, and environmental impacts. Embedding regular, ongoing foresight work to support decision-making within CGIAR can also support research prioritization.

One reason for the difficulty in understanding the net effects on GPN is that trends and innovations can be synergistic or involve tradeoffs, and they may require sequential rollout. Visioning studies describe bundling, sequencing, and menu-based approaches in their recommendations, and such approaches are helpful for understanding impacts on GPN. FOLU (2019) argues that its 10 transitions are interlinked, can produce virtuous or vicious cycles, and should be implemented nearly simultaneously. Other approaches, such as those proposed by the World Resources Institute (2019, are menu based, which allows for local and regional choice based on differences. GKI and Rockefeller (2017) contend for the careful sequencing of interventions, arguing that low-income countries will not necessarily benefit from certain technologies (e.g., big data analytics) without addressing basic infrastructure needs first. Simultaneous interventions may be required when individuals face multiple barriers (e.g., interventions in agricultural finance, inputs, and access to value chains could be bundled [Quisumbing et al. 2019]) and can help protect the most marginalized (e.g., carbon taxes could be paired with social protection to help the poorest afford healthy foods [Hasegawa et al. 2018]). Future studies that review tradeoffs and establish clear mechanisms by which to evaluate tradeoffs across interventions are important next steps. CGIAR is well placed to lead these analyses.

Conclusion

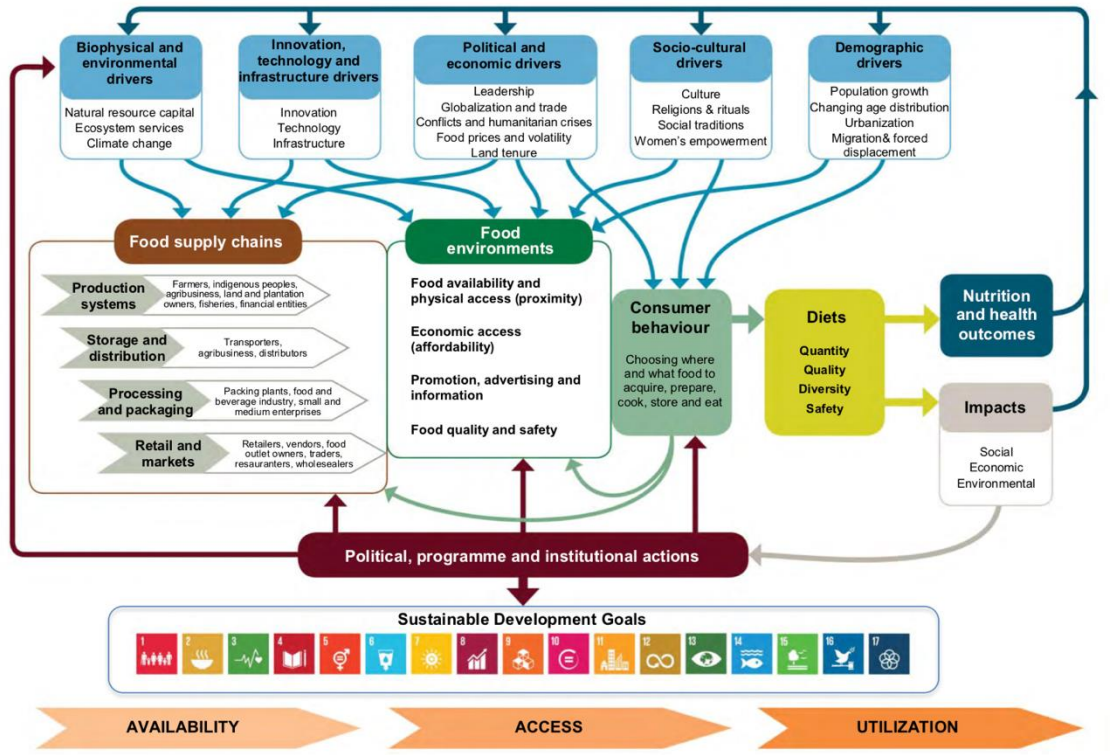
Foresight studies agree that it will be challenging to transform the agri-food system into one that is sustainable, healthy, and just. Much of the foresight work that promotes socioeconomic changes to improve the AFS in a way that prioritizes GPN outcomes relies heavily on the assumption that global coordination of policies and regulations is possible. However, history to date has shown that efforts to coordinate globally have had mixed success; that is, relying on transformative global governance to lead AFS change may be a risky strategy. At the same time, other foresight work considers the role of technology and improved management techniques in our future AFS. The paths for these innovations appear more certain and path dependent than the socioeconomic changes. Yet these innovation-led studies pay less attention to the barriers to equitable adoption and to whether these innovations will support improved nutritional outcomes. The history of development has amply demonstrated the challenges of equitable implementation of new technological innovations. While not considered directly in most of these scenarios, this history suggests that there will be a range of emergent challenges in implementing and facilitating the adoption of new and potentially game-changing innovations in ways that do not exacerbate existing social and economic inequalities.

CGIAR has a long track record with addressing this challenge and is well positioned to continue doing so. Learning from these foresight studies, CGIAR can pursue a multitrack strategy that incorporates both policy-led and innovation-led pathways to transforming the AFS through the following: (1) incorporating gender, poverty, and nutrition into the design and implementation of CGIAR-led and -supported innovations, (2) supporting and advocating for the mainstreaming of GPN into the work of others, and (3) while acknowledging that global coordination may or may not be an achievable future outcome, supporting policymakers in recognizing the importance of GPN in the agri-food system by providing them with multisectoral and multilevel tools and analyses that systematically identify the net effects of AFS changes on GPN outcomes

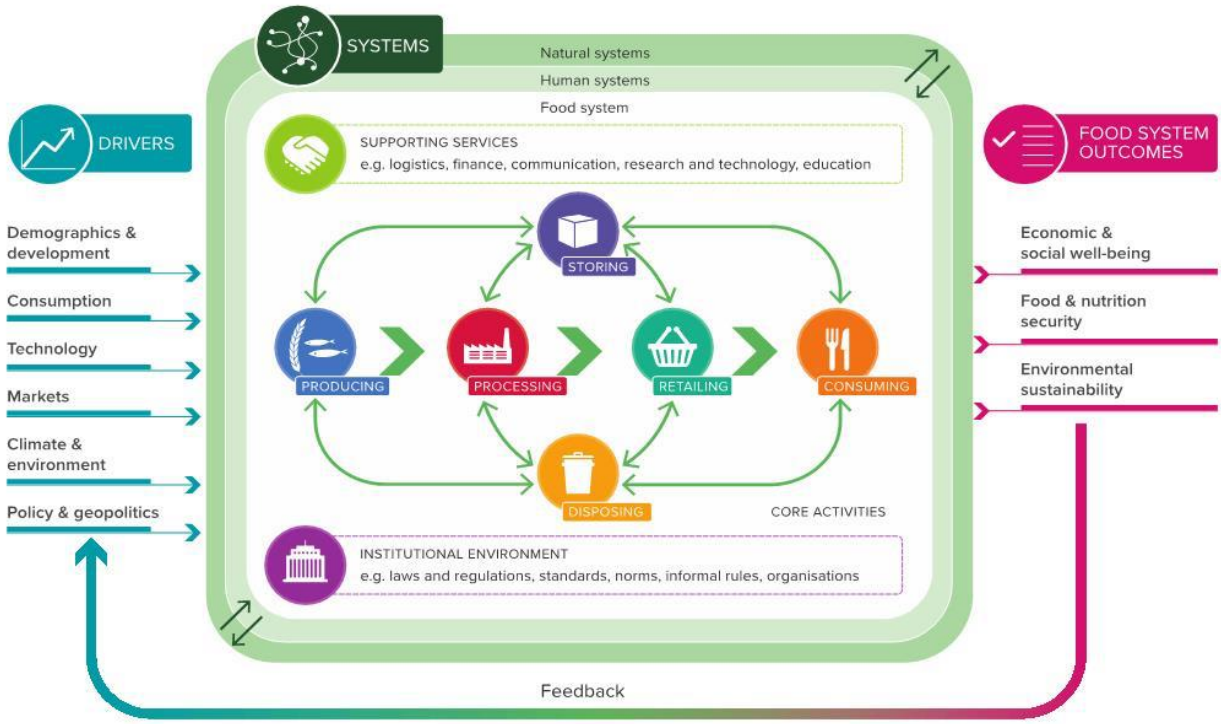
Annex A: Representations of Agri-food systems (AFS)

While the depictions of the AFS vary, each includes the constituent components of the AFS: drivers, actors, activities, and outcome.

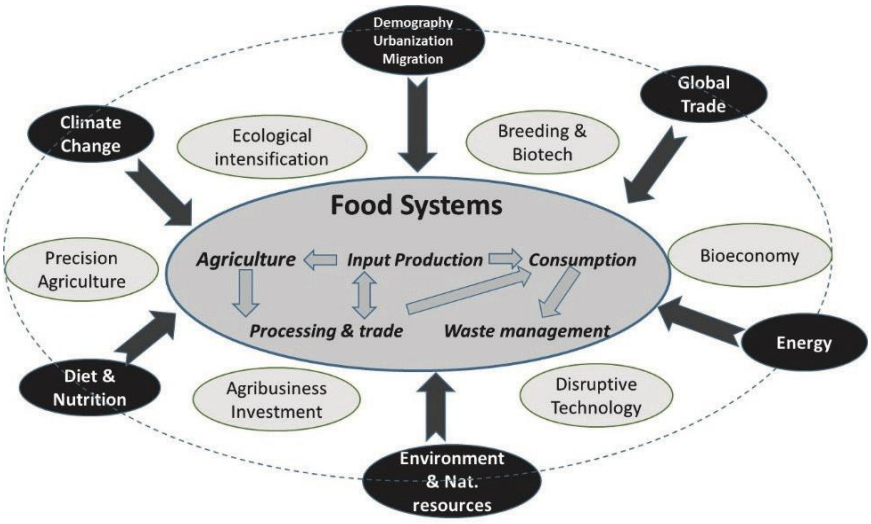
Figure 1 Conceptual framework of food systems for diets and nutrition



Source: HLPE (2019).

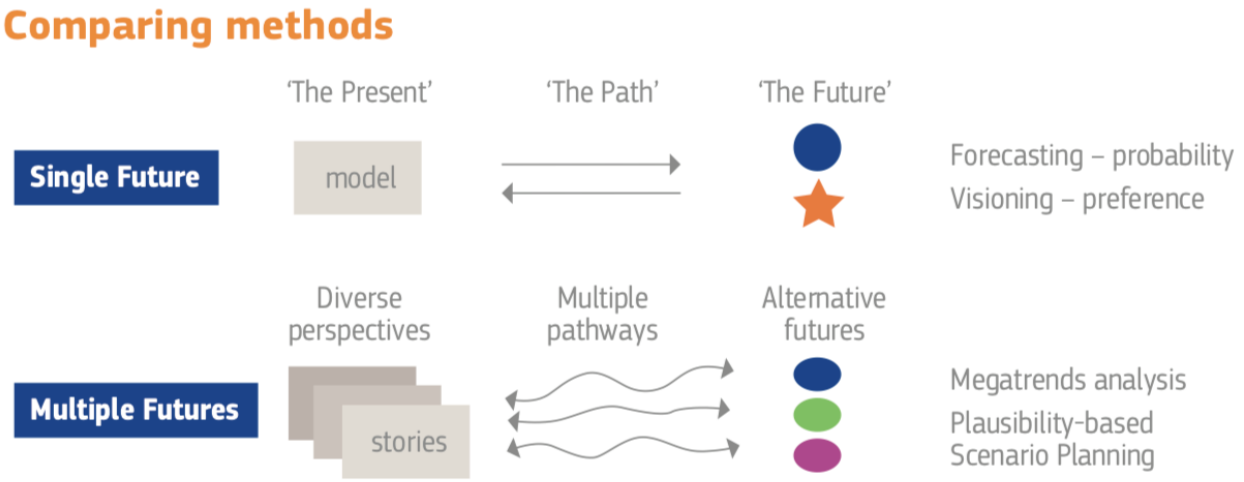


Source: Zurek et al. (2018).



Source: Serraj and Pingali (2019).

Annex B: Representation of Common Foresight Methods



Source: Wilkinson (2017).

Annex C: Terms of Reference

TERMS OF REFERENCE
Food and Agriculture Systems Foresight Study
Synthesis through Desk Review

{NAME}
(Level of Effort 35 days)

Background and Context

CGIAR is a global scientific research-for-development partnership consisting of the System Organization, Centers, CGIAR Funders, and Partners to implement its Strategy and Results Framework (SRF). CGIAR is undergoing a reform towards One CGIAR. Under this reform, CGIAR will develop a 2030 Research Strategy anchored in a unifying mission of "Ending hunger by 2030 – through science to transform food, land and water systems in a climate crisis," focused on five Impact Areas of nutrition, poverty, gender, climate, and environment.

As a prelude to the current reform of the CGIAR, the Independent Science for Development Council was created, being a reformulation of the mandate of the past Independent Science and Partnership Council (ISPC). The ISDC delivers according to a CGIAR System Council-defined Terms of Reference. Its membership has been defined as of October 2019. In order to operate, the ISDC receives the operational support of CGIAR Advisory Services Shared Secretariat (CAS Secretariat), hosted at the Rome, Italy, office of the Alliance of Bioversity International and the International Tropical Agricultural Research Center.

Assignment Details

The ISDC is seeking expert consultants with experience in applied research for development and long-term strategic thinking, in particular in one or more of the domains of food and agriculture systems (nutrition, poverty, gender, climate, and environment) that are identified impact areas of One CGIAR. Under the overall thought leadership and guidance of ISDC Member Professor Chris Barrett and under the operational supervision of CAS Secretariat Director Allison Grove Smith, the expert consultants will conduct a desk review that aligns and translates the agriculture and food systems foresight work of ISPC and other actors within and without CGIAR to clusters of specified Impact Areas of CGIAR.

The ISDC is especially interested in translating the considerable mass of recent high-quality foresight studies to the new One CGIAR context, deploying science to transform food, land and water systems in a climate crisis with a tight focus on specific impact areas. The objective is not new foresight work but rather synthesis and translation of existing work to help inform CGIAR research strategy to 2030.

The deliverable expected is a report of 15- 25 pages (not including citations) with a 2-page executive summary. Leading a presentation and discussion of the content with ISDC and guests at the ISDC April meeting is required.

Two desk studies will be commissioned. The first will focus on the implications of recent foresight studies for CGIAR research for development as it relates to impact areas of nutrition, poverty and gender. The

second will focus on the implications of recent foresight studies for CGIAR research for development as it relates to impact areas of climate and environment. ISDC recognizes that there is overlap in these areas.

In particular, the consultant for the Nutrition, Poverty, and Gender Foresight Synthesis will:

- Undertake a critical desk review to synthesize existing analyses through the lens of nutrition, poverty and gender impacts on which the One CGIAR will focus, with a horizon to at least 2030 or beyond, drawing in particular on:
  - ISPC-sponsored foresight work from 2016-2018, culminating in R. Serraj and P. Pingali, eds. (2018), *Agriculture and Food Systems to 2050: Global Trends, Challenges and Opportunities*.
  - CGIAR-sponsored foresight and ex ante impact assessment work, in particular under Global Futures and Strategic Foresight https://globalfutures.cgiar.org/project-overview/.
  - Agri-food systems foresight and ex ante impact assessment work by selected other leading organizations, including, but not limited to:
    - Committee on World Food Security High Level Panel of Experts on Food Security and Nutrition (CFS HLPE), various reports available at http://www.fao.org/cfs/cfs-hlpe/reports/en/
    - Food and Land Use Coalition (FOLU, 2019), Growing Better: Ten Critical Transitions to Transform Food and Land Use (2019).
    - Global Knowledge Initiative and Rockefeller Foundation (2017), Innovating the Future of Food Systems.
    - Graff, G.D. and I. Hamdan-Livramento (2019), Global Roots of Innovation in Plant Biotechnology (World Intellectual Property Organization).
    - Hansen, A.R., Keenan, C., and Sidhu, G. (2019). Nutritious Food Foresight: Twelve ways to invest in good food in emerging markets. Global Knowledge Initiative and Global Alliance for Improved Nutrition.
    - National Academies of Sciences (2019), Science Breakthroughs to Advance Food and Agricultural Research by 2030.
    - RethinkX (2019), Rethinking Food and Agriculture 2020-2030.
    - World Economic Forum (2018), Innovation with a Purpose: The role of technology innovation in accelerating food systems transformation.
    - World Resources Institute (2019), World Resources Report: Creating A Sustainable Food Future.
- Author study of 15-25 pages that (i) makes use of past studies to define different scenarios for agri-food systems evolution over the coming 10-25 years, recognizing likely variation across agroecological and socioeconomic contexts, (ii) synthesizes the findings of prior foresight and ex ante impact assessment work through the lens of nutrition, poverty, and gender impacts, (iii) identifies key prospective roles – and specific innovation spaces – for the CGIAR in those scenarios, and (iv) highlights gaps in foresight work that ISDC might explore in the coming 2-4 years. The study should include complete citations and references for key innovations and findings.
- Prepare a two-page executive summary for CGIAR that points to the strategic planning implications on areas for One CGIAR to prioritize to improve economic, gender and nutritional outcomes based on the foresight work.
- Present and discuss the findings in an April meeting with ISDC members.
- Arrange three virtual meetings during February and March with Prof Barrett and Dr Suneetha Kadiyala to update on progress and discuss emergent findings and themes.

References

Anderson, K. 2019. “Global Trade Futures.” In Serraj and Pingali (2019), 569–608.

Arslan, A., Egger, E.-M., and Winters, P. 2019. “Migration, Demography, and Agri-Food Systems.” In Serraj and Pingali (2019), 87–135.

Birner, R., and Pray, C. 2019. “Bioeconomy.” In Serraj and Pingali (2019), 503–544.

Chomitz, K. 2020. “Measuring and managing impact at the Global Innovation Fund.” Paper presented at the CGIAR “Big Lifts” workshop, Eschborn, Germany, February 5–7.

Doss, C., and Quisumbing, A. 2019. “Why Gender Matters for Agricultural Productivity in Africa.” In Quisumbing et al. (2019), 72–78.

Fuglie, K., and Wiebe, K. 2020. “Informing research prioritization.” Paper presented at the CGIAR “Big Lifts” workshop, Eschborn, Germany, February 5–7.

FAO (Food and Agriculture Organization of the United Nations). 2018a. *The future of food and agriculture: Alternative pathways to 2050.* Rome.

FAO. 2018b. *Transforming food and agriculture to achieve the SDGs: 20 interconnected actions to guide decision-makers.* Rome.

FOLU (Food and Land Use Coalition). 2019. *Growing better: Ten critical transitions to transform food and land use*. www.foodandlandusecoalition.org/global-report/.

Future Today Institute. 2020. *2020 tech trends report: Strategic trends that will influence business, government, education, media and society in the coming year*. New York.

GKI (Global Knowledge Initiative) and Rockefeller Foundation. 2017. *Innovating the future of food systems*. Washington, DC, and New York. http://globalknowledgeinitiative.org/wp-content/uploads/2018/01/GKI-Innovating-the-Future-of-Food-Systems-Report-October-2017.pdf.

Graff, G. D., and Hamdan-Livramento, I. 2019. *Global roots of innovation in plant biotechnology*. Geneva: World Intellectual Property Organization. https://www.wipo.int/publications/en/details.jsp?id=4473&plang=AR.

Hansen, A. R., Keenan, C., and Sidhu, G. 2019. *Nutritious food foresight: Twelve ways to invest in good food in emerging markets*. Washington, DC, and Geneva: Global Knowledge Initiative and Global Alliance for Improved Nutrition. http://globalknowledgeinitiative.org/wp-content/uploads/2019/05/Nutritious-Food-Foresight_GKI-and-GAIN-2019.pdf.

Hasegawa, T., Fujimori, S., Havlik, P., Valin, H., Bodirsky, B. L., Doelman, J. C., et al. 2018. “Risk of increased food insecurity under stringent global climate change mitigation policy.” *Nature Climate Change* 8: 699–703.

Hazell, P. B. R. 2019. “Urbanization, Agriculture, and Smallholder Farming.” In Serraj and Pingali (2019), 137–160.

Hirvonen, K., Bai, Y., Headey, D., and Masters, W. 2020. “Affordability of the EAT–Lancet reference diet: A global analysis.” *Lancet Global Health* 8 (1): e59–e66. https://www.thelancet.com/journals/langlo/article/PIIS2214-109X(19)30447-4/fulltext.

HLPE (High Level Panel of Experts on Food Security and Nutrition). 2017. *Nutrition and food systems*. Rome. http://www.fao.org/3/a-i7846e.pdf.

HLPE. 2018. *Multi-stakeholder partnerships to finance and improve food security and nutrition in the framework of the 2030 Agenda.* Rome.

HLPE. 2019. *Agroecological and other innovative approaches for sustainable agriculture and food systems that enhance food security and nutrition*. Rome. http://www.fao.org/3/a-i7846e.pdf.

Huang, Y., and Brown, M. E. 2019. “Advancing to the Next Generation of Precision Agriculture.” In Serraj and Pingali (2019), 285–314.

Huyer, S., Gumucio, T., Chanana, N., Cramer, L., Mungai, C., Ouedraogo, M., et al. 2019. *Learning and action for gender-transformative climate-smart agriculture*. CCAFS Working Paper No. 279. Wageningen, Netherlands: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).

Ingram, J., and Zurek, M. 2019. “Food Systems Approaches for the Future.” In Serraj and Pingali (2019), 547–567.

Langridge, P. 2019. “Innovation in Breeding and Biotechnology.” In Serraj and Pingali (2019), 245–284.

Maggio, A., Scapolo, F., van Criekinge, T., and Serraj, R. 2019. “Global Drivers and Megatrends in Agri-Food Systems.” In Serraj and Pingali (2019), 47–83.

Mason D’Croz, D., Vervoort, J., Palazzo, A., Islam, S., Lord, S., Helfgot, A., et al. 2016. “Multi-factor, multi-state, multi-model scenarios: Exploring food and climate futures for Southeast Asia.” *Environmental Modelling and Software* 83 (September): 255–270.

Meenakshi, J. V., and Webb, P. 2019. “Food Systems, Diets, and Nutrition.” In Serraj and Pingali (2019), 215–242.

Myers, S. S., Zanobetti, A., Kloog, I., Huybers, P., Leakey, A. D. B., Bloom, A., et al. 2014. “Increasing CO_2 threatens human nutrition.” *Nature* 510 (7503): 139–142.

NAS (National Academies of Sciences). 2019. *Science breakthroughs to advance food and agricultural research by 2030*. Washington, DC: National Academies Press. https://www.nap.edu/download/25059.

O’Neill, B., Kriegler, E., Riahi, K., Ebi, K. L., Hallegatte, S., Carter, T. R., et al. 2014. “A new scenario framework for climate change research: The concept of shared socioeconomic pathways.” *Climatic Change* 122: 387–400.

Palazzo, A., Vervoort, J., Havlik, P., Mason-D'Croz, D., and Islam, S. 2014. *Simulating stakeholder-driven food and climate scenarios for policy development in Africa, Asia and Latin America: A multi-regional synthesis*. CCAFS Working Paper No. 109. Copenhagen: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).

Palazzo, A., Vervoort, J., Mason-D'Croz, D., Rutting, L., Havlik, P., Islam, S., et al. 2017. "Linking regional stakeholder scenarios and shared socioeconomic pathways: Quantified West African food and climate futures in a global context." *Global Environmental Change* 45 (July): 227–242.

Pingali, P., and Aiyar, A. 2019. "Food, Agriculture, and Nutrition Policy: Looking Ahead to 2050." In Serraj and Pingali (2019), 609–653.

Quisumbing, A., Meinzen-Dick, R., and Njuki, J., eds. 2019. *Annual trends and outlook report: Gender equality in rural Africa: From commitments to outcomes*. Washington, DC: International Food Policy Research Institute. https://www.ifpri.org/publication/2019-annual-trends-and-outlook-report-gender-equality-rural-africa-commitments-0.

Rawe, T., Antonelli, M., Chatrchyan, A., Clayton, T., Fanzo, J., Gonsalves, J., et al. 2019. *Transforming food systems under climate change: Local to global policy as a catalyst for change*. CCAFS Working Paper No. 271. Wageningen, Netherlands: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).
https://cgspace.cgiar.org/bitstream/handle/10568/101601/CCAFS%20WP%20No.271%20-%20Local%20to%20global%20policy%20as%20a%20catalyst%20for%20change.pdf.

RethinkX. 2019. *Rethinking food and agriculture 2020–2030: The second domestication of plants and animals, the disruption of the cow, and the collapse of industrial livestock farming*. San Francisco.

Riahi, K., van Vuuren, D. P., Kriegler, E., Edmonds, J., O'Neill, B. C., Fujimori, S., et al. 2017. "The shared socioeconomic pathways and their energy, land use, and greenhouse gap emissions implications: An overview." *Global Environmental Change* 42 (January): 153–168.

Rosenzweig, C., Mbow, C., Barioni, L. G., Benton, T. G., Herrero, M., Krishnapillai, M., et al. 2020. "Climate change responses benefit from a global food system approach." *Nature Food* 1: 94–97.

Ruane, A. C., and Rosenzweig, C. 2019. "Climate Change Impacts on Agriculture." In Serraj and Pingali (2019), 161–191.

Schwoob, M.-H., Timmer, P., Anderson, M., and Treyer, S. 2019. "Agricultural Transformation Pathways toward the SDGs." In Serraj and Pingali (2019), 417–436.

Serraj, R., Krishnan, L., and Pingali, P. 2019. "Agriculture and food systems to 2050: A synthesis." In Serraj and Pingali (2019), 3–45.

Serraj, R., and Pingali, P., eds. 2019. Agriculture and food systems to 2050: Global trends, challenges and opportunities. Singapore, World Scientific. https://www.worldscientific.com/doi/pdf/10.1142/11212.

Simelton E, and Kawarazuka N. 2019. When the strong arms leave the farms. Presentation at Seeds of Change conference, Canberra April 2019.

Skeer, J., and Leme, R. 2019. “Renewable energy in the energy future.” In Serraj and Pingali (2019), 473–502.

Tittonell, J. 2019. “Ecological intensification of agriculture.” In Serraj and Pingali (2019), 437–472.
United Nations 1987. “Towards sustainable development.” Chapter 2 in *Our common future: Report of the World Commission on Environment and Development*. New York. http://www.un-documents.net/ocf-02.htm.

Van der Elst, K., and Williams, A. 2019. “Environment and natural resources.” In Serraj and Pingali (2019), 193–214.

Vervoort, J., Thornton, P. K., Kristjanson, P., Förch, W., Ericksen, J., Kok, K., et al. 2014. “Challenges to scenario-guided adaptive action on food security under climate change.” *Global Environmental Change* 28 (September): 383–394.

WEF (World Economic Forum). 2017. *Shaping the future of global food systems: A scenarios analysis*. Geneva.
http://www3.weforum.org/docs/IP/2016/NVA/WEF_FSA_FutureofGlobalFoodSystems.pdf.

WEF. 2018. *Innovation with a purpose: The role of technology innovation in accelerating food systems transformation*. Geneva. http://www3.weforum.org/docs/WEF_Innovation_with_a_Purpose_VF-reduced.pdf.

Wiebe, K., Zurek, M., Lord, S., Brzezina, N., Gabrielyan, G., Libertini, J., et al. 2018. “Scenario development and foresight analysis: Exploring options to inform choices.” *Annual Review of Environmental Resources* 43: 545–570.

Wilkinson, A. 2017. *Strategic foresight primer.* Brussels: European Political Strategy Centre.
http://www.reglab.se/wp-content/uploads/2017/09/epsc_-_strategic_foresight_primer.pdf.

Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., et al. 2019. “Food in the anthropocene: The EAT–Lancet Commission on healthy diets from sustainable food systems.” *Lancet Commissions* 393 (10170): 447–492. http://dx.doi.org/10.1016/S0140-6736(18)31788-4.

WRI (World Resources Institute). 2019. *World resources report: Creating a sustainable food future*. Washington, DC. https://wrr-food.wri.org/sites/default/files/2019-07/WRR_Food_Full_Report_0.pdf.

Zurek, M., Hebinck, A., Leip, A., Vervoort, J., Kuiper, M., Garrone, M., et al. 2018. “Assessing sustainable food and nutrition security of the EU food system: An integrated approach.” *Sustainability* 10 (11): 4271. https://doi.org/10.3390/su10114271.

Tables

Table 1: Summary of Megatrends and Drivers

STEEP-D	Description of Megatrends	Potential impact on CGIAR One outcomes (U=uncertain; O=opportunity; C=challenge; M=mixed)			
		Gender Equality	Reduced Poverty for AFS Income Earners	Reduced Poverty for AFS Consumers	Improved Nutrition
	Common Megatrends				
Environmental	**Climate change** may increase volatility of agricultural production, increase pests and diseases, decrease productivity, and increase prices. Climate change can also decrease key nutrients in plants; women may bear a disproportionate burden of absorbing volatility in food access and availability (Willett et al. 2019; Ruane and Rosenzweig 2019; Myers et al. 2014; Meenakshi and Webb 2019; FAO 2016; Van der Elst and Williams 2019; HLPE 2019).	C	C	C	C
Environmental	**Depletion of natural resources** may decrease agricultural productivity, harm individuals reliant on biodiverse environments (e.g., indigenous populations), and increase food prices. Water stress may increase the work burden for women in particular and could contribute to poor health and nutrition outcomes (WEF 2017; Meenakshi and Webb 2019; FAO 2016; Van der Elst and Williams 2019).	C	C	C	C
Demographic	**Increasing migration, urbanization, and increasing global middle class** will likely adversely change diet patterns, with risk of lack of nutritious foods in low-income neighborhoods. In some regions, migration may be gendered and women's off-farm options may be constrained. Migrants also tend to be younger and less risk averse, leaving older, more risk-averse farmers behind who may be less willing to try farming innovations. If structural transformation occurs with out-migration, farming may become more profitable, or rural-to-urban migration may further increase inequality between rural and urban households (HLPE 2017; Hazell 2019; Arslan et al. 2019; HLPE 2019; Maggio et al. 2019; Meenakshi and Webb 2019; Willett et al. 2019).	U	U	O	C
Demographic	**Population growth and age distribution**. Fertility rates fall faster in urban than rural areas. Some women may face increased caring responsibilities for an aging population and children. Small farmers may split plots into smaller and smaller sizes among their children (Hazell 2019; HLPE 2017).	M	U	U	U
Technological	**Innovations in clean energy** can offset increased demand for natural resources. Several innovative technologies could change the AFS, including grid management, green technology, renewable energy, charging stations, ultra high-voltage direct current and macro grids, better batteries and more wireless charging, energy trading platforms, zero-carbon natural gas, floating nuclear energy, and subsea power grids.	O	O	O	U

Table 1: Summary of Megatrends and Drivers

STEEP-D	Description of Megatrends	Potential impact on CGIAR One outcomes (U=uncertain; O=opportunity; C=challenge; M=mixed)			
		Gender Equality	Reduced Poverty for AFS Income Earners	Reduced Poverty for AFS Consumers	Improved Nutrition
Technological	**Logistics and supply-chain innovations such as a**utomating the supply chain, sustainability in supply chains and logistics, and rebuilding the cold chain may help improve efficiency and/or sustainability in the AFS (Future Today Institute 2020).	O	O	O	O
Technological	**Synthetic biology** aims to redesign organisms at a molecular level for new purposes or new environments. **Precision biology** creating "modern food" could replace other products, such as livestock (RethinkX 2019) but likely has economies of scale, putting it out of reach of small farmers (Huang and Brown 2019). Similarly, **cellular agriculture and insect agriculture** can provide protein sources that are more sustainable (Future Today Institute 2020). Whether consumer acceptance (HLPE 2017) and intellectual property restrictions (Graff and Hamdan-Livramento 2019) will be barriers to adoption are open questions.	U	C	O	O
Technological	**Agricultural technologies to decrease unpredictability and risk of production**. Aeroponic growing, vertical farming, indoor plant factories, big data for better produce, precision agriculture, and others can support more controlled growing environnments (Future Today Institute 2019). Small farmers are risk averse. Technology companies are getting into agriculture, which could improve food supply but may also squeeze out smaller farmers.	U	U	O	O
Technological	The impact of **artificial intelligence** (AI) will depend on the regulatory environment put in place and how it is used (Future Today Institute 2020). AI has the ability to increase the speed of learning (e.g, through deep learning, multitask learning, continuous learning), which could include identifying ways to increase global food production.	U	U	O	U
Technological	**Accelerating technological change** in areas such as robotics, nanotechnology, phototonics, and quantum computing could increase agricultural productivity. Across all technologies, questions of whether new technologies are scale neutral, how they are regulated, and consumer acceptance may ultimately determine whether technologies are adopted (Langridge 2019; Hazell 2019).	U	U	O	O

Table 1: Summary of Megatrends and Drivers

STEEP-D	Description of Megatrends	Potential impact on CGIAR One outcomes (U=uncertain; O=opportunity; C=challenge; M=mixed)			
		Gender Equality	Reduced Poverty for AFS Income Earners	Reduced Poverty for AFS Consumers	Improved Nutrition
Social	**Shift in consumer preferences** toward a Western diet (due to availability of low-cost foods, urbanization, other factors). Prepared foods could decrease meal preparation by women; convenience and processed foods may increase malnutrition for poor households; small farmers who can access new higher-value food chains (horticulture and livestock) can benefit from changes in demand; others will be left behind (Meenakshi and Webb 2019; Willett et al. 2019; Hazell 2019).	M	M	C	C
	Less Common Megatrends				
Environmental	**Agricultural pests and diseases** can decrease agricultural productivity (Maggio et al. 2019).	C	C	C	C
Environmental	**Human disease and pandemics** could disrupt AFS (Serraj et al. 2019; NAS 2019).	C	C	C	C
Environmental	**Inadequate water and sanitation,** without improved infrastructure, could harm the AFS (Maggio et al. 2019).	C	C	C	C
Environmental	**Lack of key fertilizer ingredients** could reduce yields (Maggio et al. 2019).	C	C	C	C
Economic	**Declines in public research funding** could slow technological advancement (NAS 2019).	C	C	C	C
Economic	**Increasing inequality** between rural and urban residents and between rural farmers (as some with access to storage, markets, knowledge, institutions, and technology are able to increase incomes while others' incomes decline or stagnate) could further fuel (gendered) migration and land extensification (WEF 2017; Hazell 2019; Maggio et al. 2019).	C	M	U	C
Social	**Sociocultural drivers**, **cultural traditions, and women's empowerment** (HLPE 2017) shape eating, food purchases, and the food environment; policies are necessary to promote the right to adequate food (for women and in general) from a sustainable food system beyond measures of access to health care and food.	U	U	U	U
Technological and Political	**Agricultural biotechnology** combined with adequate **intellectual property** can address food security, but diffusion may be limited without (1) absorptive power of LICs to commercialize inventions; (2) effective intellectual property regimes such that poor countries and poor farmers have access; and (3) positive public perception of biotech (Graff and Hamdan-Livramento 2019).	U	U	U	U
Political	**Geopolitical dynamics**, including nationalist and isolationist tendencies, are increasing food insecurity (WEF 2017).	C	C	C	C

Table 1: Summary of Megatrends and Drivers

STEEP-D	Description of Megatrends	Potential impact on CGIAR One outcomes (U=uncertain; O=opportunity; C=challenge; M=mixed)			
		Gender Equality	Reduced Poverty for AFS Income Earners	Reduced Poverty for AFS Consumers	Improved Nutrition
Political and Economic	**Political and economic drivers**, such as leadership, globalization and trade, food, agriculture and nutrition policies, food prices and volatility, land tenure, and conflicts and humanitarian crises influence the AFS. HLPE points out that leadership may not fully understand the implications of their decisions for impoverished individuals or for power struggles (HLPE 2017, p. 72).	U	U	U	U
Technological	**Global food supply technology**, such as artificial trees, could sequester carbon; **intelligent packaging** can cut costs and extend shelf life (Hansen: GKI and GAIN 2019; Future Today Institute 2020).	O	O	O	O
Political	**Multistakeholder partnerships** (MSPs) (collaborative arrangements between stakeholders from at least two spheres: public, private, and/or civil society) could improve governance at multiple scales in the AFS. However, there are transaction costs, power dynamics, and conflicts of interest that can limit the ability of MSPs to support better AFS governance (HLPE 2018). MSPs (if done well) can foreground approaches that improve outcomes for impoverished and marginalized groups.	O	O	O	O

Notes: Megatrends raised in multiple studies are listed as common; consensus indicates that the direction and magnitude of the megatrend is generally agreed upon. Mixed indicates that the trend is commonly identified, but the expected direction and/or (more commonly) the expected magnitude varies.

A few megatrends are uncommonly included in foresight work (see Maggio et al. 2019). Given their somewhat distal impacts on the AFS and unclear impacts on gender, poverty, and nutrition, I do not analyze them. These include diversifying approaches to education and learning, the changing security paradigm, the increasing influence of new governance systems, and the expanding influence of the East and global South.

Table 2: Summary of Scenarios

Scenario & Author	Drivers	Worlds within Scenario	Axes	World and AFS in it	Potential impact on CGIAR ONE outcomes (U=uncertain)		
					Gender	**Poverty**	**Nutrition**
FAO Global Agricultural Perspectives Systems and Environmental Impact and Sustainability Applied General Equilibrium Model to 2050 (FAO 2018a)	The SSP2 is the BAU starting point. Then FAO uses two economic models: Global Agricultural Perspectives Systems and Environmental Impact and Sustainability Applied General Equilibrium Model to 2050. 3 distinct scenarios are characterized by the way the key challenges to food security, nutrition and sustainability are dealt with: boldly, partially or not at all. Considers population, economic growth, demand for resource-intensive food, and demand for non-food agricultural commodities. Demographic trends have a substantial impact on the results of foresight trend (p. 25). Focus on responses: (1) managing food demand and changing people's dietary preferences (including full costs of food); (2) sustainably address the scarcity and reduced quality of land and water resources (3) addressing poverty and inequality to achieve food security and nutrition goals (4) tackling the nexus between climate change, agricultural sectors and livelihoods.	Business as usual	Middle challenges for food availability and stability and middle challenges for food access and utilization	Global economy grows at moderate rates, with regional disparities and inequalities. Limited investment to increase sustainability of AFS and other sectors, such as the energy sector.	Gender imbalances will not be met in a BAU world (p. xvi)	Underpricing of food continues, potentially helping poor households without adequate social protection (p. 39)	Without the full cost of food, overconsumption may continue, contributing to obesity and poor health.
		Toward sustainability	Lower challenges for food availability and stability and lower challenges for food access and utilization	Similar growth to BAU, but more equitable distribution due to pro-active policies. Diets shift in HIC and LMIC to more sustainable and less wasteful. Significant investments to increase environmental sustainability of AFS and other sectors. Stronger reduction in climate change (P. 25)	Permanently reducing poverty includes addressing gender imbalances in access to health, education, professional opportunities, particularly for marginal farmers prone to leaving agricultural (p. 152)	Prices rise quickly as move to true costs of food. Improvements in food waste and adoption of sustainable farming will help prices to level off. Incomes in both ag and nonag sector will increase faster than in BAU.	Changing consumer preferences leads to healthier nutritional outcomes and reduction of per capita consumption of animal products. Less undernutrition and more food security compared to other scenarios due to higher purchasing power in LMICs and greater focus on equity. Need for progressive commitments to maintain food security achievements in the long run.
		Stratified societies scenario	Higher challenges for food availability and stability and higher challenges for food access and utilization	Exacerbated income inequalities, with sub-Saharan Africa lagging far behind. Consumption of animal products increase, food waste worsens in HIC. Limited investment in sustainability of AFS and other sectors, resulting in depletion of natural resources, exacerbated climate change, severe impacts on human activities.	Gender imbalances will be exacerbated, particularly in labor markets due to lax enforcement of regulations (p. 170)	Bulk of production is extensification, which could harm indigenous groups; underpricing of food would continue, potentially helpful for poor households without adequate social protection (p. 39). Climate change, if left unaddressed, will exacerbate poverty and inequalities. (p. 52). Prices will increase slowly at first, then quickly as production limits are reached.	Worsening nutritional outcomes due to poor diets; Without the full cost of food, overconsumption may continue, contributing to obesity and poor health.
	Ten assumptions vary between the two scenarios. The Current Trends relies on SSP#2 Unchecked Consumption assumptions. The Better Futures scenario makes ten assumptions (1) Agricultural productivity grows at rate of 1.1. percent (2) food waste and loss is reduced by 25 percent (3) from 2020	Current Trends (SSP2)		Takes IPCC Assessment Report 5 SSP #2 scenario (Business as usual) as starting point, and grounds future outcomes in today's trends. The Current Trends scenario shows a food and land use system riddled with inefficiencies and misallocations. FOLU (2019, p. 192) provides a graphic that shows the differences between Current Trends and Better Futures.			

Table 2: Summary of Scenarios

Scenario & Author	Drivers	Worlds within Scenario	Axes	World and AFS in it	Potential impact on CGIAR ONE outcomes (U=uncertain)		
					Gender	**Poverty**	**Nutrition**
Food and Land Use Coalition (FOLU) SSP2 - Global to 2050 (FOLU 2019)	reduced by 25 percent (5) from 2020 onward, negligible conversion of forests and natural ecosystems (4) systematic increase in energy efficiency to reduce demand by 40 percent (5) enough food will be produced by 2030 (6) the world converges to "human and planetary health" diets by 2050 (7) the ocean will deliver 40 percent more sustainable proteins in next 30 years (8) investment in human capital, technology diffusion, and the digital revolution will help young rural entrepreneurs (9) increased investment in rural infrastructure and (10) rural population is more resilient due to combination of investment in rural assets and design of new safety nets.	Better Futures		The Better Futures scenario makes more aggressive assumptions; underlying such assumptions is sustained political commitment and increased pace of change relative to the Current Trends. Five major outcomes of the Better Futures scenario include (1) higher productivity, reduced food loss and waste, and dietary shifts will shift 1.5B acres of land away from agriculture, to reduce GHGs and biodiversity loss (2) the advantages of high intensity agriculture erode, decreasing input overuse, lowering food prices, and improving health (3) the economic gains to society of reducing hidden costs in the food and land systems are conservatively estimated as between $5.7-$10.5 trillion per year. (4) Rural incomes grow twice as fast compared to the Current Trends scenarios (5) Financing the food and land use transformation requires substantial capital ($300-$350 billion per year).	Transitions to a healthier diet will benefit men and women, although women may benefit more as they are at greater risk of undernutrition. Women in particular need greater attention during efforts to transform the food and land use system, given pervasive inequalities.	Affordable, healthy food will reduce food insecurity broadly, and will be achieved through increases in production of healthy foods, decreased overuse of inputs, decreased food waste and loss, and shifts to healthier diets. Expansion of well-paying rural jobs will support rural residents, as will addressing structural barriers around trade policy (FOLU p. 188).	Affordable healthy food could improve nutrition - requiring transformation of tax policy, agricultural subsidies, targeted investment and innovation, and behavior change.
SSP2 - Global in 2050 (Hasegawa et al. 2018)	Consider the impact of ambitious mitigation efforts on SSP2. (1) the carbon tax on agricultural GHG emissions; (2) the carbon tax on the carbon emissions/sequestration associated with land-use change; (3) the carbon tax induces an increase in the biofuel demand from the energy system. Hasegawa et al. (2018) start with SSP2 as a benchmark and use a multimodel approach (the 8 models used are AIM/CGE, CAPRI, GCAM, GLOBIOM, IMAGE, IMPACT, MAGNET, and MagPIE) to understand the impacts of climate mitigation efforts on costs of agricultural production and food prices.			The authors compare 8 global agricultural economic models across three dimensions, for a change temp in 2100 to be between 2 or 2.7 C and ambitious mitigation efforts versus no mitigation efforts. In all models, ambitious mitigation efforts (i.e., carbon prices) lead to an increase in the cost of production and food prices through three main channels simultaneously: (1) the carbon tax on agricultural GHG emissions directly increases the production costs depending on the GHG intensity of the production; (2) the carbon tax on the carbon emissions/ sequestration associated with land-use change makes expansion of agricultural land more expensive, and hence leads to higher land rents; (3) the carbon tax induces an increase in the biofuel demand from the energy system, which further increases the demands for land, and hence again pushes the land rents upwards. The resulting increase in food commodity prices decreases food consumption or shifts demand to less expensive food products, with implications for the prevalence of hunger (pp. 699-700). While hunger increases consistently, the size of the increase depends on whether climate change in 2100 is 2C or 2.7C warmer.	Uncertain	Most models agree that mitigation policies linearly increase food prices and expenditure, decrease food availability, and increase the risk of hunger. Mitigation policies contribute to more than half of the overall price increases of crops and livestock products (Supplementary Fig. 12). Other policies can be more synergistic. For example, taxes on red meat and dairy products are expected to cut emissions and improve nutritional health (p. 700). Resource-efficient production technologies, including land- and emissions-saving ones, in developing regions could both contribute to climate mitigation and economic development (701). Regional variation as well.	Focus is on undernutriton rather than malnutrition. However, as food prices increase, impoverished people will shift to less expensive food products. This could undermine efforts to promote and adopt healthier diets (e.g., those rich in horticultural products) among poorer populations.

Table 2: Summary of Scenarios

Scenario & Author	Drivers	Worlds within Scenario	Axes	World and AFS in it	Potential impact on CGIAR ONE outcomes (U=uncertain)		
					Gender	Poverty	Nutrition
Great Food Transformation - Global to 2050 (Willett et al. for EAT Lancet 2019)	Start with SSP2 Three axes: Production (business as usual; improved production practice; improved production practice +); Food Waste (full waste; halve waste); and Diet (business as usual, reference, pescatarian, vegetarian, and vegan). "We focused on measures that are feasible with existing technologies but have not been widely implemented." (p. 471)	Departures from SSP2	Because the three axes have multiple outcomes, there are a wide variety of scenarios. Ultimately, the reference diet, which stays within Earth's planetary boundaries, was the focal point of the analysis (the visioning tab documents the reference diet).	Scenarios for achieving healthy diets from sustainable food systems examine the environmental effects on planetary boundaries of implementing measures considered for reducing the environmental effects of food production. To analyse environmental effects of various measures on each boundary of food production, we use a global food systems model with country-level detail that converts consumption patterns, such as the healthy reference diet, into associated requirements of food production (table 4). The model considers existing and future projections of food demand, trade, requirements of livestock feed, processing of oilseeds and sugar crops, and non-food demands for agricultural products by industry.	Uncertain		The scenarios are presented to primarily describe the effects of these axes on environmental outcomes; nutrition (due to dietary choice) is considered, but rather as a driver (e.g., move toward veganism) than as an outcome.
Scenarios not using SSP							
World Economic Forum - Global to 2030 (WEF 2017)	Market connectivity (openness of trade, trust in and resilience of commodity markets. Inclusivity of technological innovations) and demand shifts (nature of the future demand for food and agricultural products: resource intensive vs. resource efficient)	Survival of the Richest (WEF1)	Low connectivity and resource intensive consumption	Sluggish economy, high inequality; and high environmental cost. In isolated and import-dependent markets, there is increasing hunger and poverty. Population growth, rising inequality, rising food prices contribute to intensifying use of natural resources, increased migration and conflict. Technology is not accessible to many people. Climate change has not been addressed. Traditional agricultural will not be seen as attractive, perpetuating rural poverty. Aging farmers will not be replaced by younger farmers.	Women will be adversely affected by conflict and food insecurity.	Poor will get poorer; increasing poverty may contribute to conflict, migration and instability	Vast majority of consumers will eat low nutrient, high calorie diets, becoming overnourished.
		Unchecked Consumption (WEF2)	High connectivity and resource intensive consumption	Rapid growth relying on intensive use of resources with serious consequences. Technology focuses on yield improvements; natural resources are further depleted to meet the expanded demand. Global warming is unchecked.	Uncertain	Global food producers and retailers will benefit from increased sales of food, and consumers may benefit from low food prices (because costs of growing resource intensive food remain externalized). Larger producers will dominate, and small farmers may be left behind.	Focus on expanding yields will result in low cost foods that are high calorie, low nutrient diets resulting in overnutrition
		Open-source Sustainability (WEF3)	High connectivity and resource efficient consumption	Highly connected markets, resource efficient but may leave some people behind. Trade agreements make provisions for responsible practices. Climate change is partially mitigated, natural resource use has stabilized. Farmers have access to capital and technology and use resources more efficiently. Consumers demand healthier diets and accept new food products	Uncertain	Synergistic policies make rural areas vibrant; technologies to improve yield, decrease waste are available to all farmers.	Norms for healthy diets are entrenched; consumers eat new foods (bio-engineered or fermentation processes)
		Local is the New Global (WEF4)	Low connectivity and resource efficient consumption	Fragmented markets with focus on self-sufficiency and appreciate local diets. Shorter food supply chains can help environment, but effects of climatic shocks in disconnected markets can be severe. Resource efficient but highly unequal Comparative advantages among food producing regions are lost and food importing countries may face hunger. Food choices reflect full costs	Uncertain	Local, small farmers could benefit. Urban areas in net-food importing areas may face unrest and undernutrition. Technological innovations may fail to reach the poorest. Agriculture may shift to urban areas, which could harm smallholders but benefit urban residents	Relative cost of healthier diets to unhealthier diets falls; interest in eating local. Combined, can result in decreased overnutrition. In some countries unable to meet self-sufficiency, hunger may increase due to resource disparities.

Table 2: Summary of Scenarios

Scenario & Author	Drivers	Worlds within Scenario	Axes	World and AFS in it	Potential impact on CGIAR ONE outcomes (U=uncertain)		
					Gender	Poverty	Nutrition
World Economic Forum Scenarios (WEF 2017) - Emerging markets in 2035 (GKI and Rockefeller 2017)	Same as WEF (2017)	Across the four WEF scenarios (2017), certain innovations make more sense.		Specific areas for innovation can be classified as particularly relevant for each world or could "alter the course of the future offered in the four WEF scenarios" (p. 81): 1. How might we engineer production systems impervious to crop failure and spoilage? (WEF 1-4); 2. How might we reimagine the relationship between consumers and producers? (WEF 1-2); 3. How might we create closed-loop agricultural systems? (WEF 1-4); 4. How might we assure that all food everywhere is priced to account for its true cost? (WEF 2,3); 5. How might we create farm-free foods? (WEF 1, 4); 6. How might we open, share, and use data across the supply chain to eliminate information asymmetries? (WEF 1-3); 7. How might we transform conventional agriculture into regenerative agriculture? (WEF 2, 3); 8. How might we scale hyper-adaptive, localized polyculture? (WEF 1,2, 4); 9. How might we build and scale a model of self-sufficient city-based agriculture? (WEF 1, 3, 4); 10. How might we reposition rural areas as places of opportunity? (WEF 1,2). Two questions which the authors argue are relevant for all four worlds are (1) "how might we engineer production systems impervious to crop failure and spoilage?" and (2) "how might we create closed-loop agricultural systems?"	Uncertain	For each of the ten questions, GKI and Rockefeller evaluate possible innovations against a set criteria. Criteria include affordability, usability, scalability, smallholder benefits, postharvest loss reduction potential, as well as sustainability, energy and environmental impacts. Poverty is included, but gender and nutritional outcomes are less so.	Uncertain
World Resources Institute - Global in 2050 (WRI 2019)	Uses Globagri-WRR model to estimate contribution of 22 menu items toward achieving 3 great needs: addressing food supply, agricultural land area, and greenhouse gas emissions. Sustainability criteria include (1) poverty alleviation (2) empowering women farmers and (3) protecting fresh water resources. Use the scenarios to understand world outcomes based on the intensity of adoption of the 22 menu items. Thus, the scenarios offer ways to weigh the impact of different menu items based on the level of ambition. The Scenarios are additive. Therefore, what works in least ambitious scenario will also hold for the most ambitious. See pp. 408-413 for the values of each of the 22 drivers in each scenario. Three scenarios are increasing in terms of ambition, coordination, political will, and technology. The scenarios are populated with assumptions about degree of adoption of 22 menu items ("22 component actions") that can sustainably address the three great needs. WRI argues: ensuring women's	Baseline		Baseline, using trends as of 2010, assumes business as usual, with lack of coordination. Some productivity gains (per FAO projections) will be made. Agricultural productivity gains built in to the 2050 baseline close more than 80 percent of the land gap and roughly two-thirds of the GHG mitigation gap that would occur if no productivity gains occurred after 2010.	Uncertain	Boosting small farmers' productivity and income will help ensure that the structural transformation of agriculture (including mass migration to urban areas) is humane. Predictions around agricultural prices is uncertain; agricultural price increases could help or harm smalholders, depending on whether they are net purchasers, have access to storage, etc. (p. 30).	Inadequate
		Coordinated Effort	Some coordination	Success depends more on strong, coordinated, global commitment to actions that are already well understood, rather than significant advances in technology. Slower demand and increased productivity does not close the land gap. If farming becomes more profitable (e.g., due to higher yields), farmers may seek to expand. Policies are needed to restore land (e.g., reforestation), to protect biodiversity, and to store carbon. In the Coordinated Effort scenario, cropland area remains relatively constant between 2010 and 2050, but pasture area still expands by 128 Mha. Addressing GHG is the most challenging aspect of the scenarios. Measures taken in the Coordinated Effort scenario would still leave total emissions from agriculture and land-use change at 9.1 Gt of CO2e per year by 2050, more than 5 Gt above our 4 Gt target.	Empowering women farmers is a stated priority.	The authors show that increasing food productivity will have a greater impact on addressing the food gap than changing demand and decreasing food waste. The food gap is closed across all three scenarios.	Taken as given (aim of scenarios is to investigate how to close the food gap (among others), where food is defined as nutritionally balanced.

Table 2: Summary of Scenarios

Scenario & Author	Drivers	Worlds within Scenario	Axes	World and AFS in it	Potential impact on CGIAR ONE outcomes (U=uncertain)		
					Gender	Poverty	Nutrition
	equal access to productive resources could raise total agricultural output in developing countries by 2.5 to 4 percent; gains in women's production may help address food insecurity because women are more likely to spend their money on food; empowering women can also decrease fertility rate, causing less pressure on resources. (p. 31) Use calories to measure food gap among nutritionally balanced alternatives (16). Some potentially nutritionally beneficial changes, such as decreased animal consumption among those who are overnourished, are described but not explicitly linked to malnutrition in all its forms. The adequacy of plant-based protein availability is described.	Highly Ambitious	High coordination	Pushes further in terms of implementing improved technologies, even where they involve higher costs or appear somewhat impractical today. The Highly Ambitious and Breakthrough Technologies scenarios completely close the 593 Mha land gap and potentially make hundreds of millions of hectares available for other uses or for reforestation. These reductions could be used to sequester carbon by reforesting land and restoring savannas by midcentury. However, two factors (shifting of agricultural land and increasing need for land for urban development) may limit the decreases in GHG. The Highly Ambitious scenario reduces emissions to 5.8 Gt per year.	Empowering women farmers is a stated priority.	The food gap is closed across all three scenarios; Highly Ambitious and Breakthrough more than close the land gap.	Taken as given (aim of scenarios is to investigate how to close the food gap (among others), where food is defined as nutritionally balanced.
		Breakthrough Technologies	High coordination and breakthrough technologies	Builds in levels of achievement that could be realized, only with innovations that dramatically improve the performance and/or costs of technologies. The scenario includes only technologies where there are genuine grounds for optimism in that the science is demonstrating progress. Only the Breakthrough Technologies scenario, resulting in annual emissions of 4.6 Gt, gets close to the target. Reaching the 4 Gt goal would require major technological advances as well as full reforestation on at least 80 Mha of liberated agricultural land.	Empowering women farmers is a stated priority.	The food gap is closed across all three scenarios; Highly Ambitious and Breakthrough more than close the land gap; GHG is closed only in Breakthrough.	Taken as given (aim of scenarios is to investigate how to close the food gap (among others), where food is defined as nutritionally balanced.
Regional Scenarios: Start with SSPs; use GLOBIOM, IMPACT, local stakeholder expertise to identify regionally appropriate assumptions for GDP, livestock and crop yields, and production costs and regional axes of interest. Both GLOBIOM and IMPACT incorporate numerous commodities (30 and 62 respectively) in their models. However, most discussion of the impacts of these modeling exercises focus on food security rather than nutrition. This could just reflect that the prioritization of dietary quality was less a focal point prior to CGIAR One. The reported commodities tend to be staple crops rather than fruit and veggies.							
SSPs - West Africa in 2050 (CCAFS: Palazzo et al. 2014; Palazzo et al. 2017)	Choice of axes is: non-state or state actors dominate; short-term or long-term priorities dominate.	Self Determination (SSP1)		Self-determination trend indicators align closely with SSP1. Sustainability in nearly all qualitative elements describing the SSP narrative, such as investments in productivity and extension services, increased education and health and sanitation services, regulations to reduce deforestation, and effective social protection schemes. Corruption, however, may increase due to lack of strong institutions, and foreign funding may decrease.	Uncertain	the greatest improvement in food security due to the long-term high economic growth	Investments in livestock production nearly quadruples the total livestock calories produced (from dairy, ruminant and monogastric meat) for Cash, Control, Calories and Self-Determination
		Civil Society to the rescue? (SSP2)		Weak governments are replaced with strong CSOs tackling food security with a long-term focus, together with strategic investments by a more socially conscious private sector, is most closely represented by SSP2: Middle of the Road, where some actions for protection lead to a decline in deforestation rates, modest productivity and commercialization benefits fall to those who already have capacity rather than inducing a transformation of smallholders, and moderate increases in education and health issues are largely taken up by CSOs with private sector support. Goals are only partially achieved.	Uncertain	average price for crops increases over time for Save Yourself and Civil Society to Rescue?	
		Save Yourself (SSP3)		Action is not taken by the weak and unstable governments, but by CSOs in an emergency response manner, and by the private sector acting with short-term profitability interests, which mirrors the global narrative of SSP3: Regional Rivalry, of weak institutions, low technology development for the agriculture sector and food security issues due to growing inequality and high population growth. Also similar to SSP4: Inequality, although the cause of inequality could be political instability and ineffective institutions.	Uncertain	Most challenging for food security; average price for crops increases over time for Save Yourself and Civil Society to Rescue?	Likely worsens

Table 2: Summary of Scenarios

Scenario & Author	Drivers	Worlds within Scenario	Axes	World and AFS in it	Potential impact on CGIAR ONE outcomes (U=uncertain)		
					Gender	Poverty	Nutrition
		Cash, Control and Calories (SSP5)		A highly urbanized, high economic growth focused scenario, leading to reactive investments in education and health services, similar to the SSP5: Fossil-fueled Development. The difference with SSP5 is that in this scenario, investment cycles are short, creating unstable development throughout the scenario period.	Uncertain	a relatively large increase in the GDP per capita, sees a limited improvement in food security due to the nature of markets within the region ; average price for crops decreases for Cash, Control, Calories and Self-Determination.	Investments in livestock production nearly quadruples the total livestock calories produced (from dairy, ruminant and monogastric meat) for Cash, Control, Calories and Self-Determination.
SSPs - Southeast Asia in 2050 (CCAFS: Palazzo et al. 2014; Mason-D'Croz et al. 2016)	Started with 21 plausible surveys, ended with 4. Four possible axes: (1) agricultural investment (levels of public and private investments), (2) enforcement capacity and regional collaboration (level of enforcement and level of collaboration) (3) land degradation through land-use change (level of degradation), and (4) markets (unregulated, common regulated, and protectionist markets)	Land of the Golden Mekong	(1) high public and private investment (2) strong enforcement and regional collaboration (3) low degradation (4) common regulated market	Unification of Southeast Asia on political, economic and environmental issues gradually becomes a reality. Aging population and insufficient low-skill labor availability poses a challenge, leading to increasing migrant competition in the working class. This is a challenge for the region to manage increasing migration and urbanization. Ultimately, institutions, which are strong and inclusive, can manage the development process, leading to significant improvements in food security, livelihoods, and the environment. Climate resilience is therefore improved, although biophysical vulnerabilities remain, especially in the form of extreme events.	Uncertain	Income is the biggest driver of food security. Models are less able to address questions of access to food given that both income and inequality may increase (p. 267). Institutions are strengthened, increasing food security.	GM and DD scenarios will see the largest increases in terms of kilocalories per hectare, with less need of imports.
		Buffalo, Buffalo	(1) unbalanced, high private investment only (2) weak enforcement and regional collaboration (3) high degradation (4) unregulated markets	Initially, ASEAN cooperation increases. However, by 2020 problems arise, with major corruption scandals weakening national governments. The private sector in response to energy and food prices starts to increasingly acquire land, putting pressure on small shareholder farmers. Food production declines, leading to more migration and societal conflict. By 2050, unsustainable agricultural intensification has led to concentration of agricultural land, and a focus on processed foods. There are issues of inequality and access to food. Poor environmental management leads deforestation and conflicts within ASEAN. Though attempts continue to be made to improve conditions across sectors, general environmental and socioeconomic situation of the region declines.	Uncertain	High energy prices and expanding larger farmers pressure smallholders; higher food prices could harm consumers	Lowest improvements in productivity and greatest need for imports. Hunger is likely to be worst under this scenario.
		The Doreki Dragon	(1) unbalanced, high private investment only (2) strong enforcement and regional collaboration (3) high degradation (4) common regulated markets	ASEAN facilitates the development of a regional market, which spurs the growth of big businesses across the region. The agriculture sector industrializes through the use of GMOs and other advanced technologies. However, through this process large producers dominate at the expense of small-shareholders, who become laborers on industrial farms, or are forced to the cities to find work. Rapid urbanization and industrialization leads to greater environmental degradation. This leads to a very unequal society, where food security is a major concern in the lower classes, and climate resilience is decreasing.	Uncertain	Potential harm for smallholders who have less access to technology and will be squeezed out.	GM and DD scenarios will see the largest increases in terms of kilocalories per hectare, with less need of imports.

Table 2: Summary of Scenarios

Scenario & Author	Drivers	Worlds within Scenario	Axes	World and AFS in it	Potential impact on CGIAR ONE outcomes (U=uncertain)		
					Gender	Poverty	Nutrition
		Tigers on the Train	(1)Low public and private investment (2) strong enforcement and regional collaboration (3) low degradation (4) protectionist and closed market	Regional collaboration within Southeast Asia increases, but is coupled with increasing protectionism against outside economic influences. High food prices in the near future leads to targeted investments in agriculture, which spur the sector to industrialize with a focus on value added products. This focus on agriculture ebbs over time. Protectionist policies lead to tensions with China and by 2050, threatens to cripple the regional economy. Climate resilience and food security are threatened through increasing inequality, and a lack of investment in a sustainable agricultural development in the final decades of the scenario.	Uncertain	Increasing inequality and higher food prices could harm consumers	Slight improvements in productivity; still need for imports but with lower population growth, pressure on food security will be lower.
SSPs in East Africa in 2030 (CCAFS: Vervoort et al. 2014)	Two axes (1) proactive vs. reactive governance and (2) fragmented status quo to regional integration. Scenarios focused on dimensions on socio-economic changes, food security, livelihoods and environments. Therefore, there is less information on nutrition.	Industrious Ants	High proactive governance and high regional integration	'Industrious Ants' is a world where state and non-state actors are proactive and committed to regionalization. This scenario has many benefits for food security, environments and livelihoods, but new challenges emerge around an active struggle with corruption and the consequences of a regional push for autonomy in the global arena.	Uncertain	Best outcome for food insecurity	Uncertain
		Herd of Zebra	Reactive governance and low regional integration	'Herd of Zebra' is a world where regional integration has developed, but the focus is mainly on industrialization and economic growth and little attention is given to food security, environments and livelihoods until crises occur. Inequality characterizes the region.	Uncertain	High inequality and high food insecurity. Little attention given to food security until a crisis.	Uncertain
		Lone Leopards	Proactive governance and low regional integration	'Lone Leopards' is a world characterized by fragmented but proactive governments and non- state actors that achieve scattered though sometimes strong and fast successes; however, there is much mistrust among countries and organizations, and the region is marked by political and economic instability.	Uncertain	Scattered and sometimes strong successes.	Uncertain
		Sleeping Lions	Reactive governance and high regional integration	'Sleeping Lions' is a world that sees self- interested governments and non-state actors turning a blind eye or profiting from regional and international exploitation of land and resources. This leads to public unrest time and time again, but never to structural change.	Uncertain	Worst outcome for food security	Uncertain
		The New Union of South Asia (SSP1)	(1) high human capital (2) high governance and institutional capabilities (3) high transfer and availability of science and tech (4) high political stability (5) ag sector is not dominant (6) low pop growth and medium urbanization	Sustainability scenario: Net exporter; in South Asia, crop production increases by nearly 80% for most of the scenarios by 2050. In all scenarios over the time period, crop yields grow for four of the most produced crops in South Asia, rice, wheat, maize and sugar. Production is driven by increasing demand for products, and dairy production increases most significantly in the Jugaad scenario, where demand for dairy products doubles by 2050. Despite the growth in this sector, there remains unmet regional demand, met through imports. Relative to the 2010 levels, yields are highest for the New Union of South Asia reflecting the high institutional capacity and transfer of technologies for agriculture.	Uncertain	Crop yields double in new NewUSA; lower levels of inequality	Increases in caloric availability is 30%. Highest increase in demand for monogastrics and ruminants.

Table 2: Summary of Scenarios

Scenario & Author	Drivers	Worlds within Scenario	Axes	World and AFS in it	Potential impact on CGIAR ONE outcomes (U=uncertain)		
					Gender	Poverty	Nutrition
SSPs in South Asia in 2050 (CCAFS: Palazzo et al. 2014)	The scenarios developed for South Asia considered six factors of change: Knowledge, education, information (human capital); Governance and Institutions; Science, Technology, and Innovation; Political Stability and conflict; Economic Structure; and Demographics. Incorporation of assumptions about transfer and availability of technology is the main departure from SSPs. Again, heavy focus on increased availability of products. No discussion of technologies; greater focus on institutions, governance, and trade.	Jugaad (SSP3)	(1) low human capital (2) low governance and institutional capabilities (3) low transfer and availability of science and tech (4) low political stability (5) ag sector is dominant (6) high pop growth and high urbanization	In crop production, under Jugaad, the region must import by 2050 due to the growing population and an agricultural sector that faces little innovation and transfer of technology, political instability, and poor governance. In all scenarios over the time period, crop yields grow for four of the most produced crops in South Asia, rice, wheat, maize and sugar. Dairy imports in the region are highest for Jugaad and Precipice and as a share of the regional production account for 11% and 12%, respectively.	Uncertain	Demand per capita is lowest;	Increase in caloric availability is lowest, at 16%, reflecting low population growth. Lowest increase in demand for monogastrics and ruminants.
		Unstable Flourishing (SSP2)	(1) high human capital (2) high governance and institutional capabilities (3) high transfer and availability of science and tech (4) low political stability (5) ag sector is dominant (6) low pop growth and medium urbanization	Net exporter; In South Asia, crop production increases by nearly 80% for most of the scenarios by 2050. In all scenarios over the time period, crop yields grow for four of the most produced crops in South Asia, rice, wheat, maize and sugar. Production is driven by increasing demand for products, and dairy production increases most significantly in the Jugaad scenario, where demand for dairy products doubles by 2050. Despite the growth in this sector, there remains unmet regional demand, met through imports.	Uncertain	growth in agriculture sector due to increasing demand from a larger population	Increases in caloric availability is 30%.
		People Power (SSP2)	(1) high human capital (2) low governance and institutional capabilities (3) high transfer and availability of science and tech (4) low political stability (5) ag sector is not dominant (6) low pop growth and medium urbanization	Net exporter; in South Asia, crop production increases by nearly 80% for most of the scenarios by 2050. In all scenarios over the time period, crop yields grow for four of the most produced crops in South Asia, rice, wheat, maize and sugar. Production is driven by increasing demand for products, and dairy production increases most significantly in the Jugaad scenario, where demand for dairy products doubles by 2050. Despite the growth in this sector, there remains unmet regional demand, met through imports.	Uncertain	Growth in agriculture sector due to increasing demand from a larger population	Increases in caloric availability is 30%.
		Precipice (SSP3 and SSP5)	(1) high human capital (2) low governance and institutional capabilities (3) low transfer and availability of science and tech (4) low political stability (5) ag sector is dominant (6) high pop growth and high urbanization	Initially a net exporter, but by 2050, Precipice shows signs of a failing agricultural sector and makes only marginal exports of crops. In all scenarios over the time period, crop yields grow for four of the most produced crops in South Asia, rice, wheat, maize and sugar. Dairy imports in the region are highest for Jugaad and Precipice and as a share of the regional production account for 11% and 12%, respectively.	Uncertain	Crop yields are highest in NewUSA and Precipice in the early periods, but worsening outcomes over time.	Second lowest increase in demand for monogastrics and ruminants, with lowest increase in meat and diary demanded by the end of the scenario in 2050 (reflecting slowing of the ag sector)

Table 2: Summary of Scenarios

Scenario & Author	Drivers	Worlds within Scenario	Axes	World and AFS in it	Potential impact on CGIAR ONE outcomes (U=uncertain)		
					Gender	Poverty	Nutrition
		Crowded	(1) participatory, unregulated markets (2) medium institutional capacity (3) inequitable, driven by the state and (4) high water availability	Second lowest GDP due to growing population and unequal wealth distribution. Food security, measured in available kilocalories per capita per day, increases over the time period (Figure 58). Examining the changes in food demand per capita can help to understand the effect the market situation as well as the income effect on food consumption. Crop yields improve over the time period, Demand for monogastrics increases from 2010-2050 for all scenarios, due to the expansion of monogastric production and a relative decrease in monogastric meat prices.	Uncertain	Food security, measured in available kilocalories per capita per day, increases over the time period (Figure 58).	The per capita cereal consumption increases by almost 25-30% (p. 71). Demand for monogastrics increases.
		14 Baktun: the beginning of the Mayan Prophecy	(1) participatory, regulated markets (2) high institutional capacity (3) inequitable, driven by the state and (4) high water availability	Lower population growth, high GDP growth; most equitable income distribution. Highest GDP per capita. Crop yields improve over the time period, Demand for monogastrics increases from 2010-2050 for all scenarios, due to the expansion of monogastric production and a relative decrease in monogastric meat prices.	Uncertain	Food security, measured in available kilocalories per capita per day, increases over the time period (Figure 58).	The per capita cereal consumption increases by almost 25-30% (p. 71). Demand for monogastrics increases.
SSPs in Central America in 2050 (CCAFS: Palazzo et al. 2014)	Institutional capacity, markets, distribution of wealth, and water resources were chosen by stakeholders as the most relevant and uncertain	Freedom Fighters without Freedom	(1) participatory, unregulated markets (2) low institutional capacity (3) inequitable, driven by the market and (4) low water availability	GDP growth is relatively high. Crop production and livestock production grow throughout the period in all scenarios, most significantly in LiberariosSinLibertad. Agricultural area, crop areas and grasslands for livestock rearing, expand almost 80% in the region by 2050. To meet this demand for land and expand production, nearly 25% of the forest area is converted in LibertariosSinLibertad, and the GHG emissions from this land use conversion is 15% higher than in the other scenarios (Figure 56). Due to the growing demand for livestock products from a growing population, the production in ElNuevoColapsoMaya and LibertariosSinLibertad increases, but at a large environmental cost.	Uncertain	Food security, measured in available kilocalories per capita per day, increases over the time period (Figure 58).	the per capita cereal consumption increases by almost 25-30% (p. 71). Demand for monogastrics increases.
		The New Mayan Collapse	(1) un participatory, unregulated markets (2) medium institutional capacity (3) inequitable, driven by the markets and (4) low water availability	Lowest GDP growth; low institutional capacity and poor market conditions; high population growth; decreased investment in agriculture; low increase in caloric availability and low increase in demand for cereals. Demand for monogastrics increases from 2010-2050 for all scenarios, due to the expansion of monogastric production and a relative decrease in monogastric meat prices.	Uncertain	Food security, measured in available kilocalories per capita per day, increases over the time period (Figure 58). However, the demand per capita of cereals increases less than 20% over the period for ElNuevoColapsoMaya.	Kilocalories available per capita is lowest for ElNuevoColapsoMaya, 5-10% lower than the other scenarios by 2050. Demand for monogastrics increases. However, ElNuevoColapsoMaya sees a much smaller increase in demand, due to the low GDP per capita growth as well as high meat prices (Figure 59).
		Andean Autumn	Centralized political power, unsustainable and unregulated markets with low economic development and subsistence consumption patterns	Low GDP growth and increase in population from 100M to 140M. Lowest increase in yields; Demand for livestock products in OtonoAndino increases by less than 15%, because GDP per capita growth was low. Figure 69 presents one measure of food security, available kilocalories per capita per day. The food demand per capita relative to 2010 also provide a measure of change in food consumption as incomes change (Figure 70).	Uncertain	Food security in the region improves throughout the period for all scenarios.	Lower demand for livestock-based products due to low income growth.

Table 2: Summary of Scenarios

Scenario & Author	Drivers	Worlds within Scenario	Axes	World and AFS in it	Potential impact on CGIAR ONE outcomes (U=uncertain)		
					Gender	Poverty	Nutrition
SSPs in Andes in 2050 (CCAFS: Palazzo et al. 2014)	Concentration of governmental power, markets, consumer preferences, and level of economic development were chosen by stakeholders as the most relevant and uncertain.	Flipping Burgers	Decentralized government with unsustainable unregulated markets with high economic growth and sumptuous consumption patterns	Rapid economic growth. The investment in livestock production in ChachandoHamburguesas scenario increases the production of and lowers the price of livestock products, specifically ruminant meat. The number of calories coming from livestock products increases more than 30% over the time period, whereas the number of calories coming from crop products increases less than 9 percent over the time period.	Uncertain	Calorie consumption is highest for ChachandoHamburguesas and VenciendoObstaculos due to the increase in GDP per capita. For these two scenarios, demand for livestock products grows by nearly 30%.	Highest increase in meat consumption
		Overcoming obstacles	Decentralized government with sustainable and regulated markets coupled with high economic development and sustainable needs-based consumption	GDP grows slowly, but then has second highest economic growth by 2050. The investment in livestock production in ChachandoHamburguesas scenario increases the production and lowers the price of livestock products, specifically ruminant meat. The number of calories coming from livestock products increases more than 30% over the time period, whereas the number of calories coming from crop products increases less than 9 percent over the time period.	Uncertain	Calorie consumption is highest for ChachandoHamburguesas and VenciendoObstaculos due to the increase in GDP per capita. For these two scenarios, demand for livestock products grows by nearly 30%.	Caloric consumption from meat increases.
		New Dawn	Centralized political power, with sustainable regulated markets with a need-based consumption pattern coupled with low economic growth.	Medium population growth (from 100M to 120M), with low economic growth. Crop yields are highest; lower GDP growth	Uncertain	Food security in the region improves throughout the period for all scenarios.	More focus on crops than livestock

Table 3: Summary of the Shared Socioeconomic Pathways (SSPs)

Worlds within Scenario	Axes	World and AFS in It	Socioeconomic Drivers				Adaptation Scenarios	
			Population	Education	Urbanization	Econ Development	Energy	Land use
The Shared Socioeconomic Pathways (SSPs) are used to evaluate socioeconomic challenges for climate change adaptation and mitigation measures. Main socioeconomic drivers of the SSPs are population, education, urbanization, and economic development (O'Neill et al. 2014; Riahi et al. 2017).								
SSP1: Green World / Sustainability	Low adaptation and mitigation challenges	Sustainable development: decreased inequality; technological change is rapid and directed toward environmentally friendly processes	Population growth will slow (7B by 2100), decreasing demand for food	Education increases, with important implications for economic growth and vulnerability to climate change impacts	Highest urbanization rates (92% by 2100) due to high income growth, and desired increases in efficiency that compact urban areas can bring	Equitable development and rapid catch-up / economic convergence	Increased use of renewables	Sustainable land transformation with low population growth, healthy diets, and high agricultural productivity.
SSP2: Business As Usual	Moderate challenges	Intermediate case between Green World and Regional rivalry		Education increases, with important implications for economic growth and vulnerability to climate change impacts	Urbanization increases to 80% in 2100			Low to modest expansion of land use.
SSP3: Regional Rivalry	High adaptation and high mitigation challenges	Unmitigated emissions are high due to economic growth, increased population, and slow technological change in the energy sector. Inequality is high across regions, decreasing trade flows, leaving many people vulnerable to climate change and with low adaptive capacity.	Population growth is highest in SSP 3, reaching 12.6B.	Education level is stagnant or even declines	Stable urbanization (60% by 2100) due to low economic growth, limited regional mobility and poor urban planning	Development failure with strong fragmentation, and economic stagnation, with relatively high inequality	Fossil fuels and lack of policies to address energy access, resulting in increased use of biomass by households in LICs	Large pressure on land due to expansion of cropland and pasture land due to increased population and lack of increases to ag productivity and limited environmental protections
SSP4: Inequality	High adaptation and low mitigation challenges	Technological development in low carbon energy sources, leading to large mitigative capacity in regions with high emissions. Yet, regional inequality is high, leaving some parts of the world economically isolated with high vulnerability and low adaptive capacity.		Education level is stagnant or even declines	Highest urbanization rates (92% by 2100)	Highest levels of cross-national inequality, with high fragmentation.	Increased use of renewables and lack of access for LIC households, resulting in increased use of biomass	Modest expansion of land use
SSP5: Economy Leads / Fossil-fueled Development	Low adaptation and high mitigation challenges	In absence of climate policies, energy demand is high and met with carbon-based fuels. Economic development is high and human capital increases, which produces a higher distribution of resources, slower population growth and a world better able to adapt to climate impacts.	Population growth will slow (7B by 2100), decreasing demand for food	Education increases, with important implications for economic growth and vulnerability to climate change impacts	Highest urbanization rates (92% by 2100) due to technological change and large scale engineering projects to develop housing	Very rapid development and economic convergence.	Fossil fuels	Modest expansion of land use

Table 4: Summary of Visioning and Backcasting

Pathway	Proposed Response	Impact on AFS and GPN	Potential impact on CGIAR ONE outcomes (U=uncertain; O=opportunity; C=challenge; M=mixed)			
			Gender Equality	Reduce Poverty for AFS Income Earners	Reduce Poverty for Consumers	Improved Nutrition
Anderson (2019): To support farm-focused R&D and reduce poverty and hunger.						
Economics	Reduce trade restrictions. Cut farm assistance	Reduce trade restrictions and decrease farm subsidies.	O	O	O	O
Birner and Pray (2019): To achieve SDGs sustainably by 2050.						
Integrated	Bioeconomy	The bioeconomy approach aims to improve the economic system by using bio-resources and biotechnologies, and focusing on the provision of environmental services (Birner and Pray 2019, p. 503).	U	O	O	U
FOLU (2019): By 2030, food and land use systems can help bring climate change under control, safeguard biological diversity, ensure healthier diets for all, drastically improve food security, and create more inclusive rural economies.						
Integrated	Nutritious foods	Global diets need to converge towards local variations of the "human and planetary healthy diet"—a predominantly plant-based diet which includes more protective foods (fruits, vegetables, and whole grains), a diverse protein supply, and reduced consumption of sugar, salt, and highly processed foods. Affordable healthy food could improve nutrition and decrease poverty—but requires transformation of tax policy, agricultural subsidies, targeted investment and innovation, and behavior change. Women may benefit more from convergence towards a healthy diet as they are at greater risk of undernutrition.	O/U	O	O	O

Table 4: Summary of Visioning and Backcasting

Pathway	Proposed Response	Impact on AFS and GPN	Potential impact on CGIAR ONE outcomes (U=uncertain; O=opportunity; C=challenge; M=mixed)			
			Gender Equality	Reduce Poverty for AFS Income Earners	Reduce Poverty for Consumers	Improved Nutrition
Environmental	Nature-based solutions	Pursue productive and regenerative agriculture, protecting and restoring nature, and a healthy and productive ocean. Relying on external inputs creates risk for some small farmers; decreasing deforestation cuts down on air pollution and other health costs that may disproportionately affect the poorest; biodiversity loss also undermines the stewardship of indigenous peoples, which tends to outperform other forms of stewardship (FOLU 2019, pp. 97–98). Ocean farming of bivalves could substantially increase and remain within planetary boundaries, which could be an alternative protein source. Regenerative agriculture may be better at improving soil health, which can deliver more nutrients to food crops (FOLU 2019, p. 79).	O/U	O	O	O
Integrated	Wider choice and supply	Diversifying protein supply, reducing food loss and waste, local loops and linkages. Increasing the supply of affordable proteins will contribute to human nutrition and health, with particular benefits for child and maternal health in poorer households. Alternative meats might be most beneficial for poorer residents. Decreasing waste and local production may increase the availability of fresh foods and help address malnutrition in urban and peri-urban areas. However, intellectual property rights for meat alternatives may make the costs of these proteins (e.g., farmed insects) too high (p. 121). Livestock farmers may be at risk. Expanding local supply reduces risks of over-reliance on staple foods. Reducing food loss could make more nutrients available, improving nutritional outcomes, but require progressive policies and scaling and strengthening of efficient local value chains.	O	U	O/U	O

Table 4: Summary of Visioning and Backcasting

Pathway	Proposed Response	Impact on AFS and GPN	Potential impact on CGIAR ONE outcomes (U=uncertain; O=opportunity; C=challenge; M=mixed)			
			Gender Equality	Reduce Poverty for AFS Income Earners	Reduce Poverty for Consumers	Improved Nutrition
Integrated	Increase rural opportunities	Digital revolution; stronger rural livelihoods; gender and demography. Nonfarm opportunities for rural youth and rural women often have lower returns than for older men, given lack of initial and access to resources, smaller scale, and sectoral foci. Use policy to ensure the rights of women and girls, expanding access to reproductive health services. While digitization could improve efficiency of smallholders, the costs of and probability of them being left behind are both substantial. Expanding rural education, access to health, improved infrastructure, insurance, and off-farm employment opportunities could decrease poverty and increase nutritional status. Digitization can help consumers make healthier and safer food choices.	M	M	O	O
GKI and Rockefeller Foundation (2017): In face of environmental degradation, climate change, urban opportunities and rural decline, hidden costs in global supply chains and private sector influence, how can we transform food systems in emerging markets by 2035?						
Technological	Farmgate packaging and processing	Farmgate or near farmgate packaging, processing, (pre) cooling, and dehydration could decrease food waste and increase smallholders' incomes. Smallholder income may increase through premium on packaged products. Increasing commercialization of some productive activity (e.g., horticulture) may not benefit women if these value chains do not reward women's labor. Extended shelf life can help retain nutrients and decrease prices.	O/U	O	O	O
Technological	Renewable energy	Renewable energy can support energy-intensive operations such as cold storage and processing. Can be used for refrigeration and processing, helping farmers earn premiums on their products. Can indirectly impact nutrition by decreasing prices of fresh foods.	O/U	O	O	O

Table 4: Summary of Visioning and Backcasting

Pathway	Proposed Response	Impact on AFS and GPN	Potential impact on CGIAR ONE outcomes (U=uncertain; O=opportunity; C=challenge; M=mixed)			
			Gender Equality	Reduce Poverty for AFS Income Earners	Reduce Poverty for Consumers	Improved Nutrition
Technological	Storage and transport	The suitability of innovations in storage and transport technologies for foods that have a short shelf life varies by farm size. Storage crates, micro cold transport, and evaporative cooling can help link smallholders to higher-value chains. Adaptable reefer containers, cold chain as a service, and micro-warehousing and shipping may be useful for smallholders if prices are low enough and if agribusiness works with smallholders. All can potentially increase the availability and decrease the cost of nutrient-rich foods.	O/U	O	O	O
Technological	Life sciences	Biodegradable coatings and microbiomes / microbes for soil could reduce PHL; they could also be applied on-seed in place of herbicides and pesticides. Can reduce PHL, particularly if they are affordable and accessible to smallholders. Can lower prices of nutrient-rich foods. Need food safety standards; e.g., biodegradable coatings often require access to clean water and could cause illness if clean water is not available.	O/U	O	O	O/U
Technological	Data collection and monitoring	Early warning systems to identify risks of post-harvest losses. Could decrease smallholders' PHL and decrease price volatility. Requires strong government or firm institutional commitments to effectively communicate findings to farmers.	O/U	O/U	O	O
Integrated	Enabling innovations	Improved traceability, specialty marketing of crops, farm-to-fork virtual marketplace, first loss capital guarantee for PHL, mobile education centers, and behavioural economics for agriculture. If appropriate institutions are in place, decrease PHL and/or increase smallholder income; could decrease prices of nutrient-rich foods. Barriers to such opportunities may vary by gender.	O/U	O	O	O

Hansen et al. (GKI and GAIN 2019): To sustainably address malnutrition in emerging markets, focus on 12 new ideas and new technologies that could be ready to be scaled and impactful in the next five years. In all cases, the primary beneficiaries of the deployment of these innovations would be the poor (or at a minimum, those on modest incomes) in low- and middle-income countries. These 12 technologies can be bucketed into four priorities (1) start with sustainable, nutritious foods (2) invest in proximate processing, (3) tackle traceability for safety and transparency, and (4) keep it cool.

Table 4: Summary of Visioning and Backcasting

Pathway	Proposed Response	Impact on AFS and GPN	Potential impact on CGIAR ONE outcomes (U=uncertain; O=opportunity; C=challenge; M=mixed)			
			Gender Equality	Reduce Poverty for AFS Income Earners	Reduce Poverty for Consumers	Improved Nutrition
Technological	Sustainable nutritious foods	Production, processing, and consumption of sustainable local foods reduces long-term reliance on imports and can yield planetary and human health benefits, including (1) millet-based foods.	O/U	O	O	O
Technological	Invest in proximate processing	Processing and value addition closer to the point of production reduces postharvest loss, ensures nutrient retention, and increases the volume of nutritious foods on the market, including (1) cooperative processing and packaging, (2) low-cost solar dryers, (3) mobile pre-cooling and packhouses, (4) modular factories, and (5) near-farm mobile processing.	O/U	O	O	O
Technological	Tackle traceability for safety and transparency	Efficient and transparent distribution enables access to wider markets, stabilizing demand and reducing price volatility, while ensuring food safety, including (1) value-added traceability, (2) market brokerage via mobile devices, and (3) on-demand third-party logistics. Can decrease price volatility and stabilize demand, beneficial for smallholders and consumers.	O/U	O	O	O
Technological	Keep it cool	Cold-storage options at the last mile extend the life of nutritious food and make more nutrients available to vulnerable rural populations such as mothers, children, and adolescent girls, including (1) small-scale refrigerated transport, (2) small-scale cooling boxes, and (3) solar cooling.	O	O	O	O

HLPE (2017): Progressive realization of the right to adequate food and nutrition and aim to transform the food system to ensure sustainable diets that are protective and respectful of biodiversity and ecosystems; culturally acceptable; accessible; economically fair and affordable; and nutritionally adequate, safe, and healthy, while optimizing natural and human resources (pp. 11–12). HLPE argues that lack of recognition of rights, unaddressed power imbalances, and conflicts of interest are all barriers to changes in the food system.

Table 4: Summary of Visioning and Backcasting

Pathway	Proposed Response	Impact on AFS and GPN	Potential impact on CGIAR ONE outcomes (U=uncertain; O=opportunity; C=challenge; M=mixed)			
			Gender Equality	Reduce Poverty for AFS Income Earners	Reduce Poverty for Consumers	Improved Nutrition
Integrated	Production systems	Improve landscape and dietary diversity; safeguard globally important agricultural heritage systems in traditional and mixed food systems; incentivize protection of wild foods and agrobiodiversity; improve links between farms and schools; promote urban agriculture; improve women producers' livelihoods; redirect ag R&D towards diets; scale up climate-smart, nutrition-sensitive interventions.	O	O	O	O
Technological	Storage and distribution	Reduce loss and waste; preserve and improve food safety.	O	O	O	O
Technological	Processing and packaging	Promote ways to protect and add nutritional value in the food chain; facilitate fortification as appropriate; regulate food processing.	O	O	O	O
Economic	Retail and markets	Improve connectivity of smallholders to markets; encourage supermarkets to procure healthier foods; support farmer connectivity through IT.	O/U	O	O	O
Integrated	Evidence gaps in food supply chain	Need better methods; smallholder farms do not exist in isolation; need to consider several spatial scales; farmers face tradeoffs; biodiversity tradeoffs; SMEs may face specific challenges (pp. 92–93).	U	U	U	U
Policy	Availability and physical access	Address food deserts and food swamps; encourage healthier diets via public procurement of healthy food.	O	O	O	O
Policy	Economic access	Promote healthier diets through discriminatory trade policies; encourage healthier diets through taxation and subsidies; promote healthier diets through price promotions; understand remittances.	U	U	O	O
Policy	Promotion, advertising and information	Promote healthier foods; strengthen regulations for advertising; increase transparency of labeling.	O	O	O	O

Table 4: Summary of Visioning and Backcasting

Pathway	Proposed Response	Impact on AFS and GPN	Potential impact on CGIAR ONE outcomes (U=uncertain; O=opportunity; C=challenge; M=mixed)			
			Gender Equality	Reduce Poverty for AFS Income Earners	Reduce Poverty for Consumers	Improved Nutrition
Policy	Food quality and safety	Certify food safety across all food systems; improve quality across all systems.	O	O	O	O
Research	Evidence gaps in food environment	Document the extent of changes in food environments in different contexts and the specific role of certain drivers (Kimenju and Qaim 2016). Second, effects of different aspects and drivers of the nutrition transition on diets and nutrition may differ by context and age group and may involve several tradeoffs and by the effect of complex and dynamic drivers, such as trade and globalization, on diets (Thow 2009; Kearney 2010). The third stream of research could investigate how to influence the food environment to supply healthier food products (GloPan 2016a) (HLPE 2017, p. 100).	U	U	U	U
Policy	Nutrition education	Strengthen nutrition education; use mass media and social communication to encourage consumer behavior change; develop food-based guidelines for healthy and sustainable diets; ensure that social protection programmes lead to improved nutrition outcomes.	O	O	O	O
Policy	Food acceptability	Change aesthetic standards to decrease food loss and waste.	O	O	O	O
Policy	Social norms and tradition	Promote traditional food cultures to improve health and nutritional status; promote traditional food preparation skills.	O	O	O	O
Research	Evidence gaps in consumer behavior	"Further research is needed to better understand consumer behaviour and demand, as well as the determinants of that demand now and in the future (Cirera and Masset, 2010; Godfray et al., 2010). A second stream of research is needed on measuring affordability, convenience and desirability from the consumer's perspective. The third stream of research will be on understanding how policies can influence consumer choice and diets in this era of changing food environments, particularly in LMIC settings" (HLPE 2017, p. 106).	U	U	U	U

Table 4: Summary of Visioning and Backcasting

Pathway	Proposed Response	Impact on AFS and GPN	Potential impact on CGIAR ONE outcomes (U=uncertain; O=opportunity; C=challenge; M=mixed)			
			Gender Equality	Reduce Poverty for AFS Income Earners	Reduce Poverty for Consumers	Improved Nutrition
Policy	Investments in interventions	One approach to prioritizing investment is to consider the global food system to consist of three main subtypes of systems: a traditional system, a mixed system, and a modern system. The types of interventions needed (e.g., food safety) will vary by food system subtype.	O	O	O	O
HLPE (2019): To address Agenda 2030, ... the HLPE explores the nature and potential contributions of agroecological and other innovative approaches to formulating transitions towards sustainable food systems (SFSs) that enhance FSN.... Many transitions need to occur in particular production systems and across the food value chain to achieve major transformation of whole food systems" (HLPE 2019, p. 13). Sustainable food systems (SFSs) "ensure food security and nutrition for all in such a way that the economic, social and environmental bases to generate food security and nutrition of future generations are not compromised" (HLPE 2014, p. 28). Several controversies about conventional and agroecological agriculture remain.						
Environmental	Incremental sustainable intensification of production systems	Incremental movement toward climate-smart agriculture, nutrition-sensitive agriculture, and sustainable food value chains that reduce inputs, foster diversity, andfocus on improving ecological and human health, and address equity and governance issues while increasing productivity per unit of land (p. 15).	O	O	U	O
Environmental	Transformative agroecological and related approaches	Transformative changes including organic agriculture, agroforestry, and permaculture may contribute to access and utilization dimensions and to social equity. However, these approaches may not increase productivity per unit of land (p. 16).	O	O	U	O

Table 4: Summary of Visioning and Backcasting

Pathway	Proposed Response	Impact on AFS and GPN	Potential impact on CGIAR ONE outcomes (U=uncertain; O=opportunity; C=challenge; M=mixed)			
			Gender Equality	Reduce Poverty for AFS Income Earners	Reduce Poverty for Consumers	Improved Nutrition
Research	Farm size	Controversy: There is an increasing recognition that economies of scale in agriculture are context-dependent and vary with the extent to which environmental and social externalities are factored into performance measurement metrics. Smaller farms may often be labour-intensive as opposed to capital-intensive, and while overall yields (assessed through the land equivalent ratio) may be high for polycultures, the yield of a single staple crop may often be lower than in large-scale monocultures. Economies of scale, which may exist within current regulatory frameworks, subsidies, and avoided costs of externalities (impact of pollution, lowering soil carbon, or providing less rural labour), would require interventions to avoid market failures resulting in continued degradation of agroecosystems associated with the increased scale of operation (p. 16).	U	U	U	U
Research	Modern biotech	Controversy: Despite substantial uptake of gene modification (GM) technology, debates continue to be polarized with public concerns about safety, environmental impacts, concentration of power within food systems, and the ethics of gene modification. Some people consider that the uncertainties linked to modern biotechnologies may be addressed through research on a case-by-case basis. However, most agroecological proponents do not consider modern biotechnologies as part of a transition towards SFSs because, as presently constituted, there are conflicts with core agroecological principles associated with ecology, democratic governance, and sociocultural diversity (p. 17).	U	U	U	U

Table 4: Summary of Visioning and Backcasting

Pathway	Proposed Response	Impact on AFS and GPN	Potential impact on CGIAR ONE outcomes (U=uncertain; O=opportunity; C=challenge; M=mixed)			
			Gender Equality	Reduce Poverty for AFS Income Earners	Reduce Poverty for Consumers	Improved Nutrition
Research	Digital technologies	Controversy: Digital technologies, if more widely adopted, could, according to sustainable intensification proponents, contribute to the sustainability of food systems. Technology transfer, farmer education, and a transdisciplinary approach involving all actors (scientists, farmers, industry, governments) are considered necessary to realize the potential of digital technologies. Proponents of agroecological approaches emphasize a need to focus on democratic governance, agency, and knowledge systems, to scrutinize *what* is being attempted through the use of digital technologies, *by whom* , and *what kinds* of future food systems are being fostered through their application (p. 17).	U	U	U	U
Research	Synthetic inputs	Controversy: Use of synthetic fertilizers has been a major source of yield gains in agriculture as well as of environmental pollution resulting both from their manufacture and their use in farming.… There has been much progress recently in more efficient use of fertilizer through microdosing and integrated soil fertility management that combines the use of organic and inorganic amendments. The viability of different strategies for maintaining soil fertility in high-yielding agricultural practices is highly context-dependent, in relation to soil type, the nature of the farming system, and what sources of fertilizer are locally available (p. 17).	U	U	U	U

Table 4: Summary of Visioning and Backcasting

Pathway	Proposed Response	Impact on AFS and GPN	Potential impact on CGIAR ONE outcomes (U=uncertain; O=opportunity; C=challenge; M=mixed)			
			Gender Equality	Reduce Poverty for AFS Income Earners	Reduce Poverty for Consumers	Improved Nutrition
Research	Biofortification	Controversy: growing diverse crops vs. biofortification. Biofortification has resulted in improved nutritional outcomes in specific contexts, but there is less information about its impacts on other dimensions of FSN. Diversified production has been positively correlated with improved FSN through both direct consumption and sale of products increasing income that then confers greater FSN. Critics suggest that biofortification may contribute to reliance on single food solutions that may be an inherently risky and "less-resilient" approach than to maintain a diversity of crops and the knowledge required to grow, process, prepare, and eat them. The two strategies can be integrated with producers and consumers being offered informed choices about adopting biofortified crops, diversified production, or both (p. 17).	U	U	U	U
Research	Biodiversity	Controversy: conserving biodiversity within agricultural landscapes to meet conservation goals vs. maximizing land for conservation while maximizing yield on agricultural land. Agroecological approaches to FSN challenge the assumptions underlying this apparent dichotomy. First, in terms of whether conservation-friendly agricultural practices are necessarily low yielding, and, second, the extent to which the impacts on biodiversity of chemical-intensive agriculture are confined to the areas where it is practised. There is growing consensus that the overall impact of agriculture on insect and other biodiversity is reaching alarming proportions that exceed planetary boundaries (p. 18).	U	U	U	U
Policy	Performance measures and monitoring frameworks	Comprehensive performance metrics, covering all the impacts of agriculture and food systems, are a key requirement for rational decision-making (p. 19).	O	O	O	O

Table 4: Summary of Visioning and Backcasting

Pathway	Proposed Response	Impact on AFS and GPN	Potential impact on CGIAR ONE outcomes (U=uncertain; O=opportunity; C=challenge; M=mixed)			
			Gender Equality	Reduce Poverty for AFS Income Earners	Reduce Poverty for Consumers	Improved Nutrition
Integrated	Transition toward diversified and resilient food systems	Redirect subsidies to support farms based on sustainability performance metrics; recognize true cost accounting; refine ecological footprint accounting to capture regenerative practices; reduce food loss; take greater steps to integrate local and scientific knowledge; call for public investment in R&D in pulses, fruits and vegetables, and orphan crops (p. 19).	O	O	U	O
Policy / Social	Agency and empowerment	Agroecology initiatives that advocate for women's formal rights are essential. These ensure land access, more equitable family and community relationships, and reorientation of institutions and organizations to explicitly address gender inequality. This latter inequality is a key barrier to transitions to SFS in many contexts. There is increasing momentum in the policy arena for gender transformative actions that address gender inequality in agriculture and food systems. These actions aim to challenge the underlying causes of gender inequality, such as norms, gender relations in households and society, and institutional structures that perpetuate discrimination and imbalances, rather than merely addressing its symptoms. Addressing gender inequality requires recognition of (i) women's central roles in agriculture and food systems; and (ii) the often-high labour demands in holistic agricultural management systems, making greater income equality for those providing important labour (p. 20).	O	O	U	O
Policy	Need for effective policy	Risk of relying on the market to motivate movement toward SFS. Government policy, regulation, and moves towards true pricing aim at internalizing all ecological and social effects of production in the price of food, enabling markets to function in ways that would foster transitions towards SFSs (p. 18).	O	O	U	O

Table 4: Summary of Visioning and Backcasting

Pathway	Proposed Response	Impact on AFS and GPN	Potential impact on CGIAR ONE outcomes (U=uncertain; O=opportunity; C=challenge; M=mixed)			
			Gender Equality	Reduce Poverty for AFS Income Earners	Reduce Poverty for Consumers	Improved Nutrition
National Academy of Sciences (2019): To achieve efficiency, resilience, and sustainability of AFS (p. 29) in the context of Increasing and changing demand, environmental degradation, and climate change.						
Technological	Transdisciplinary science and systems approach	Transdisciplinary science and systems approaches should be prioritized in AFS research.	U	U	O	U
Technological	Biosensors and new sensing technologies	Field-deployable sensors and biosensors will enable rapid detection and monitoring capabilities across various food and agricultural disciplines. Biosensors could decrease postharvest loss, increase productivity, and decrease prices. Unclear if it will reach smallholders.	U	U	O	O
Technological	Data science, artificial intelligence	Facilitate the adoption and development of information technology, data science, and artificial intelligence in food and agricultural research. Unclear if it will reach smallholders.	U	U	O	O
Technological	Gene editing	Gene editing will allow for precise and rapid improvement of traits important for productivity and quality. Could be used to improve nutritional qualities of foods; could help smallholders reduce use of synthetic inputs and curtail antibiotic resistance.	O/U	O / U	O	O/U
Technological	Microbiome	Understand microbiome and harness knowledge to improve crop production, transform feed efficiency, and increase resilience to stress and disease. May decrease pests, and improvements in microbiome may increase nutrient availability.	O/U	O / U	O	O
Pingali and Aiyar (2019): To support food, agriculture, and nutrition in 2050, given demand challenges (increasing population, increasingly urbanized, changing consumption patterns) and supply challenges (climate change).						
Integrated	Integrated food systems approach	Shift from sector-specific goals to integrated, climate-sensitive agriculture systems and shift from caloric production towards nutritious foods. Address both gender discrimination and barriers women face, and address barriers to technology adoption to support smallholders.	O	O	O	O
Quisumbing et al. (2019): Attention to gender is required to achieve inclusive agricultural growth (through 2025).						

Table 4: Summary of Visioning and Backcasting

Pathway	Proposed Response	Impact on AFS and GPN	Potential impact on CGIAR ONE outcomes (U=uncertain; O=opportunity; C=challenge; M=mixed)			
			Gender Equality	Reduce Poverty for AFS Income Earners	Reduce Poverty for Consumers	Improved Nutrition
Policies	Achieve greater gender equity	Achieving a gender-transformative food system would require a focus on four key elements of gender equality that have been addressed in this report, but in combination—increasing access to control over productive resources, investing in women's leadership, addressing gender and social norms, and removing structural and institutional barriers. The latter two strategies—addressing gender and social norms and removing structural and institutional barriers—are less common in the agriculture sector, yet they are the most fundamental to creating a gender-transformative food system (Quisumbing et al. 2019, p. 211).	O	O	O	O
Rawe et al. (2019): Feeding and nourishing a growing and changing global population in the face of rising numbers of chronically hungry people, slow progress on malnutrition, environmental degradation, systemic inequality, and the dire projections of climate change, demands a transformation in global food systems.						
Policies	Reduce greenhouse gas emissions	Numerous policies include: mitigation and adaptation to climate change; extension services to address equity and equality issues; financial or market mechanisms like subsidies or payment for ecosystem services; carbon prices; good governance and level playing field. Land tenure is a prerequisite to incentivize the adoption of practices that can not only reduce emissions and increase resilience but also improve the health (and value) of land. Nutrient dense foods should be prioritized for production. Women face systemic inequality within the food systems and bear a disproportionate labor burden in the AFS. Policies should support extension to small farmers and women farmers rather than subsidies to large farmers. Systemic inequalities make marginalized households most at risk of climate stress.	O	O	O	O
Integrated	Tackle food loss and waste	Measures for tackling food waste can be (1) information-based, (2) market-based, (3) regulatory, (4) voluntary commitment, and (5) 'nudging' (p. 17).	O	O	O	O

Table 4: Summary of Visioning and Backcasting

Pathway	Proposed Response	Impact on AFS and GPN	Potential impact on CGIAR ONE outcomes (U=uncertain; O=opportunity; C=challenge; M=mixed)			
			Gender Equality	Reduce Poverty for AFS Income Earners	Reduce Poverty for Consumers	Improved Nutrition
Integrated	Shift diets	Food systems policies that address diets and the environments can target (1) the food environment to help consumers make healthy choices through dietary guidelines to promote sustainable diets, and (2) the food supply to increase production of diverse, nutrient rich foods, to support farmers to diversify production, and to climate proof infrastructure and transportation. Gender equality must be prioritized.	O	O	O	O
Schwoob et al. (2019): To achieve SDGs by 2050						
Environmental/ Integrated	Redesign agricultural systems	Agronomy-centered farming system transformation aimed at improving environmental performance, and improve agricultural system's socioeconomic performance. Need for national-level work.	U	M	C	O
Skeer and Leme (2019): To support efforts to keep global warming below 2C by 2050.						
Environmental	Renewable energy and bioenergy	There has been a rapid uptake of renewable energy. If yield gap in agriculture closes, opportunity to grow bioenergy crops on degraded lands, which could benefit marginalized farmers; if done carelessly, this could increase greenhouse gas emissions.	U	O	O	O
Tittonell (2019): To feed 9 billion people nutritious food, decrease poverty, increase sustainability and work within planetary boundaries by 2050.						
Environmental	Ecological intensification (EI)	Ecological Intensification (EI) decouples agriculture from nonrenewable resources, improves soil health, integrates crop and livestock, ecological intensive smallholder agriculture, focuses on nutrition sensitive agriculture and ecological management.	U	U	C	O
WEF (2018): To feed 10 billion people and meet SDGs by 2050 requires a global food system that is inclusive, sustainable, efficient, and nutritious and healthy. Fourth Industrial Revolution can disrupt current food system technology. Three main categories of technological innovation are required: (1) Change the shape of demand (2) Promote value chain linkages (3) Create effective production systems. Also required is creating an enabling environment for technological development as well as investing in basic infrastructure and regulatory policy. Moving toward full cost accounting, recognizing that interventions are complementary and more likely to be effective when bundled, including when bundled with health, education, and environmental innovations (p. 31).						

Table 4: Summary of Visioning and Backcasting

Pathway	Proposed Response	Impact on AFS and GPN	Potential impact on CGIAR ONE outcomes (U=uncertain; O=opportunity; C=challenge; M=mixed)			
			Gender Equality	Reduce Poverty for AFS Income Earners	Reduce Poverty for Consumers	Improved Nutrition
Technological	Change the shape of demand	Technologies including alternative proteins, food sensing technologies for food safety, quality, and traceability and nutrigenics have the potential to shape consumer diets and consumption behaviours . Consumer acceptance of and health implications of alternative proteins are still unclear. Adoption of some technologies (food sensing and nutrigenetics) may be in HICs first; ultimately nutrigenetics may decrease obesity.	O/U	O/U	O	O/U
Technological	Promote value chain linkages	Technologies including digital infrastructure and mobile technologies, big data and advanced analytics for insurance, internet of things for real-time supply chain transparency and traceability, and blockchain enabled traceability can impact value chains via improved collaboration, simplified efficient supply chains and transparency. Improved traceability technology and blockchain for traceability could provide consumers more information on the nutritional quality of foods but will need to be widely adopted by farmers. Insurance could reduce farmers' risk; mobile technologies could improve efficiencies. Low literacy may limit farmers' (perhaps especially women's) abilities to use some of these technologies.	O/U	O/U	O	O

Table 4: Summary of Visioning and Backcasting

Pathway	Proposed Response	Impact on AFS and GPN	Potential impact on CGIAR ONE outcomes (U=uncertain; O=opportunity; C=challenge; M=mixed)			
			Gender Equality	Reduce Poverty for AFS Income Earners	Reduce Poverty for Consumers	Improved Nutrition
Technological	Create effective production systems	Technologies include precision agriculture for input and water use optimization, gene editing for multi-trait seed improvements, microbiome technologies to enhance crop resilience, biological-based crop protection and micronutrients for soil management, and off-grid renewable energy generation and storage for access to electricity could help to sustainably produce the right quantity and quality of food to meet the nutrition demands of the world. Gene and microbiome technologies could significantly decrease waste, increase production, and increase farmers' income. However, decentralized ownership of such technologies is required to not leave smallholder farmers behind. Biological-based crop protection could save smallholders input costs; however, applications need to be developed for specific locations and consumers need to be willing to accept them. The use of biological-based crop nutrients could improve the health and safety of farmers who would no longer apply dangerous herbicides and pesticides; food safety would also be improved. Gene editing could improve nutrient content of foods. The nutritional impacts of microbiome technologies is unclear. The use of biological-based crop nutrients could improve the health and safety of farmers who would no longer apply dangerous herbicides and pesticides; food safety would also be improved.	U	U	O	O/U

Willett et al. EAT Lancet (2019): EAT Lancet proposes a reference diet (composition varies by region) that remains within Earth's planetary boundaries ("safe operating space for food systems"). The reference diet (2500 kcal/day) would require a 50% reduction in global consumption of unhealthy foods and a 100% increase in consumption of healthy foods. Willet et al. (2019) also includes scenarios. See scenario summaries as well.

Table 4: Summary of Visioning and Backcasting

Pathway	Proposed Response	Impact on AFS and GPN	Potential impact on CGIAR ONE outcomes (U=uncertain; O=opportunity; C=challenge; M=mixed)			
			Gender Equality	Reduce Poverty for AFS Income Earners	Reduce Poverty for Consumers	Improved Nutrition
Integrated	International and national commitment to shift towards healthy diets	Wide variety of proposals, which vary by region, country income status, and urban-rural needs within countries (e.g., expanding transportation, public distribution programs, contracts and procurement for food in schools, role of education and dietary guidelines, portion control). Other policies are broadly applicable, such as food prices should reflect true costs. Poverty alleviation, particularly for women, is crucial for securing healthy diets from sustainable food systems. Attends to the specific nutritional needs of women and girls. Dietary changes from current diets to healthy diets are likely to substantially benefit human health. Hirvonen et al. (2020) have computed affordability and cost of the proposed reference diet. They argue that without a combination of higher income, lower prices, and nutritional assistance, the cost of the reference diet will exceed household per capita income for an estimated 1.58 billion people.	O	O	M	O
Integrated	Reorient agricultural priorities from producing large quantities of food to producing healthy food	Need for better tools to track diet quality; incentives to produce nutritious plant-based foods may be useful, as well as decreasing animal production. Some areas will continue to produce meat; these areas may be already marginalized (e.g., ASAL regions) and, if meat is no longer demanded, could harm small (as well as large) livestock producers.	O/U	U	U	O
Environmental / Technological	Sustainably intensify food production, generating high-quality output	Mixture of technological innovations (precision agriculture), agroecological techniques (cover crops), and biodiversity conservation. Technologies vary by whether they are scale neutral, labor intensive. Variable impact on small farmers, possibly gender equity, and prices. Given the focus on biodiversity conservation, it may be that sustainable intensification does not decrease prices.	M	M	U	O

Table 4: Summary of Visioning and Backcasting

Pathway	Proposed Response	Impact on AFS and GPN	Potential impact on CGIAR ONE outcomes (U=uncertain; O=opportunity; C=challenge; M=mixed)			
			Gender Equality	Reduce Poverty for AFS Income Earners	Reduce Poverty for Consumers	Improved Nutrition
Policy	Strong and coordinated governance of land and oceans	Need for effective governance and collective action, including restoration of degraded land. Regionally specific. May be that conservation and restoration techniques benefit indigenous groups; some farmers without formal holdings may lose access to land.	U	M	O	O
Integrated	At least halve food loss and waste, in line with global SDGs	Steep reductions in food loss and waste will require cooperation among multiple actors in the food system to assess sources of food loss and waste and develop targeted solutions. Because of the high involvement of women in postharvest handling (as well as many other activities), these services should be designed to engage with and be accessed by women producers in developing countries (p. 482).	U	O	O	O
World Resources Institute (2019): Focus on technical opportunities and policies for cost-effective scenarios to meet food, land-use, and greenhouse gas emissions goals in 2050 in ways that can also help alleviate poverty and do not exacerbate water challenges. An additional sustainability criterion is empowering women farmers (p. 31). WRI (2019) is also considered a scenario. See scenario summary as well.						
Integrated	Reduce growth in demand for food and other agricultural products	(1) Reduce food loss and waste; (2) shift to healthier and more sustainable diets; (3) avoid competition from bioenergy for food crops and land; and (4) achieve replacement-level fertility rates. To decrease fertility, pursue education of girls, increase access to reproductive health care, and decrease maternal and infant mortality. All of these would also increase the well-being of women in general. Increasing production via advances in molecular biology and breeding technologies could improve productivity. They could also leave out smallholders, depending on costs and intellectual property.	O	U	O	O

Table 4: Summary of Visioning and Backcasting

Pathway	Proposed Response	Impact on AFS and GPN	Potential impact on CGIAR ONE outcomes (U=uncertain; O=opportunity; C=challenge; M=mixed)			
			Gender Equality	Reduce Poverty for AFS Income Earners	Reduce Poverty for Consumers	Improved Nutrition
Environmental / Technological	Increase food production without expanding agricultural land	(1) Increase livestock and pasture productivity; (2) improve crop breeding to boost yields; (3) improve soil and water management; (4) plant existing cropland more frequently; and (5) adapt to climate change. Adoption may be limited, reflecting high (gendered) labor inputs. Some farmers may be too small to adopt these technologies, and policies are needed to help small farmers access markets and off-farm income. The authors warn that producing pulses and higher-nutrient-dense foods (e.g., fruits and vegetables) may take more land per calorie than the staple grains that are currently used in animal feeds.	O/U	O/U	O	O/U
Policies	Protect and restore natural ecosystems and limit agricultural sand-shifting	(1) Link productivity gains with protection of natural ecosystems; (2) limit inevitable agricultural expansion to lands with low environmental opportunity costs; (3) reforest abandoned, unproductive, and liberated agricultural lands; and (4) conserve and restore peatlands. If marginalized or indigenous populations rely on forest resources, more protection of those resources could leave them worse off.	O/U	O/U	U	U
Integrated	Increase fish supply	(1) Improve wild fisheries management; and (2) improve productivity and environmental performance of aquaculture. More research is needed to develop fish oil substitutes from microalgae, macroalgae (seaweeds), or oilseeds for aquaculture feeds.	O/U	O	O	U

Table 4: Summary of Visioning and Backcasting

Pathway	Proposed Response	Impact on AFS and GPN	Potential impact on CGIAR ONE outcomes (U=uncertain; O=opportunity; C=challenge; M=mixed)			
			Gender Equality	Reduce Poverty for AFS Income Earners	Reduce Poverty for Consumers	Improved Nutrition
Technological	Reduce greenhouse gas emissions from agricultural production	(1) Reduce enteric fermentation through new technologies; (2) reduce emissions through improved manure management; (3) reduce emissions from manure left on pasture; (4) reduce emissions from fertilizers by increasing nitrogen use efficiency; (5) adopt emissions-reducing rice management and varieties; (6) increase agricultural energy efficiency and shift to nonfossil energy sources; and (7) focus on realistic options to sequester carbon in agricultural soils. The benefits of these technologies turn on their accessibility, IP, and labor requirements.	O/U	O/U	U	O
Policies	Cross-cutting policies for a sustainable food future	(1) Farm structures, large land acquisitions, property rights, and contractual arrangements; (2) carbon-pricing strategies and financing of climate-smart agriculture; and (3) strengthening research and development. Addressing land rights using a gender lens (e.g., ensuring women have the right to inherit land) can support sustainable intensification of land. Smallholders will be disadvantaged when participating in carbon-offset programs because the transactions costs are so high. Large-scale land acquisitions ("land grabs") should occur in places with relatively low environmental opportunity costs and in countries where crop expansion is inevitable.	O/U	O	U	U