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THE ROLE OF SCIENCE, TECHNOLOGY AND INNOVATION IN ENSURING FOOD SECURITY BY 2030

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ACRONYMS

CFS	Committee on World Food Security
GHG	greenhouse gas
HLPE	High-level Panel of Experts on Food Security and Nutrition
ICT	information and communications technology
IFAD	International Fund for Agricultural Development
IP	innovation platform
IPES	International Panel of Experts on Sustainable Food Systems
NGO	Non-governmental organization
STI	science, technology and innovation
UNCTAD	United Nations Conference on Trade and Development
UNDP	United Nations Development Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
WFP	World Food Programme
WRI	World Resources Institute

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INTRODUCTION

About 795 million people, or every ninth person, is undernourished, with the majority living in developing countries and rural areas. New, existing, and emerging technologies can address the four dimensions of food security. For example, genetic modification, methods for improving soil fertility, and irrigation technologies can increase food availability. Post-harvest and agro-processing technologies can address food accessibility, biofortification can make food more nutritious, and climate-smart solutions anchored in science, technology and innovation (STI) – including the use of precision agriculture and early warning systems – can mitigate food instability. New and emerging technologies, including synthetic biology, artificial intelligence and tissue engineering may have potential implications for the future of crop and livestock agriculture. However, harnessing the potential of such technologies for food security requires investments in research and development, human capital, infrastructure and knowledge flows. Creating an environment for agricultural innovation also benefits from an enabling environment, gender-sensitive approaches to technology development and dissemination, regional and international collaboration, and technology foresight and assessment for agricultural innovations.

The report is divided into four sections. Chapter 1 provides an introduction to the challenge of ensuring food security, highlighting the geography of food insecurity, specific socioeconomic, environmental and political challenges that exacerbate food insecurity, and the role of the Sustainable Development Goals in ensuring “Zero Hunger” by 2030. Chapter 2 discusses how various scientific and technological applications can address the four dimensions of food security, namely availability, access, use/utilization and stability. Chapter 3 explores how countries can reimagine their food systems as innovation systems with attention to the building of local innovative capabilities, enabling infrastructure for agricultural innovation, developing coherent policies and strengthening knowledge flows to facilitate technology dissemination. Chapter 4 presents policy considerations and strategic recommendations for national Governments, the private sector, agricultural research institutions and other stakeholders.

CHAPTER 1. THE CHALLENGE OF FOOD SECURITY

1.1 What is food security?

Providing sufficient, safe and nutritious food to all people is one of the major global concerns historically and in the twenty-first century. Food security is usually framed in four dimensions food availability, access to food, food use/utilization and food stability (FAO, 2016a).[1] These dimensions build the overall framework of the definition established by the Food and Agriculture Organization of the United Nations (FAO): "Food security exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life" (FAO, 2016b). For each of these dimensions, a series of indicators has been defined in order to assess progress in improving food security (Appendix, Box 1).

In addition to the short-term effects of food insecurity, there are also long-term developmental impacts of lack of food security. Beyond the direct obvious cost in terms of lost human lives and well-being, there is an indirect economic cost: Malnourished people are less productive, hungry children get no or little education, and become less capable adults even if hunger is overcome. Even short-term food insecurity has a long-term lasting impact on growth potential for the economy. This section will explore the geography of food security, its implications for economic development and the environment, and recent efforts by the international community to achieve "zero hunger".

1.2 The geography of food insecurity

About 795 million people, or every ninth person, is undernourished, including 90 million children under the age of five (FAO, IFAD and WFP 2015). The vast majority of them (780 million people) live in the developing regions, notably in Africa and Asia. Depending on the region considered, the share of undernourished people differs considerably, between less than 5 per cent and up to more than 35 per cent (Figure 1). In particular, sub-Saharan Africa shows high values, with almost 25 per cent of the population undernourished (FAO et al., 2015). While the hunger rate - the share of undernourished in the total population - has fallen in the region, the number of undernourished people has increased by 44 million since 1990 due to population growth. In absolute terms, the number of people exposed to food insecurity is highest in Southern Asia, with 281 million undernourished people (FAO et al., 2015).[2]

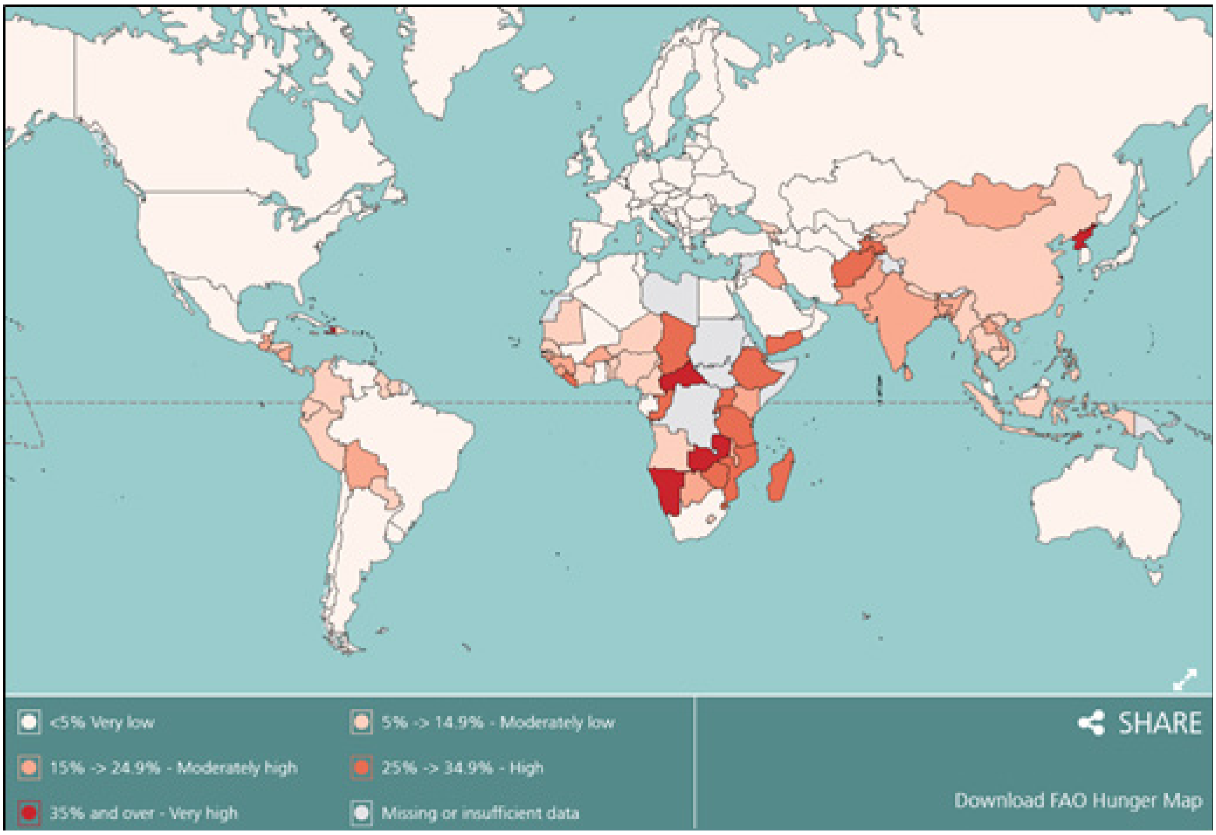
1.3 The importance of smallholder farmers in food security

Across all countries, people living in rural areas are the most exposed to food insecurity, owing to limited access to food and financial resources (FAO et al., 2015). Among them, 50 per cent are smallholder farmers, producing on marginal lands that are particularly sensitive to the adverse effects of weather extremes, such as droughts or floods. An additional 20 per cent are landless farmers, and 10 per cent are pastoralists, fishers and gatherers. The remaining 20 per cent live in the periphery of urban centres in developing countries. The demographics of hunger are tightly coupled with the demographics of poverty, where approximately 70 per cent of global poverty is represented by the rural poverty of smallholder farmers, many of whom are dependent on agriculture. The same applies to hunger and undernourishment that are prevalent in rural areas (HLPE, 2013).

[1] Those dimensions have been identified by an expert meeting at FAO that had the task to develop indicators that allow to measure food security globally (FAO, 2016a).

[2] Comparing the numbers of the undernourished population from 1990–92 with the projected number for 2014–16, the proportion of undernourished people in the developing regions decreased significantly from 23.3 per cent to 12.9 per cent. However, this promising development has to be seen in a different light when accounting for the fact that the daily calorific value used as definitional criterion for undernourishment has been significantly reduced in recent years. If the value had remained unchanged, the figure of undernourished people would have been well over 1 billion, thus reflecting a reduction in relative terms but not so in absolute numbers. FAO revised the methodology for calculating the number of undernourished in 2011, which led to a decline in the figures. The new calculation method includes food losses, the assumption that people are less physically active and somewhat smaller, and that injustice in food distribution is less pronounced than in the past. With regard to the calculation of figures relating to undernourishment, FAO now assumes a less physically active life style, which is set at 1,840 kcal per day. If FAO had taken a "normal life style" as a basis for the calculation – some 2,020 kcal per day – the number of undernourished people would have been 55 per cent higher in 2011–2013 (GLS Treuhand, 2013 and FAO food security methodology).

Figure 1. Projected number and proportion of undernourished people in developing regions from 1990/1992–2014/2016



Source: United Nations, 2015

The importance of smallholder farms was backed up by FAO (2015), which states that more than 90 per cent of the 570 million farms worldwide are managed by an individual or a family, relying predominately on family labour. In Asia and sub-Saharan Africa, these farms produce more than 80 per cent of the food; 84 per cent of family farms are smaller than 2 hectares, and family farmers manage only 12 per cent of all agricultural land (FAO, 2015b). Given the structural change towards large-scale farms in developed countries, where the labour force in agriculture has dropped drastically over the past decades, the role of smallholder farms in developing countries may have an ambivalent character. On the one hand, the impact of globalization and market liberalization is likely to encourage more specialized and large-scale industrialized production systems. On the other hand, the environmental, social and economic challenges, as well as rapid population growth might require a much more prominent role of smallholder farming, based on knowledge and labour-intensive agro-ecological production methods that rely on eco-functional intensification. Thus, the role of smallholder farms in food security remains key, while for a longer-term horizon, their role may change depending on structural change.[3]

1.4 What are the challenges of food security?

FAO et al. (2015) identified differences in progress not only among individual countries but also across regions and subregions. This section will cover, among other factors, the importance of economic

[3] Structural change is desirable; it must involve profound changes in agriculture and the transfer of most of its workforce to higher productivity sectors with increasing returns to scale, unlike agriculture. The issue is how to handle the transition without substantially destroying the existing social fabric and in an environmentally acceptable way.

and environmental change in exacerbating the global challenge of food insecurity.[4]

1.4.1 Agriculture, economic development, and international trade

Economic development is a key success factor in reducing undernourishment, but it has to be inclusive and provide opportunities for improving the livelihoods of the poor. FAO et al. (2015) point out that enhancing the productivity and incomes of smallholder family farmers, investment and social protection are key to progress. Smallholder farmers across the globe are challenged by the globalization and liberalization of markets, technological advances, and climate change. Previously well-established systems of political, social, economic and environmental resilience are shifting. Food systems have also undergone a rapid transformation in recent years with significant implications for people's diets, in part because of a number of factors such as globalization, expanding food trade, technological innovations, longer food supply and processing chains, and volatile prices of food commodities. There is also concern about increasing deforestation, as well as the prospects for biofuel production to displace land allocated for food crops.

International trade is required to bring the production and supply of agri-food products at national level in line with demand. In addition, it is possible to realize absolute and relative comparative cost advantages through trade. Those may improve the livelihoods of farmers. Furthermore, trade evens out local production instability, which is expected to increase in times of weather extremes caused by climate change. However, trade can be a two-edged sword, which can also result in worsening certain producers' situations (e.g. in case products from other producers reach the markets with lower costs). Relevant for international trade rules is the World Trade Organization (WTO), and the related bilateral, regional and plurilateral liberalization agreements (outside WTO). Both have an impact on agricultural production, trade and consumption.

Agriculture in developing countries now accounts for slightly less than 10 per cent of GDP. However, if non-market and subsistence production is taken into consideration, the sector generates half or more of total gross production and directly or indirectly employs 50–80 per cent of the population in many developing countries (UNCTAD, 2015). Together with mining, agriculture is still the most important economic sector, with a high socioeconomic importance for many countries (for employment, income generation, nutrition, rural development and the social fabric). Against this background, primary production, some service sectors, in particular agriculture, appear to be the only realistic drivers of economic and social development in many countries in the nearer future.

1.4.2 Environmental change and agriculture

Growing demand for food is a key driver of global environment change. FAO statistics show that maximizing food production by intensifying production has increased the world's cereal supply by a factor of almost 2.2, outpacing the 1.3 fold increase in population growth in the last 50 years (DeFries et al., 2015). However, this 2.2 fold increase in global cereal production occurred in tandem with a five-fold increase in the global use of fertilizers (UNCTAD, 2013a). Furthermore, biomass production (food, feed, fibre and energy) for developed countries has become a driver for environmental pressures, competition for land and nutrients in supply regions, whereas

[4] Other factors are directly implicated in the achievement of food security, including increasing population and urbanization, changing consumption patterns, conflicts and particular topographical features in certain geographies. First, population growth is of main importance, especially the increasing concentration in urban regions. By 2050, two thirds of the population is expected to live in cities and shift from agricultural-based economic activities to other economic sectors. Unlike the rural population, such urban dwellers will be unable to be at least partly self-sufficient in food production (WFP, 2016). In combination with rising food prices, unemployment and limited social security, this could lead to more people living in urban and suburban areas who will be exposed to food insecurity (Bazerghi et al., 2016). Second, the human population is expected to become wealthier and consume more resource-intensive food, such as animal products (Ranganathan et al., 2016). Third, as illustrated by the food security hotspots identified by the World Food Programme (WFP) in September 2016, conflicts are the main drivers for food insecurity in a number of countries (34.5 million people). Fourth, even at a country level, food insecurity might differ between regions. For example, a significant number of the world's population prone to food insecurity resides in mountainous regions. From 2000 to 2012, the number of people vulnerable to food insecurity increased in the mountain areas of developing countries across the world. This means that vulnerability had increased to include nearly 329 million people – a number corresponding to 39 per cent of the 2012 mountain population (FAO, 2015a).

overconsumption and eutrophication of ecosystems occur in importing regions.

Food production all over the globe is not only a source of global environmental change, but is also strongly affected by it. Agriculture is primarily challenged by climate change; the related increase in natural disasters such as floods, tropical storms, long periods of drought and new pests and diseases are the most relevant drivers of food insecurity (IPCC, 2014). Drought is one of the most common causes of food shortages in the world. In 2011, recurrent drought caused crop failures and heavy livestock losses in parts of Eastern Africa. In 2012, there was a similar situation in the Sahel region of Western Africa. Similar drought events have also occurred in Australia, Central Europe, the Russian Federation, and the United States (California). Furthermore, high dependence on a few crops (and a few varieties within these crops) to meet food needs, increasing water scarcity and salinization of soils in many areas of heavy irrigation, continued soil loss due to wind and water erosion, and resistance of pests and diseases against a growing number of agro-chemicals, and biodiversity loss create challenges for agricultural production. Future projections also indicate that climate change impacts may hinder future yield increases, thus challenging FAO forecasts to meet the projected food demand in the future without much increase of cropland areas (Müller et al., 2010; Challinor et al., 2014; Porter et al., 2014; Müller and Robertson, 2014; Lobell et al., 2011; Asseng et al., 2014).

Rockström et al. (2016) conclude that agriculture has become the single largest driver of environmental change and, at the same time, is the most affected by these changes. The authors call for a global food revolution based on a new paradigm for agricultural development based on sustainable intensification within planetary boundaries. Without this shift, the twin objectives of feeding humanity and living within the boundaries of biophysical processes that define the safe operating space of a stable and resilient earth system will not be achieved (Steffen et al., 2015).

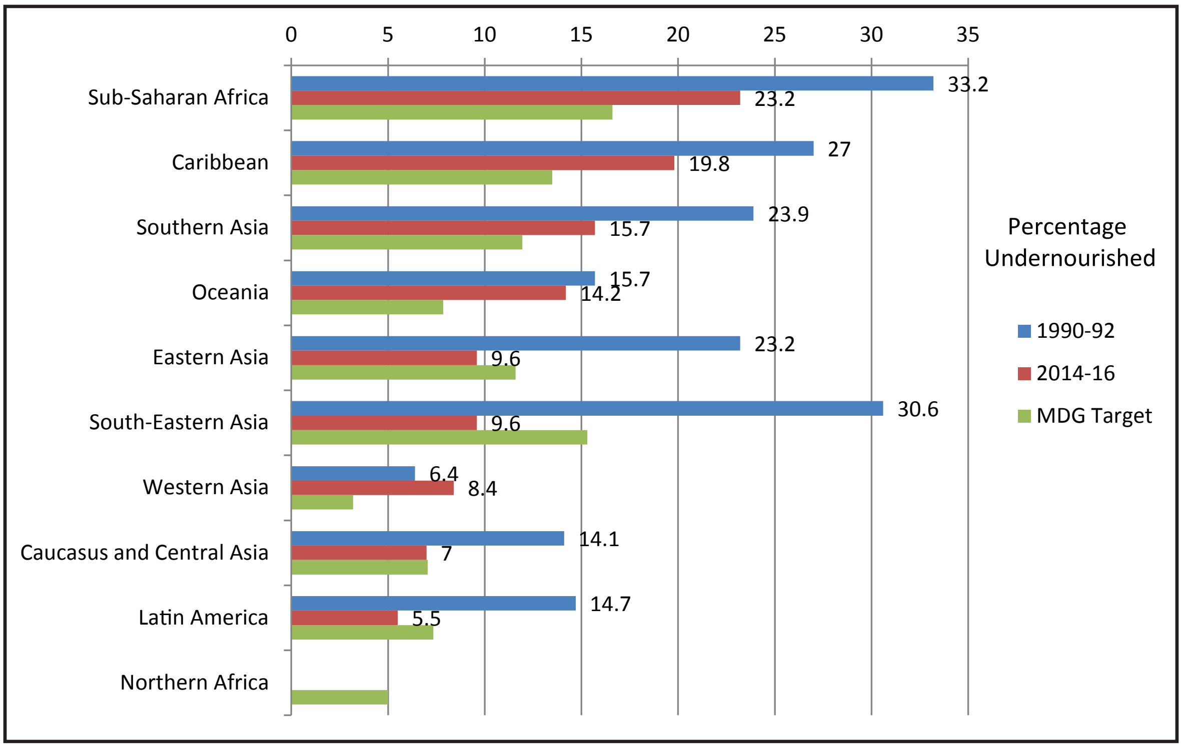
1.5 Millennium Development Goals to halve hunger

One of the recent international efforts to address the challenges of food security is the recently concluded Millennium Development Goals. Goal 1, to end hunger and poverty, included three distinct targets: halving global poverty, achieving full and productive employment and decent work for all, and cutting by half the proportion of people who suffer from hunger. The year 2015 marked the end of the monitoring period for the Millennium Development Goal targets. Using the three-year period 1990–92 as the starting point, FAO, IFAD and WFP concluded in 2015 that 72 of the 129 countries monitored for progress had reached the target of Goal 1. Most of those countries enjoyed stable political conditions and economic growth, accompanied by sound social protection policies targeting vulnerable population groups (FAO, 2015b). In those countries, the commitment to fight food insecurity proved successful in spite of the difficulties posed by rapid population growth, volatile commodity prices, high food and energy prices, rising unemployment and the economic recessions of the late 1990s and again after 2008 (FAO, 2015b). Figure 2 shows that some regions achieved the Millennium Development Goal target (e.g. Caucasus and Central Asia, South-Eastern Asia, Eastern Asia and Latin America), some regions missed the overall goal (e.g. sub-Saharan Africa, the Caribbean, Southern Asia, Oceania) and the percentage of undernourished people in Western Asia even increased during the period.

1.6 Sustainable Development Goals to achieve zero hunger

On 1 January 2016, the 17 Sustainable Development Goals officially came into force as successors to the Millennium Development Goals (for more detail, see Appendix, Box 2). Sustainable Development Goal 2 aims to end hunger and ensure access to sufficient, safe and nutritious food by all people all year round. The Goal addresses a large diversity of tasks, starting from an increase in yield and improved infrastructure to the functioning of local markets and international commodity trading. In detail, Goal 2 has a series of eight targets to support the three interrelated components of the Goal: ending hunger, achieving food security and improved nutrition, as well as promoting sustainable agriculture. Target 2.1 focuses on 2030 access to food, and target 2.2 refers to undernutrition. The other six targets relate directly or indirectly to sustainable production systems, trade, biodiversity and climate change.

Figure 2. Undernourishment trends: Progress made in almost all regions, but at very different rates



Source: FAO et al., 2015

Note: Data for 2014–16 are provisional estimates.

However, upon analysis of the other Sustainable Development Goals, the different food security dimensions of availability, access, stability and use/utilization are to some extent represented within the new post-2015 development agenda (for further explanations on the four dimensions of food security, see Appendix, Table 1. Except for Goal 17 (building partnerships), the targets of each Goal deal with at least one dimension of food security, if not all (see Appendix, table 2 for further detail). However, Goals 3, 4, 10, 11 and15 focus on just one aspect of the four dimensions of food security, most likely because such dimensions concern people exposed to hunger and food-insecure situations, mainly in rural areas, whereas the Sustainable Development Goals should have a global reach.

Overall, most of the Sustainable Development Goal targets are related to the overarching issue of achieving food security on a global scale. Related to Goal 1 (no poverty) and Goal 2 (end hunger), some indirect STI activities can be identified (table 3), mainly where STI is needed to achieve the goals or STI has to develop indicators to measure the achievement of the Sustainable Development Goals.

1.7 Conclusion

Achieving zero hunger by 2030 will require new and existing applications of science, technology, and innovation across the food system, addressing all dimensions of food security. This report not only highlights tools and techniques for specific challenges (e.g. improving productivity or minimizing post-harvest loss) but also draws attention to the need for countries, particularly developing countries, to invest in the capability to innovate. Innovative capabilities are critical not only for ensuring nutritious food at all times but also for harnessing agriculture and the broader food system as a driver of economic and sustainable development.

CHAPTER 2. SCIENCE AND TECHNOLOGY FOR FOOD SECURITY

As highlighted in the previous chapter, achieving food security by 2030 will be a major challenge and will remain so throughout the twenty-first century. The Sustainable Development Goals and other international efforts to achieve food security involve new technologies as an indispensable tool for eradicating hunger. This chapter discusses how certain scientific and technical applications may play a role in addressing the various aspects of food security.

This chapter highlights examples of scientific and technical applications that can address the four dimensions of food security, namely availability, access, use/utilization and stability. Though the list of technologies in this chapter is not exhaustive, it will provide illustrative cases of how every component of the food system – from farm to market – can potentially be improved with the application of science and technology.[5]

A number of technologies can play a role in addressing concerns related to the four dimensions of food security (Table 1). New and existing technologies to combat biotic and abiotic stresses, raise crop and livestock productivity, improve soil fertility and make water available can potentially increase the amount of food produced. Storage, refrigeration, transport and agro-processing innovations can address the dimension of food accessibility. Science to produce high-nutrient staple crops can combat malnutrition, improving food utilization and use. Finally, STI for change mitigation and adaptation, including precision agriculture, index-based insurance and early warning systems, can address food instability.

Table 1. Examples of science, technology, and innovation for food security

Food security	Challenge	Examples of science, technology, and innovation
Food availability	Biotic stresses	• Disease- or pest-resistant crops • Pest-resistant eggplant • Rust-resistant wheat varieties • Pesticides • Herbicides • Tilling machines • Spatial repellent for on-farm pests • Improved agronomic practices (for example, push-pull mechanisms)
	Abiotic stresses	• Salt-tolerant crops (for example, quinoa, potato) • Climate-resistant crops
	Improving crop productivity (in general)[6]	• Conventional breeding • Tissue culture and micropropagation • Marker-assisted breeding • Advanced genetic engineering • Low-cost diagnostic toolkit for extension workers
	Improving livestock agriculture (in general)	• High-nutrient, low-cost animal fodder • Liquid nitrogen and low-cost alternatives for animal semen preservation • Low-cost diagnostic toolkits for livestock veterinarians • Tissue engineering for laboratory-grown animal products • Low-cost veterinary pharmaceuticals (ideally thermostable)

[5] Chapters 2 and 3 incorporate case studies and examples of scientific and technical applications of food security from CSTD Member States that have submitted inputs on the aforementioned priority theme.

[6] STI for improving food availability could include existing technical approaches, along with new and emerging technologies. For example, techniques such as the System of Rice Intensification can lead to higher average productivity (contribution from the United Nations Educational, Scientific and Cultural Organization (UNESCO)).

Table 1. Examples of science, technology, and innovation for food security

	Lack of water availability[7]	• Water storage technologies (subsurface water technologies, aquifers, ponds, tanks, low-cost plastic water tanks, natural wetlands, reservoirs) • Canal irrigation • Micro-irrigation technologies, drip irrigation, bubbler irrigation, microsprinkler irrigation • Water lifting (hand-powered mechanical pumps, treadle pumps, solar-power irrigation pumps, hydrogen-powered pumps, electric and fossil fuel pumps) • Fungal seed and plant treatment for water-related stress • Stabilized silicic acid for drought tolerance • Irrigation scheduling systems and decision-support systems • Planting technology for increased water efficiency • Water pads (water-buffering technology) • Rainwater harvesting mechanisms • Water desalination technologies • Wastewater reuse • Conservation agriculture • Portable sensors for groundwater detection
	Soil	• Synthetic and organic fertilizers • Biogas digesters • Slurry separation systems • Zero or conservation tillage • Soil microorganisms • Natural nitrogen fixation • Point-of-use kits for evaluating soil nutrient content
	Need for precise integration, scheduling of inputs for increased yield	• Imaging and associated analytics • Drones • Internet of things • Big data • Farm management software and applications
	Farming in urban environments	• Indoor farming • Vertical farming • Aquaponics • Low-cost greenhouses
	Power and control-intensive operations	• Tractors • Robotic technologies • Animal-drawn implements
Food access	Post-harvest loss (storage, refrigeration, transport)	• Fruit preservation technologies • Hexanal formulations • Thermal battery-powered milk chillers • Nanotechnology • Improved genetic varieties • Seed and grain drying, aeration and storage technology • Innovative packaging • Biowax coating • Rice parboiling technology • Efficient processing technology for pulses • Rice-drying technology • Cool stores • Cleaning, grading, and packing technology • Off-grid refrigeration • Low-cost refrigerated vehicles • Low-cost solar dryers • Vacuum or hermetic sealing

[7] Many technologies for addressing water availability were provided as a contribution by the Government of the United States of America.

Table 1. Examples of science, technology, and innovation for food security

	Need for harvest and agro-processing equipment	• Crop threshers (motorized and bicycle-powered) • Agro-processing technologies (crop, meat, dairy products, fish)
Food use and utilization	Lack of nutritious foods, especially staple crops	• High-nutrient staple crops • Vitamin A-enriched cassava, maize, orange-fleshed sweet potato • Iron and zinc-fortified rice, beans, wheat and pearl millet quality protein maize
	Lack of information on healthy diets	• Dissemination of nutrition information (for example, health mobile applications)
Food stability	Inability to predict when and how to farm	• Weather-forecasting technologies • Infrared sensors for detecting crop stress • Hyperspectral imaging, based on drones and satellites
	Lack of financial mechanisms to ensure income	• Index-based insurance (crop and livestock)

Source: UNCTAD

2.1 Food availability: Science and technology to improve agricultural productivity

FAO (2006) identified a food gap of close to 70 per cent between the crop calories available in 2006 and the expected calorie demand in 2050. To close this gap, it would be necessary to increase food production by making genetic improvements, reduce food loss and waste, shift diets and raise productivity by improving or maintaining soil fertility, pastureland productivity and restoring degraded land (Ranganathan et al., 2016). In this context, food availability will have to make up for this food gap, while taking into account decreasing arable land, limited water resources and other environmental, ecological, and agronomic constraints. It is estimated that in the past 40 years, almost 33 per cent of the world's arable land has been lost to pollution or erosion.[8]

Science, technology, and innovation can play a critical role in producing more food by creating plant varieties with improved traits, as well as optimizing the inputs needed to make agriculture more productive. This section covers genetic improvements to crops by conventional cross-breeding and transgenic modification. This section also reviews a number of inputs critical for increased agricultural productivity, including innovative techniques for soil management and irrigation, especially for and by smallholder farmers.[9]

2.1.1 Conventional cross-breeding for improved plant varieties and increased crop yields

Genetic modification of plant varieties can be used for nutrient fortification, tolerance to drought, herbicides, diseases, or pests, and for higher yields. Earlier forms of genetic modification in agriculture have involved conventional cross-breeding approaches. In the mid-1800s, Gregor Mendel formalized a technique of breeding a primary cultivar with a "relative crop" with desirable traits through successive generations until a resulting variety matched the characteristics of the target variety. Although plant improvements are limited to the best traits available within the same family of crops (Buluswar et al., 2014), such a technology continues to be useful, especially for smallholder farmers across a number of geographies.

Recent efforts that harness conventional cross-breeding, facilitate capacity-building among farmers, and involve North–South cooperation include the Nutritious Maize for Ethiopia project as well as the Pan-Africa Bean Research Alliance.[10] The former aims to improve household food security and nutrition in Ethiopia for an estimated 3.98 million people by promoting widespread adoption of quality protein maize (QPM) varieties among growers and consumers of maize. Farmers (28 per cent women), researchers, extension agents, local and regional government officials, and media personnel learned about the nutritional benefits of quality protein maize and how to increase its productivity during 1,233 farmer-focused learning events. This project

[8] See http://www.fao.org/docrep/014/am859e/am859e01.pdf and http://grantham.sheffield.ac.uk/wp-content/uploads/2015/12/A4-sustainable-model-intensive-agriculture-spread.pdf.

[9] This section does not specifically discuss conservation (or zero) tillage, introduction of legumes to biologically fix nitrogen, pest management, or increasing agricultural productivity for livestock or fish farming.

[10] Contribution from the Government of Canada.

introduces new populations to a maize variety with higher protein content in order to improve nutrition and productivity of participating farmers.

Other countries use conventional cross-breeding, along with technology transfer, to make staple crops more productive in harsh climactic and environmental conditions. The Government of Peru has been implementing a programme since 1968 to genetically improve cereals for sustainable crop production.[11] Cereals (barley, wheat and oats) and native grains (quinoa and amaranth) are mostly cultivated by peasant communities as basic crops for food, in small fields mainly located above 3,000 metres, where few food species can develop due to limiting factors of climate and soil. Farmers in the Peruvian highlands, along with university, government, private sector, international and civil society actors used conventional methods involving the genetic improvement of plants and biotechnology support to develop rustic varieties adapted to the variable and adverse sierra environments. Along with the development of new seed technologies, the programme facilitated technology transfer through a participatory evaluation of improved varieties using established channels in agricultural communities.[12]

2.1.2 Improving agricultural productivity through transgenic crops

Transgenic modification involves the insertion of genetic organisms from unrelated organisms that cannot be crossed by natural means. Transgenic modification confers a number of benefits, including tolerance to biotic stresses (insects and disease), abiotic stresses (drought), improved nutrition, taste and appearance, herbicide tolerance and reduced use of synthetic fertilizers. Given the challenges of increasing water scarcity and land degradation, such technologies potentially increase productivity per area unit or plant. A number of countries such as Bulgaria, through its Institute of Plant Physiology and Genetics, are developing capabilities in these modern agricultural biotechnologies to increase the tolerance of crops to environmental stressors (Box 1). Well-known examples of modern genetically modified crops include:

- Bt-cotton in India and China and Bt-Maize in Kenya[13]
- Disease-resistant and early maturing maize varieties that drove maize production in Nigeria in the 1980s
- Nigerian cassava resistant to cassava mosaic virus that improved production in the 1990s
- New Rice for Africa (NERICA) rice varieties that are hybrid combinations of African and Asian rice species
- *Banana Xanthomonas wilt* (developed by Ugandan researchers)
- *Maruca vitrata* (developed by Nigerian scientists)
- African Orphan Crops Consortium that sequences African indigenous plants and crops
- The NextGen Cassava Project that uses genomic selection to improve crops (Buluswar et al., 2014; Grosskurth, 2010; World Bank and FAO, 2009)

Box 1. Bulgaria's Institute of Plant Physiology and Genetics

The mission of the Institute of Plant Physiology and Genetics (IPPG) of the Bulgarian Academy of Sciences is to contribute to the resolution of global issues such as feeding the population despite adverse climatic changes. It has the following the main priorities:

- Creation of new plant forms for the arable sector, food processing and pharmaceuticals industries, health and environmental protection.
- Research into the physiological and biochemical bases of regulation of a plant's metabolism in plants and safeguard mechanisms that help to overcome the negative effects of the environment and increase their resilience.
- Studies on the organization and functioning mechanisms of the researched structures in order to characterize the enrichment of genetic resources and their use for the enhancement of economic importance for the country's plant species.

To identify environmentally sustainable solutions for feeding the populace, IPPG is testing plants at the molecular level, as well testing as their relationship with environmental air, soil and water. The resulting scientific data concern raising the productivity of plant by optimizing

[11] The case study was provided as input by the Government of Peru.

[12] The next chapter addresses issues of technology dissemination in more depth.

[13] Bt is a family of proteins originating from strains of the bacterium *Bacillus thuringiensis.*

their water exchange mineral nutrition, maintaining an optimal environment for active symbiotic relationships with microorganisms, minimizing adverse effects on the environment, increasing resilience photosynthesis through phytohormones and plant growth regulators. The project is developing and exploring new genotype cultivars with improved food and biological properties — maize (Zea mays L.), tobacco (Nicotiana tabacum L.), cultural sunflower (Helianthus annuus), tomato (Solanum lycopersicum L.) and pepper (Capsicum annuum L.). Assessment will be performed of the genetic diversity of varieties of wheat (Triticum aestivum L.) with a high tolerance of drought, leaf pathogens and increased nitrogen efficiency.

New innovative biotechnologies are being encouraged, such as seaweed biomass production, protecting and enhancing biodiversity through a complex survey of valuable medicinal herbs (oregano, white oil, the valerian, peppermint, thyme, sage), Bulgarian endemic and rare species that are critically endangered or new species (gooseberry Stevia, echinacea, tayberries) in favour of agriculture, the pharmaceutical, cosmetic and food industries. Genes that are key to increasing the tolerance of crops are being identified to stress environmental conditions through the use of protein and chromosomal DNA markers and examined the regulation of gene expression.

Source: Contribution from the Government of Bulgaria.

Genetically modified crops, which historically have been developed commercially by transnational seed and agrochemical companies, may be costly and externally input-dependent for smallholder farmers (World Bank, 2008), but recent philanthropic initiatives are making such technologies available to them.[14] Given that much biotechnology has been developed in the private sector, there is also concern about technology access, the patenting of life forms, benefit sharing, market dynamics, risk evaluation and mitigation, and related issues.[15] While such issues continue to be debated at the global, regional and national levels, salient challenges for developing countries may involve the innovation capacities to assess, select, diffuse, adapt, and evaluate such technologies to address local agricultural challenges, owing to the knowledge intensity of modern agricultural biotechnology (UNCTAD, 2002). These innovation capacities involve not only human capital, research and development institutions, and enabling infrastructure, but also legal and regulatory policies that promote trade and innovation, recognize traditional and indigenous knowledge, and establish biosafety regulations and institutions that ensure human, plant, animal, and environmental safety (UNCTAD, 2004).

2.1.3 Soil management for increasing agricultural yields

Genetically improved varieties might not increase yields if constraints such as slow soil fertility are not overcome. Fertile soils play a pivotal role in sustaining agricultural productivity and thus food security. The focus on innovations and technological developments is more on crops and fighting pests and diseases. and less on sustainable soil management practices. However, healthy plants grow on healthy soils that are less affected by pests and diseases.[16]

Synthetic fertilizers have been used to increase agricultural yields for decades but their capital intensity, dependence on natural gas – particularly in the case of nitrogen – and a large ecological footprint make them unsustainable. Fertilizer and water overuse can cause environmental damage and represent an economic waste for smallholder farmers. Furthermore, the Intergovernmental Technical Panel on Soils concluded that farmers are essentially mining the soil, which is why soil should be considered a non-renewable resource (ITPS, 2015).

A number of new technologies and techniques are making more sustainable fertilizer use viable. New methods of nitrogen fixation and other fertilizer components that avoid the current

[14] For example, the African Agricultural Technology Foundation and the Bill and Melinda Gates Foundation negotiate licences to provide some of these technologies to smallholder farmers.

[15] There have been differing perspectives on the role of intellectual property rights in genetically improved crops. For more information, see IP Handbook (www.iphandbook.org); E Marden, R Godfrey and R Manion, eds., 2016, *The Intellectual Property-Regulatory Complex: Overcoming Barriers to Innovation in Agricultural Genomics* (UBC Press, Vancouver); C Chiarolla, 2011, *Intellectual Property, Agriculture and Global Food Security: The Privatization of Crop Diversity* (Edward Elgar, Cheltenham, United Kingdom); UNCTAD-ICTSD, 2005, *Resource Book on TRIPS and Development* (Cambridge University Press, New York); J Reichman and C Hasenzahl, 2003, Non-voluntary licensing of patented inventions: Historical perspective, legal framework under TRIPS, and an overview of the practice in Canada and the USA, on IPRs and Sustainable Development, Issue Paper No. 5 (ICTSD, Geneva).

[16] As illustrated in a report of the CGIAR Research Programme on Climate Change, Agriculture and Food Security (CCAFS, 2012), “some modern agricultural practices adversely affect soil quality through erosion, compaction, acidification and salinization, and reduce biological activity as a result of pesticide and herbicide applications, excessive fertilization, and loss of organic matter”.

capital- and energy-intensive methods could make nutrient supplementation more environmentally sustainable. A recent study found that nitrogen-fixing trees within critical water and temperature thresholds can increase yields by improving both the water-holding capacity of soil and water infiltration rates (Folberth, 2014; United Nations, 2015b). For example, "N2Africa" is a large-scale, science-based development-to-research project focused on putting nitrogen fixation to work for smallholder farmers growing legume crops in Africa (Giller et al., 2013).[17]

New technologies to make biological fertilizers (composting, manure or dung) more viable and effective could also increasingly replace the use of synthetic fertilizers. Nigeria's National Research Institute for Chemical Technology (NARICT) has developed neem-based fertilizer and organic fertilizer from *Moringa oleifera*, which is environmentally friendly.[18] However, such biological fertilizers, in particular those made from human waste, may require sanitation infrastructure. Furthermore, precision agriculture can help facilitate the precise application of inputs to crop type and soil conditions in ways that increase yields while minimizing potential environmental impacts (Box 2) (Buluswar et al., 2014).

Box 2. Information and communications technologies for improved soil quality in Bangladesh

The Katalyst programme in Bangladesh aims to increase income for citizens in a number of sectors, including agriculture and food security. The Soil Resource Development Institute of the Ministry of Agriculture partnered with Katalyst to develop an ICT-based service providing farmer recommendations on fertilizer use customized for different crops and locations.

Through an analysis of soil sample data, the service developed recommendations to optimize the cost of inputs and yield. In collaboration with Bangladink and Grameenphone, a mobile-based fertilizer information service was launched, and eGeneration – a local information technology company – developed the software application in the local language (Bangla), with attention to the agricultural users and local context. Since its launch in July 2009, users have incurred reduced fertilizer costs – up to 25 per cent – and higher crop yields – up to 15 per cent. This success has led Katalyst to initiate a similar project for irrigation-relation information as well.

Source: UNCTAD, based on information provided by Katalyst in UNCTAD, 2012.

2.1.4 Irrigation technologies: Technologies that make water available for food production[19]

Like soil fertility, the availability of water is a critical input for ensuring and improving crop productivity. Approximately 70 per cent of global freshwater supply is devoted to agriculture.[20] Many farmers do not have access to water for agriculture because of physical water scarcity (not enough water to meet demands) or economic water scarcity (lack of investments in water infrastructure or insufficient human capacity to satisfy water demand), among other factors (Figure 3). In response to such challenges, low-cost and affordable drills, renewable energy-powered pumps and technologies for desalination and improved water efficiency can potentially make water more available for food production.

Lightweight drills for shallow groundwater and equipment to detect groundwater can potentially make groundwater more accessible as a form of irrigation. Solar-powered irrigation pumps could potentially increase access to irrigation where manual irrigation pumps that may be strenuous to use are inadequate or expensive motorized pumps with recurring fuel costs are financially out of reach (Buluswar et al., 2014). Affordable rainfall storage systems are also a potential technology for addressing irrigation (UNCTAD, 2010).

Where diesel- or solar-powered pumps are not feasible, hydro-powered pumps (e.g. aQysta Barsha pump) can be used to irrigate fields wherever there is flowing water.[21] Greenhouses can mitigate the unavailability of water caused by unpredictable rainfall and enable farmers to have a year-round growing season. For example, World Hope's Greenhouses Revolutionizing Output (GRO) allows farmers to construct low-cost greenhouses

[17] Contribution by Wageningen University.

[18] Contribution from the Government of Nigeria.

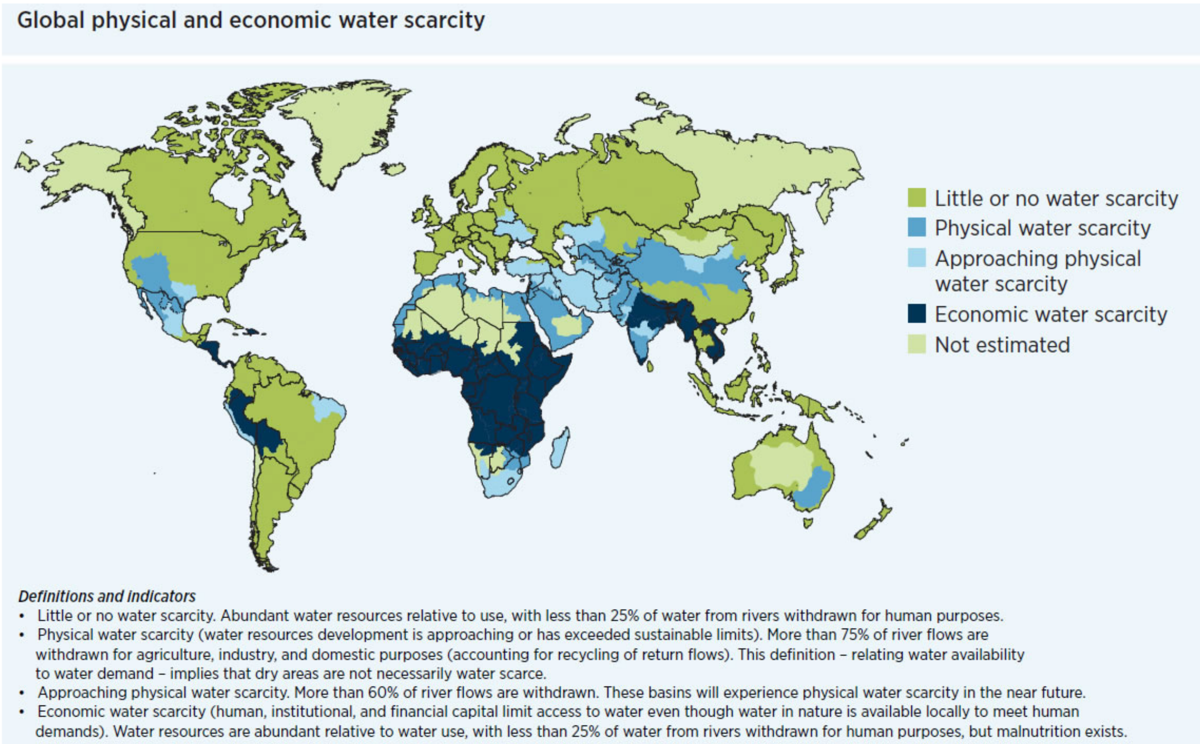
[19] Many of the technologies mentioned in this section were provided as input by the Government of the United States as part of their Securing Water for Food Initiative.

[20] For a more detailed review of agricultural water management technologies, see UNCTAD, 2011, *Water for Food: Innovative Water Management Technologies for Food Security and Poverty Alleviation*, UNCTAD Current Studies on Science, Technology and Innovation, No. 4 (United Nations publication, Geneva).

[21] http://securingwaterforfood.org/innovators/the-barsha-pump-aqysta

($500) in as little as two days that last over five years in Sierra Leone and Mozambique.[22] Even when groundwater is available, brackish water may not be suitable for human consumption or crop irrigation. Water desalination technologies such as off-grid solar-powered electrodialysis reversal

Figure 3. Global water scarcity



Source: Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture, 2007 (Earthscan, London).

(EDR) systems can remove salts and minerals from such brackish water.[23]

Other technologies improve water efficiency for increased demand for agricultural products in fragile natural environments. For example, the Groasis Waterboxx is an integrated planting technology that surrounds the bases of a plant, building up a water column by collecting dew and rainwater under the plant, and avoiding evaporation by distributing such water over long periods of time.[24] New fungal seed and plant treatments can help crops, such as okra, maize, millet, and wheat, use 50 per cent less water, with a 29 per cent crop yield increase.[25]

Beyond physical technologies and crop inputs, data can be used as a resource to improve water availability and efficiency. In Peru, information access to weather and climate patterns is expensive and limited. The Institute for University Cooperation Onlus provides an irrigation scheduling system that recommends the best irrigation practices based on climate, meteorological, and soil data through a mobile platform.[26] In countries such as Mozambique, farmers may not have reliable information on crop status and may be afraid of using costly inputs (high-quality seeds, fertilizer, and irrigation) in the

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22 http://securingwaterforfood.org/innovators/affordable-greenhouses-world-hope

23 http://news.mit.edu/2016/solar-powered-desalination-clean-water-india-0718; http://securingwaterforfood.org/innovators/edr-mit-jain.

24 http://securingwaterforfood.org/wp-content/uploads/2016/03/2015-SWFF-Annual-Report_Press_Print-Version.pdf.

25 http://securingwaterforfood.org/innovators/adaptive-symbiotic-technologies-bioensure.

26 http://securingwaterforfood.org/wp-content/uploads/2016/03/2015-SWFF-Annual-Report_Press_Print-Version.pdf

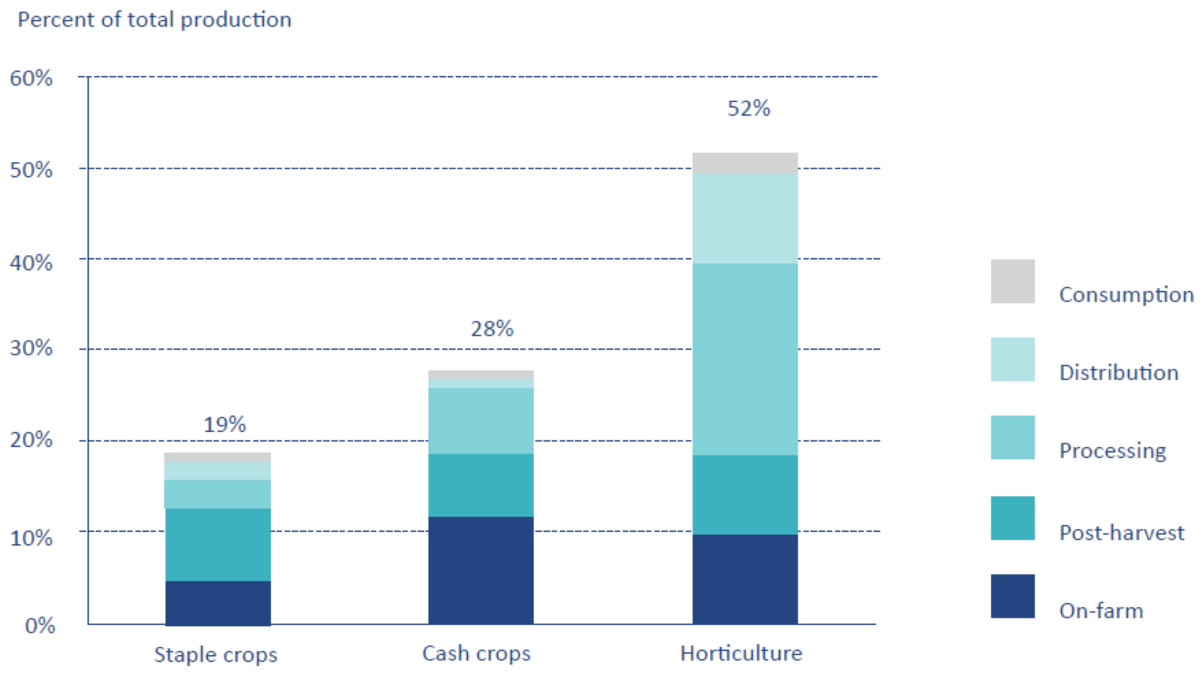
absence of such information. FutureWater's Flying Sensors use near-infrared sensors that can detect crop stress up to two weeks before it is visibly observable. In its first year of operation, a subset of households benefitting from the technology reported a 39 per cent reduction in water usage.[27] Lastly, it is important to address the gender dimension of water for food, as women disproportionately serve as agricultural labour, while having limited access to water, among other inputs for increasing agricultural productivity (UNCTAD, 2011).[28]

2.2 Food access: Technologies for food accessibility

A key aspect of accessing food is minimizing food losses during production, storage and transport, and waste of food by retailers and consumers. Because many African smallholder farmers lack access to ready markets, they tend to store their grains in inadequate facilities (e.g. no protection from moisture, excess heat, rodents, and pests) and end up with spoiled grains. Refrigeration needed for meats, fruits, and vegetables is typically lacking. And a lack of local processing facilities to produce consumable foods from raw products means that much high value produce is produced outside of the region. The need to import processed goods limits agribusiness employment prospects and drives up the costs of agricultural products farmers have to import. Lack of affordable refrigeration and of electricity limits the production, preservation, and sale of high value perishables such as vegetables, fruits, dairy, and meat. There is also a need for affordable refrigerated transport to move food from the farm to the market, while preserving freshness and navigating unpaved, rough terrain (Buluswar et al., 2014; African Cashew Alliance, 2010). The result is that all crops, particularly perishables, are susceptible to agricultural losses (Figure 4).

A number of post-harvest-loss technologies are useful for storage, handling, refrigeration, transport and processing[29]. Despite challenges in

Figure 4. Agricultural losses in sub-Saharan Africa across the value chain for different types of crops



Source: FAO, 2011.

[27] http://securingwaterforfood.org/wp-content/uploads/2016/03/2015-SWFF-Annual-Report_Press_Print-Version.pdf

[28] Section 3.5 covers the gender dimension of harnessing science, technology, and innovation for food security

[29] However, a meta-analysis in six African countries found that most innovations for smallholder farmers focused on storage pests to the exclusion of other issues, including processing, transport, and handling (Affogon, 2015; United Nations, 2015b).

widening the applicability of innovative solutions to post-harvest loss, a number of recent example demonstrate various approaches to minimize the losses that smallholder farmers often experience. For example, Uganda is one of eight African countries participating in a project to improve rice post-harvest handling, and marketing and development of new rice-based products.[30] The six-year project, which started in 2011, provides improved rice-threshing technologies (ASI and NARO Lightweight Rice threshers) to smallholder rice farmers, particularly women and youth; farmer cooperatives; rice millers; traders and local agro-machinery manufacturers. Technology transfer and dissemination are facilitated by the adoption of a business model, training of the beneficiaries on the use of the technologies and business skills, training of local private agro-machinery fabricators, and field days and radio announcements in the local languages for creating awareness. The threshers are expected to reduce post-harvest grain loss from 4.87 per cent to 0.01 per cent, translating to a savings of $12 million. The threshers should also improve the grain quality, labour productivity (saving up to 59 per cent threshing labour) and employment opportunities. Other projects include meat, dairy and fishery agro-processing in Cuba[31] and recent efforts to create mobile processing units for cassava in Nigeria.[32] Furthermore, genetically improved varieties can also limit (post-)harvest losses and preserve foods for transport to local, national, and international markets.

Nanotechnology is being used in a number of projects to improve the preservation of crops.[33] The Canadian International Food Security Research Fund and the International Development Research Centre support a programme to enhance the preservation of fruits in collaboration with five other countries: India, Kenya, Sri Lanka, Trinidad and Tobago, and the United Republic of Tanzania. It aims to increase environmentally sustainable food security for poor people, especially small-scale farmers and women, through applied, collaborative, results-oriented research that informs development practice. A key part of the project involves hexanal, an affordable and naturally occurring compound produced by all plants to slow the ripening of soft fruits and extend their storage life. The use of hexanal spray has increased fruit retention time by up to two weeks in mango and five to seven days in peaches and nectarines. A nanotechnology smart packaging system was also developed with hexanal-impregnated packaging and coatings made from banana stems and other agriculture waste to keep fruit fresh. The technologies are transferred using different mechanisms, including through technology transfer workshops, field days, seminars and public–private model centres.

A significant number of smallholder farmers in tropical areas do not have access to affordable harvest equipment. The cost, size, energy needs and maintenance requirements of imported threshers can create a burden for such smallholder farmers. In such cases, investing in the creation of local talent to fabricate and repair small to medium-sized threshers can address the affordability and availability of such technologies. Initiatives such as Soybean Innovation Lab supported by the United States Agency for International Development offer training workshops and have been recently piloted in Ghana.[34]

There is a need to better link smallholder farmers to local, regional, and international markets. Because many developing countries face regulatory costs related to international trade, investments should be made in sanitary and phytosanitary standards that can not only ensure compliance with trade regulations but also address national food and animal safety (IAASTD, 2009). Improving the capabilities of smallholder farmers to produce for regional and international markets could potentially create the economic and financial stimulus to escape smallholder farming status. In particular, low levels of intraregional trade among African LDCs (compared with other regions) may be an unexploited opportunity for increasing regional agricultural exports, harmonizing product standards within regional trading blocs and promoting regional agricultural innovation (UNCTAD, 2015d;

30 The case study is provided as input by the Government of Uganda.

31 The case study is provided as input by the Government of Cuba.

32 http://www.dadtco.nl/

33 Contribution from the Governments of Canada and Sri Lanka. More information is available at http://www.theepochtimes.com/n3/1835789-canadian-innovations-showcased-at-un/; http://www.abc.net.au/news/2015-03-17/nanotechnology-mangoes-india-srilanka-canada/6325346; and http://www.cbc.ca/news/canada/kitchener-waterloo/guelph-fruit-spray-extends-shelf-life-1.3647271.

34 Contribution from the Government of the United States. More information is available at http://soybeaninnovationlab.illinois.edu/sites/soybeaninnovationlab.illinois.edu/files/Thresher%20Training%20Brochure_0.pdf .

Juma, 2015). Knowledge aid, where international donors promote the intensification of knowledge for development, could potentially support standards compliance in addition to the development of specific agricultural technologies (UNCTAD, 2007).

2.3 Food use and utilization: Science for nutrition

One billion people worldwide suffer from insufficient calories and nutrients, 2 billion people have sufficient calories but insufficient nutrients and 2.5 billion consume excess calories, but many with insufficient nutrients. Thus, only about 3 billion have sufficient but not excessive calories and sufficient nutrients (Ingram, 2016). Malnutrition is both a driver and an outcome of poverty and inequality. Undernutrition can also lead to hidden hunger, wasting and stunting, which causes irreversible damage to people and society.

Biofortification – or the breeding of critical micronutrients and vitamins into staple crops – has emerged as an effective approach for combating malnutrition, especially in developing countries.[35] To date, the most successful example of vitamin and micronutrient biofortification is the orange-fleshed sweet potato, developed at the International Potato Centre. HarvestPlus, based at the International Food Policy Research Institute, has pioneered biofortification as a global plant-breeding strategy for a variety of crops such as vitamin A-enriched cassava, maize and orange-fleshed sweet potatoes, and iron and zinc-fortified rice, beans, wheat and pearl millet in over 40 countries. These combined efforts have already had a positive effect on 10 million people, and several hundred million more stand to benefit in the coming decades.[36] Complementary to such efforts, countries such as Guatemala are pursuing comprehensive efforts to improve nutrition while ensuring livelihoods and resilience through the Purchase for Progress programme of the World Food Programme (Box 3).

Box 3. Purchase for Progress and scaling up nutrition in Guatemala

The World Food Programme (WFP) Purchase for Progress project in Guatemala aims to improve the nutrition and health of thousands of women and children and help small-scale farmers increase their profits.

This project (2013–2018) promotes an integrated strategy comprising three components: Purchase for Progress, which improves the incomes of smallholder farmers through the increased quantity and quality of production and sales of surpluses to markets; scaling-up nutrition, which helps prevent and reduce chronic malnutrition through the distribution of fortified food and nutrition education; and resilience, which improves community conditions in disaster-prone areas and enhances food availability throughout the year.

Project activities include the following:

- Providing technical assistance to and sharing best practices with small-scale farmers on crop management and technologies to increase the quality and quantity of their yields
- Promoting better post-harvest management to reduce crop losses
- Assisting farmer organizations to increase sales and receive fair market prices from buyers
- Purchasing food from participating farmer organizations' crop surpluses to feed up to 17,500 infants and children aged 6–23 months per year and up to 10,000 pregnant and lactating women per year to complement breastfeeding and prevent stunting or chronic undernutrition
- Strengthening the business management skills of small-scale farmer organizations and increasing women farmers' participation, representation and skills

Source: Contribution from the Government of Canada.

2.4 Food stability: New ways to combat acute and chronic food insecurity

Sustainable food systems deliver food security and nutrition for all in such a way that the economic, social and environmental bases to generate food security and nutrition for future generations are not compromised. The effects of climate change will require sustainable and climate-compatible

[35] The four recipients of the 2016 World Food Prize were recognized for their exemplary contributions to biofortification.

[36] https://www.worldfoodprize.org/en/laureates/2016__andrade_mwanga_low_and_bouis/.

agriculture practices, including diversifying production.

2.4.1 Adapting food production to climate change

STI should focus on re-integrating crop and livestock production and related closed nutrient cycles. In related to this, the mitigation potential of carbon sequestration in optimally managed agricultural crop- and grasslands should be exploited more deeply. This potential is of the same order of magnitude as total agricultural emissions at the beginning (Smith et al., 2007a; Bellarby et al., 2008), but declines over time while approaching a new, higher soil carbon equilibrium level in soils, generally reaching zero sequestration rates after few decades. Soil carbon losses can be reduced by protecting existing permanent grassland, and soil carbon sequestration can be increased in arable land by the application of organic fertilizers, minimal soil disturbance, agroforestry, mixed cropping and the planting of legumes.

When addressing climate change mitigation and adaptation in agriculture, it becomes evident that this is less about developing new practices than about making the available knowledge and skills widely available and supporting sustained implementation in the field. In particular, STI for climate change mitigation and adaptation should focus on information provision and knowledge transfer and should include social, as well as technical, innovations. Many practices, however, deliver both, and many of the effective adaptation, resilience and mitigation approaches to a changing climate offer important ecological, agronomic, economic and social co-benefits. In addition, locally adapted breeding for drought or heat-tolerant crop varieties, with a focus on underutilized crops, has great potential to support climate change adaptation in agriculture.[37]

2.4.2 Using big data and the Internet of things for precision agriculture

Big data and the Internet of things can be harnessed for a number of agricultural applications, including farmer decision support, precision farming, and insurance. Nubesol offers crop health-related data to farmers and corporations based on a vegetation index it developed using satellite imagery that ultimately provides decision support to farmers about do's and don'ts for ensuring crop health. The Smart Pesticide project utilizes ultrasonic sensors to identify crop pests and sprinkle pesticides in a limited target area using a drone.[38] A programme coordinated by the Government of Indonesia, United Nations Global Pulse, and the World Food Programme used public tweets mentioning food prices to develop a real-time food index (United Nations Global Pulse).[39] In addition, the International Centre for Tropical Agriculture uses big data on weather and crops to better adapt to climate change (Box 4).

[37] The annual Subsidiary Body for Scientific and Technological Advice (SBSTA) research dialogue is a forum for sharing experiences on the application of STI for addressing climate change, including food production and security. (Contribution from the United Nations Framework Convention on Climate Change)

Box 4. Big data for sustainable food production in Colombia

The International Centre for Tropical Agriculture is an organization that promotes agricultural technologies, innovations and new knowledge to help smallholder farmers improve their crop yields, incomes and usage of natural resources. Scientists collaborated with the Colombian Ministry of Agriculture and the National Federation of Rice Growers to collect a big volume of weather and crops data in last decade in Colombia. The initiative predicted upcoming climate changes in Córdoba, a major rice-growing area in Colombia. The results are highly localized. In the town of Saldaña, for example, the analysis showed that rice yields were limited mainly to solar radiation during the grain-ripening stage. In the town of Espinal, rice yields suffered from sensitivity to warm nights. Solutions do not have to be costly – farmers can avoid losses simply by sowing crops at the right time. Climate change projections helped 170 farmers in Córdoba avoid direct economic losses of an estimated $3.6 million and potentially improve productivity of rice by one to three tonnes per hectare. To achieve this, different data sources were analysed in a complementary fashion to provide a more complete profile of climate change. So-called data fusion is a typical big data technique. Additionally, analytical algorithms were adopted and modified from other disciplines, such as biology and neuroscience, and were used to run statistical models and compare with weather records. With support from national and international organizations such as the World Bank and the Fund for Irrigated Rice in Latin America, the initiative has started to approach rice growers associations in other countries, for example, Argentina, Nicaragua, Peru, and Uruguay.

Sources: UNCTAD compilation, based on Cariboni, 2014; CCAFS, 2015

[38] Pratap Vikram Singh, "The Startup Revolution: Smart Solutions for Social Good," Governance Now, August 1, 2015.

[39] United Nations Global Pulse (http://www.unglobalpulse.org/nowcasting-food-prices)

The International Livestock Research Institute (ILRI) created a programme known as Index-Based Livestock Insurance to provide financial protection based on a rainfall index to trigger payments for pastoralists in the Horn of Africa.[40] Results of a household survey on impact evaluation in that region demonstrate that households insured by the programme were less likely to reduce meals or sell livestock and more likely to have veterinary services, higher milk productivity and better nourished children.[41]

Because data relating to meteorology and the Internet of things are increasingly valuable as agricultural inputs, a number of new initiatives focus on sharing data to support agricultural productivity.[42] For example, the Global Open Data for Agriculture and Nutrition initiative, a network of over 430 partners, focuses specifically on the universal benefits of open data ownership and governance, with particular attention to capacity-building for grassroots initiatives in developing countries.[43]

Despite the potential of big data and the Internet of things, stakeholders have expressed concern about the privacy and security concerns of agricultural data, the politics of data ownership and transparency, data breaches and access of smallholder farmers to such data. In this respect, regional and international organizations can potentially work with stakeholders to define appropriate data standards to minimize the potentially negative consequences of data sharing.

2.4.3 Early warning systems

Eighty per cent of the estimated 1.4 billion hectares of global cropland is rain fed, accounting for approximately 60 per cent of worldwide agricultural output.[44] Accurate and reliable weather forecasts enable farmers, especially near the equator, to capitalize on rainfall for crop production in regions of extreme weather variability.

Global systems have played critical roles in disseminating country and region-specific information to help farmers maximize productivity. These include the Global Information and Early Warning System on Food and Agriculture, and Rice Market Monitor (FAO); the Famine Early Warning System Network (United States Agency for International Development) the Early Warning Crop Monitor (Group on Earth Observations) and the cloud-based global crop-monitoring system called Crop Watch (Chinese Academy of Sciences,). Regional initiatives such as the Regional Cooperative Mechanism for Drought Monitoring and Early Warning in Asia and the Pacific (Economic and Social Commission for Asia and the Pacific) and the Trans-African Hydro-meteorological Observatory also make high-quality data available to their respective regions to improve crop productivity and food security.

Box 5. Crop Watch: Cloud-based global crop monitoring system

Crop Watch, which is being developed and operated by the Institute of Remote Sensing and Digital Earth of the Chinese Academy of Sciences, supports emergency responses through the periodic release of agricultural information across the world. Taking advantage of multiple new remote-sensing data sources, Crop Watch adopts a hierarchical system covering four spatial levels of detail: global, regional, national (31 key countries, including China) and "subcountries". The 31 countries encompass more than 80 per cent of the production and export of maize, rice, soybean and wheat. The methodology uses climatic and remote-sensing indicators on different scales. The global patterns of crop environmental growing conditions are first analysed with indicators for rainfall, temperature, photosynthetically active radiation and potential biomass. On the regional scale, the indicators pay more attention to crops and include factors such as the vegetation health index, vegetation condition index, cropped arable land fraction and cropping intensity. Together, they characterize crop situation, farming intensity and stress.

Source: Chinese Academy of Sciences Institute of Remote Sensing and Digital Earth, Digital Agriculture Unit.

[40] https://www.worldfoodprize.org/en/nominations/norman_borlaug_field_award/2016_recipient/

[41] https://cgspace.cgiar.org/bitstream/handle/10568/66652/ResearchBrief52.pdf?sequence=1&isAllowed=y (accessed 21 February 2017).

[42] Other initiatives include the World Meteorological Organization's Resolution 40 on sharing meteorological and other data, Planet Lab's Open Regions programme that make satellite imagery accessible online (some for free), and CIARD (Coherence in Information for Agricultural Research for Development) which advocates for open data among agricultural data holders.

[43] http://www.godan.info

[44] http://securingwaterforfood.org/wp-content/uploads/2016/03/2015-SWFF-Annual-Report_Press_Print-Version.pdf.

In particular, the Famine Early Warning Systems Network (FEWS NET) offers objective, evidence-based analysis to Governments and relief agencies across the world.[45] Created by USAID in 1985 after famines ravaged Western and Eastern Africa, FEWS NET provides timely alerts on expected or emerging crises, monthly reports and maps of current or project food insecurity, and specialized reports on various topics (e.g. nutrition, markets, trade, agricultural production and livelihoods).[46]

Similarly to FEWS NET, the United Nations Institute for Training and Research (UNITAR) and its Operational Satellite Applications Programme (UNOSAT) has been deployed for the past 15 years to provide satellite imagery for development, humanitarian and human rights communities. In the context of food security, applications include rapid mapping for natural disasters and groundwater mapping for sustainable development. Not only are data provided, but knowledge transfer ensures that beneficiaries have the capabilities to harness satellite technologies for flood and drought management, deforestation, and climate change adaptation. UNOSAT serves as a go-to place for satellite imagery within the United Nations system.[47]

A number of new technologies are enabling novel early warning systems conferring unique predictive advantages. For example, Sweden-based Ignitia accurately predicts weather forecasts in tropical areas with a combination of algorithmic techniques based on convective processes, complex modelling of physics, and small (spatial and temporal) forecasting windows. The result is a reported 84 per cent accuracy rate over two rainy seasons in Western Africa (2013 and 2014), compared with other weather service providers with a 39 per cent rate. Low-cost daily messages help farmers anticipate rainfall for the next 48 hours.[43]

2.5 Convergence of new and emerging technologies

The convergence of a number of emerging technologies, such as synthetic biology, artificial intelligence, tissue engineering, three-dimensional printing, drones and robotics, may have profound impacts on the future of food production and food security. Many of these applications are currently in the research and development or demonstration phase in developed countries. However, such technologies have the potential to reshape the future of food production, either individually or as part of converged applications.

Recent advances in biotechnology have created a new approach to genome editing, based on CRISPR/Cas9 (Box 6). Based on this method, the transformation of nucleotide sequences (genome editing) can involve inserting disease-resistant genes from related wild plant species in modern plants. Newly formed companies are using synthetic biology to develop biological nitrogen fixation to sustainably increase yields for smallholder African farmers. Such methods could reduce reliance on synthetic fertilizers allowing the crops to fix nitrogen from soil bacteria.[49] Other companies are leveraging synthetic biology to make food flavourings (e.g. vanilla) that minimize oil inputs while mimicking the flavour of the natural product.[50]

Box 6. The potential of synthetic biology: CRISPR/Cas9

CRISPR stands for clustered regularly interspaced short palindromic repeats. It was originally a bacterial immune system conferring resistance to foreign genetic elements such as those from viral infections. Recently, CRISPR technology has emerged as a powerful tool for targeted genome modification in virtually any species. It allows scientists to make changes in the DNA in cells that have the potential to cure genetic diseases in animals or develop new traits in plants. The technology works through a protein called Cas9 that is bound to an RNA molecule and thus forms a complex. RNA is a chemical cousin of DNA and it enables interaction with DNA molecules that have a matching sequence. The complex functions like a sentinel in the cell and searches through the entire DNA in the cell that matches the sequences in the bound RNA. When the sites are found, it allows the protein complex to cut and break DNA at that site. Its success is due in large part to its ability to be easily programmable to target different sites.

CRISPR differs from classic genetic engineering techniques because it opens up an opportunity for target modification, or the modification of specific

45 Contribution from the Government of the United States.

46 http://www.fews.net/about-us.

47 http://www.unitar.org/unosat/

48 http://www.ignitia.se

49 https://www.ensa.ac.uk/

50 See http://www.evolva.com/ and https://techcrunch.com/2015/09/28/synthetic-biology-is-not-just-good-its-good-for-you/

regions and sequences in genomes. Because it can modify a specific gene of interest, the technology is also called gene editing. CRISPR has the potential to operate as a stand-alone technology. However, until now, its application in plants has relied on other genetic engineering tools (e.g. recombinant DNA, biolistics, electroporation). Trait improvement through classic breeding in crops can be accelerated by CRISPR-based genome engineering. CRISPR has been tested in commercial crops to increase yield, improve drought tolerance and increase growth in limited nutrient conditions to breed crops with improved nutritional properties and to combat plant pathogens.

The opportunity to do this genome editing also raises various safety and ethical issues that should be considered. One of the safety concerns relates to the possibility to generate permanent DNA breaks at other, unintended sites in a genome. The rules governing the off-target activity of CRISPR are just beginning to be understood in more detail. In addition, the ability of CRISPR to edit small bits of DNA sequences generates minimal modifications, and also makes it more difficult for regulators and farmers to identify a modified organism once it has been released. Lack of detection of CRISPR modified crops would raise concerns over labelling and consumer rights, as well as risk-monitoring issues.

CRISPR gene editing is likely to have commercial and socioeconomic implications similar to those of conventional genetically modified organisms. The results of gene editing are bound to be protected by intellectual property rights and therefore have market power and purchasing power implications for seed and biotechnology companies as suppliers, on the one hand, and farmers, on the other.[51]

Source: Sarah Agapito-Tenfen, GenØk Centre for Biosafety, Tromsø, Norway

Some innovations have the potential to transform or make obsolete current forms of livestock agriculture. Researchers at the University of Delaware are mapping the genetic code of African naked-neck chickens to see if their ability to withstand heat can be bred into other chickens that are resilient to climate change. Similar work is being conducted at Michigan State University on turkeys resilient to heat waves.[52]

As biology becomes an information technology, it may be possible to grow certain foods outside of the conventional factory farm model to produce animal products in the laboratory. Start-up companies are developing animal-free egg whites that use less water and land inputs while preserving the taste and nutritional value of hen-borne egg whites.[53] Other companies are making meat and cheese products directly from plants,[54] while some academics and researchers are leveraging advances in tissue engineering technologies to three-dimensional print meat. It has been claimed that laboratory-grown meat[55] could potentially use less land and water and produce lower greenhouse gas emissions. On the other hand, if such developments reach an industrial scale, it could potentially have implications for livestock agricultural production based in developing countries.

Big data, the Internet of things, drones, and artificial intelligence may catalyse precision farming, requiring fewer agrochemical inputs for existing agricultural processes (see Figure 5). Some companies are using novel genetic sequencing, along with machine learning, to detect soil quality and help increase crop quality.[56] Machine learning is being applied to drone and satellite imagery to build detailed weather models that help farmers make more informed decisions to maximize their yield.[57] It is also being used with plant genomic and phenotypic data to predict the performance of new plant hybrids.[58] Robots are increasingly automating farming through the ecological and economical weeding of row crops.[59] Beyond rural areas, Big data and the Internet of things are enabling urban, indoor and vertical farming, which in some cases can improve agricultural productivity and water efficiency with

[51] The intellectual property implications of synthetic biology are not clear. Initiatives such as iGem have created a registry of standard biological parts, making 20,000 documented genetic parts available for building synthetic biology devices and systems (see igem.org/Registry). At the same time, given that no foreign genes are inserted into genetically edited crops, it may have implications for regulatory processes involving biotech crops.

[52] http://www.latimes.com/nation/la-na-climate-chickens-20140504-story.html.

[53] http://www.clarafoods.com/aboutus/#theclarastory.

[54] http://impossiblefoods.com.

[55] https://culturedbeef.org and www.modernmeadow.com/.

[56] https://www.tracegenomics.com.

[57] A number of companies provide satellite imagery solutions based on machine learning and artificial intelligence. Examples include https://www.nervanasys.com/solutions/agriculture/, http://www.descarteslabs.com/;https://pix4d.com/, http://gamaya.com/, http://www.bluerivert.com/, http://prospera.ag/, https://www.tuletechnologies.com/ and http://www.planetaryresources.com.

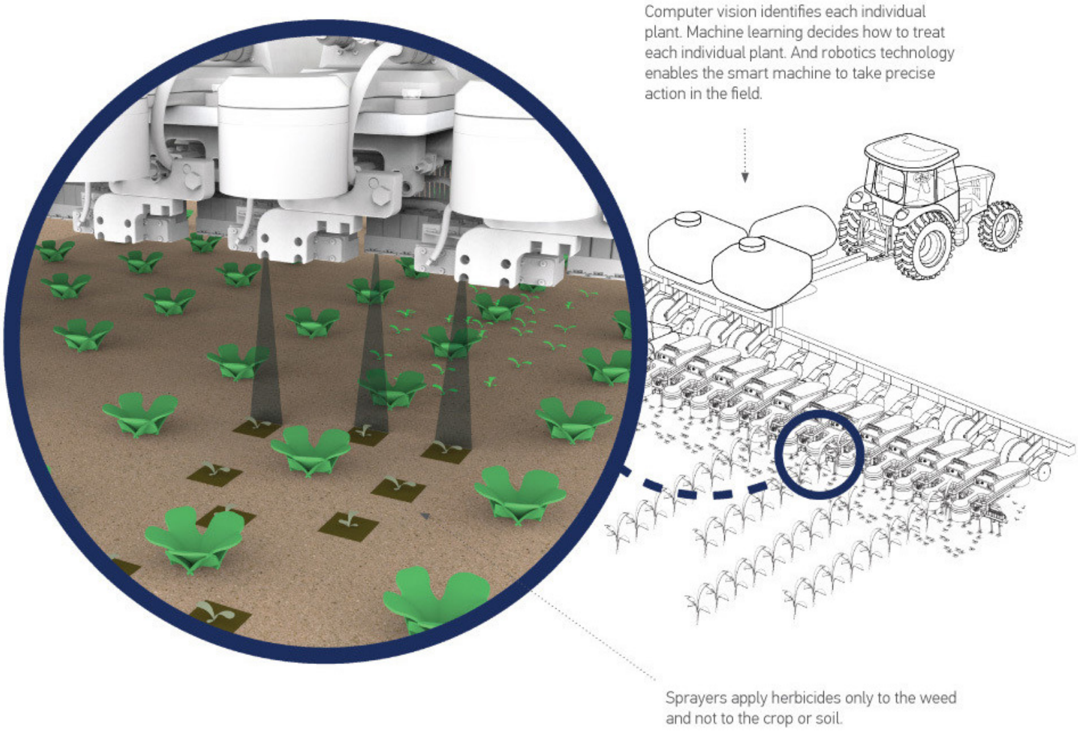
[58] A number of companies provide satellite imagery solutions based on machine learning and artificial intelligence. See https://www.nervanasys.com/solutions/agriculture/.

[59] See http://www.ecorobotix.com/ and https://www.deepfield-robotics.com/.

minimal or negligible need for pesticides, herbicides, and fertilizers.[60] A number of these technologies (sensors, artificial intelligence, imaging, and robotics) can be combined for automated precision farming. The potential impacts of these converging technologies are unclear, leading to the need for robust mechanisms to evaluate such technologies.

In order to harness STI for the achievement of food security in 2030, it is essential to manage the risks and public perceptions relating to STI. New technologies have been credited with creating new opportunities but also destroying the status quo, and technological risks are not necessarily confined to the sectors or countries in which are they applied.

Figure 5. Example: Application of the Internet of things, robotics, and artificial intelligence to farming



Source: Blue River Technology

Potential benefits and positive impacts are often difficult to predict, while risk perceptions can include scientific, technical, economic, cultural and ethical concerns. Managing such technological uncertainty requires scientific and institutional capacities to respond swiftly with available knowledge to both emerging challenges and technological failure (Juma and Yee-Cheong, 2005). In this respect, United Nations entities – such as the Commission on Science and Technology for Development – could potentially play a more prominent role in working with Member States to assess the potential benefits and risks of new and converging technologies, with a view towards immediate and longer-term impacts (Box 7).

[60] See https://urbanfarmers.com/, http://cool-farm.com/, http://light4food.com/en/ and http://www.newsweek.com/2015/10/30/feed-humankind-we-need-farms-future-today-385933.html.

Box 7. The need for an international technology assessment and foresight mechanism

The notion of technology assessment was extensively developed in the 1960s and coincided with the rise of the environmental movement during the same period. The notion that policymakers needed informed, objective information on the potential benefits and risks of new technologies became more prominent in international institutions and national governments.

The United States Congressional Office of Technology Assessment (OTA) was established on the premise that the federal branch needed expertise on science, technology and innovation. With over 700 published reports during its tenure, a number of studies were conducted that leveraged the expertise of scientists and academics, as well as a range of stakeholders potentially affected by the technologies. OTA conducted major studies, briefed congressional committees, and assisted in the analysis of technical and scientific issues that affected the legislative process. With a staff of 90 professionals, OTA worked with nearly 2000 experts on a large and constantly shifting set of subjects. Though the work did not make specific policy recommendations, it played a role in influencing policy. Other countries – such as the United Kingdom and several members of the European Union – built their offices of Technology Assessment on the OTA model.[a]

The former Centre for Science and Technology for Development had a similar role at the international level within the United Nations system. An example of technology assessment and foresight carried out within the United Nations system is the Advanced Technology Assessment System bulletin, which analyses the implications of new developments in areas ranging from biotechnology, new materials, energy and information technology to new approaches to science and technology cooperation.[b]

Technology foresight, though related to technology assessment, has more of a future orientation with the aim of not only anticipating potential future outcomes but using policy to shape desired futures. A number of organizations help conduct foresight specifically for agricultural technologies. These include the Global Forum on Agricultural Research, the Asian Farmers Association, Plateforme régionale des organisations paysannes d'Afrique centrale, Forum for Agricultural Research in Africa (FARA), Central Asia and the Caucasus Association of Agricultural Research Institutions (CACAARI), Young Professional for Agricultural Development (YPARD), Centre for International Forestry Research (CIFOR), and World Fish.[c]

There is a need for a global initiative that can systematically convene experts from across disciplines to address agricultural technologies and their potential impacts on society, the economy and the environment. Such a global initiative should ideally conduct both technology assessment and foresight exercises to evaluate the immediate and long-term impacts of new technologies on food security, agriculture, and sustainable development more broadly.

A global network of experts across disciplines and domains coordinated at the international level could help the international community better understand the implications of technology – both individually and converged – in ways that would help policymakers make more informed decisions. Such an international body could also assist countries with capacity-building to develop their own technology assessment and foresight capacities. Many countries may not have the domestic expertise across a vast range of scientific disciplines and technology areas for the purposes of national technology assessment and foresight. International capacity-building activities could increase scientific and technological cooperation among countries.

In its resolution 2014/28, the Economic and Social Council encourages the Commission on Science and Technology for Development to do the following:

to help to articulate the important role of information and communications technologies and science, technology, innovation and engineering in the post-2015 development agenda by acting as a forum for horizon scanning and strategic planning, providing foresight about critical trends in science, technology and innovation in areas such as food security, the management of water and other natural resources, urbanization, advanced manufacturing and related education and vocational needs, and drawing attention to emerging and disruptive technologies that can potentially affect the achievement of that agenda.[d]

The Commission has also conducted multi-year panels on biotechnology[e] and ICT[f] and their implications for development, based on high-level meetings and expert-based reviews. In this context, the Commission is well placed to continue its work as a forum for assessing and anticipating the social, economic and environmental impacts of new and emerging technologies in food security and agriculture.

Source: UNCTAD

a More information and historical documentation on the United States OTA can found at http://www.princeton.edu/~ota/.

b See, for example, http://unctad.org/en/docs/psiteiipd9.en.pdf (accessed 20 February 2017).

c http://www.gfar.net/our-work/foresight-better-futures-0

d Resolution 2015/27 of the Economic and Social Council makes a similar statement.

e Findings of biotechnology expert group meetings can be found at http://unctad.org/en/docs/iteipc20042_en.pdf and http://unctad.org/en/Docs/poditctedd12.en.pdf (both accessed 20 February 2017).

f Findings from panel meetings on ICT were published in R Mansell and U Wehn, eds., 1998, Knowledge Societies: Information Technology for Sustainable Development (Oxford University Press, Oxford).

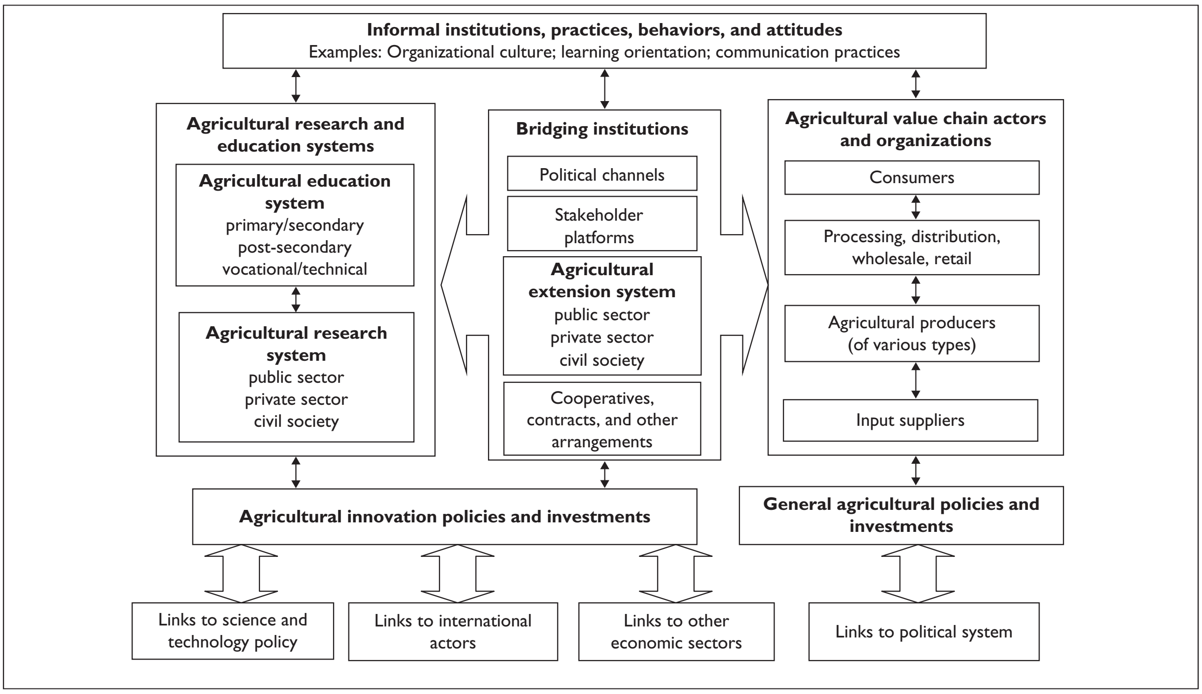
2.6 Conclusion

As demonstrated in this chapter, science and technology can be applied across all dimensions of food security. The examples provided were illustrative – not comprehensive – and provide a window into some of the new and emerging technologies that can be used throughout agriculture, with a focus on smallholder farmers. However, using these scientific and technical applications, tools, and techniques require the know-how, skills, and ability to adapt, diffuse, and apply such technologies to local food security-related challenges. The next chapter discusses how countries can develop the innovative capabilities to apply knowledge in agricultural development.

CHAPTER 3. DEVELOPING INNOVATIVE FOOD SYSTEMS

To harness science and technology for the various dimensions of food security, it is necessary to make the food system itself more innovative. This includes, among other things, defining a research agenda that focuses on smallholder farmers, investing in human capacity, enabling infrastructure for food systems, putting appropriate governance structures in place for agricultural innovation and strengthening knowledge flows between farmers and scientists. The agricultural innovation system is a useful tool to analyse the ecosystem and supporting mechanisms and infrastructure that facilitate agricultural innovation (Figure 6). Key stakeholders include farmers, research and education systems, firms (e.g. input suppliers, agricultural producers, processing, distribution, wholesale and retail), agricultural extension, government ministries, and international and non-governmental actors (Larsen et al., 2009; UNCTAD, 2015c).

Figure 6. Agricultural innovation system



Source: Larsen et al., 2009.

Designing and strengthening an agricultural innovation system involves promoting research and development, investing in infrastructure, building human capacity, creating an enabling environment and strengthening knowledge flows, particularly among scientists and farmers. Because women account for a significant share of agricultural labour, a gender-sensitive lens should be applied to agricultural innovation. Regional and international collaboration can address research priorities, while international technology assessment and foresight can help countries evaluate the immediate and long-term implications of innovations for food security.

The design of innovative food systems should ideally support pro-poor and frugal agricultural innovations, promote the participatory engagement of smallholder farmers, recognize local and traditional knowledge systems, facilitate gender equity and be clearly linked to economic empowerment and livelihoods.[61] This analytical framework can help policymakers and other stakeholders consider the different ways that the broader food system can be strengthened to support the application of science and technology in addressing food security challenges.

3.1 Promoting a smallholder farmer-focused research agenda

There is an urgent need to increase investment in high-quality research that is coherent with production models adapted to the needs of smallholder farmers. The constantly changing ecological, environmental and biodiversity contexts require continuous research and development to produce inputs and disseminate knowledge that maximizes agricultural yields while safeguarding the environment. Research – at the national and international levels – must address a more complex set of objectives: on the one hand, the new challenges (climate change, renewable energy and energy efficiency, biodiversity and resource management), and on the other hand, the old challenges (productivity growth and production quality), as well as the promotion of diversification. At the national level, for example, the Agricultural Academy of Bulgaria supports high-quality agricultural research and development (Box 8)[62], and the Thailand Research Fund has granted more than 800 research projects on foods since 1994 with a focus on local community engagement.[63]

In this regard, it has been recommended that orientation of science, technology, and innovation research for food security include the following elements:

- Partnership with rural producers' organizations and NGOs
- Use of non-proprietary genetic material and research to develop locally adapted genetic material that can be produced in difficult conditions

Box 8. Bulgaria's Agricultural Academy

The Agricultural Academy is an institution that engages in scientific, applied, support and ancillary activities in the field of agriculture, helping to achieve the strategic objective of ensuring food security, preserve natural resources and improve the quality of life in Bulgaria.

The Academy's 562 scientists conduct research projects related to food security in the following areas: sustainable use of natural plant resources, animals, soil and water; reduction of the adverse impacts associated with climate change; maintenance of genetic resources and creation of new, high-yielding varieties and animal breeds that are well adapted to changing climatic and economic conditions; development of healthy foods to improve the length and quality of life; and provision of certified and quality seeds, seedlings and breeding material.

The Academy offers strong advantages for work in sustainable development: integration of all functional units of the innovation process in agriculture from idea to research product and a regional network of institutes and experimental stations engaged in scientific, applied and consultancy located geographically in all regions of the country.

Project proposals are evaluated and approved by expert councils, composed of prominent academics serving a four-year term. Projects in the selection and maintenance of genetic resources have a long-term duration and their continuity is ensured. Many of the projects result in the creation of a new research product – new varieties, new technological solutions or integrated technologies for growing different crops or breeding animals that can be directly embedded in agricultural production. Some 345 scientific products are owned by the institutes and experimental stations of the Academy that have certificates issued by the Bulgarian Patent Office. In 2016, eight new varieties of crops and two breeds received new certificates.

In 2016, the structural units of the Academy participated in 130 projects in the following areas: plant breeding (38), animal husbandry (31), soil science, agricultural technology and the protection of plants (46), food safety and quality (10) and management of agricultural production (5). These projects were funded through a budgetary subsidy provided by the Ministry of Agriculture and Food and through their own income provided by the sale of scientific products.

Source: Contribution from the Government of Bulgaria.

- Development of low-cost innovative proposals for investments
- Promotion of diversification of production systems
- Support to the development of activities that increase the value added at smallholder level[64]

[61] Adapted from a contribution from E Daño, Asia Director, Erosion, Technology and Concentration Group, the Philippines.

[62] Contribution from the Government of Bulgaria.

[63] Contribution from the Government of Thailand.

[64] These specific recommendations are from the High-level Panel of Experts on Food Security and Nutrition (HLPE).

International research institutions, such as the Consortium of International Agricultural Research Centres (CGIAR), are important for the international research agenda on food security. However, CGIAR may not necessarily be responsive to the research needs of the least developed countries (UNCTAD, 2007). Recent international discussions on the development of a new strategy and results framework for the Consortium of International Agricultural Research Centres (formerly the Consultative Group of International Agricultural Research) for the period 2016–2030 emphasize a more cross-cutting approach to research topics, due consideration of the socioeconomic dimension and overcoming the lack of integrated agricultural research for development. In this regard, collaborative research remains a challenge: In addition to leading and coordinating international agricultural research, CGIAR could potentially play a greater role as a facilitator and networker, promoting innovation platforms at strategic and international levels, particularly fostering dialogue and clarity of complex phenomena of the sector and its context (Box 9).

Box 9. A new CGIAR strategy and results framework for 2016-2030

CGIAR is a global partnership that unites organizations engaged in research for a food secure future. Research is carried out through a network of 15 research centres, known as the Consortium of International Agricultural Research Centres. These centres are spread around the globe, with most centres located in the global South. The centres are generally run in partnership with other organizations, including national and regional agricultural research institutes, civil society organizations, academia and the private sector.

In 1970, the Rockefeller Foundation proposed a worldwide network of agricultural research centres under a permanent secretariat. This was further supported and developed by the World Bank, FAO and UNDP; CGIAR was established in May 1971 to coordinate international agricultural research efforts aimed at reducing poverty and achieving food security in developing countries. CGIAR is not a formal international political or intergovernmental institution, but an ad hoc network, which receives funds from its public and private members. CGIAR played a key role in the "green revolution", placing emphasis on the development of high-yielding crop varieties that required an externally input-intensive form of production. The initial focus of research centred on the genetic improvement of staple cereals (rice, wheat and maize), later widened to include cassava, chickpea, sorghum, potatoes, millet and some other food crops, as well as livestock. Heightened international concern regarding resource scarcities and environmental challenges in the 1990s also prompted research work on the conservation of genetic resources[65], plant nutrition, water management and policy research.

International consultations are under way to develop a new CGIAR strategy and results framework for the period 2016–2030 to identify new and creative solutions to the key challenges of agriculture, rural development and nutrition:

- Agri-food systems today are not sustainable, nor do they provide healthy food for all
- Poor diets are the leading cause of ill health in the world
- There is a serious and escalating global environmental crisis affecting the agricultural sector
- Massive un(der)employment of young people in rural areas is a key challenge
- Radical and fast transformation is urgently needed to meet these daunting challenges

The consultations on the new framework propose three strategic goals as system level outcomes: reduced poverty, improved food and nutrition and security for health and improved natural resource systems and eco-system services.

Four cross-cutting themes are considered critical to attaining the new CGIAR goals: mitigating and adapting to climate change risks and shocks, ensuring gender and youth equity and inclusion, strengthening the policy and institution enabling environment and developing the capacity of national partners and beneficiaries.

Against this background, eight priority research topics are proposed for the first six years of the new framework:

- Genetic improvement of crops, livestock, fish and trees to increase productivity, resilience to stress, nutritional value and efficiency of resource use
- Use of system-based approaches to optimize economic, social and environmental co-benefits in agricultural systems in areas with a high concentration of poor people

65 CGIAR gene banks form the world's largest germplasm collections for staple food crops, providing over 90 per cent of all recorded transfers under the International Treaty on Plant Genetic Resources.

- Create opportunities for women, young people and marginalized groups to increase access to and control over resources
- Enabling policies and institutions to improve the performance of markets, enhance delivery of critical public goods and services and increase the agency and resilience of poor people
- Natural resources and eco-system services, focusing on productive eco-systems and landscapes that offer significant opportunities to reverse environmental degradation and enhance productivity
- Nutrition and health, emphasizing dietary diversity, nutritional content and safety of food, and development of value chains of particular importance for the nutrition of poor consumers
- Climate-smart agriculture, focusing on urgently needed adaptation and mitigation options for farmers and other resource users
- Nurturing diversity, ensuring that CGIAR in-trust plant genetic resources collections are safely maintained and genetically and phenotypically characterized to maximize the exploitation of these critical resources for food security, productivity, nutrient rich crops and resilient farming systems

Sources: www.cgiar.org, www.cgiarfund.org, www.consortium.cgiar.org, Renkow and Byerlee, 2010, and Thönnissen, 2016.

3.2 Enabling infrastructure for food systems

Infrastructure enables many of the scientific and technical applications that address aspects of the food system. More people having access to improved water sources and sanitation facilities, and affordable access to water may provide a means to increase the percentage of arable land equipped for irrigation. Ensuring access to affordable, reliable, sustainable and modern energy for all is also important for reducing greenhouse gas emissions while maintaining agricultural productivity. Inclusive, resilient and sustainable development within cities may help build up local markets, provide a means for people to travel to nearby markets to buy agricultural goods and open up new export and import markets. Moreover, ICTs have a critical role to play in food security in general, and with respect to the provision of extension services, insurance, finance and risk prevention in particular (Box 10).

3.3. Governing agricultural innovation and policy coherence

Sustainable agricultural development is possible if effective governance mechanisms are in place and policy coherence is fostered between sustainable agricultural development, food systems, environmental concerns, social protection, education, nutrition and health policies and programmes, as well as between their respective institutions, agencies and ministries at the national and international levels

Box 10. Employing ICTs to build farmer communities in the United Republic of Tanzania

An example of a community-building support ICT tool can be found in the Sauti ya wakulima project. The project implements a transdisciplinary methodology called ERV (enabling reciprocal voice) methodology, developed within a transdisciplinary PhD research project at the Applied University of the Arts Zurich (ZHdK) IBZ/ETHZ. The methodology is based on the usage and exchange of shared smartphones to create an audiovisual documentation of farmers' agricultural and social environments published on a collaborative web platform (Tisselli, 2016). The audiovisual documentation consists of a photo, an explanatory voice recording and a key word used to categorize the contents. These elements are enriched by geographical reference information on an interactive web-based map.

Since 2011, groups of farmers in the United Republic of Tanzania (Bagamoyo District) have participated in a proof-of-concept project. The farmers documented their coping strategies in relation to erratic weather events, pests and diseases and other aspects farmers find relevant for describing their agricultural realities. After five years, Sauti ya wakulima has been fully embraced by farmer communities and runs in an autonomous fashion, with support from the Bagamoyo Agricultural Office and the farmers themselves. A rich knowledge base of over 3,000 images and audio recordings has been created by the farmers. This knowledge base also includes a fine-grained map of local knowledge, through the interviews farmers held with people from inside and outside their communities. The local government has provided grants to the group of participating farmers, encouraging them to document farmers' shows and agricultural fairs in other towns, including the largest agricultural fair in Morogoro. The ERV methodology was upgraded in 2016 and is currently being upscaled by the Swiss development organization Swissaid to reach thousands of smallholder farmers in the food insecure Masasi region in the southern United Republic of Tanzania.

Sources: Angelika Hilbeck, Swiss Federal Institute of Technology, Institute of Integrative Biology, Zurich, Switzerland, and Eugenio Tisselli, information technology expert and freelance consultant, Barcelona, Spain.

(CFS and HLPE, 2014, 2015, 2016). Governance processes can include frameworks for agricultural intellectual property, biosafety and technology and/or risk assessment mechanisms, and multi-stakeholder forums for priority setting within the agricultural research and development system.

Policy coherence and participation require a system approach, where achieving food security is considered an encompassing task among different sectors and stakeholders, rather than as a single sectoral task. Furthermore, the governance processes related to food security and sustainable agriculture have to take into account the needs and interests of marginalized and poor disadvantaged users of common lands and pastures, water and fisheries. In particular, these are indigenous people and those whose rights are enshrined in customary arrangements. It is essential to ensure their full and effective participation in relevant decision and planning processes.

3.4 Facilitating farmer–scientist knowledge flows: Strengthening agricultural extension and human capacity

Extension services can help farmers with a range of issues, including agronomic practices, natural resource management, livestock health and management, accessing financial support and accessing markets and/or market intermediaries. A prominent example of the impact of extension services on agronomic practice is the case of Ethiopian teff farmers (teff is the national grain). Farmers traditionally broadcast their seeds (i.e. seeds manually scattered all over the field) in the belief that more seed would result in more harvest. Researchers in Ethiopia demonstrated that planting the seeds in rows (rather than broadcasting them) could improve yields 50–80 per cent, reduce the amount of seeds needed for sowing by 90 per cent, and produce teff with bigger leaves and stronger stalks (Ethiopia ATA, 2012; IFPRI, 2013; Swanson, 2006; Swanson, 2008; Buluswar et al., 2014). In another example in Western Africa, a regional programme for integrated pest management serving 30,000 farmers resulted in 75 per cent median reduction in pesticides, 23 per cent yield increases, and 41 per cent net margins (FAO, 2009; United Nations, 2015b).

3.4.1 Participatory cooperative research among farmers and scientists

Innovative forms of knowledge production and transfer are needed. Examples are community-based innovation, innovation platforms and participatory, cooperative research (box 11). Research involving smallholder farmers in the definition of research priorities and the design and execution of research according to participatory and empowering methodologies is one of the best ways to ensure that research results respond to the complex social, economic, and ecological contexts of smallholders. In order to achieve this, research systems must be more accountable to smallholders in terms of their institutional priorities, impact of their work, and funding. High-quality research and extension services can develop cooperative, context-specific research approaches for food security and nutrition (Box 11).

Box 11. Improving cotton-farming systems in Western Africa through participatory research

Approximately 2 per cent of the 2 million cotton farms in Western Africa produce for the global organic markets. The Europe Aid-financed project Syprobio (2011–2015) aimed at improving farmer-adapted, low-cost technologies with science and action research in order to cope with declining soil fertility, low yields and inappropriate seeds for small-scale organic farmers and other technical and institutional constraints. Currently, supply cannot meet the high demand for organic and fair trade, and the complexity of this commodity requires new ways of conducting agricultural research. The Syprobio project was based on the existing organic cotton value chain developed by Helvetas (a non-governmental development network located in Switzerland) since 1999 and reinforced by national (IER, INERA,[66] INRAB[67]) and international (FiBL) research organizations. With the assistance of these researchers, extensionists and market brokers, and small-scale farmers were identified to test their own innovations and technologies towards improved cereal-cotton farming.

[66] Institut de l'Environnement et des Recherches Agricoles.
[67] Institut National de Recherche Agronomique du Bénin.

Centred around these locally organized researcher-farmers, within a reach of a two-hour bicycle ride, innovation platforms (IPs) were established to promote appropriate technologies favouring the livelihood and increasing the family or household farming resilience among all other farmers. The farmers taking part in these IPs met several times per year to exchange experiences and coordinate actions. In total, 10 groups of farmers (each comprising 10 individual farmers) acted as on-farm researchers and were guided by 20 extensionists, technicians and market brokers from farmer organizations. Together with FiBL, the lead research organization, 10–20 researchers from national research institutes accompanied the on-farm tests and conducted parallel on-station trials to confirm findings.

The project office of FiBL coordinated the activities and communication. The main actors remained the 100 elected farmer-researchers, of which 40 per cent were women who reported directly to their over 2,500 colleagues across multiple villages. All IPs are connected at national level to promote the democratic model of generating sustainable innovations through participatory research. The platforms adopted innovation as a systemic and dynamic institutional or social learning process after the researchers could confirm the viability of each technology. It was recognized that innovation could emerge from various sources (science or indigenous knowledge or else), complex interactions and knowledge flows. The creativity, determination and curiosity of the farmer groups, embedded in a supportive research network and existing value chains, allowed fast identification of innovations to be tested and applied, and local resources to be used and experimented at field level.

The main challenges lay in communication, cost reduction for field visits by researchers, and institutional stability and durability (research, farmer organizations and markets). The participatory approach at the centre of the research method materialized through IP social learning among the involved stakeholders. Farmers' capacities to analyse and make decisions were improved. The best performing technologies that were identified and developed in this setting were new biopesticides, maize and sorghum seeds adapted to organic farming, and improved ways of producing and applying compost and better associations of crops within the rotation. Each technology alone has the potential to increase the yields by over 10 per cent, while applying combinations of various technologies could increase yields by more than 30 per cent.

Source: Gian L. Nicolay, FiBL

3.4.2 Information and communications technologies for extension services

ICTs can improve the quality, reach and efficiency of extension services. For example, a pilot trial of the Avaaj Otal mobile agricultural advisory services for Gujarat-based cotton farmers reduced distribution costs from $8.5 to $1.13 per farmer per month (UNCTAD, 2015). The potential benefits of ICTs do not necessarily depend on the sophistication of the ICT device, with deployments involving mobile phones, locally produced how-to videos for farmers and participatory radio campaigns. For example, Access Agriculture is an online platform that showcases high-quality agricultural training videos translated into 74 local languages for farmer-to-farmer capacity-building.[68] The non-governmental organization Digital Green trains farmers in remote locations – such as Narma Dih in Bihar, India – with locally produced how-to videos (World Bank, 2016). Similarly, participatory radio campaigns allow farmers to exchange knowledge and experiences about their agricultural practices. Randomized control trials of 25 radio stations in five countries demonstrated that farmers listened to such radio programmes, that agricultural knowledge was acquired and that such knowledge translated into improved agricultural practices (Farm Radio International, 2011).[69]

3.4.3 Sharing plant genetic resources

Public investment in breeding programmes and support for local seed systems that allow the diffusion of locally adapted genetic material, which farmers would have the right to freely save, exchange and market, is a good example of the need for public investment in research and technology diffusion (CFS and HLPE, 2013).[70] Examples of seed bank programmes include the Portuguese national gene bank (Box 12) and the Navdanya network of seed keepers and organic producers spread across 18 states in India.[71]

[68] Contribution from the Swiss Agency for Development and Cooperation.

[69] The Government of Canada also provided information on their support of Farm Radio International for farmer value-chain development.

[70] Finding proposed by the Governments of Chile and Peru.

[71] Contribution from the United Nations Major Group for Children and Youth.

Box 12. Portuguese information system for plant genetic resources[72]

On 13 February 2015, the Banco Português de Germoplasma Vegetal – the Portuguese national gene bank – officially launched a new information system to manage their precious collection of plant genetic resources. The collection has a strategic importance for food security at the national and global levels. Located in Braga, Portugal, it includes 45,000 samples from 150 species and 90 genus of cereals, aromatic and medicinal plants, fibres, forages and pasture, horticultural crops and other species.

The new system is based on GRIN-Global, a free platform developed in a joint effort by the Global Crop Diversity Trust, the Agricultural Research Service of the United States Department of Agriculture and Bioversity International. The full collection of plant genetic resources and the associated knowledge conserved at the Banco Português de Germoplasma Vegetal is now managed by a powerful and efficient system and, for the first time, the information will be available online for public consultation.

Since 2011, Bioversity International has been working with the Portuguese gene bank to implement and evaluate the system, strengthening the capacity of staff to use the system along the way. The lessons learned from this process are crucial for the deployment, adoption and implementation of GRIN-Global in other countries and regions. The goal of GRIN-Global is to provide the world's crop gene banks with a powerful, flexible, easy-to-use global plant genetic resource information management system that will allow gene banks around the world to permanently safeguard plant genetic resources vital to global food security, and to encourage the use of these resources by researchers, breeders and farmers.

3.5 Making innovative food systems gender-sensitive

Women account for a significant and growing share of the workforce in agriculture worldwide (Agarwal, 2012). They comprise about 43 per cent of the agricultural labour force in developing countries and 50 per cent of the agricultural labour force in the least developed countries (FAO, 2011a; UNCTAD, 2015d). Despite their prominent role in food production and processing, women typically have limited access to resources (for example, technology, training, education, information, credit, and land) to increase their output and are often excluded from decision-making processes in managing water and other natural resources (UNCTAD, 2011; FAO, 2010; UIS, 2010; Huyer et al., 2005; Meinzen-Dick et al., 2010; Carr and Hartl, 2010). Promoting community-driven approaches to the development of new farming technologies and crop diversification can benefit women and smallholder farmers more generally. Extension services can consciously account for gender roles in agricultural and rural development, including through the recruitment of female extension workers (Wakhungu, 2010; Carr and Hartl, 2010; Christoplos, 2010). Furthermore, more emphasis should be placed on encouraging women to become involved in agricultural science and extension (UNESCO, 2007; AAUW, 2010).

CHAPTER 4. POLICY CONSIDERATIONS

While science can play a key role in developing adapted technologies, STI in support of context specific needs of smallholder farmers and beyond the production remains essential. The Sustainable Development Goals lay the groundwork and pave the way for further development. The process can be accelerated not only through scientific and social approaches but also by appropriate laws and policies. A number of policy considerations could potentially assist countries in their efforts to harness science and technology for food security and build agricultural innovation systems as part of broader agriculture-led strategies for sustainable development.

4.1 Increase investments in agricultural R&D at the global and national levels

National and global R&D for agricultural development can tangibly impact productivity and the quality of inputs. The constantly changing ecological, environmental, and biodiversity contexts requires continuous research and development to produce inputs and disseminate knowledge that maximizes agricultural yields while safeguarding the environment. China's government-sponsored R&D, which increased 5.5 per cent annually between 1995 and 2000 and 15 per cent annually after 2000, was considered key to the adoption of advanced technologies by poor farmers (UNCTAD, 2015b). Globally, it has been estimated by FAO, IFAD and WFP that eradicating hunger by 2030 will require an additional $267 billion annually (United Nations, 2015b; FAO et al., 2015). Based on estimates of

[72] Contribution from the Government of Portugal.

the United Nations Environment Programme green economy models, 0.16 per cent of global GDP devoted to sustainable agriculture per year ($198 billion between 2011 and 2050) could provide significant returns (United Nations, 2015b).

4.2 Promote sustainable food systems

STI for achieving food security in the context of the 2030 agenda should be put into a three-pronged context of a sustainable food system: the socioeconomic dimension, mainly understood as a reduction of poverty and (socioeconomic and gender) inequality, particularly in rural areas; the environmental dimension, focusing primarily on environmental integrity and the reproductive capacity of the agro-ecological system; and the resilience dimension, emphasizing social and ecological resilience. Governments should ensure a balanced and system-focused approach to the production of food, feed and fibre, so that food security, poverty eradication and sustainable resource use can be achieved, while strengthening the resilience of the agro-food system. This means in particular that food security does not only relate to improvements in production and supply, but also to changes in consumption and demand.

Agriculture should be reoriented around ecological practices, whether the starting point is highly industrialized agriculture or subsistence farming in the world's poorest countries. Environmental change, mainly climate change, and economic change have an impact on all dimensions of food security, not only agricultural production. In order to achieve Goal 2, locally adapted, context-specific pathways to sustainable agricultural development for food security, including adaptation strategies and coping mechanisms, are needed. For example, the Swiss Federal Office for Agriculture is co-leader of the Sustainable Food Systems Programme of the 10-year Framework for Programmes on Sustainable Consumption and Production Patterns,[73] a multi-stakeholder initiative to accelerate the shift towards more sustainable food systems that deliver food security and nutrition for present and future generations.[74]

4.3 Encourage development of science, technology, and innovation applications on key food security challenges

There are broader topics that should play a role when planning and implementing STI related to food security. They should be addressed by developed and developing countries and at all levels, from international cooperation down to communities. Not every topic will be of similar relevance in all cases, but their importance and interaction is decisive in achieving the goal of completely eradicating hunger and malnutrition by 2030 in a truly sustainable way.

- Role of fertile soils and soil protection. It should always be ensured that loss of soils is halted and soil fertility is conserved or increased. This may be achieved by amending any monitoring plan for STI project performance by a small number of key soil fertility and soil protection indicators that are easy to measure and most adequate for a given context, as well as by a number of concrete management changes to be implemented in case soil protection indicators point to deteriorating situations.

- Adaptation to climate change. Planning and performance assessments of STI should always refer to a number of climate change adaptation indicators, covering overall projections on expected change in climatic and weather patterns in the coming years, in particular water availability and temperatures, but also extreme events. When production conditions become adverse, some assessment of potential alternative livelihood sources should be undertaken at an early stage.

- Support agro-ecological, low external input and extensive production systems. STI for agro-ecological, low external input and extensive production systems play a crucial role for achieving food security. Such systems tend to increase diversity and resilience of agricultural production systems, thus contributing to a reliable standard of living, particularly for smallholder farmers and agricultural labourers. Such systems in particular support biodiversity, whose loss is a major challenge for the future productivity, sustainability and resilience of the food system. In particular, functional biodiversity plays an extraordinary role in the wider use of agro-ecological production and eco-functional intensification approaches, which should be reflected in STI approaches.

- Breeding programmes on orphan crops. Breeding programmes on orphan crops need to be developed, adequately differentiated for country- and region-specific preferences and needs.

[73] Commonly known as the 10YFP Sustainable Food Systems Programme.

[74] Contribution from the Government of Switzerland.

Participatory approaches and ensuring farmer's rights for further breeding and seed production, for example, are necessary for the success of such programmes. These programmes need considerable funding and coordination, which should be taken over by most suited institutions for this.

4.4 Support policy coherence for food security

Policies from the local to the global level should support the transition towards sustainable food and farming systems in a coherent and targeted way. Policymakers should promote an adaptive system thinking and management approach due to the fact, that a variety of environmental factors, farming systems, market actors and consumption patterns are systemically interrelated and connected to food security. For instance, waste is generated at all stages of the life cycle, from production to consumption. Policies related to food waste and loss reduction are tantamount to an increased production volume being made available for consumption with the added advantage of zero additional ecological impact. Another example are food policies to support healthy and sustainable diets, urban–rural linkages and local food processing and value generation. Furthermore, as mentioned in the first chapter, the links between agricultural and environmental change are extensive and may require an integrated policy approach (World Bank, 2008). If food security is considered to be a critical component of a broader innovation-driven development agenda and supported by the highest levels of Government, sufficient political will can exist to facilitate interministerial and intersectoral coordination and collaboration.[75] The e-agriculture strategy guide and toolkit, jointly prepared by FAO and the International Telecommunication Union, demonstrates potential synergies among ICT and agriculture ministries.[76]

4.5 Improve extension services and the farmer–scientist interface

It is important to better align farmer needs (e.g. women and young farmers), research methods of national agricultural research stations and universities, and policies at the national level in order to create functioning institutions dealing with technology development in a sustainable and reliable way with a long-term perspective. In addition, the governance processes related to food security and sustainable agriculture should take into account the needs and interests of marginalized and poor disadvantaged users of common lands and pastures, water, and fisheries (see section 3.4.1). In particular, these are indigenous people and those whose rights are enshrined in customary arrangements. It is essential to ensure their full and effective participation in relevant decision and planning processes. There is a strong need for stepping up the current agricultural extension services, but also education and access to information and knowledge related to food production and nutrition in general to break the vicious circle of "poor research and extension for poor farmers".

The potential of stakeholder participation and cooperation for the development of locally adapted research and development strategies could improve agricultural production and sustainable consumption. There is an urgent need to increase investment in research and advisory extension services that are coherent with models of productions adapted to smallholder farmers' needs. Research must address a more complex set of objectives: on the one hand, the new challenges (i.e. climate change, renewable energy and energy efficiency, biodiversity and resource management), and, on the other hand, the old challenges (productivity growth and production quality) as well as promotion of diversification. The key message is to break the vicious circle of "poor research and extension for poor farmers" (CFS and HLPE, 2013). A key policy consideration is to promote the proper funding of extension services from government funds.

Participatory development could also be enhanced with the utilization of ICTs, big data and related new developments (for example, drones, three-dimensional printers and remote sensing). One example would be to utilize remote sensing and big data to support site-specific precision farming (i.e. more efficient use of resources and inputs) and crop planning for eco-functional intensification approaches. Extension services with the use of mobile phones are already being explored in a range of projects, but there needs to be a somewhat coordinated approach towards these issues. It is important to make available options such as specific applications that are widely known; for this, a number of key websites as entry-points to these services should be set up by institutions with a long-term

[75] An example of food security policy is the SAN CELAC Plan of Costa Rica for Food Security, Nutrition, and Hunger Eradication, an input from the Government of Costa Rica.

[76] Contribution from the International Telecommunication Union; see http://www.fao.org/3/a-i5564e.pdf (accessed 21 February 2017).

commitment to host those sites, to keep them up to date and operational with a changing context of further soft- and hardware developments. FAO and CGIAR centres may play a coordinating role in this regard. However, attention must be paid to issues of privacy, security, and data ownership and access.

4.6 Improve access to agricultural technologies and data for smallholder farmers

New and existing United Nations mechanisms for technology transfer, facilitation, and dissemination, such as the United Nations Technology Facilitation Mechanism and the United Nations Technology Bank should continue to promote the sharing of key agricultural technologies, especially for smallholder farmers. Such initiatives should consider how its work contributes to developing countries and the least developed countries to access emerging technologies that increase yields, mitigate on-farm and off-farm losses, and broadly promote sustainable agriculture. Foundations, non-profit organizations and civil society organizations that help facilitate access to proprietary agricultural technologies (e.g. African Agricultural Technology Foundation) should continue to strengthen their efforts, especially in light of the imperative for sustainable food production. Countries should also consider that technology transfer can happen in a number of directions, including North–North, North–South and South–South. Irrigation technologies such as the treadle pump developed in Bangladesh in the 1980s are widely used in Africa today.

Beyond the transfer of technologies, institutions and mechanisms within and outside the United Nations system should consider how to make available data relating to agriculture meteorology, the Internet of things, satellites and other data that could help optimize yields and support rural livelihoods. Civil society and non-profit organizations such as GODAN[77] and others are encouraged to continue and strengthen their work even as more forms of data collected both passively and actively can potentially inform agricultural practices.

4.7 Build human capacity for agricultural innovation

The establishment of new education and research programmes and institutions can help create a knowledge base and pool of experts to develop the capacity to innovate within agriculture. For example, the Cuban Institute for Fundamental Research in Tropical Agriculture not only conducts scientific research but also trains talent from Cuba and from other countries, including developing countries.[78] Talent-building efforts may include targeted master's programmes at existing applied and research universities, as well as at new university institutes, departments and curricula.[79] This requires significant funds and a long-term commitment. FAO and CGIAR centres, in close collaboration with national agricultural research institutions, could potentially support and coordinate such efforts.

4.8 Collaborate with international partners to harness science, technology, and innovation for food security

Knowledge aid can be a tool for providing STI support as part of official development assistance. This can occur in the agricultural sector where donors can contribute to agricultural research, especially in the least developed countries. With respect to stimulating industry and infrastructure, knowledge aid as part of official development assistance can focus on value-chain development schemes, foreign direct investment complementation and linkage development, project funding for industrial and physical infrastructure, the promotion of global engineering associations and non-governmental organizations, and the facilitation of South-South collaboration.[80] Regional cooperation can achieve economies of scale to address research priorities for a specific region, as demonstrated by the work of the Forum for Agricultural Research in Africa, the Latin American Fund for Irrigated Rice, and FONTAGRO, the Regional Fund for Agricultural Technology for Latin America and the Caribbean (World Bank, 2008).

Funding from international cooperation activities can also be a potential source of funding for developing countries. For example, the United States National Institutes of Health, the European Union Framework Programme, and the Canada Grand Challenges programme earmark funding for collaboration

[77] Global Open Data for Agriculture and Nutrition: www.godan.info.

[78] Contribution from the Government of Cuba.

[79] The international Master curriculum "Safety in the Food Chain" (www.safetyinthefoodchain.com) is a potential model for agricultural education, provided as input by the Government of Austria.

[80] UNCTAD, The Least Developed Countries Report 2007: Knowledge, Technological Learning and Innovation for Development, Sales No. E.07.II.D.8 (Geneva: United Nations publication, 2007), pp. 161-180 http://unctad.org/en/pages/aldc/Least%20Developed%20Countries/The-Least-Developed-Countries-Report.aspx.

with scientists from Africa. In this context, they recommend that research institutes and universities increase their applications to international research tenders, possibly in partnership with the private sector. Funding from Governments, foundations and other international entities (e.g. CGIAR) could fund local researchers and innovators.[81]

4.9 Strengthen the enabling environment for agriculture and food security

Roads, electricity, cold storage and agro-processing facilities, information and communications technologies, sanitation and other forms of infrastructure enable the innovations that improve the quantity and quality of agricultural production. Strengthening innovative food systems should include increasing public investment in high-quality research and advisory extension services that are coherent with agro-ecological production systems adapted to smallholder farmers' needs.

Countries may consider encouraging entrepreneurship based on agricultural innovations. For example, the Government of Pakistan supported the creation of an indigenous tractor industry that currently meets 95 per cent of local demand. Public and private efforts helped build local manufacturing capabilities.[82] Similarly, the recently launched Food Innovation Network of the United Kingdom of Great Britain and Northern Ireland aims to tackle the issues that are currently impeding innovation, productivity and growth in agri-food and drink businesses in that country.[83]

Other measures include strengthening knowledge and extension links among the scientific community, rural producers' organizations and NGOs; facilitating technology transfer, especially with the use of non-proprietary genetic material and research to develop locally adapted genetic material that can produce in difficult conditions; diversifying production systems; supporting the development of activities that increase the value added at smallholder level; and promoting activities that result in keeping downstream value chain activities in the production countries, thus working towards exporting processed commodities rather than primary products.

[81] UNCTAD, "Science, Technology and Innovation Policy Review - Ghana," (New York and Geneva: United Nations, 2011), 7, 9-10.

[82] Contribution from the Government of Pakistan.

[83] Contribution from the Government of the United Kingdom.

APPENDIX

Box 1 The four dimensions of food security

Dimension 1. Food availability

- Average dietary energy supply adequacy
- Average value of food production
- Share of dietary energy supply derived from cereals, roots and tubers
- Average protein supply
- Average supply of protein of animal origin

Dimension 2. Food access

- Percentage of paved roads over total roads
- Road density
- Rail lines density
- Gross domestic product per capital (in PPE)
- Domestic food price index
- Prevalence of undernourishment
- Share of food expenditure of the poor
- Depth of food deficit
- Prevalence of food inadequacy

Dimension 3. Food stability

- Cereal import dependency ration
- Percentage of arable land equipped for irrigation
- Value of food imports over total merchandise exports
- Political stability and absence of violence/terrorism
- Domestic food price volatility
- Per capita production variability
- Per capita food supply variability

Dimension 4. Food use/utilization

- Access to improved water source
- Access to improved sanitation facilities
- Percentage of children under 5 years of age affected by wasting
- Percentage of children under 5 years of age who are stunted
- Percentage of children under 5 years of age who are underweight
- Prevalence of adults who are underweight
- Percentage of anaemia among pregnant women
- Prevalence of anaemia among children under 5 years of age
- Prevalence of vitamin A deficiency in the population
- Prevalence of school-age children (6–12 years) with insufficient iodine intake

Source: FAO, 2016.

Box 2 Sustainable Development Goals and food security

Goal 1 addresses poverty. It calls for an end to poverty in all its manifestations by 2030. It also aims to ensure social protection for the poor and vulnerable, increase access to basic services and support people harmed by climate-related extreme events and other economic, social and environmental shocks and disasters.

Goal 2 is aimed at ending hunger and ensuring access by all people, in particular the poor and people in vulnerable situations, including infants, to safe, nutritious and sufficient food all year round. The first step is double the agricultural productivity with resilient agricultural practices. Goals 1 and 2 cover most of the relevant aspects of food security. Correct and prevent trade restrictions and distortions in world agricultural markets, including through the parallel elimination of all forms of agricultural export subsidies and all export measures with equivalent effect, in accordance with the mandate of the Doha Development Round. The target of Goal 2 is to "adopt measures to ensure the proper functioning of food commodity markets and their derivatives and facilitate timely access to market information, including on food reserves, in order to help limit extreme food price volatility".

The target of **Goal 3** is to ensure healthy lives and promote well-being for all at all ages. It focuses on how to reduce mortality ratios and the incidence of diseases prevented. Target 3.3 directly acknowledges the relationship between waterborne diseases and deaths and aims to reduce them. This may help to foster the investments into improved water sources and is thus in line with the food security dimension of use/utilization to provide access to improved water sources.

Goal 4, to ensure inclusive and equitable quality education and promote lifelong learning opportunities for all, is not explicitly related to the four dimensions of food security. However, one of the potential influences of achieving the targets from this goal may be that youth and adults receive technical training (target 4.4) and the knowledge and skills to promote a sustainable development (target 4.7).

Similarly, **Goal 5**, which aims to achieve gender equality and empower all women and girls, may help to increase food availability, stability and use/utilization by ensuring that discrimination against women and girls is ended (target 5.1), that violence against them is eliminated (target 5.2) and that they receive access to sexual and reproductive health and reproductive rights (target 5.6).

By acknowledging these targets, women and girls may receive the chance to be become more actively integrated into the food production chain and their economic profitability may increase. Concerning technology and innovation, it has to be taken into account that mostly women are involved in fruit, vegetable, protein crops and cereal production and need appropriate tools and access to information.

Goal 6, which aims to ensure the availability and sustainable management of water and sanitation for all, may help to achieve food stability and food use/utilization indicators of the food security dimensions. Targets 6.1/6.2 and 6.a deal with the access to, improvement of and investments in safe and affordable water and sanitation structures. Achieving these targets is likely to facilitate access of more people to improved water sources and sanitation facilities (food security use/utilization dimension); furthermore, affordable access to water (target 6.a) may provide a means to increase the percentage of arable land equipped for irrigation (food security stability dimension).

Goal 7 aims at to ensuring access to affordable, reliable, sustainable and modern energy for all. The agricultural sector is one the fossil fuel intensive production systems, which currently emits 13% of global GHG emissions (IPCCC). In order to ensure long-term sustainability, it is unavoidable that GHG emissions from this sector be reduced, while productivity is maintained.

Goal 8, which is about promoting sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all ,may help to increase these investments. Target 8.2, to achieve higher economic productivity through diversification, technological upgrading and innovation, may directly help to increase the average value of food production (food availability indicator).

Goal 9, to build resilient infrastructures, promote inclusive and sustainable industrialization and foster innovation, mainly covers the aspects of food availability and access. It highlights the necessity to promote investments into infrastructures/research/technology and innovation, which will help ensure that more people will have sufficient availability of food. Additionally, target 9.3, to increase the access to affordable credits, may provide a means to invest in rural and agricultural structures and/or to build new agricultural cooperation. Targets 9.1/9.2/9.4 and 9.a aim to increase the share of resilient infrastructures, particularly in developing countries, where food security continues to be limited to some extent by sole access to food and its markets.

Goal 10. As mentioned previously, one dimension of food security deals with political stability and the absence of violence/terrorism. This may be influenced by target 10.2, to empower and promote the social, economic and political inclusion of all.

While **Goal 11** mainly concentrates on the inclusive, safe, resilient and sustainable development within cities, one of the targets may help to promote the food security dimension of food access. Target 11.2 aims to promote transportation systems, which comes with the development of roads and railways. If those become implemented and extended, in particular within developing countries, food access may increase, as transportation of agricultural goods become easier in some remote areas as currently.

This may help to build up local markets or provide a means for people to travel more comfortably to the nearby markets to buy agricultural goods. Further, the investments in infrastructures may open up new export/import markets and thus help to increase the amount of available food.

Goal 12. One of the developed food security concepts within the Goals, in comparison with the four dimensions, is the integration of the global food waste challenge. Target 12.3 obliges the global society to halve per capita global food waste. This may help to increase the amount of available food, in particular for the poor. However, the consideration of food waste and thus the question of how the produced food is used within the Goals may help to achieve food security in the long run.

Goal 13 aims to reduce climate change, while adapting the different sectors to the impacts. The integration of climate change into the context of food security is essential to ensure long-term sustainability.

Goal 14 aims to conserve and sustainably use the oceans, seas and marine resources and therefore has an influence on the food security dimensions of food availability, access, stability and use/utilization.

Goal 15 aims to protect, restore and promote the sustainable use of terrestrial ecosystems. It may also have an impact on the food security indicator of the access to improved water sources. Through the protection, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services (target 15.1), the quality and quantity of water sources may improve; therefore, more people, particularly in rural areas, may use natural bodies of water more safely as water sources (food use/utilization).

Goal 16 aims to promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable institutions at all levels.

Additionally, Goal 16, to promote peaceful and inclusive societies, may influence the food security dimensions of food access (by the reduction of violent conflicts road infrastructures are less harmed) and food stability.

Goal 17 aims to strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development; it may have an impact on the four dimensions of food security through investments in agriculture and access to science, technology, and innovation appropriate for addressing food security.

Table 1 Relationship between the four dimensions of food security and the Sustainable Development Goals

	Availability	Access	Stability	Use/ utilization
Goal 1: no poverty		X		X
Goal 2: zero hunger	X	X	X	X
Goal 3: good health and well-being				X
Goal 4: quality education			X	
Goal 5: gender equality	X	X	X	X
Goal 6: clean water and sanitation			X	X
Goal 7: affordable and clean energy	X	X	X	X
Goal 8: decent work and economic growth	X	X		
Goal 9: industry, innovation and infrastructure	X	X		
Goal 10: reduced inequalities		X	X	
Goal 11: sustainable cities and communities		X		
Goal 12: sustainable production and consumption	X			X
Goal 13: climate action	X		X	
Goal 14: life below water	X	X	X	X
Goal 15: life on land				X
Goal 16: peace, justice and strong institutions	X	X	X	
Goal 17: partnerships for the Goals				

Note: X indicates coverage of the respective dimension of food security by the relevant Sustainable Development Goal.

Table 2. Sustainable Development Goal targets related to Goal 2: End hunger with a relation to science, technology and innovation

	STI to measure improvement	STI needed to achieve improvement	STI related to access to knowledge sharing and access to technologies	STI related to policy and governance	STI related to the financial and economic sector	STI related to social processes and innovations
Task Goal 2: End hunger, achieve food security and improved nutrition and promote sustainable agriculture						
Task 2.1 End hunger and ensure access to nutritious and sufficient food all year round	X	X	!	!	!	!
Task 2.2 End all forms of malnutrition	X	X	!	!	!	!
Task 2.3 Double agricultural productivity and incomes of small-scale food producers	X	X	X	!	!	!
Task 2.4 Ensure sustainable food production systems and implement resilient agricultural practices	X	X	!	!	!	!
Task 2.5 Maintain diversity of seeds and animals	X	X	X	!	!	!
Task 2.a Increase investment in agricultural research, extension services and technology development	X	X	X	!		
Task 2.b Correct and prevent trade restrictions	X	X	!	!	!	!
Task 2.c Ensure functioning of food commodity markets and limit extreme food price volatility	X	X		!	!	!
Task Goal 6						
Task 6.1 Universal and equitable access to safe and affordable drinking water	X	X		!	!	!
Task 6.4 Increase water-use efficiency across all sectors and	X	X		!	!	!
Task 6.b Support and strengthen the participation of local communities in improving water and sanitation management	X	X	!			!
Task Goal 9						
Task 9.b Support domestic STI for e.g. industrial diversification and value addition to commodities	X	X	X			
Task Goal 12						
Task 12.2 By 2030, achieve the sustainable management and efficient use of natural resources	X	X	!	!	!	!
Task 12.3 Halve per capita global food waste at the retail and consumer levels and reduce food losses including post-harvest losses	X	X	!	!	!	!
Task Goal 13						
Task Goal 13.1 Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries	X	X	!	!	!	!
Tasks Goal 17						
Task 17.6 Enhance North-South, South-South and triangular regional and international cooperation on and access to science, technology and innovation and enhance knowledge sharing on mutually agreed terms, including through improved coordination among existing mechanisms, in particular at the United Nations level, and through a global technology facilitation mechanism	X	X	!			

Note: X means addressed STI directly or indirectly through quantitative targets in the relevant Sustainable Development Goal.
!: STI not addressed in the SDG.

GLOSSARY

Food insecurity	A situation that exists when people lack secure access to sufficient amounts of safe and nutritious food for normal growth and development and an active and healthy life. It may be caused by the unavailability of food, insufficient purchasing power, inappropriate distribution or inadequate use of food at the household level. Food insecurity may be chronic, seasonal or transitory (SOFI, 2015)
Food security	A situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life. Based on this definition, four food security dimensions can be identified: food availability, economic and physical access to food, food use/utilization and stability over time (SOFI, 2015)
Hunger	"The term hunger is used as being synonymous with chronic undernourishment." (http://www.fao.org/hunger/glossary/en/)
Malnutrition	An abnormal physiological condition caused by inadequate, unbalanced or excessive consumption of macronutrients and/or micronutrients. Malnutrition includes undernutrition and overnutrition, as well as micronutrient deficiencies. (http://www.fao.org/hunger/glossary/en/)
Macronutrients	In this document, this means the proteins, carbohydrates and fats that are available to be used for energy. They are measured in grams (FAO et al., 2015).
Micronutrients	Vitamins, minerals and certain other substances that are required by the body in small amounts. They are measured in milligrams or micrograms (FAO et al., 2015).
Undernourishment	"Undernourishment means that a person is not able to acquire enough food to meet the daily minimum dietary energy requirements, over a period of one year. FAO defines hunger as being synonymous with chronic (lasting for at least one year) undernourishment." (FAO, 2016c)
Undernutrition	"The outcome of undernourishment, and/or poor absorption and/or poor biological use of nutrients consumed as a result of repeated infectious disease. It includes being underweight for one's age, too short for one's age (stunted), dangerously thin for one's height (wasted) and deficient in vitamins and minerals (micronutrient malnutrition)." (http://www.fao.org/hunger/glossary/en/)

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