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Issues Paper

On

The role of science, technology and innovation in ensuring food security by 2030

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Acronyms and abbreviations

CFS	Committee on World Food Security
GHG	Greenhouse Gas
HLPE	High Level Panel of Experts on Food Security and Nutrition
IFAD	International Fund for Agricultural Development
IPES	International Panel of Experts on Sustainable Food Systems
MDG	Millennium Development Goal
NGO	Non-governmental Organization
SDG	Sustainable Development Goal
UN	United Nations
UNCTAD	UN Conference on Trade and Development
UNDP	UN Development Programme
UNESCO	UN Educational, Scientific and Cultural Organisation
WFP	World Food Program
WRI	World Resources Institute

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Introduction

"The future of humanity and our planet lies in our hands. It lies also in the hands of today's younger generation who will pass the torch to future generations. We have mapped the road to sustainable development; it will be for all of us to ensure that the journey is successful and its gains irreversible." (UN, 2015): A call for action to change our world (Art. 53).

In its resolution E/RES/2016/23, the Economic and Social Council encouraged the CSTD to "help to articulate the important role of information and communications technologies and science, technology and innovation as enablers in the 2030 Agenda by acting as a forum for strategic planning and providing foresight about critical trends in science, technology and innovation in key sectors of the economy and drawing attention to emerging and disruptive technologies."

The United Nations (UN) Commission on Science and Technology for Development (CSTD), during its 19th session held in May 2016, selected "The role of science, technology and innovation in ensuring food security by 2030" as one of its two priority themes for the 2016-2017 inter-sessional period.

This draft Issues Paper has been prepared by the UNCTAD Secretariat, as a contribution to the work of the Commission in its Inter-sessional Panel, in order to identify, analyze and present for discussion key issues concerning the role of science, technology, and innovation in ensuring food security by 2030, particularly in developing countries.

The paper is structured in 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 articulates 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 via the four dimensions *(i)* food availability, *(ii)* access to food, *(iii)* food utilization and *(iv)* food stability (FAO, 2016a).[2] These dimensions build the overall framework of the FAO definition that *"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 (Table 2 in the Appendix).

In addition to the obvious 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 the hunger is overcome. Even temporary 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 to achieve "zero hunger."

1.2 The Geography of Food Insecurity

When considering the developments throughout the last decades and the recent statistics, worldwide about 795 million people, or every ninth person, is undernourished, among them 90 million of children under five years (FAO, IFAD&WFP 2015). The vast majority of them (780 million people) live in the developing regions, in particular in African and Asian countries. 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, i.e. one in four people (FAO et al., 2015). While the hunger rate (i.e. the share of undernourished in total population) has fallen in the region, the number of undernourished people increased by 44 million since 1990 due to population growth. In absolute terms, the number of people exposed to food insecurity is the highest in South Asia, with 281 million undernourished people (FAO, IFAD&WFP 2015).[3]

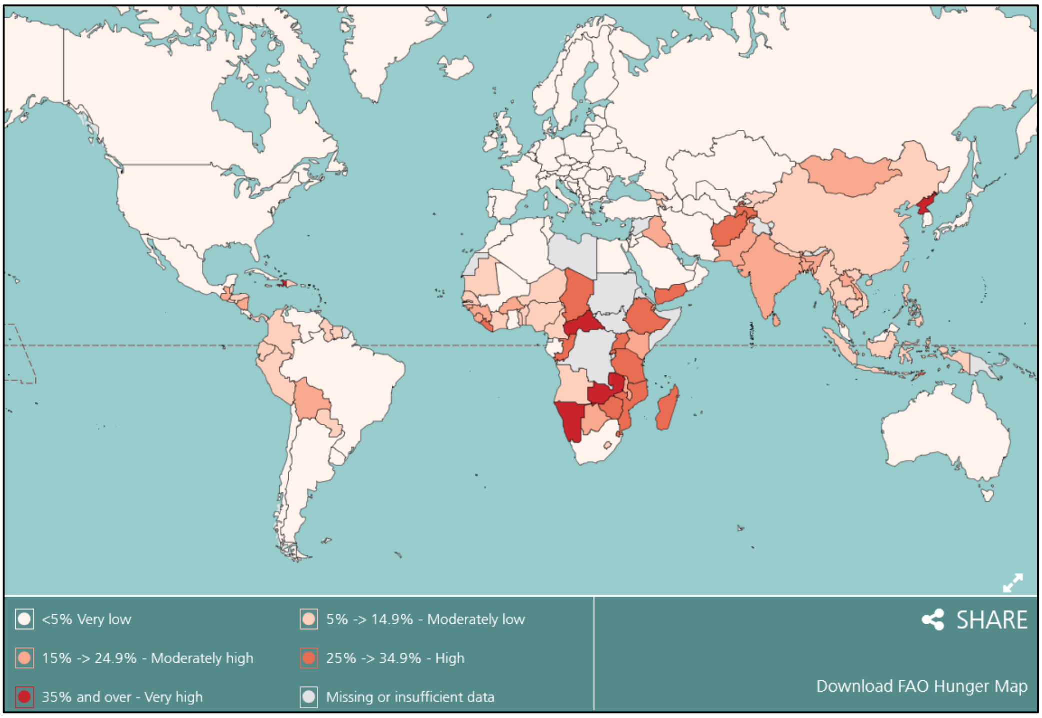
[2] Those dimensions have been identified by an expert meeting at the FAO that had the task to develop indicators that allow to measure food security globally (FAO, 2016a).

[3] 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 reduced significantly from 23.3% to 12.9%. 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 quite 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 of 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. For the calculation of the undernourishment figures 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 basis for the calculation – some 2,020 kcal per day – the number of undernourished people would have been 55% higher in 2011-2013 (GLS Treuhand, 2013 and FAO Food security methodology).

1.3 The Importance of Smallholder Farmers in Food Security

Across all countries, those who live in rural areas are the most exposed to food insecurity, due to limited access to food and financial resources (FAO, IFAD&WFP 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, fishermen and gatherers. The remaining 20 per cent live in the periphery of urban centers in developing countries. The demographics of hunger are tightly coupled with the demographics of poverty, where approximately 70% 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).

Figure 1: Number and proportion of undernourished people in developing regions from 1990/1992 – 2014/2016 (projection)



Source: UN 2015

The importance of smallholder farms was backed up by FAO in 2015, stating that more than 90 percent of the 570 million farms worldwide are managed by an individual or a family, relying predominately on family labor. In Asia and Sub-Saharan Africa, these farms produce more than 80 percent of the food. 84 percent of family farms are smaller than 2 hectares and manage only 12 percent of all agricultural land (FAO 2015b). Given the structural change towards large-scale farms in developed countries, where the labor force in agriculture 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 labor-intensive agro-ecological production methods that rely on eco-functional intensification. Thus, the role of smallholder farms in food security remains key, for sure till 2030, while for a longer-term horizon their role may change depending on structural change.[4]

1.4 What are the challenges of food security?

FAO, IFAD and WFP (2015) identified differences in progress not only among individual countries but also across regions and sub-regions. This section will cover, among other factors, the importance of economic and environmental change in exacerbating the global challenge of food insecurity.[5]

<u>1.4.1 Agriculture, Economic Development, and International Trade</u>

Economic development is a key success factor for reducing undernourishment, but it has to be inclusive and provide opportunities for improving the livelihoods of the poor. FAO, IFAD & WFP (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 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, including: 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 for bringing the production and supply of agri-food products at national level in concordance with demand for them. In addition, it is possible to realize absolute and relative comparative cost advantages through trade. Those may improve the livelihoods of the 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' situation (e.g., in case products from other producers reach the markets with lower costs). Relevant for international trade rules is the World Trade Organisation (WTO), and the related bilateral,

[4] Structural change is desirable and 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.

[5] 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, esp. 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 an increased number of 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 Program (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 mountain 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 percent of the 2012 mountain population (FAO 2015a).

regional and plurilateral liberalization agreements (outside of WTO). Both have an impact on agricultural production, trade and consumption.

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

1.4.2 Environmental Change and Agriculture

Growing demand for food is one key driver of global environment change. FAO statistics show that maximizing food production through intensifying production 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 happened in tandem with a 5-fold increase in the global use of fertilizers (UNCTAD, Trade and Environment Review 2013a). Furthermore, biomass production (food, feed, fiber, energy) for developed countries has become a driver for environmental pressures, competition for land and nutrients in supply regions whereas overconsumption and eutrophication of ecosystems occur in importing regions.

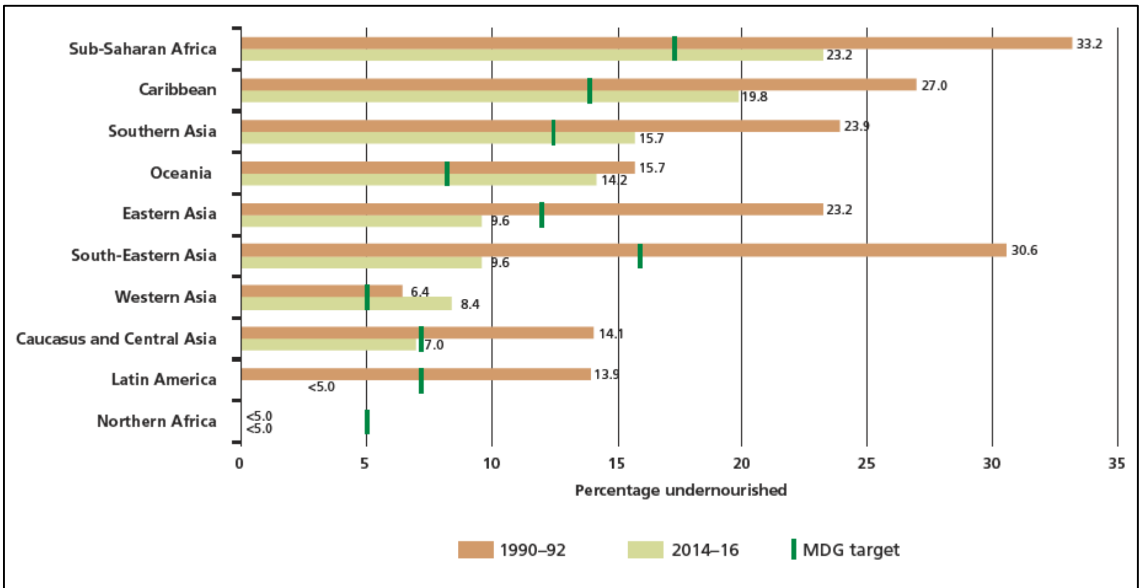
Food production all over the globe is not only a source of global environmental change, but is also strongly affected by it. Agriculture is primarily challenged by climate change and the related increase in natural disasters such as floods, tropical storms, long periods of droughts and new pests and diseases are 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 East Africa. In 2012, there was a similar situation in the Sahel region of West Africa. Similar drought events are also known from the USA (California), Central-Europe, Russia and Australia. 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 the 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, it is 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 the planetary boundaries. Without this shift the twin objectives of feeding humanity and living within 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 The Millennium Development Goals to "Halve Hunger"

One of the recent international efforts to address the challenges of food security is recently concluded Millennium Development Goals (MDGs). The MDG 1, "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 (MDG) 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 have reached the MDG 1 target. Most of these countries enjoyed stable political conditions and economic growth, accompanied by sound social protection policies targeted towards vulnerable population groups (FAO 2015b). In these 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 that occurred in the late 1990s and again after 2008 (FAO 2015b). Figure 2 shows that some regions achieved the MDG target (e.g. Caucasus and Central Asia, South-East Asia, East Asia and Latin America), some regions missed the overall goal (e.g. Sub-Saharan Africa, Caribbean, South Asia, Oceania) and in West Asia the percentage of undernourished people even increased during the period.

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



Note: Data for 2014–16 refer to provisional estimates.
Source: FAO.

Source: (FAO et al., 2015)

1.6 The Sustainable Development Goals to achieve "Zero Hunger"

On 1 January 2016, the 17 Sustainable Development Goals (SDGs) officially came into force as successors of the MDGs (for more detail, see Table 3 in the Appendix). The main goal, dealing with food security is the SDG 2, which aims at ending hunger and ensuring access to sufficient, safe and nutritious food by all people all year round, in particular the poor and those in vulnerable situations, including infants. The goal addresses a large diversity of tasks, starting from an increase in yield and improved infrastructure up to the functioning of local markets and international commodity trading. In detail, the SDG 2 has a series of 8 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.

However, when one analyses the other SDGs, the different food security dimensions of availability, access, stability and utilization are to some extent represented within the new post-2015 development agenda (for further explanations on the 4 food security dimensions, see Appendix Table 2). Except SDG 17 (on building partnerships) the respective SDG targets of each goal deal at least with one of the dimensions of food security, if not even all (for further analysis, please consider Appendix Table 3). However, SDG 3, SDG 4, SDG 10, SDG 11 and SDG 15 focus on just one aspect of the four dimensions of food security, probably because the four dimensions of food security address people exposed to hunger and food insecure situation, mainly in rural areas, whereas the SDG should have a global reach.

Overall, most of the SDG targets are somehow related to the overarching issue of achieving food security globally and support that achieving food security should be tackled with considering a food-system approach, acknowledging all the different dimensions. Related to the SDG 1 “No Poverty” and SDG 2 “End Hunger”, some indirect STI activities can be identified (Table 3: SDG targets related to the SDG 2 End Hunger with a relation to STI), mainly where STI is needed to achieve the goals or STI has to come up with 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 will not only highlight tools and techniques for specific challenges (e.g., improving productivity or minimizing post-harvest loss) but also draw attention to the need for countries, and 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 will be a major challenge for 2030 and 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 will present how certain scientific and technical applications can play a role in addressing the various aspects of food security.

This chapter will highlight examples of scientific and technical applications that can address the four dimensions of food security, namely availability, access, use/utilization, and stability. Though the listing of technologies within this chapter are by no means 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.[6]

There are a number of technologies that can play a role in addressing concerns related to food availability, access, utilization/use, and stability (Table 1). These scientific and technological applications are not necessarily mutually-exclusive. For example, new plant varieties can improve productivity with resistance to diseases, pests, and drought (food availability) while also providing more nutrition content (food use/utilization) and ensuring harvests even during periods of ecological or environmental change (food stability). Similarly, efforts to reduce post-harvest losses in storage or transport of food from farm to market (food access) can also help preserve the nutritional content of the food (food use/utilization). Because of the multi-dimensional nature of the technologies involved, the examples throughout this chapter are illustrative of how science and technology can address specific challenges of food security.

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/pest resistant crops • Pest-resistant eggplant (Bangladesh) • Rust-resistant wheat varieties • Pesticides • Herbicides • Tilling machines • Spatial repellant for on-farm pests • Improved agronomic practices (e.g., push-pull mechanisms)
	Abiotic Stresses	• Salt-Tolerant crops (e.g., quinoa, potato) • Climate-resistant crops
	Improving Crop Productivity (generally)	• Conventional breeding • Tissue culture and micro-propagation • Marker-assisted breeding • Advanced genetic engineering • Low-cost diagnostic toolkit for extension workers
	Improving Livestock Agriculture (generally)	• High-nutrient, low-cost animal fodder • Liquid nitrogen (and low-cost alternatives)

[6] 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.

		for animal semen preservation • Low-cost diagnostic toolkit for livestock veterinarians • Tissue engineering for lab grown animal products • Low-cost veterinary pharmaceuticals (ideally thermostable)
	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, micro-sprinkler irrigation • Water lifting (hand-powered mechanical pumps, treadle pumps, solar-power irrigation pumps, hydrogen-powered pumps, electric/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 system • Zero/conservation tillage • Soil microorganisms • Natural nitrogen fixation • Point-of-use kit 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/apps

[7] Many of the technologies addressing water availability were provided as a contribution by the Government of the United States of America as part of their Securing Water for Food Initiative.

	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 chiller • Nanotechnology • Improved genetic varieties • Seed/grain drying, aeration and storage technology • Innovative packaging • Bio wax coating • Rice par-boiling 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
	Need for Harvest and Agro-Processing Equipment	• Crop threshers (motorized and bicycle-powered) • Agro-processing technologies (crop, meat, dairy, and fish)
Food Use and Utilization	Lack of nutritious foods, esp. staple crops	• High-nutrient staple crops • Vitamin A-enriched cassava, maize, and orange-fleshed sweet potato (OFSP) • Iron and zinc-fortified rice, beans, wheat and pearl millet Quality Protein Maize
	Lack of information on healthy diets	• Nutrition information dissemination (e.g., GAIN health mobile app)
Food Stability	Inability to predict when/how to farm	• Weather forecasting technologies • Infrared sensors for detecting crop stress • Hyperspectral imaging, based on drone/satellite
	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

The FAO (2006) identified a "food gap" close to 70 per cent between the crop calories available in 2006 and the expected calorie demand in 2050. Closing this nearly 70 per cent food gap may require increasing food production through genetic improvements, reducing food loss and waste, shifting diets and increasing productivity by improving and maintaining soil fertility, pastureland productivity, and restoring degraded land is imperative (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. In fact, it has been estimated that in the past 40 years, almost 33% 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 will cover genetic improvements to crops via conventional cross-breeding and transgenic modification. This section will also review a number of inputs critical for increased agricultural productivity, including innovative techniques for soil management and irrigation, especially for and by smallholder farmers.[9]

<u>2.1.1 Conventional Cross-Breeding for Improved Plant Varieties and Increased Crop Yields</u>

One of the mostly commonly adopted technologies to increase agricultural production is the development and diffusion of new plant varieties. Genetic modification of plant varieties can be used for nutrient fortification, tolerance to drought, herbicides, diseases, or pests, and for higher yields. The earliest days of agriculture have involved genetic modification through cross-breeding. Gregor Mendel (in the mid-1800's) formalized the technique of breeding a primary cultivar with a "relative crop" with desirable traits through successive generations until a resulting variety matches the characteristics of the target variety. Its disadvantage is that plant improvements are limited to the best traits available within the same family of crops (Buluswar et al., 2014). Such 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 Nutritious Maize for Ethiopia project 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 amongst growers and consumers of maize. Farmers (28 percent 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 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. Since 1968, the

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

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

[10] Both case studies were provided as input by the Government of Canada.

government of Peru has embarked on a program 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 meters, where few food species can develop due to limiting factors of climate and soil. The farmers in the Peruvian highlands along with university, government, private sector, international and civil society actors used conventional methods involving genetic improvement of plants (along with support of biotechnology) to develop rustic varieties adapted to the variable and adverse sierra environments. Along with the development of new seed technologies, the program facilitated technology transfer through 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. Such crops confer a number of benefits, including tolerance to biotic (insects and disease) and abiotic (drought) stresses, 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 and a number of countries (like Bulgaria, Box 1) are developing capabilities in these modern agricultural biotechnologies. 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 1990's;
- 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; and
- The NextGen Cassava Project that uses genomic selection to improve crops (Buluswar et al., 2014; Grosskurth, 2010; World Bank & FAO, 2009).

Box 1: Bulgaria's Institute of Plant Physiology and Genetics (IPPG)

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 the plant's metabolism in plants and safeguard mechanisms that help to overcome the negative effects of the environment and to increase their resilience.

[11] The case study was provided as input by the Government of Peru.
[12] The next chapter will address issues of technology dissemination in more depth.
[13] Bt is a family of proteins originating from strains of the bacterium *Bacillus thuringiensis*.

- 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, the IPPG is testing plants both at the molecular level as well as their relationship with environmental air, soil and water. The resulting scientific data concerns raising the productivity of plant by optimising their water exchange mineral nutrition, maintaining an optimal environment for active symbiotic relationships with micro-organisms, 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 shall 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 commercially developed by transnational seed and agro-chemical companies, may be costly and externally input-dependent for smallholder farmers (World Bank, 2008), but recent philanthropic initiatives are making such technologies available to smallholder farmers.[14] There is also concern about technology access (given that much biotechnology has been developed in the private sector), 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 global, regional, and national levels, the knowledge intensity of modern agricultural biotechnology means that the more salient challenges for developing countries may involve the innovation capacities to assess, select, diffuse, adapt, and evaluate such technologies to address local agricultural challenges (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

[14] For example, the African Agricultural Technology Foundation and the Bill and Melinda Gates Foundation negotiate licenses 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, consider the following resources: IP Handbook (www.iphandbook.org); Marden, E., Godfrey, R., & Manion, R. (eds.) 2016. *The Intellectual Property-Regulatory Complex: Overcoming barriers to innovation in agricultural genomics*. Vancouver: UBC Press; Chiarolla, C. 2011. *Intellectual Property, Agriculture and Global Food Security: The privatization of crop diversity.* Cheltenham, UK: Edward Elgar.; UNCTAD-ICTSD. 2005. *Resource Book on TRIPS and Development*. New York: Cambridge University Press.; Reichman, J. & Hasenzahl, C. 2003. "Non-voluntary licensing of patented inventions: Historical perspective, legal framework under TRIPS, and an overview of the practice in Canada and the USA." UNCTAD-ICTSD Project on IPRs and Sustainable Development. Issue Paper No. 5. Geneva: ICTSD.

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 may not increase yields without overcoming other constraints like low soil fertility. Fertile soils play a pivotal role in sustaining agricultural productivity and thus food security. Usually, the focus on innovations and technological developments is however primarily on the crops and on 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 (in the case of nitrogen), and large ecological footprint make them unsustainable. Fertilizer and water overuse can cause environmental damage as well as represent an economic waste for smallholder farmers. Furthermore, the Intergovernmental Technical Panel on Soils concluded that farmers are essentially mining the soil and this is why soil should indeed be considered as 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 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 could increase yields by improving both the water-holding capacity of soil and water infiltration rates (Folberth, 2014; UN, 2015b). New technologies to make biological fertilizers (composting, manure/dung) more viable and effective could also increasingly replace the use of synthetic fertilizers. However, such biological fertilizers (esp. made from human waste) may require sanitation infrastructure. Furthermore, precision agriculture can help facilitate the precise application of inputs to crops type and soil conditions in ways that increase yields while minimizing potential environmental impacts (Box 2) (Buluswar et al., 2014).

Box 2: Information and Communication 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 Ministry of Agriculture's Soil Resource Development Institute 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 IT company - developed the software application with attention to the agricultural users and local context and in the local language (Bangla). Since its launch in July 2009, users have incurred reduced

[16] As well illustrated in a report of the CGIAR Research Program 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".

fertilizer costs (in some cases up to 25 per cent) and higher crop yields (in some cases as much as 15 per cent). The 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[17]

Like soil fertility, the availability of water is a critical input for ensuring and improving crop productivity. Approximately seventy percent of global freshwater supply is dedicated to agriculture.[18] Unfortunately, many farmers are unable to sufficiently irrigate because of lack of water, given physical or economic constraints (Figure 3). Most African smallholder farmers do not have access to irrigation facilities and typically rely on rainfall. A number of factors limit the digging of wells, renting of expensive drilling equipment and identification of exact locations of groundwater.

Despite these challenges, science, technology, and innovation can potentially make water more available and efficient for agricultural activities. 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 (strenuous to use, esp. for women) or expensive motorized pumps (with recurring fuel costs) are inadequate or financially out of reach, respectively (Buluswar et al., 2014). And 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 anywhere there is flowing water.[19] Greenhouses can mitigate the water unavailability 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 ($500) greenhouses in as little as two days that last over five years in Sierra Leone and Mozambique.[20] Even when groundwater is available, brackish water may not be suitable for human consumption or crop irrigation (leading to soil salinization and low crop yield). Water desalination technologies like off-grid solar- powered electrodialysis reversal (EDR) systems disinfect and pull charged particles out of water.[21]

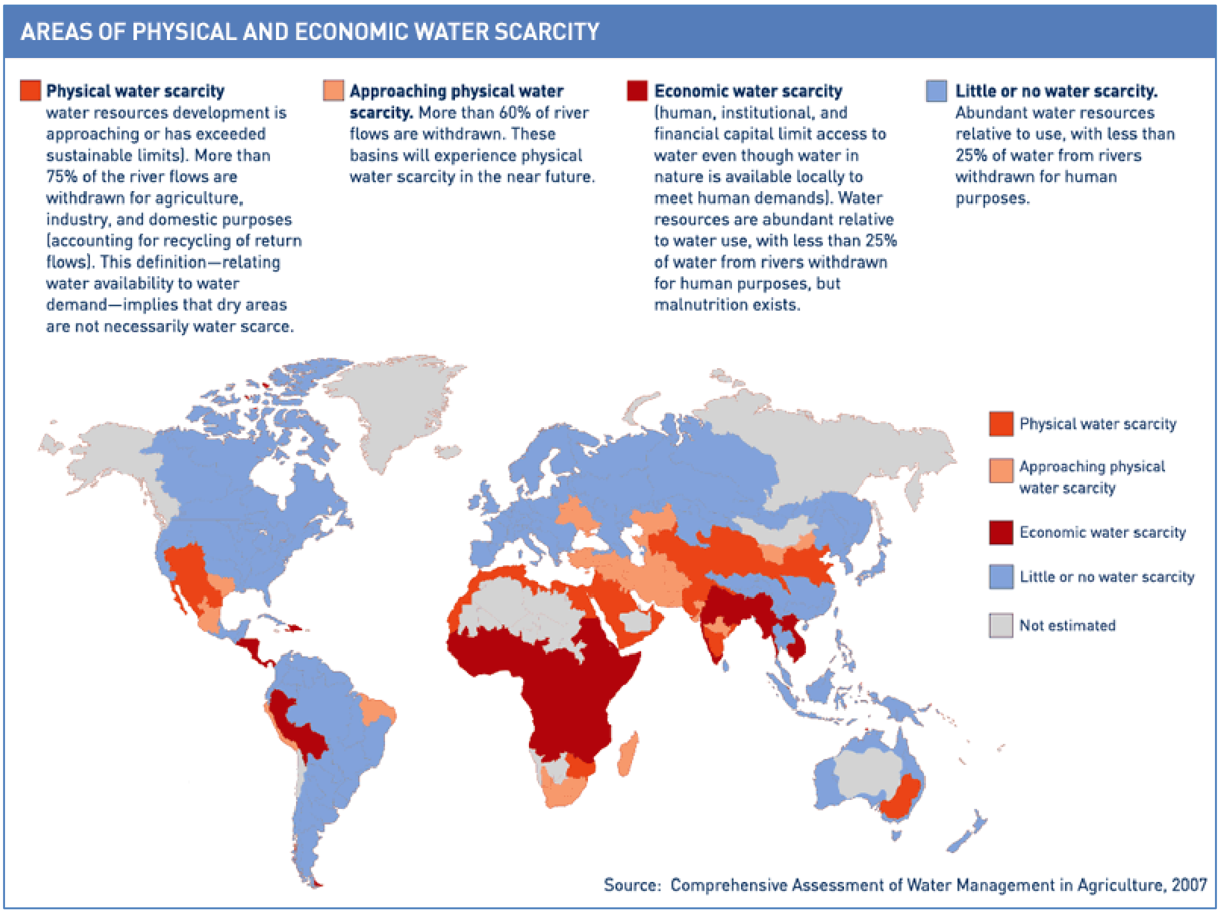
Other technologies improve water efficiency for increased demand for agricultural products in fragile natural environments. For example, the Groasis Waterboxx is an integrated planting technology that surrounds the bases of a plant, building up a water column by collecting dew and rainwater under the plant, and avoiding evaporation by distributing such water over long

[17] Many of the technologies mentioned in this section were provided as input by the Government of the United States of America as part of their Securing Water for Food Initiative.
[18] For a more detailed review of agricultural water management technologies, please 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. Geneva: UNCTAD. UNCTAD/DTL/STICT/2011/2.
[19] http://securingwaterforfood.org/innovators/the-barsha-pump-aqysta
[20] http://securingwaterforfood.org/innovators/affordable-greenhouses-world-hope
[21] http://news.mit.edu/2016/solar-powered-desalination-clean-water-india-0718; http://securingwaterforfood.org/innovators/edr-mit-jain

periods of time.[22] New fungal seed and plant treatments can help crops (e.g., okra, maize, millet, and wheat) use 50% less water, with a 29% crop yield increase.[23]

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 typically expensive and limited. The Institute for University Cooperation provides an irrigation scheduling system that recommends the best irrigation practices based on climate, meteorological, and soil data through a mobile platform.[24] In countries like 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 absence of such information. FutureWater's Flying Sensor use near-infrared sensors that can detect crop stress up to two weeks before visibly observable. In its first year of operation, a subset of households benefitting from the technology reported 39% reduction in water usage.[25] Finally, it is important to address the gender dimension of water for food, as women disproportionately serve as agricultural labor while having limited access to water, among other inputs for increasing agricultural productivity (UNCTAD, 2011).[26]

Figure 3: Global Water Scarcity



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

[23] http://securingwaterforfood.org/innovators/adaptive-symbiotic-technologies-bioensure

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

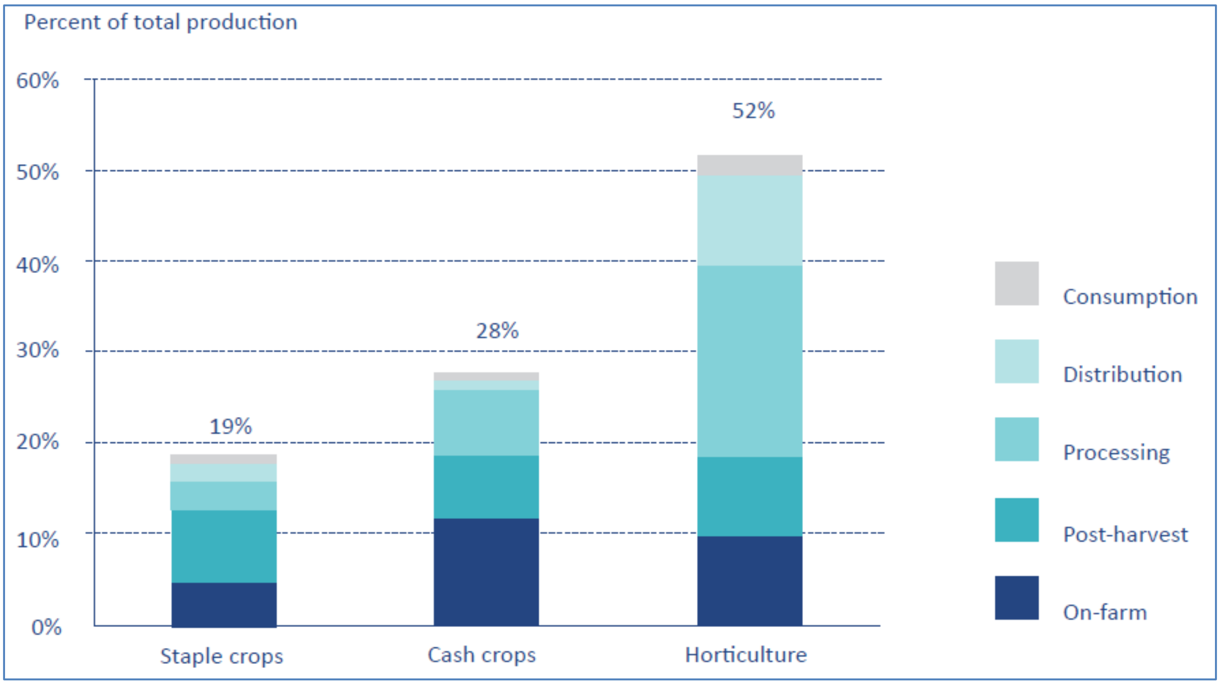
[25] http://securingwaterforfood.org/wp-content/uploads/2016/03/2015-SWFF-Annual-Report_Press_Print-Version.pdf

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

2.2 Food Access: Technologies for food accessibility

One 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 the agribusiness employment prospects and drives up the costs of agricultural products farmers have to import. Lack of affordable refrigeration along with electricity limits the production, preservation, and sale of high value perishables like 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, and particularly perishables, are susceptible to agricultural losses (Figure 4).

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



Source: (FAO, 2011)

A number of post-harvest loss technologies address storage, handling, refrigeration, transport, and processing.[27] Despite challenges in 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 too often experience. For example, Uganda is one of eight African countries participating in a project to improve rice post-harvest handling, marketing and development of new rice-based products.[28] The six-year project, which started in 2011,

[27] 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; UN, 2015b).
[28] The case study is provided as input by the Government of Uganda.

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. The technology transfer and dissemination is facilitated by 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 postharvest grain loss from 4.87% to 0.01%, translating to a savings of USD 12 million. The threshers should also improve the grain quality, labour productivity (saving up to 59% threshing labor) and employment opportunities. Other projects similar to the Uganda case focus on agro-processing, including Cuba's[29] meat, dairy, and fishery agro-processing and recent efforts to create mobile processing units for cassava in Nigeria.[30] Furthermore, genetically improved varieties can also limit (post-) harvest losses and preserve foods for transport to markets local, national, and international markets.

Nanotechnology is being used in a number of projects to improve the preservation of crops.[31] The Canadian International Food Security Research Fund and International Development Research Center is supporting a nine-year, two-phase program on enhancing the preservation of fruits in collaboration with five other countries (India, Sri Lanka, Kenya, Tanzania and Trinidad and Tobago). 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 extends their storage life. The use of hexanal spray has increased fruit retention time by up to 2 weeks in mango and 5-7 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 centers.

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 a local talent to fabricate and repair small-to-medium sized threshers can address the affordability and availability of such technologies. Initiatives like the USAID-supported Soybean Innovation Lab offer training workshops and have been recently piloted in Ghana.[32]

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

[29] The case study is provided as input by the Government of Cuba.
[30] http://www.dadtco.nl/.
[31] The case studies are provided by the governments of Canada and Sri Lanka. More public information is available at the following URL's: 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.
[32] Contribution provided as input by the Government of the United States of America. For more information: http://soybeaninnovationlab.illinois.edu/sites/soybeaninnovationlab.illinois.edu/files/Thresher%20Training%20Brochure_0.pdf

smallholder farming status. In particular, low levels of intraregional trade among African LDCs (compared with other regions) is possibly an unexploited opportunity for increasing regional agricultural exports, harmonizing product standards within regional trading blocs, and promoting regional agricultural innovation (UNCTAD 2015d; 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 Utilization: Science for Nutrition

Globally 1 billion people suffer from insufficient calories and insufficient 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 and 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 both individuals and society.

Biofortification - or the breeding of critical micronutrients and vitamins into staple crops - has emerged as an effective approach for combating malnutrition, esp. in developing countries.[33] To date, the most successful example of vitamin and micronutrient biofortification is the orange-fleshed sweet potato (OFSP), developed at the International Potato Center (CIP). HarvestPlus (based at IFPRI) has pioneered biofortification as a global plant breeding strategy for a variety of crops (e.g., Vitamin A-enriched cassava, maize and OFSP and iron and zinc-fortified rice, beans, wheat and pearl millet) in over 40 countries. These combined efforts have already positively affected 10 million people, with several hundred million potentially affected in the upcoming decades.[34] Complementary to such efforts, countries like Guatemala are pursuing comprehensive efforts to improve nutrition while ensuring livelihoods and resilience (Box 3).

Box 3: Purchase for Progress (P4P) and Scaling Up Nutrition in Guatemala

The World Food Programme's (WFP) Purchase for Progress (P4P) Program 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: i) Purchase for Progress, which improves the incomes of smallholder farmers through the increased quantity and quality of production and sales of surpluses to markets; ii) Scaling-up Nutrition, which helps prevent and reduce chronic malnutrition through distribution of fortified food and nutrition education; and iii) Resilience, which improves community conditions in disaster-prone areas, and enhances food availability throughout the year.

Project activities include the following: (1) 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; (2) promoting better post-harvest management to reduce crop losses; (3) assisting farmer organizations to increase sales and receive fair market prices from buyers; (4) 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

[33] In fact, the four recipients of the 2016 World Food Prize were recognized for their exemplary contributions to biofortification.
[34] https://www.worldfoodprize.org/en/laureates/2016__andrade_mwanga_low_and_bouis/

and lactating women per year to complement breastfeeding and prevent stunting or chronic undernutrition; and (5) 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 agriculture practices, including diversifying production and making it as climate-resilient as possible.

2.4.1 Adapting food production to climate change

STI should focus on re-integrating crop and livestock production and related closed nutrient cycles. 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, reaching zero sequestration rates after few decades, typically. Soil carbon losses can be reduced by protecting existing permanent grassland and soil carbon sequestration can be increased in arable land by application of organic fertilizers, minimal soil disturbance, agroforestry, mixed cropping and planting 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. STI for climate change mitigation and adaptation should thus in particular also focus on information provision and knowledge transfer, and innovations needed are rather on the social than technical level. Many practices however deliver both (as e.g. organic amendments that increase soil organic carbon and thus also soil fertility and structure, with positive effects on water retention capacity, for example) and many of the effective adaptation/resilience and mitigation approaches to a changing climate have important ecological, agronomic, economic and social co-benefits. Finally, locally adapted breeding for drought or heat tolerant crop varieties, with a focus on underutilized crops, has big potential to support climate change adaptation in agriculture.

2.4.2 Using Big Data and the Internet of Things for Precision Agriculture

Big Data and the Internet of Things (IoT) are also creating new possibilities in agriculture and food security. “Big data” can have applications related to site-specific precision farming (i.e. more efficient use of resources and inputs), targeted crop protection and crop planning for eco-functional and agro-ecological intensification approaches as well as enhanced resilience to climate change. Remote sensing can be utilized for improved data collection as a basis for extension services and information provision (e.g. weather forecasts). And 3D-printing and drones could help assure supply to remote and inaccessible regions in the future.

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.[35] A program coordinated by UN Global Pulse, the Indonesian government, and the World Food Programme used public tweets mentioning food prices to develop a real-time food index (UN Global Pulse).[36] And the International Center for Tropical Agriculture uses big data on weather and crops to better adapt to climate change (Box 4).

Box 4: Big Data for Sustainable food production in Colombia

The International Center for Tropical Agriculture is an organization that strengthens agricultural technologies, innovations, and new knowledge that helps small farm owners improve their crop yields, incomes, and usage of natural resources. Scientists collaborated with the Colombian Government, Agriculture and Food Security, and Colombia's 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 by solar radiation during the grain-ripening stage. Meanwhile, in the town of Espinal, the team found that it suffered from sensitivity to warm nights. Solutions do not have to be costly, as such information can help farmers to avoid losses simply by sowing crops in right period of time. The climate change foresight helped 170 farmers in Córdoba avoid direct economic losses of an estimated \$3.6 million and potentially improve productivity of rice by 1 to 3 tons per hectare. To achieve this, different data sources were analyzed 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, including Nicaragua, Peru, Argentina and Uruguay. Sources: (Cariboni, 2014; CCAFS, 2015).

Source: UNCTAD

The International Livestock Research Institute (ILRI) created a program "Index-Based Livestock Insurance (IBLI)" to provide financial protection based on a rainfall index to trigger payments for pastoralists in the Horn of Africa.[37] Since 2010, 11,750 herders in Northern Kenya and 3,905 herders in Southern Ethiopia have purchased IBLI insurance contracts with more than \$200,000 in payouts. Results from the 2011 Horn of Africa shows that IBLI-insured households were less likely to reduce meals or sell livestock and more likely to have veterinary services, higher milk productivity, and better nourished children.[38]

Because meteorological, weather, and Internet of Things data is increasingly valuable as an agricultural input, a number of new initiatives focus on sharing data to support agricultural productivity.[39] For example, the Global Open Data for Agriculture & Nutrition Program aims

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[35] Pratap Vikram Singh, "The Startup Revolution: Smart Solutions for Social Good," *Governance Now*, August 1, 2015.
[36] UN Global Pulse (http://www.unglobalpulse.org/nowcasting-food-prices)
[37] https://www.worldfoodprize.org/en/nominations/norman_borlaug_field_award/2016_recipient/
[38] https://news.ilri.org/2016/10/12/kenyan-accepts-2016-norman-borlaug-award-for-field-research-and-application-at-world-food-prize-event-in-iowa/
[39] 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

to make data available, usable, and accessible to help achieve food security. Its mandate is based on the New Alliance for Food Security and Nutrition, agreed up on by leaders at the G-8 2012 Summit, where they committed to "share relevant agricultural data available from G-8 countries with African partners and convene an international conference on Open Data for Agriculture, to develop options for the establishment of a global platform to make reliable agricultural and related information available to African farmers, researchers and policymakers, taking into account existing agricultural data systems." With 409 partners representing diverse stakeholder groups, the initiative seeks to:

- advocate for new and existing open data initiatives to set a core focus on agriculture and nutrition data;
- encourage the agreement on and release of a common set of agricultural and nutrition data;
- by increasing widespread awareness of ongoing activities, innovations, and good practices;
- advocate for collaborative efforts on future agriculture and nutrition open data endeavors; and,
- advocate programs, good practices, and lessons learned that enable the use of open data particularly by and for the rural and urban poor.[40]

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

Before big data and the Internet of Things created new possibilities for precision farming, countries and international agencies were leveraging satellite and meteorological data to provide early warning systems to predict and adapt to changing climactic and environmental conditions. Eighty percent of the estimated 1.4 billion hectares of global cropland is rainfed, accounting for approximately 60% of worldwide agricultural output.[41] Accurate and reliable weather forecasts enable farmers (especially near the equator) to capitalize on rainfall for crop production in regions of extreme weather variability.

Systems like the International Food Policy Research Institute (IFPRI's) Global Food Security Portal, the Food and Agriculture Organization (FAO) Global Information and Early Warning Systems (GIEWS), FAO's Rice Market Monitor, USAID's Famine Early Warning System Network (FEWS NET), the Trans African Hydro-Meteorological Observatory (Box 5), and the Group on Earth Observations' (GEO) Early Warning Crop Monitor have played critical

free), and CIARD (Coherence in Information for Agricultural Research for Development) which advocates for open data among agricultural data holders.

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

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

roles in disseminating country and region-specific information to help farmers maximize productivity.

In particular, the Famine Early Warning Systems Network (FEWS NET) offers objective, evidence-based analysis to governments and relief agencies across the world.[42] Created by USAID in 1985 after famines ravaged West 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, livelihoods, etc.).[43]

Similar to FEWS NET, the UN Institute for Training and Research (UNITAR) and its Operational Satellite Applications Programme (UNOSAT) has been deployed for the past fifteen 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 ground water mapping for sustainable development. Not only is 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 UN system.[44]

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 modeling of physics, and small (spatial and temporal) forecasting windows. The result is a reported 84% accuracy rate over 2 rainy seasons in West Africa (2013 and 2014), compared to other weather service providers with a 39% rate. Low-cost daily messages help farmers anticipate rainfall for the next 48 hours.[45]

Box 5: Trans African Hydro-Meteorological Observatory (TAHMO)

Challenge: Without climate information, you cannot optimize crop selection or ensure it without knowing the risks.

Solution: The TAHMO weather system is the first continent-wide weather network that allows free data to non-commercial users including researchers. The innovative, solar-powered sensor system delivers accurate, localized, and timely meteorological and water resource information to farmers multiple times per day via a mobile device. The network helps enhance food security and reduce the risk to smallholder farmers that rely on rain-fed agriculture to cultivate crops.

Milestones and Achievements: In addition to reducing agricultural water consumption in targeted areas, TAHMO tested alternative business modalities and is having some success with a direct-marketing approach to schools. The system was presented at the Addis GEF meeting, where weather observation was the focus of the meeting for East Africa. Ministers saw the stations and invited TAHMO to pilot in 5 countries.

Source: USAID Securing Water for Food[46]

[42] Contribution provided as input by the Government of the United States of America.
[43] http://www.fews.net/about-us
[44] http://www.unitar.org/unosat/
[45] http://www.ignitia.se
[46] Contribution provided as input by the Government of the United States of America. For more information: http://securingwaterforfood.org/innovators/tahmo-weather-system

2.5 Convergence of New and Emerging Technologies

The convergence of a number of emerging technologies - including synthetic biology, artificial intelligence, tissue engineering, 3D 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 either individually or as part of converged applications have the potential to reshape the future of food production.

Recent advances in bio-technology have created a new approach to genome editing, based on CRISPR/Cas9 (Box 6). Based on this method, 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.[47] Other companies are leveraging synthetic biology to make food flavorings (e.g., vanilla) that minimize oil inputs while mimicking the flavor of the natural product.[48]

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 that confers 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 much due to its ability to be easy programmable to target different sites.

It differs from classic genetic engineering techniques because it opens up the opportunity for target modification, or the modification of specific regions and sequences in the genome. 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, up until now, its application in plants still relies on other genetic engineering tools (e.g. recombinant DNA, biolistic, 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 have to be considered. One of the safety concerns relates to the possibility to generate permanent DNA breaks at other, unintended sites in the genome. The rules governing off-target activity of CRISPR are just beginning to be understood in more detail. In addition, CRISPR ability to edit small bits of DNA sequences generates minimal modifications, and it

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

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

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 labeling and consumer's rights, as well as risk monitoring issues.

CRISPR gene-editing is likely to have similar commercial and socio-economic implications as classical genetically modified organisms. 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 bio-tech companies as suppliers, on the one hand, and farmers, on the other.[49]

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

In fact, some innovations have the potential to transform or make obsolescent 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.[50]

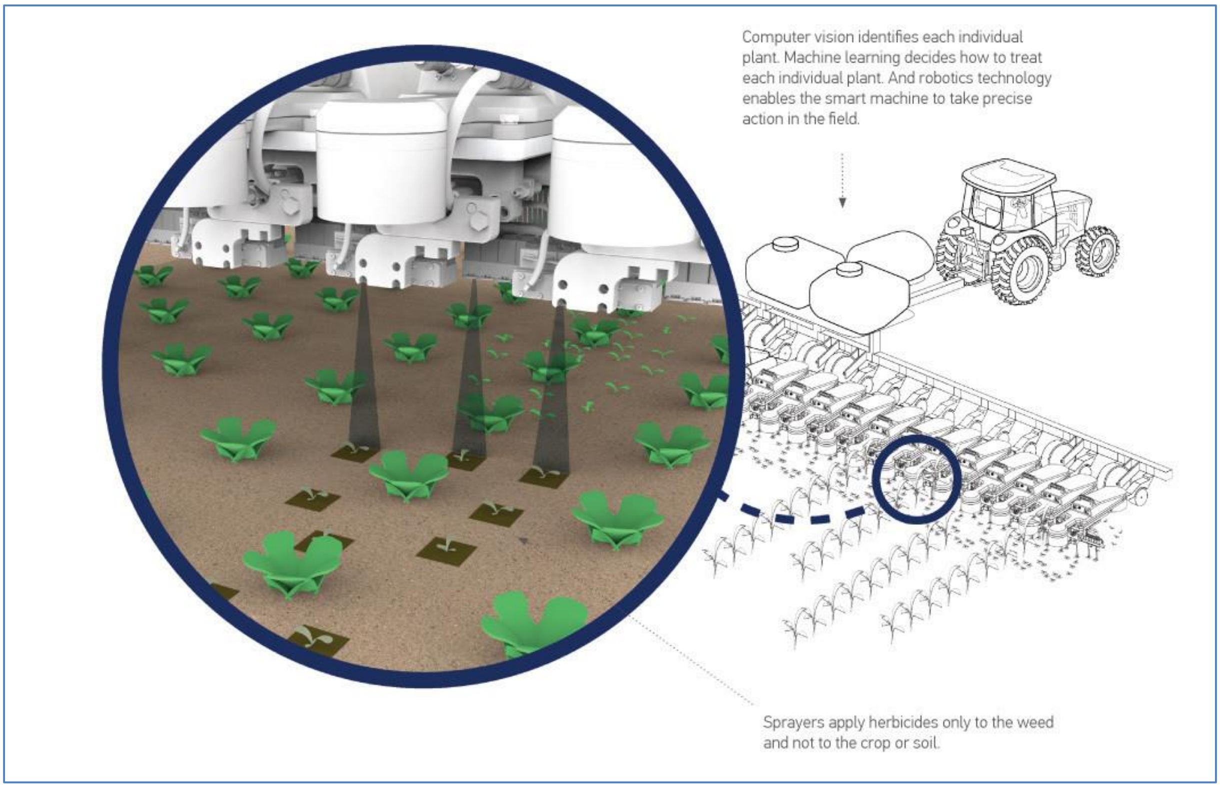
As biology becomes an information technology, it may be possible to grow certain foods outside of the conventional factory farm model to produce animal products in the lab. Startup companies are developing animal-free egg whites which use less water and land inputs while preserving the taste and nutritional value of hen-borne egg whites.[51] Other companies are making meat and cheese products directly from plants[52], while some academics and researchers are leveraging advances in tissue engineering technologies to 3D print meat.[53] These technologies could potentially make the creation of animal products more environmentally sustainable. However, on the other hand, if such developments reach industrial scale, it could have trade implications for livestock agricultural production based in developing countries.

Big data, the Internet of Things, drones, and artificial intelligence may catalyze "precision farming", requiring fewer agrochemical inputs for existing agricultural processes. Some companies are using novel genetic sequencing, along with machine learning, to detect soil quality and help increase crop quality.[54] 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.[55] It is also being used with plant genomic and phenotypic data to predict the performance of new plant hybrids.[56] Robots are increasingly automating

[49] The intellectual property implications of synthetic biology are not clear. Initiatives like 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.
[50] http://www.latimes.com/nation/la-na-climate-chickens-20140504-story.html
[51] http://www.clarafoods.com/aboutus/#theclarastory
[52] http://impossiblefoods.com
[53] https://culturedbeef.org and www.modernmeadow.com/.
[54] https://www.tracegenomics.com.
[55] 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/; http://www.planetaryresources.com.
[56] A number of companies provide satellite imagery solutions based on machine learning and artificial intelligence. Examples include: https://www.nervanasys.com/solutions/agriculture/

farming through the ecological and economical weeding of row crops.[57] Beyond rural areas, Big data and IoT is enabling urban, indoor, and vertical farming which in some cases can grow 20 percent faster, with 90% less water, and minimal or negligible need for pesticides, herbicides, and fertilizers.[58] A number of these technologies (sensors, artificial intelligence, imaging, and robotics) can be combined for automated precision farming (Figure 5). The potential impacts of these converging technologies are unclear, leading to the need for robust mechanisms to evaluate such technologies.

Figure 5: Example of application of IoT, robotics, and artificial intelligence to farming



Source: Blue River Technology

Managing risks and public perceptions of science, technology, and innovation are essential to harnessing them for the achievement of food security in 2030. New technologies have been credited with creating new opportunities but also destroying the status quo, and unlike the past, technological risks are not necessarily confined to the sectors or countries in which are they applied. 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 to emerging challenges with available knowledge and swiftly respond to technological failures (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

[57] See: http://www.ecorobotix.com/ and https://www.deepfield-robotics.com/.
[58] See: https://urbanfarmers.com/; http://cool-farm.com/; http://light4food.com/en/; http://www.newsweek.com/2015/10/30/feed-humankind-we-need-farms-future-today-385933.html.

risks of new (and converging) technologies, with a view towards immediate and longer-term impacts (Box 7).

Box 7: Need for International Mechanism for Technology Assessment and Foresight

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. The US 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, the US 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 - like England and several members of the European Union - built their offices of Technology Assessment on the US OTA model.[59]

The former UN Center on Science and Technology for Development had a similar role at the international level within the UN system. The United Nations launched the Advanced Technology Assessment (ATAS) Series in 1984 for the purposes of "initiating arrangements for the early identification and assessment of new scientific and technological developments which may adversely affect the development process as well as those which may have specific and potential importance for that process and for strengthening the scientific and technological capacities of the developing countries." The program covered a range of technologies including biotechnology, new materials, energy, information and communications technologies, and science and technology cooperation.

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, including 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), Center for International Forestry Research (CIFOR), and WorldFish.[60]

There is need for a global initiative that can systematically convene experts from across disciplines to address not only agricultural technologies but also other scientific, technical, and innovative developments and their potential impacts for the economy, society, and environment. Such a global initiative should ideally conduct both technology assessment and foresight to evaluate the immediate and long-term impacts of new technologies.

[59] More information and historical documentation on the US OTA can found at http://www.princeton.edu/~ota/.
[60] http://www.gfar.net/our-work/foresight-better-futures-0

A global network of experts across disciplines and domains and coordinated at an international level could help the international community better understand the implications of technology - both individually and converged - in ways that 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 the 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.

The UN Commission on Science and Technology for Development is responsible, amongst other things, for "initiating arrangements for the early identification and assessment of new scientific and technological developments which may adversely affect the development process as well as those which may have specific and potential importance for that process ..." (UN Resolution 34/218, 1979). The Commission has historically conducted multi-year technology assessments on biotechnology and ICTs and embraces multi-stakeholder engagement in its annual meetings and thematic working groups. The UN CSTD could potentially fill the need for an international institution with an explicit responsibility for technology assessment and foresight.

Source: UNCTAD

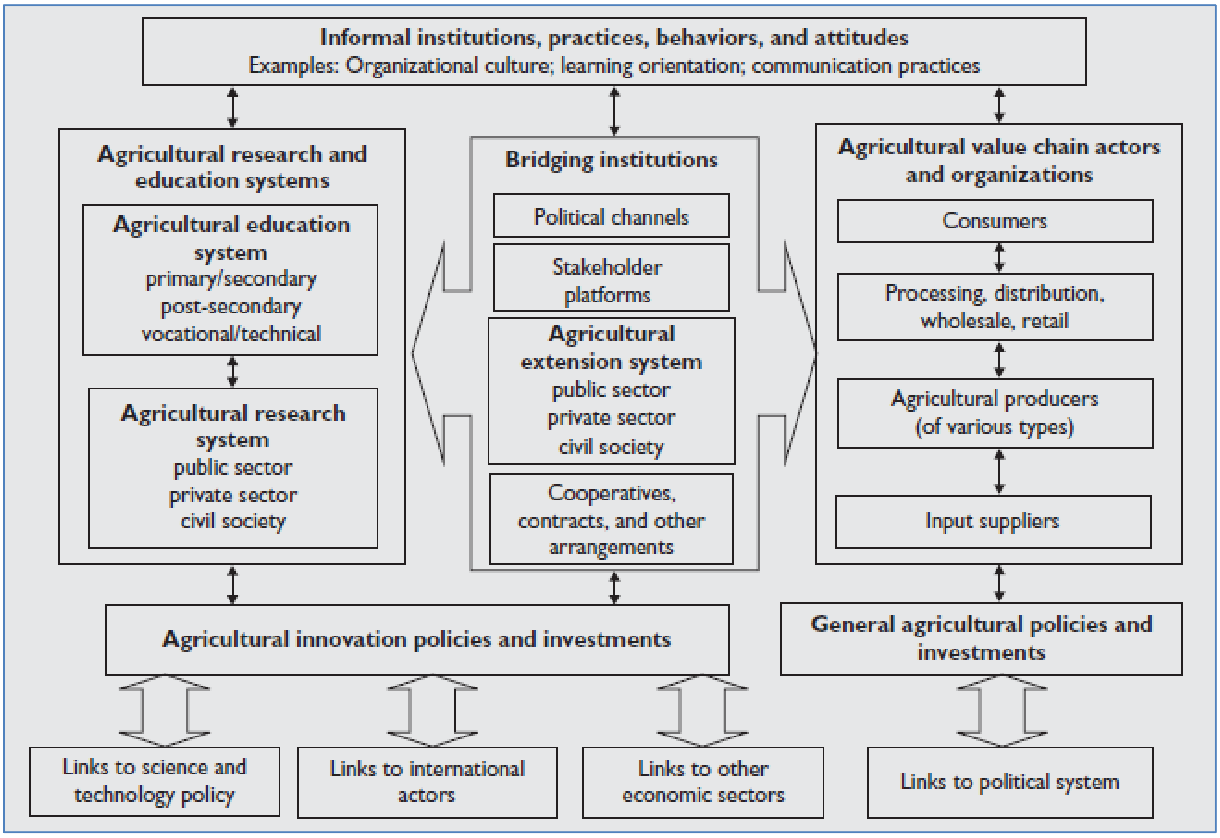
2.6 Conclusion

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 will discuss how countries in particular can develop the innovative capabilities to apply knowledge in agricultural development.

Chapter 3: Developing Innovative Food Systems

Harnessing science and technology for the various dimensions of food security (as illustrated in the last chapter) requires making 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 farmer-scientist knowledge flows. One useful analytical tool for thinking about the ecosystem (institutions, actors, organizations, and policies) and supporting mechanisms and infrastructure that facilitate agricultural innovation is the agricultural innovation system (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 nongovernmental actors (Larsen, K. et. al., 2009; UNCTAD 2015c). 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.

Figure 6: Agricultural Innovation System



Source: (Larsen, K. et. al., 2009)

3.1 Promoting a Smallholder Farmer-Focused Research Agenda

There is an urgent need to increase investment in high-quality research and advisory extension services that are coherent with models of productions adapted to smallholder farmers' needs. Research - at the national and international levels - 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 & HLPE, 2013). Countries like Bulgaria have created institutions to support such high-quality agricultural R&D (Box 8).

Box 8: Bulgaria's Agricultural Academy

The Agricultural Academy (AA) is an organization for scientific, applied, support and ancillary activities in the field of agriculture, helping with the realization of the strategic objective of ensuring food security of the country, preservation of natural resources and improving the quality of life.

In AA operate 562 scientists carrying out research projects related to food security in the following major areas: sustainable use of natural plant resources, animals, soil and water and reduce the adverse impacts associated with climate change; maintenance of genetic resources and creating new, high-yielding varieties and animal breeds, well adapted to changing climatic and economic conditions; develop healthy foods to improve the length and quality of life; provision of certified and quality seeds, seedlings and breeding material.

The strongest advantages of the research institution (AA) for sustainable development are:
•The integration of all functional units of the innovation process in agriculture from idea to research product
•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 accepted by expert councils, composed of authoritative academic rank for a term of four years and are in accordance with previously adopted long-term priorities. Projects in the selection and maintenance of genetic resources have a long-term duration and their continuity is ensured. Much of the projects result with the creation of a new research product - a new variety, new technological solutions or integrated technologies for growing different crops or animals that can be directly embedded in agricultural production. There are 345 scientific products owned by the institutes and experimental stations of the AA which have certificates for protection from the Bulgarian Patent Office.. Just recently in 2016, 8 new varieties of different cultures and 2 breeds received new certificates.

In 2016, the structural units of the AA participated in 130 projects - 38 in plant breeding, 31 in animal husbandry, 46 in the field of soil science, agricultural technology and the protection of plants, 10 in the field of safety and quality of food and 5 the field of management of agricultural production. These projects are 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

In this regard, it has been recommended that orientation of science, technology, and innovation research for food security include the following elements: *(i)* partnership with rural producers' organizations and NGOs; *(ii)* use of non-proprietary genetic material and research to develop locally adapted genetic material able to produce in difficult conditions; *(iii)* development of low-cost innovative proposals for investments; *(iv)* promotion of diversification of production systems; and *(vi)* support to the development of activities that increase the value added at smallholder level.[61]

International public goods (such as the CGIAR) are important for the international research agenda on food security. However, it has been observed that 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 Centers (formerly the Consultative Group of International Agricultural Research CGIAR) for the period 2016-2030 emphasize a more cross-cutting approach to research topics, due consideration of the socio-economic 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 dialog and clarity of complex phenomena of the sector and its context (Box 9).

Box 9: A new Strategy and Results Framework for CGIAR for the period 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 centers, known as the CGIAR Consortium of International Agricultural Research Centers. These research centers are spread around the globe, with most centers located in the Global South. The centers 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 centers under a permanent secretariat. This was further supported and developed by the World Bank, FAO and UNDP, and the 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 within the framework of the ‘green revolution’, placing emphasis on the development of high-yielding crop varieties that however required an externally input-intensive form of production. The initial focus of research centered on 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[62], plant nutrition, water management, and policy research.

International consultations are now underway 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: (i) agri-food systems today are not sustainable, nor are they providing healthy food for all; (ii) poor diets are now the number one cause of ill health globally; (iii) there is a serious and escalating global environmental crisis of agriculture; (iv) massive un(der)employment of young people in rural areas is a key

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

[62] CGIAR genebanks form the world’s largest germplasm collections for staple food crops, providing over 90% of all recorded transfers under the International Treaty on Plant Genetic Resources.

challenge; and (v) radical and fast transformation is urgently needed as the challenges are formidable.

The consultations on the new framework propose three strategic goals as system level outcomes, which are (i) reduced poverty; (ii) improved food and nutrition and security for health; and (iii) improved natural resource systems and eco-system services. Four cross-cutting themes have been singled out for being critical to attaining the new CGIAR goals: (a) mitigating and adapting to climate change risks and shocks; (b) ensuring gender and youth equity and inclusion; (c) strengthening the policy and institution enabling environment; and (d) developing the capacity of national partners and beneficiaries.

Against this background, eight priority research topics are proposed for the first 6 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 system-based approaches to optimize economic, social and environmental co-benefits in agricultural systems in areas with a high concentration of poor people.
- 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, genetically and phenotypically characterized to maximize the exploitation of these critical resources for food security, productivity, nutrient rich crops and resilient farming systems.

Source: 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. For example, investment in improved water sources is in line with the food security dimension of utilization to provide access to improved water sources. Ensuring availability and sustainable management of water and sanitation for all may help to achieve food stability and food utilization indicators of the food security dimensions. More people having access to improved water sources and sanitation facilities (food security utilization dimension) and affordable access to water may provide a means to increase the percentage of arable land equipped for irrigation (food security stability dimension).

Ensuring access to affordable, reliable, sustainable and modern energy for all is also key. 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 are reduced, while productivity is maintained.

Inclusive, resilient and sustainable development within cities may help to promote the food security dimension of food access. The promotion of transportation systems may increase food access, as transportation of agricultural goods become easier in some remote areas as currently. This may help to build up local markets or may provide a means for people to travel more comfortable to the next nearby market to buy agricultural goods. Further, the investments into infrastructures may open up new export/import markets and thus may help to increase the available food. In 2050, more than two thirds of global population will live in urban and peri-urban areas (UN 2016). Thus sustainable cities and the importance of rural-urban linkages are connected to food supply and food security. To make sure that food production, processing and marketing are reliable and sustainable in the long term, rural-urban linkages need to be strengthened. This includes the investment in infrastructure adapted to environmental disasters, but also farmers markets, consumer- producer cooperation as well as urban gardening and farming.

Finally, information and communication technologies have a critical role to play in food security in general, and more specifically with respect to the provision of extension services.[63] Mobile phones have proliferated in developing countries, foremost in Africa, at an unprecedented scale with most of the smallholder farmers owning at least one phone, often more. ICTs can empower farmers and their networks in less obvious but more profound and lasting ways by allowing for multidirectional communication throughout digital networks, thus opening the opportunity of integrating farmer-held information and farmer-reported observation into the local collection of expert agricultural knowledge (Tisselli et all 2012). Moreover, technologies that go beyond the limitations of SMS and voice services can open new, socially-oriented areas of action within e-agriculture (Box 10).

Box 10: ICTs for Farmer Community Building in 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 at the Applied University of the Arts Zurich (ZHdK) IBZ/ETHZ. The ERV Methodology is based on the usage and exchange of shared smartphones to create an audiovisual documentation of the 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 keyword 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 Tanzania (Bagamoyo District) have participated in a proof-of-concept project. The farmers documented their coping strategies in relation to erratic weather events, pests & diseases and other aspects farmers find relevant for describing their agricultural realities. After 5 years, 'Sauti ya wakulima' has been fully embraced by the farmers’ communities, and runs in an autonomous fashion, with support from the Bagamoyo Agricultural Office and the farmers themselves. A rich knowledge base of over 3000 images

[63] Other application areas for ICT in food security include insurance, finance, and risk prevention.

& 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. Since summer 2016, the ERV Methodology has been upgraded and is currently being upscaled by the Swiss development organisation Swissaid to reach thousands of smallholder farmers in the food insecure Masasi region in southern Tanzania.

Source: Angelika Hilbeck, Swiss Federal Institute of Technology, Institute of Integrative Biology, Zurich, Switzerland & Eugenio Tisselli, IT expert, freelance consultant, Barcelona, Spain

3.3 Governing Agricultural Innovation and Policy Coherence

One of the relevant aspects that concerns food security is to assure policy coherence. Sustainable agricultural development is possible if effective governance mechanisms take place and policy coherence 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 level is fostered (CFS & HLPE, 2014, 2015, 2016). Such 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 R&D system.

Policy coherence and participation require a system approach, where achieving food security is considered as 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 improve agricultural yield and quality through the better management of on-farm inputs (e.g., fertilizers, herbicides, and water), better maintenance of soil health, and the use of appropriate harvest and post-harvest technologies. Extension services can include the following activities: creating or disseminating valuable information; facilitating training; and value-added interventions that can save crops and livestock or improve the quality of cash crops for the market.[64] In particular, extension services training can include a range of issues including agronomic practices, natural resource management, livestock health and management, accessing financial support, and accessing markets (and/or market intermediaries).

[64] For example, the World Food Programme's (WFP) "Magic Box" can be used by extension agents or farmers to test the quality of products before selling to private sector companies or organizations like WFP.

One prominent example of the impact of extension services on agronomic practice is the case of Ethiopian farmers of teff (the national grain). Farmers traditionally broadcast their seeds (i.e., manually scattered seeds 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%, reduce the amount of seeds needed for sowing by 90%, and result in teff with bigger leaves and stronger stalks (Ethiopia ATA, 2012; IFPRI, 2013; Swanson, 2006; Swanson, 2008; Buluswar et al., 2014). In another example in West Africa, a regional program for integrated pest management serving 30,000 farmers resulted in 75 percent median reduction in pesticides, 23 percent yield increases, and 41 percent net margins (FAO, 2009; UN, 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 (see text box below). 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, the impact of their work, and their 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 West Africa through Participatory Research

Approximately 2% of the 2 million cotton farms in West Africa produce for global organic markets. The EuropeAid-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[65], INRAB[66]) 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.

Centered around these locally organized researcher-farmers, within a reach of 2 hours bicycle ride, innovation platforms (IP) were established to promote appropriate technologies favoring the livelihood and increasing the family or household farming resilience among all other farmers. The farmers taking part in this IP met several times per year to exchange experiences and coordinate actions. In total, ten 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

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

remained the 100 elected farmer-researchers, of which 40% were women who reported back directly to their over 2,500 colleagues across multiple villages. All IP 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 were in communication, cost reduction for field visits by researchers and institutional stability and durability (research, farmer organizations and markets). The participatory approach at the center of the research method materialized through the IP's social learning among the involved stakeholders. Farmers' capacities to analyze 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%, while applying combinations of various technologies could increase yields by more than 30%.

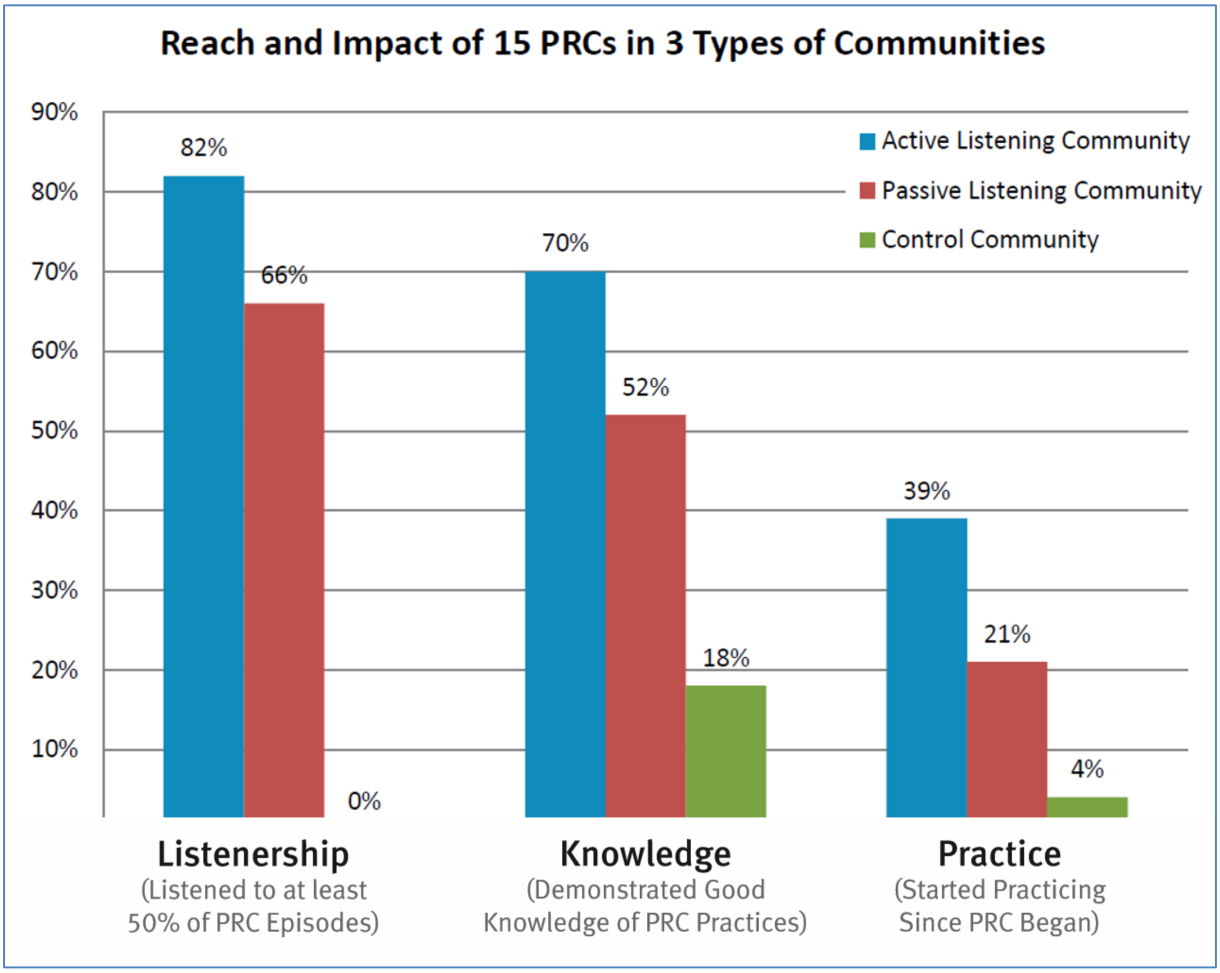
Source: Gian L. Nicolay, FiBL

3.4.2 Information and Communication Technologies for Extension Services

Information and communication technologies (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. The nongovernmental organization Digital Green trains farmers in remote locations - like Narma Dih in Bihar, India - with locally-produced how-to videos (World Bank, 2016). Similarly, participatory radio campaigns (PRCs) 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 programs, that agricultural knowledge was acquired, and that such knowledge translated into improved agricultural practices (Figure 7) (Farm Radio International, 2011).[67]

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

Figure 7: Impact of Participatory Radio Campaigns for Extension Services



Source: (Farm Radio International, 2011)

<u>3.4.3 Sharing Plant Genetic Resources</u>

Public investment in breeding programs 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 & HLPE, 2013) An excellent program based in Portugal demonstrating the public benefits of seedbanks is described below (Box 12).

Box 12: Portuguese Information System for Plant Genetic Resources[68]

On 13 February 2015, the Banco Português de Germoplasma Vegetal – the Portuguese national genebank – 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 level. Hosted in Braga, Portugal, it includes 45,000 samples from 150 species and 90 genus of cereals, aromatic and medicinal plants, fibers, 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 genebank 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 genebanks with a powerful, flexible, easy-to-use global plant genetic resource information management system that will allow genebanks 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, as men are much more likely than women to move to non-farm jobs (Agarwal, 2012). In developing countries, women comprise approximately 43 percent of the agricultural labour force, ranging from 20 percent in Latin America to 50 percent in South Eastern Asia and sub-Saharan Africa (FAO, 2011a). Despite their prominent role in food production and processing, women typically have limited access to resources (e.g., 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, there should be more emphasis placed on encouraging women to become involved in agricultural science and extension (UNESCO, 2007; AAUW, 2010).

[68] The case study provided as input by the Government of Portugal.

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 SDGs pave the ground and framework for the 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 (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% annually between 1995 and 2000 and 15% annual after 2000 was considered key to the adoption of advanced technologies by poor farmers (UNCTAD, 2015b). Globally, it has been by estimated by FAO, IFAD and WFP that eradicating hunger by 2030 will require an additional $267 billion annually (UN, 2015b; FAO, IFAD and WFP 2015). It has been estimated that by the United Nation's Environment Programme's green economy models that 0.16 per cent of global GDP devoted to sustainable agriculture per year ($198 billion between 2011 and 2050) could provide significant returns (UN, 2015b).

4.2 Promote Sustainable Food Systems

STI for achieving food security in the context of the 2030 agenda have to be put into a three-pronged context of a sustainable food system: (i) the socio-economic dimension, mainly understood as a reduction of poverty and (socioeconomic and gender) inequality, particularly in rural areas; (ii) the environmental dimension, focusing primarily on environmental integrity and the reproductive capacity of the agro-ecological system; and (iii) the resilience dimension, emphasizing socio-ecological resilience. Governments should assure a balanced and system-focused approach to the production of food, feed and fiber, 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 impact on all dimensions of food security, not only agricultural production. In order to achieve SDG 2, locally adapted, context-specific pathways to sustainable agricultural development for food security incl. adaptation strategies and coping mechanisms are needed. For example, the Swiss Federal Office for Agriculture FOAG is co-leading the 10YFP Sustainable Food Systems Programme, a multi-stakeholder initiative to accelerate the shift towards more sustainable food systems that deliver food security and nutrition for present and future generations. A major strength of the Programme is that it brings together existing initiatives and partnerships working in related areas, aiming to promote sustainability all along the food value chain.[69]

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 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 for achieving the goal of completely eradicating hunger and malnutrition by 2030 in a truly sustainable way.

- The role of fertile soils and soil protection: It should always be assured 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. In case 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 livelihood basis, particularly for smallholder farmers and agricultural laborers. 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 programs on orphan crops: Breeding programs on orphan crops need to be developed, adequately differentiated for country- and region-specific preferences and needs. Participatory approaches and assuring farmer's rights for further breeding and seed production, etc. are necessary for the success of such programs. These programs need considerable funding and coordination, which should be taken over by most suited institutions for this.

4.4 Develop Coherent Policy for Food Security

Policies from the local to the global level have to support the transition towards sustainable food and farming systems in a coherent and targeted way. Policy makers 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 inter-related 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

[69] This case study is provided as input by the Government of Switzerland.

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 as 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 inter-ministerial and inter-sectoral coordination and collaboration.[70]

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 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 have to 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 high-quality 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 & HLPE, 2013). One 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 (drones, 3d-printers, remote sensing, etc.). 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 via mobile phones are already explored in a range of projects, but there needs to be a somewhat coordinated approach towards these issues. One key aspect is to make available options such as specific apps widely known; for this, a number of key web-sites as entry-points to these services should be set up, by institutions with a long-term 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 centers may play a coordinating role in this regard. However, attention must be paid to issues of privacy, security, and data ownership and access.

[70] One example of food security policy is the SAN CELAC Plan of Costa Rica for Food Security, Nutrition, and Hunger Eradication, as pointed out by the Government of Costa Rica.

4.6 Improve access to agricultural technologies and data for smallholder farmers

New and existing UN mechanisms for technology transfer, facilitation, and dissemination like the UN Technology Facilitation Mechanism and the UN 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 Least Developed Countries to access emerging technologies that increase yields, mitigate on-farm and off-farm losses, and broadly promote sustainable agriculture. Foundations, nonprofit 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, esp. 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. In fact, irrigation technologies like 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 UN system should consider how to make available agricultural, meteorological, Internet of things, satellite, and other data that could help optimize yields and support rural livelihoods. Civil society and nonprofit organizations like GODAN[71] 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

Establish education and research programs and institutions in areas where results are urgently needed. This concerns in particular the establishment of a knowledge base and pool of experts for developing the capacity of agriculture to adapt to climate change and related resilience of agro-ecological, economic and social systems. This may encompass targeted master programs at existing applied and research universities, as well as at new university institutes, departments and curricula.[72] This requires significant funds and a long-term commitment, but it could lay the foundation for many of the activities mentioned in the report. FAO and CGIAR centers, 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 ODA. This can happen in the agricultural sector where donors can contribute to agricultural research, esp. in LDCs. Other measures include encouraging investments from the private sector as well as making sure that CGIAR work reflects the realities of smallholder farmers in LDCs. With respect to stimulating industry and infrastructure, ODA "Knowledge Aid" can focus on value-chain development schemes, FDI complementation and linkage development, project funding for industrial and physical infrastructure, promoting global engineering associations and NGO's, and facilitating South-South collaboration.[73] Regional cooperation can also achieve

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[71] Global Open Data for Agriculture & Nutrition: www.godan.info.

[72] 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.

[73] 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.

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 international cooperation activities can be a potential source of funding for developing countries. For example, the US National Institutes of Health, the European Union's Framework Programme, and Canada's Grand Challenges programme earmark funding for collaboration 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.[74]

4.9 Strengthen the enabling environment for agriculture and food security

Roads, electricity, cold storage and agro-processing facilities, information and communication 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. Other measures include strengthening knowledge and extension links among the scientific community, rural producers' organizations and NGOs; facilitating technology transfer, esp. with the use of non-proprietary genetic material and research to develop locally adapted genetic material able to 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.

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

Appendix

*Box 13: The four dimension of food security (*FAO 2016)

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 and*
- *average supply of protein of animal origin.*

Dimension 2: Food access

- *percent 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 the food deficit and*
- *prevalence of food inadequacy.*

Dimension 3: Food stability

- *cereal import dependency ration,*
- *percent 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 and*
- *per capita food supply variability.*

Dimension 4: Food 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 and*
- *prevalence of school-age children (6-12 years) with insufficient iodine intake*

Box 14: The Sustainable development goals and food security

The **SDG 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.
SDG 2 aims at ending hunger and ensure 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. SDG 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. 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 **SDG 3** is to ensure healthy lives and promote well-being for all at all ages deals with the question how mortality ratios could be reduces and the incidence of diseases prevented. The target 3.3 directly acknowledges the relationship between water-born 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 utilization to provide access to improved water sources.
The **SDG 4**, to ensure inclusive and equitable quality education and promote lifelong learning opportunities for all is not explicitly related to the four food security dimensions. However, one of the potential influences of achieving the targets from this goal may be that youth and adults are trained technical (target 4.4) and that they receive the knowledge and skills to promote a sustainable development (target 4.7).
Similar, the **SDG 5**, which aims to achieve gender equality and empower all women and girls, may help to increase food availability, stability and utilization by ensuring that discrimination against women and girls are 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, 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.
The **SDG 6** is to ensure availability and sustainable management of water and sanitation for all, may help to achieve food stability and food utilization indicators of the food security dimensions. The targets 6.1/6.2 and 6.a deal with the access, improvement and investments into safe and affordable water and sanitation structures. To achieve these targets is likely to promote that more people have access to improved water sources and sanitation facilities (food security utilization dimension) and that 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).
SDG 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 consumes XYXY percent of the global fossil fuels and emits 13% of global GHG emissions (IPCCC).
In order to ensure long-term sustainability, it is unavoidable that GHG emissions from this

sector are reduced, while productivity is maintained.
The **SDG 8** is about promoting sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all may help to increase these investments. The 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).
The **SDG 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 that more people will have sufficient availability of food. Additionally, the 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. The targets 9.1/9.2/9.4 and 9.a additionally aim to increase the share of resilient infrastructures, particular in developing countries, where food security is partly still limited by the sole access to food and its markets.
SDG 10 As mentioned beforehand, one of the food security dimension covers the political stability and the absence of violence/terrorism. This may be influenced by the target 10.2, to empower and promote the social, economic and political inclusion of all.
Additionally, the 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. The prevention of war and political conflicts is essential for the long-term food availability and access as shown by research from J. Sachs and covers all the four food security dimensions (here, I need to add a proper reference on this).
While the **SDG 11** mainly concentrates on the inclusive, sage, resilient and sustainable development within cities, one of the target may help to promote the food security dimension of food access. The target 11.2 aims to promote transportation systems, which comes along 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 may provide a means for people to travel more comfortable to the next nearby market to buy agricultural goods. Further, the investments into infrastructures may open up new export/import markets and thus may help to increase the available food.
SDG 12 One of the further developed food security concepts within the SDGs in comparison to the four dimensions is the integration of the global food waste challenge. Target 12.3 obliges the global society to halve the per capita global food waste. This again may help to increase the available food, in particular for the poor. However, the consideration of food wastes and thus the question of how the produced food is used within the SDGs may help to achieve food security in the long-run.
The **SDG 13** aims to reduce climate change, while adapting the different sectors to the impacts. The integration of climate change consideration into the context of food security is essential to ensure long-term sustainability.
The **SDG 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 utilization.
The complementing **SDG 15**, to protect, restore and promote sustainable use of terrestrial ecosystems may has also an impact on the food security indicator of the access to improved water sources. By 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 become improved and thus more people, particular in rural areas, may use natural water bodies more safely as water sources (food utilization).
SDG 16 is dedicated to the promotion of peaceful and inclusive societies for sustainable development, the provision of access to justice for all, and building effective, accountable institutions at all levels.
Last, the **SDG 17**, to strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development, may has effects on all the four food security dimensions. Depending on the investments done and the access to science, technology and innovation promoted global inequalities of food availability, access, stability and utilization may be reduced. One of the potential leakages from this goal may be target 17.11 that aims to increase the exports from the developing countries.

Table 2: The relationship between the 4 food security dimensions and the SDGs (2016). The X indicates coverage of the respective dimension of food security by the SDG.

	Availability	**Access**	**Stability**	**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				

Table 3: SDG targets related to the SDG 2 End Hunger with a relation to STI

	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 SDG 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 SDG 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 SDG 9						
Task 9.b Support domestic STI for e.g. industrial diversification and value addition to commodities	X	X	X			
Task SDG 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 SDG 13							
13.1 Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in al1	X	X	!	!	!	!
Tasks SDG 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	X	X	!			

X: STI directly or indirectly through quantitative targets, addressed in the SDG. !: 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. (Source: 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 utilization and stability over time. (Source: SOFI 2015)
Hunger	"The term hunger is used as being synonymous with chronic undernourishment." (Source: 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. (Resource: http://www.fao.org/hunger/glossary/en/)
Macronutrients	In this document, the proteins, carbohydrates and fats that are available to be used for energy. They are measured in grams (FAO, IFAD, WFP 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, IFAD, WFP 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)." (Resource: http://www.fao.org/hunger/glossary/en/)

References

AAUW (American Association of University Women) (2010). Why so few? Women in science, technology, engineering and mathematics. Washington, DC, February.

ActionAid (2010). Fertile ground: How governments and donors can halve hunger by supporting small farmers. London.

Affognon, H. and others, "Unpacking postharvest losses in sub-Saharan Africa: a meta-analysis", World Development, vol. 66 (February 2015).

ALEXANDRATOS, N. & BRUINSMA, J. 2012. World agriculture towards 2030/2050: the 2012 revision. ESA Working paper.

Asseng, S., Ewert, F., Martre, P., Rötter, R., Lobell, D., Cammarano, D., Kimball, B., Ottman, M., Wall, G. & White, J. 2014 Rising temperatures reduce global wheat production. Nat. Clim. Change 5, 143-147.

Bazerghi, C., McKay, F.H. and Dunn, M. 2016. The Role of Food Banks in Addressing Food Insecurity: A Systematic Review. Journal of Community Health 41: 732.

H. Baumüller. Mobile technology trends and their potential for agricultural development. ZEF Working Paper 123, November 2013.

Bellarby J, Foereid B, Hastings A and Smith P 2008. Cool Farming: Climate impacts of agriculture and mitigation potential. Amsterdam, Greenpeace International. Available at: http://www.greenpeace.org/international/Global/international/planet-2/report/2008/1/cool-farming-full-report.pdf.

Brennan, H. and Kilic, B. 2015. Freeing Trade at the Expense of Local Crop Markets?: A Lookt at the Trans‑Pacific Partnership's New Plant‑Related Intellectual Property Rights from a Human Rights Perspective. Harvard Human Rights Journal Online. Available at: http://harvardhrj.com/wp-content/uploads/2015/04/Brennan_Kilic_HRJ_04-11-152.pdf

Buluswar, S., et. al (2014). *50 Breakthroughs: Critical scientific and technological advances needed for sustainable global development.* Food Security and Agricultural Development Report. Berkeley, CA: Institute for Globally Transformative Technologies, Lawrence Berkeley National Lab.

CCAFS (2012), CGIAR Research Program on Climate Change, Agriculture and Food Security. Achieving food security in the face of climate change. Final report from the Commission on Sustainable Agriculture and Climate Change. Available at: https://cgspace.cgiar.org/bitstream/handle/10568/35589/climate_food_commission-final-mar2012.pdf

CFS & HLPE 2013. Investing in Smallholder Agriculture for Food Security: Extract from the Report, Summary and Recommendations. Committee on World Food Security, High Level Panel of Experts on Food Security and Nutrition, Rome.

CFS & HLPE 2014. Food losses and waste in the context of sustainable food systems. Committee on World Food Security, High Level Panel of Experts on Food Security and Nutrition, Rome.

CFS & HLPE 2016. Sustainable agricultural development for food security and nutrition: what roles for livestock? Committee on World Food Security, High Level Panel of Experts on Food Security and Nutrition, Rome.

Challinor, A., Watson, J., Lobell, D., Howden, S., Smith, D. & Chhetri, N. 2014 A meta-analysis of crop yield under climate change and adaptation. Nat. Clim. Change 4, 287-291.

Christoplos I (2010). Mobilizing the potential of rural and agricultural extension. Rome, FAO

DEFRIES, R., FANZO, J., REMANS, R., PALM, C., WOOD, S. & ANDERMAN, T. L. 2015. Metrics for land-scarce agriculture. Science, 349, 238-240.

DESA. 2015. United Nations Department of Economic and Social Affairs: World population projected to reach 9.7 billion by 2050 [Online]. Available: http://www.un.org/en/development/desa/news/population/2015-report.html [Accessed 07/10/2016.

De Schutter, O. 2011. The World Trade Organization and the post-global food crisis agenda: putting food security first in the international trade system. In: Activity Report of the UN Special Rapporteur on the Right to Food.

P. Dillenbourg and M. Evans. Interactive tabletops in education. International Journal of Computer-Supported Collaborative Learning, 6, (4), pp. 491–514, 2011.

Ericksen, Polly J., John SI Ingram, & Diana M. Liverman. 2009. Food security and global environmental change: emerging challenges. Environmental Science & Policy 12.4,373-377.

Ethiopia ATA, 2012. Annual report.

FAO Food security methodology, accessible at: http://www.fao.org/economic/ess/ess-fs/fs-methods/fs-methods1/en/

FAO 2006 World agriculture: towards 2030/2050 – Interim report. Rome http://www.fao.org/fileadmin/user_upload/esag/docs/ Interim_report_AT2050web.pdf

FAO, Investing in Food Security(2009). Available from http://www.fao.org/fileadmin/templates/ ag_portal/docs/i1230e00.pdf.

FAO (2010). Gender: Crops. Available at: http://www.fao.org/gender/gender-home/gender-programme/gender-crops/en/.

FAO, 2011. The State of Food and Agriculture 2010-2011.

FAO. 2015 a. Mapping the vulnerability of mountain peoples to food insecurity. Romeo, R.,Vita, A., Testolin, R. & Hofer, T. Rome.

FAO, 2015 b. The State of Agricultural Commodity Markets, Trade and food security: achieving a better balance between national priorities and the collective good

FAO. 2016a. Food Security Indicators [Online]. Available: http://www.fao.org/economic/ess/ess-fs/ess-fadata/en/ [Accessed 02/09/2016.

FAO. 2016b. Food security statistics [Online]. Available: http://www.fao.org/economic/ess/ess-fs/en/ [Accessed 02/09/2016.

FAO. 2016c. World Hunger Map 2015 [Online]. Available: http://www.fao.org/hunger/en/ [Accessed 02/09/2016.

FAO, IFAD & WFP 2015. The State of Food Insecurity in the World. Meeting the 2015 international hunger targets: taking stock of uneven progress. Rome: Food and Agriculture Organisation of the United Nations.

Farm Radio International, 2011, "Agricultural Radio That Works." URL: http://www.farmradio.org/wp-content/uploads/Farm-Radio-Agriculture-Radio-That-Works.pdf.

FiBL/Adamtey 2016. http://www.systems-comparison.fibl.org/fileadmin/images/subdomains/syscom/News/SysCom_Kenya_International_media_release.pdf

Fjeld, M., P. Woźniak, J. Cowls and B. Nardi. Ad hoc encounters with big data: Engaging citizens in conversations around tabletops. First Monday 20, no. 2, 2015.

Folberth, G. and others, "Effects of ecological and conventional agricultural intensification practices on maize yields in sub-Saharan Africa under potential climate change", Environmental Research Letters, vol. 9, No. 4 (April 2014).

GLS Treuhand, Zukunftsstiftung Landwirtschaft (2014). Wege aus der Hungerkrise, Berlin, p.5. Available at: http://www.weltagrarbericht.de/fileadmin/files/weltagrarbericht/Neuauflage/WegeausderHungerkrise_klein.pdf

Guo,L, W. Wang and N. Xie. A Study of the Application of Big Data in a Rural Comprehensive Information Service. Data Science Journal, 14: 12, pp. 1-8, 2015.

Huyer S et al. (2005). "Women in the information society." In: Sciadas G, ed. From the Digital Divide to Digital Opportunities: Measuring Infostates for Development. Montreal, Orbicom.

IFOAM, 2015. Feeding the people: Agro-ecology for nourishing the world and transforming the agri-food system, Brussels. Available at: http://www.ifoam-eu.org/sites/default/files/ifoameu_policy_ffe_feedingthepeople.pdf

IFPRI, 2013. A Little Seed Goes a Long Way. [Online]. http://reap.ifpri.info/2013/08/07/a-little-seed-goes-a-long-way

INGRAM, J. 2016. What determines food security status? Presentation at the colloquim on Food Security an Nutrition in the Context of the 2013 Agenda: Science and Knowledge for Action, University of Hohenheim, Germany. 27 September 2016. Available at: https://gfe.uni-hohenheim.de/fileadmin/einrichtungen/gfe/Dateien/HLPE_John_Ingram.pdf

Intergovernmental Technical Panel on Soils (IPTS) (2015). Status of the World's Soil Resources (SWSR).

IPES-Food. 2014. The new science of sustainable food systems. Overcoming barriers to food systems reform. http://www.ipes-food.org/images/Reports/UniformityToDiversity_FullReport.pdf

IPES-Food. 2016. From uniformity to diversity: a paradigm shift from industrial agriculture to diversified agroecological systems. International Panel of Experts on Sustainable Food systems. http://www.ipes-food.org/images/Reports/UniformityToDiversity_FullReport.pdf

ITPS. 2015. Status of the World's Soil Resources. Main report, prepared by the Intergovernmental Technical Panel on Soils. FAO, Rome. Available at: http://www.fao.org/documents/card/en/c/c6814873-efc3-41db-b7d3-2081a10ede50/

Juma, C. 2015. *The New Harvest: Agricultural Innovation in Africa*. Second Edition. New York: Oxford University Press.

Juma, C., & Yee-Cheong, L. 2005. *Innovation: Applying knowledge in development*. Report of the UN Millennium Project Task Force on Science, Technology, and Innovation. London: Earthscan.

Ki-Seok Kim and Ki-Seok Lee (forthcoming). Literace and its embedded transformative power for development: The case of Burkina Faso. Seoul National University.

Larsen, K. et. al., 2009. *Agribusiness and Innovation Systems in Africa.* Washington, DC: World Bank.

Lobell, D., Schlenker, W. & Costa-Roberts, J. 2011 Climate Trends and Global Crop Production Since 1980. Science 333, 616-620.

Massawe, F., Mayes, S., & Cheng, A. 2016. Crop diversity: an unexploited treasure trove for food security. *Trends in plant science*, *21*(5), 365-368.

Mekonnen, M., & Hoekstra, A. 2016. "Four billion people facing severe water scarcity." *Science Advances*. 12 February. Vol. 2 No. 2. URL: http://advances.sciencemag.org/content/2/2/e1500323

Meera, S.N., V. Balaji, P. Muthuraman, B. Sailaja and S. Dixit. Changing Roles of Agricultural Extension: Harnessing Information and Communication Technolog y (ICT) for Adapting to Stresses Envisaged under Climate Change. In Crop Stress and Its Management: Perspectives and Strategies, edited by B. Venkateswarlu, A. K. Shanker, C. Shanker and M. Maheswari, 585–605. Amsterdam: Springer, 2012.

Meinzen-Dick R et al. (2010). "Engendering agricultural research." IFPRI Discussion Paper 973, International Food Policy Research Institute, Washington, DC.

Müller A., Gattinger A. 2013. Conceptual and practical aspects of climate change mitigation through agriculture: reducing greenhouse gas emissions and increasing soil carbon sequestration. In; UNCTAD Trade and Environment Review 2013.

Müller A., Niggli, U. 2013. The Potential of Sustainable Agriculture for Climate Change Adaptation. In: UNCTAD Trade and Environment Review 2013.

Müller, C., Bondeau, A., Popp, A., Waha, K. & Fader, M. 2010 Climate Change Impacts on Agricultural Yields. In World Development Report 2010, Background Note (Potsdam Institute for Climate Impact Research).

Müller, C. & Robertson, R.D. 2014 Projecting future crop productivity for global economic modeling. Agr. Econ. 45, 37-50.

Pearce. J.M. Applications of Open Source 3-D Printing on Small Farms, Organic Farming 1(1): 19-35, 2015

Ponisio L.C. and Ehrlich, P.R., 2016. Diversification, yield and a new agricultural revolution: problems and prospects. Sustainability, No. 8. Available at: www.mdpi.com/journal/sustainability.

Porter, J.R., Xie, L., Challinor, A.J., Cochrane, K., Howden, S.M., Iqbal, M.M., Lobell, D.B. & Travasso, M.I. 2014. Chapter 7: Food Security and Food Production Systems. In Climate Change 2014, Contribution of the WG II to the 5th Assessment Report of the IPCC (Cambridge University Press).

Ranganathan, J., Vennard, D., Waite, R., Dumas, P., Lipinski, B. & Searchinger, T. 2016. Shifting diets for a sustainable food future. Working paper, installment 11 of creating a sustainable food future, World Resources Institute, Washington, DC, USA.

Reid, P., & Vogel, C. 2006. Living and responding to multiple stressors in South Africa—Glimpses from KwaZulu-Natal. Global Environmental Change, 16(2), 195-206.

Renkow M. and Byerlee D. 2010. The impacts of CGIAR research: A review of recent evidence. Food Policy, 35 (5):391-402. Available at: http://impact.cgiar.org/sites/default/files/pdf/RenkowByerlee2010.pdf

Rockström, J., Williams, J., Daily, G., Noble, A., Matthews, N., Gordon, L., et al. 2016. Sustainable intensification of agriculture for human prosperity and global sustainability. Ambio, 1-14.

Ruddiman, W. F., Ellis, E. C., Kaplan, J. O., & Fuller, D. Q. (2015). Defining the epoch we live in. Science, 348(6230), 38-39.

Rundren, G. 2015. Global Eating Disorder. Regeneration Publishers, Uppsala, Sweden.

Schader, C., Müller, A., El-Hage Scialabba, N., Hecht, J., Isensee, A., Erb, K.-H., Smith, P., Makkar, H. P. S., Klocke, P., Leiber, F., Schwegler, P., Stolze, M., and Niggli, Urs (2015). 'Impacts of feeding less food-competing feedstuffs to livestock on global food system sustainability '. Journal of Royal Society Interface 12: 20150891.

Schneider, M., et al. "Cocoa and total system yields of organic and conventional agroforestry vs. monoculture systems in a long-term field trial in Bolivia." Experimental Agriculture (2016): 1-24.

Smith P, Martino D, Cai Z, Gwary D, Janzen H, Kumar P, McCarl B, Ogle S, O'Mara F, Rice C, Scholes B and Sirotenko O (2007). Agriculture. In: IPCC, Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, Cambridge University Press.

Steffen, Will, et al.2015 "Planetary boundaries: Guiding human development on a changing planet." Science 347.6223: 1259855.

Swanson, B., 2006. The Changing Role of Agricultural Extension in a Global Economy. Journal of International Agricultural and Extension Education.

Swanson, B., 2008. Changing Paradigms in Agricultural Extension. International Seminar on Strategies for Improving Livelihood Security of Rural Poor. Goa, India.

Thönnissen, C., 2016. The contribution of the Swiss Agency for Development and Cooperation (SDC) to CGIAR 2016-2019. Presentation of the SDC Global Programme Food Security, 21 April 2016.

UN 2015. Transforming our world: the 2030 Agenda for Sustainable Development (A/RES/70/1). In: UNITED NATIONS GENERAL ASSEMBLY (ed.). New York.

UN 2015b. "Agricultural Technology for Development." Report of the Secretary-General. United Nations. http://www.un.org/ga/search/view_doc.asp?symbol=A/70/298&Lang=E.

UNCTAD. 2002. *Key Issues in Biotechnology*. New York and Geneva: United Nations.

UNCTAD. 2004. *The Biotechnology Promise: Capacity-Building for Participation of Developing Countries in the Bioeconomy*. New York and Geneva: United Nations.

UNCTAD. 2007. *The Least Developed Countries Report 2007*. New York and Geneva: United Nations.

UNCTAD. 2010. *Technology and Innovation Report 2010: Enhancing food security in Africa through science, technology and innovation*. New York and Geneva: United Nations.

UNCTAD. 2011. Applying a Gender Lens to Science, Technology and Innovation. Geneva: UNCTAD.

UNCTAD. 2012. Information Economy Report 2012, Geneva: United Nations.

UNCTAD, 2013b. UNCTAD Handbook of Statistics 2013. Online version accessible at: www.unctad.org.

UNCTAD 2015. UNCTAD Handbook of Statistics. United Nations, New York.

UNCTAD. 2015b Commodities and Development Report. Geneva: United Nations.

UNCTAD 2015c. *Science, Technology & Innovation Policy Review: Thailand.* Geneva and New York: United Nations.

UNCTAD. 2015d. *The Least Developed Countries Report 2015: Transforming Rural Economies*. New York and Geneva: United Nations.

UNCTAD 2016. TRADE AND DEVELOPMENT REPORT, 2016. United Nations, New York.

UNCTAD 2013a. Trade and Environment Review 2013: Wake up before it is too late: Make agriculture truly sustainable now for food security in a changing climate. United Nations, Geneva.

UNESCO (2007). Science, Technology, and Gender: An International Report. Paris.

Wakhungu JW (2010). “Gender dimensions of science and technology: African women in agriculture.” Paper prepared for the UN Women Expert Group Meeting on Gender, Science and Technology. Paris, 28 September–1 October 2010. Available at: http://www.un.org/womenwatch/daw/egm/gst_2010/index.html.

World Bank. 2008. *World Development Report 2008: Agriculture for Development*. Washington, DC: World Bank.

World Bank and FAO (2009). Awakening Africa’s Sleeping Giant

World Bank. 2016. *World Development Report 2016: Digital Dividends*. Washington, DC: World Bank.