United Nations Food Systems Summit 2021
Scientific Group
Scientific Group https://sc-fss2021.org/

Ensuring Access to Safe and Nutritious Food for all Through Transformation of Food Systems

- a paper on Action Track 1 -

Updated draft for discussion

November 25th, 2020

Sheryl Hendriks, Jean-François Soussana,
Martin Cole, Andrew Kambugu,
David Zilberman

The Scientific Group for the UN Food Systems Summit is an independent group of leading researchers and scientists from around the world. Its members are responsible for ensuring the robustness, breadth and independence of the science that underpins the Summit and its outcomes. https://www.un.org/en/food-systems-summit/leadership

Joachim von Braun (Germany) Chair of the Scientific Group. Director of the Center for Development Research (ZEF), Bonn University, and Professor for economic and technological change.

Kaosar Afsana (Bangladesh) Vice Chair of the Scientific Group. Professor Public Health, BRAC University.
Louise Fresco (Netherlands) Vice Chair of the Scientific Group. President of the Executive Board, Wageningen University & Research.
Mohamed Hassan (Sudan) Vice Chair of the Scientific Group. President of The World Academy of Sciences for the advancement of science in developing countries (TWAS).
Mario Herrero Acosta (Costa Rica) Chief Research Scientist of Agriculture and Food, The Commonwealth Scientific and Industrial Research Organisation (CSIRO).
Ousmane Badiane (Senegal) Chairperson of Akademiya2063, former Africa Director for the International Food Policy Research Institute (IFPRI).
Patrick Caron (France) Vice President of the University of Montpellier, President of Agropolis International and Director of the Montpellier Advanced Knowledge Institute on Transitions
Martin Cole (Australia) is Professor for Agriculture and Food within the Commonwealth Science and Industrial Research Organisation (CSIRO). Chairperson of the HLPE Steering Committee of CFS.
Ismahane Elouafi (Morocco) Chief Scientist, Food and Agriculture Organization of the United Nations (FAO).
Frank A. Ewert (Germany) Scientific Director, Leibniz Centre for Agricultural Landscape Research (ZALF).
Sheryl L. Hendriks (South Africa) Professor of Food Security & Director, Institute for Food, Nutrition and Well-being, University of Pretoria.
Thomas W. Hertel (USA) Professor of Agricultural Economics at Purdue University and Executive Director of the Global Trade Analysis Project (GTAP).
Jikun Huang (China) Professor at School of Advanced Agricultural Sciences and Director of China Center for Agricultural Policy (CCAP), Peking University.
Marta Hugas (Spain) Chief Scientist at European Food Safety Authority (EFSA).
Elizabeth Hodson de Jaramillo (Colombia) Professor Em. School of Sciences of the Pontificia Universidad Javeriana, and member of Inter American Network of Academies of Sciences (IANAS).
Andrew Kambugu (Uganda) Executive Director Infectious Diseases Institute (IDI), College of Health Sciences, Makerere University. Co-founder of the Researchers for Global Health (R4GH) initiative.
Kaoru Kitajima (Japan) Professor at Kyoto University Graduate School of Agriculture; a forest ecologist, especially in tropical America and Asia.
Rattan Lal (India) Professor of Soil Science, Director of the Carbon Management and Sequestration Center at Ohio State University. World Food Prize Laureate 2020.
Hoesung Lee (South Korea) Chair, Intergovernmental Panel on Climate Change (IPCC), Professor at Korea University Graduate School of Energy and Environment, Seoul.
Uma Lele (India) is President of the International Association of Agricultural Economists (IAAE).
Lynnette M. Neufeld (Canada) incoming President of the International Union of Nutrition Scientists (IUNS), Director Knowledge Leadership, Global Alliance for Improved Nutrition (GAIN).
Urs Niggli (Switzerland) Scientist focusing on sustainable farming systems, from 1990 to 2020 he led the Research Institute of Organic Agriculture (FiBL)
Claudia Sadoff (USA) Executive Management Team Convener and Managing Director, Research Delivery and Impact, of the Consultative Group on International Agricultural Research
Lisa Sennerby Forsse (Sweden) past President, Royal Swedish Academy of Agriculture and Forestry (KSLA) and was the vice-chancellor of the Swedish University of Agricultural Sciences 2006-2015.
Jean-François Soussana (France) is Vice-President of International Policy at the Institute national de la recherche agronomique (INRAE).
Morakot Tanticharoen (Thailand) Professor and Senior Advisor to the President of the National Science and Technology Development Agency (NSTDA), research in microbiology and biotechnology.
Maximo Torero (Peru) ex-officio Member Chief Economist, Food and Agriculture Organization of the United Nations (FAO).
Aman Wirakartakusumah (Indonesia) Professor Em. at Department of Food Science and Technology and Senior Scientist at SEAFAST Center, Bogor Agricultural University (IPB), President-Elect, International Union of Food Science and Technology.
David Zilbermann (Israel, USA) Professor in the Department of Agricultural and Resource Economics, University of California at Berkeley. One of the Founders of the International Consortium of Applied Bio-economy Research (ICABR).

ENSURING ACCESS TO SAFE AND NUTRITIOUS FOOD FOR ALL THROUGH TRANSFORMATION OF FOOD SYSTEMS

Sheryl Hendriks[1], Jean-François Soussana[2], Martin Cole[3], Andrew Kambugu[4] and David Ziberman[5]

1. University of Pretoria; 2. INRAE, Paris (National Research Institute for Agriculture, Food and Environment); 3. University of Adelaide; 4. Makerere University; 5. University of California at Berkeley.

1. Introduction

Action Track 1 of the World Food Summit offers an opportunity to bring together the crucial elements of food safety, nutrition, poverty and inequalities in the framework of food systems that underlie the achievement of the other Action Tracks (See Box 1). These elements are embedded in the fundamental human rights, including the right to food, the rights to safe water and sanitation (essential for safe food) as well as the right to be free from discrimination (enjoy equality). Inequalities in society and the food system make affordable and healthy diets inaccessible to the most vulnerable populations. Malnutrition includes undernourishment, micronutrient deficiencies, as well as overweight and obesity. Malnutrition increases susceptibility to foodborne diseases, creating a vicious cycle for health, reducing productivity and compromising development. The current COVID-19 pandemic has exposed long-standing inequalities in our food and health systems that affect the access to safe and nutritious food as well as income to enable this (Laborde et al., 2020).

Food systems provide a framework to advance access to safe and nutritious food[1] for all. A food system encompasses all the elements and activities that relate to the production, processing, distribution, preparation and consumption of food, as well as the output of these activities, including socio-economic and environmental outcomes (HLPE, 2020).

Box 1: How Action Track 1 (AT1) relates to the other Tracks

Ensuring safe and nutritious food for all (AT1) will require a shift to sustainable production (AT3) and consumption patterns (AT2). If carefully planned and implemented, these changes should lead to co-benefits for climate and the environment (AT3), inclusive development and the development of equitable livelihoods (AT4). Increased coordination, transparency and accountability will help build resilience to vulnerabilities (AT5) across the food system and for the most vulnerable people.

2. What is a safe and nutritious diet?

Established guidelines for dietary intakes for energy, macronutrients, micronutrients and trace elements at different stages of the life cycle, sex and level of activity exist (WHO, 2020). Meeting these requirements demands a diversified diet and small, frequent meals for children. Safe food promotes health and is free of foodborne diseases caused by microorganisms including bacteria, virus, prionics, parasites and chemicals as well as foodborne zoonoses

[1] Including all crops, fish, forest foods and livestock

transferred from animals to humans and other associated risks in the food chain (WHO, 2013). Diet quality comprises four key aspects: variety/diversity, adequacy, moderation and overall balance (FAO, IFAD, UNICEF, WFP and WHO, 2020).

Recent analyses draw attention to the affordability of a healthy diet (FAO, IFAD, UNICEF, WFP and WHO, 2020); Masters et al., 2018). Shocks, including the COVID-19 pandemic, make healthy diets less accessible and affordable, while at the same time increasing the need for a nutritious diet. While the definitions of an adequate diet and safe food are established and widely accepted, there is debate in the literature about what constitutes a sustainable diet. Each proposed diet has trade-offs in terms of affordability, climate and environmental impacts. These trade-offs are discussed in the sections that follow.

3. **We are not on track to meet international targets for ensuring safe and nutritious food for all by 2030**

Despite some progress in reducing the rate of extreme poverty, with only ten years to go to 2030, the world is not on track to meet nutrition-related targets. Updated global data is not available regarding progress on reducing the incidence of foodborne diseases. The scale of foodborne outbreaks has become more extensive and affecting more countries since 2004 (INFOSAN, 2019). Table 1 presents a summary of the international targets related to ensuring safe and nutritious food for all. While the proportion of population undernourished, stunting, low birth weight and anaemia among women of reproductive age have declined, the reductions are not sufficient to meet the global targets. The experience of food insecurity (FIES) has increased slightly as have the numbers of overweight children and adults.

No country is exempt from the surge of malnutrition. Undernutrition coexists with overweight, obesity and other diet-related non-communicable diseases (NCDs), even in poor countries. UNICEF et al. (2020) report that 37% of overweight children reside in low and middle-income countries, highlighting the important role that food systems play in nutrition outcomes. Likewise, fragile and extremely fragile countries are disproportionally burdened by high levels of all three forms of malnutrition compared to non-fragile countries (GNR, 2020).

While some progress has been made in certain countries and in some regions, the 2020 Global Nutrition report shows that no country is 'on course' to meet all eight WHO global nutrition targets being tracked, and just eight countries are on course to meet four WHO 2025 targets for malnutrition (GNR, 2020). Although the actions required for reducing all forms of malnutrition are well documented (Lancet report, various WHO guidelines) and the benefits also (Hoddinott, etc.), progress is far too slow. Unless nutrition-specific (direct) and nutrition-sensitive (indirect) interventions are implemented at scale and in a sustainable way with complementary services (such as regular deworming of children), the impact will be suboptimal (Ruel et al. 2018). In addition, urgent action is necessary to minimise the impact of the Covid-19pandemic on children's nutrition (Ruel et al. 2020)

Table 1 demonstrates the fragmented nature of data on nutrition and food safety in particular. National nutrition assessments are costly and infrequently conducted, constraining the monitoring of progress and the impact of interventions at scale. Even where the indicators have been included in the SGD indicator set, current data on foodborne diseases, some malnutrition indicators (such as wasting), poverty and inequality data are not updated or are missing comparative baselines. Very few sex-disaggregated indicators are available, constraining analysis and the tracking of progress towards gender equality. One recent innovation is the assessment of the adequacy, affordability and access to healthy diets included in the 2020 SOFI report. If continually updated, this indicator could become a comprehensive proxy for monitoring progress on ensuring safe, nutritious food for all.

Table 1: Taking stock

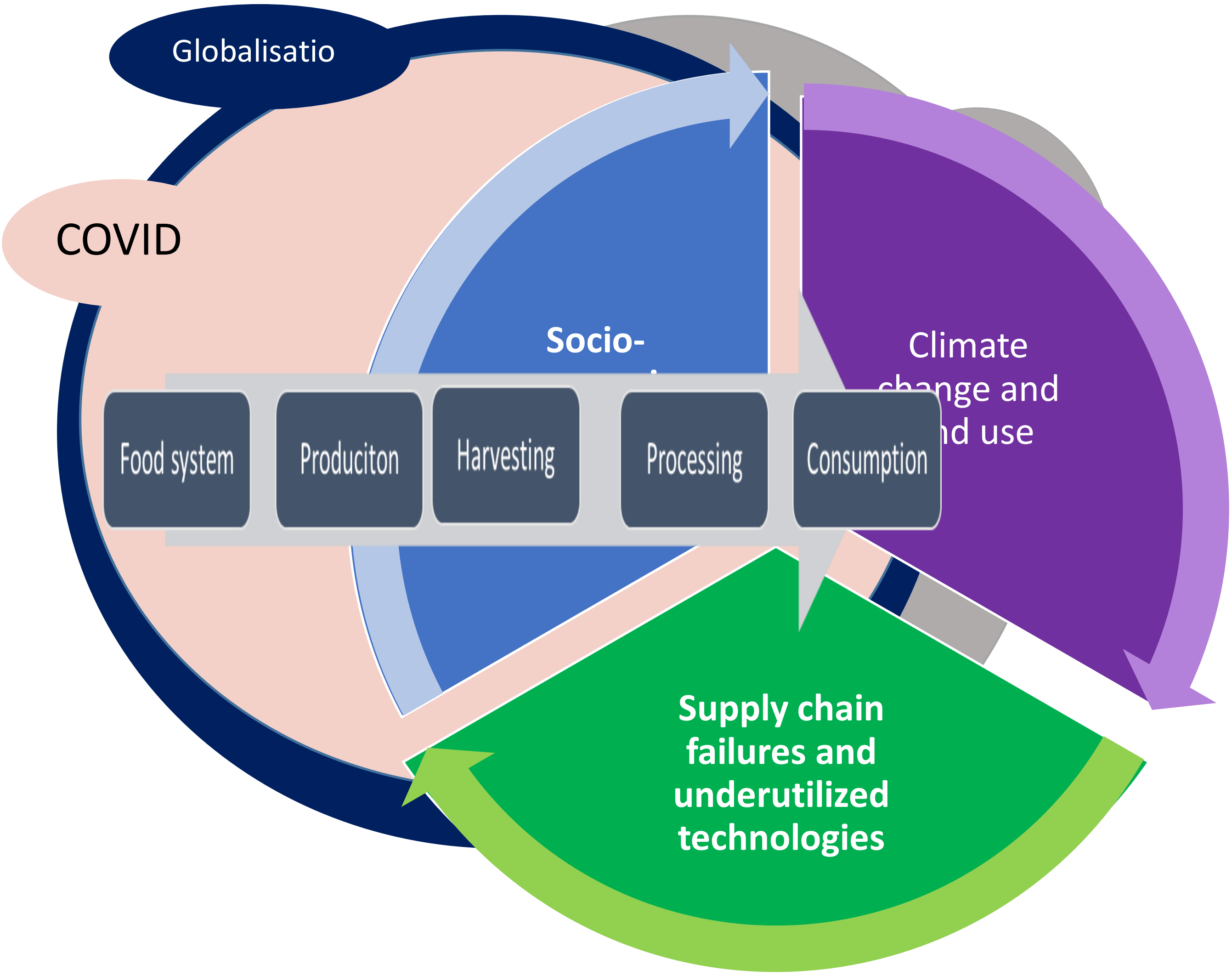
om pon ent	Element	International target/s	Latest global estimates	Progress to date (global)
Nutrition	Hunger (Proportion of the population that is undernourished - PoU)	SGD2: By 2030, end hunger and ensure access by all people, in particular, the poor and people in vulnerable situations, including infants, to safe, nutritious and sufficient food all year round	PoU 8.8% (690M) (SOFI, 2020)	Down from 12.5% in 2004
	Food insecurity (Food Insecurity experience Scale or FIES) moderate or severe food insecurity in the population		FIES - severe = 9% and moderate = 25% (SOFI, 2020)	Severe - up from 8.1% in 2014 Moderate – up from 22.7% in 2014
	Stunting (being short for age)	40% reduction in the number of children under five years of age who are stunted by 2025 and 50% by 2030 (WHO & UNICEF, 2017)	21.3% (moderate and severe) = 149.0 million children under 5 years of age (UNICEF, WHO and the World Bank, 2020)	Down from 24.6% in 2012
	Wasting (being underweight for height)	WHO target: Reduce and maintain childhood wasting at less than 5% by 2025 and less than 3% by 2030 (WHO & UNICEF, 2017)	6.9% (moderate and severe) = 49.5 million children (UNICEF, WHO and the World Bank, 2020)	No available historical estimates, baseline is 2019
	Overweight[2] (children <5 years)	WHO 2025 target: No increase in child overweight	5.6% (SOFI 2020) = 40.1 million under 5 years of age are overweight (UNICEF, WHO and the World Bank, 2020).	Up from 4.9% in 2000
	Obesity[2] (Adults)	WHO 2025 target: halt the rise in levels	13.1% in 2016, there were 677.6 million obese adults (GNR, 2020).	Up from 11.8% in 2012
	Low birthweight	WHO 2025/2030 target: A 30 percent reduction in low birth weight	In 2015 = 14.6% (SOFI, 2020)	Slightly down from 15% in 2012

[2] Body Mass Index (BM) over 30 – calculated as weight/height^2

om pon ent	Element	International target/s	Latest global estimates	Progress to date (global)
	Anaemia (iron deficiency)	WHO 2025/2030 target: A 50 percent reduction of anaemia (iron deficiency) in women of reproductive age	In 2016, 32.8% (SOFI, 2020)	Slightly up from 30.3% in 2012
Food safety	Foodborne Disease Burden	WHO Foodborne Disease Burden Epidemiology Reference Group (FERG 2007-2015), foodborne diseases caused 600 million illnesses, 420,000 deaths, and 33 million Disability Adjusted Life Years (DALYs) in 2010	2010: unsafe food caused 600 million cases of foodborne diseases and 420 000 death equivalent to 33 million years of healthy lives are lost (WHO, 2015).	Unknown – only data for 2010 published
Poverty and inequality	Inequality	SGD1: By 2030 eradicate extreme poverty for all people everywhere, currently measured as people living on less than $1.90 a day.	SGD indictor 1.1.1 Proportion of population below the international poverty line, by sex, age, employment status and geographical location (urban/rural) 2015 = 10% (World Bank, 2018)	Down from 11.2 % in 2013. Data on the split between rural and urban poverty is not yet available.
		Access to affordable and healthy diets (FAO et al., 2020) - SOFI 2020 says 3 billion cannot afford healthy diets	% population that cannot afford an energy-sufficient diet in 2019 = 4.6% % population that cannot afford a nutrient- adequate diet in 2019 = 23.3% % population that cannot afford a healthy diet in 2019 = 38.3% (FAO et al., 2020)	Unknown – this is a new indicator without historical data

4. **Interconnected drivers affect the access to safe and nutritious food for all**

Several interconnected socio-economic and biophysical drivers affect access to safe and nutritious food. Nutrition is both a health and food system concern. While some drivers are global (e.g. trade liberalization, climate change), others are regional (e.g. conflicts) and many are differentiated across geographies (e.g. poverty, demography, technologies, land degradation). Below, we provide a brief overview of the main drivers, which are also depicted in Figure 1.



a) Socio-economic drivers

There is a vast array of socio-economic drivers that increase the global food demand, including population growth (Gerten et al., 2020), westernization of diets, increased food wastes and overweight (including obesity) (Hasegawa et al., 2019), increased demand for animal-sourced foods in diets leading to increased demand of feed from arable crops (Mottet et al., 2017), and rapid urbanisation (van Vliet et al., 2017). These trends could cause a doubling of food demand by 2050 and would require a mean global increase of crop yields by over 30% for a range of scenarios without climate change (FAO, 2018), a value lower than in previous projections that were assuming rapid economic growth (Alexandratos and Bruinjsma, 2012).

Globalisation. Lockdowns caused by the COVID-19 pandemic's of zoonotic origin have disrupted the production, transportation, and sale of nutritious, fresh and affordable foods, forcing millions of families to rely on nutrient-poor alternatives (Fore, Dongyu, Beasley, &

Ghebreyesus, 2020). Globalized food trade narrows food diversification and biodiversity (Khory et al., 2019), since the diversity of agricultural production diminishes as farm size increases (Herrero et al., 2019), and accelerates land and water degradation (Rosa et al., 2019). The availability of cheap, high-energy, fatty and, sugary foods, the high price of nutritious fresh foods and the demand for more 'westernised' and often obesogenic foods increases the incidence of nutrition-related non-communicable diseases (NCDs) (Chaudhary et al. 2018). Nevertheless, globalized supply chains support the wide distribution of foods, , reducing shortages in import-dependent regions (Janssens et al., 2020), improving seasonal availability and often reducing food loss through technological advances in processing, packaging and storage (Zilberman et al., 2019).

Demography and urbanization. Although population growth has slowed globally, the population in the 47 least developed countries (mostly in Africa and Asia) is projected to double between 2019 and 2050. By 2030 the number of youth in Africa will have increased by 42 per cent. Nevertheless, in 2018, for the first time in history, the proportion of older persons (above 65) outnumbered children under five years – a trend that is predicted to continue (UNDESA, 2019). A growing proportion of older people will put a strain on the health system and change nutritional needs and dietary preferences. Moreover, by 2050, 68% of the global population could be urban, shifting the proportion of producers to consumers and of rural to rural poverty, increasing land take (Van Vliet et al, 2019) and pressures on food systems.

Poverty and inequality. Poverty traps millions in poor nutrition, depriving them of their potential (Victoria, 2008). The prevalence of undernutrition and overweight adults are directly linked with relative food prices (Headey and Alderman, 2019). Healthy diets cost between 60 and 400% more than nutrient adequate and energy sufficient diets, respectively (FAO et al., 2020). Currently, more than 1.5 billion people cannot afford a nutrient-adequate diet and over three billion cannot afford even the cheapest healthy diet (FAO, 2020). Food system disruptions caused by COVID measures aggravate this situation (Headly et al., 2020). Despite the catastrophic out-of-pocket costs on health care spent by the poorest billion due to non-communicable diseases and injuries, these conditions account for 60–70% of the public health care costs in low-income and lower-middle-income countries (Zuccala and Horton, 2020). In total, it has been estimated by the World Bank that under and malnourishment costs 3% of global GDP and overweight and obesity another 2% of GDP (Jaffee et al., 2018).

. Women play a key role in multiple components of food systems but inequalities and barriers related to access to opportunities and services such as extension, credit, digital platforms for knowledge and market access constrain their participation. Inequalities and barriers also affect the nutrition and health of minorities and off-farm and food system workers (including migrants and undocumented workers) and this is an important barrier for food system and societal transformation (CFS, 2020).

Conflict and fragility. Conflict can be an outcome and cause of food insecurity. While widespread famine has largely been eradicated, the nature of food crises has changed in recent times. FSIN (2020) reports that in the year 2019 about 135 million people were affected by crisis levels of acute food insecurity – an increase of 11 million people over the previous year (FSIN Food Security Information Network, 2020). While these crises are largely driven by conflict and economic downturns, they have a severe effect on the ability of people to access food. The largest numbers of acutely food-insecure people are in Africa where extreme weather events in the Horn of Africa and Southern Africa have led to widespread hunger. In East Africa, armed conflicts, intercommunal violence and other localised tensions create insecurity (FSIN, 2020). Adverse climate events and stresses compound violence, displacement and disrupted agriculture and trade. Often those affected by crises flee to neighbouring countries, putting additional stress on the international humanitarian response system and on the food systems of the host countries. Women and girls are disproportionately affected by crises. Populations in crisis are disproportionally vulnerable to the impact of the COVID pandemic and have little capacity to cope with the health and socio-economic aspects of the shock (FSIN, 2020). WFP predicts that the number of people in LMICs facing acute food insecurity will nearly double to 265 million by the end of 2020 (WFP, 2020). Moreover, fragile and extremely fragile countries are disproportionally burdened by high levels of malnutrition compared to non-fragile countries (GNR, 2020).

b) **Supply chain failures and underutilized technologies**

While UN Agencies and their partners have converged and coordinated various mechanisms for food security coordination (e.g. FSIN, the Global Network against Food Crises, expanding the SOFI collaborators, the CFS Global Strategic Framework etc.), no global governance system exists for food security and no coordination system exists for coordinated action and accountability with regards to sustainable food systems (see Box 2).

Almost one-third of total food production is discarded as food loss and waste, equating about one-quarter of land, water, and fertilizer used for crop production (Shafiee-Jood and Cai, 2016). Food losses and food waste occur throughout the food chain. They constrain food system sustainability due to their adverse effects on food security, natural resources, environment, climate and human health (e.g., toxic emissions from incineration) (Xue et al., 2017).

> Box 2: Sustainable food systems
>
> "Sustainable food systems are: productive and prosperous (to ensure the availability of sufficient food); equitable and inclusive (to ensure access for all people to food and to livelihoods within that system); empowering and respectful (to ensure agency for all people and groups, including those who are most vulnerable and marginalized to make choices and exercise voice in shaping that system); resilient (to ensure stability in the face of shocks and crises); regenerative (to ensure sustainability in all its dimensions); and healthy and nutritious (to ensure nutrient uptake and utilization)" (HLPE, 2020).

Approximately 600 million people fall ill through consumption of contaminated food each year, with considerable differences among sub-regions; with the highest burden observed in Africa (WHO, 2020). More than 420 000 die every year, equating to the loss of 33 million Disability-Adjusted Life Years (WHO, 2015). Foodborne diseases disproportionately affect children, accounting for 40% of the foodborne disease burden. The consumption of unsafe foods cost low- and middle-income countries at least US$ 110 billion in lost productivity and medical expenses annually (Jaffee et al., 2019). With a large proportion of emerging human infectious diseases originating from animal sources (zoonotic diseases), there is also an increasing need to consider both animal and human health as a 'one health' issue.

While technology advances (including biotechnology, digitalisation and mechanisation) can have significant benefits for the food system, these advances can also drive negative food system changes. One example is the advance of biofuel production that, when based on food crops, can drive staple food prices up and compete for land, exacerbating inequalities. Biotechnology is mostly used for fibre and animal feed, and less often for food, to a large extent, because of regulatory constraints and intellectual property rights barriers (Barrows et al., 2014). Orphan crops would likely benefit from new technologies as could disease control in animals and plants. Reduced support for public research and extension (as part of budget cuts and privatisation efforts), and reduced foreign aid hamper the dissemination and adoption of new and innovative technologies.

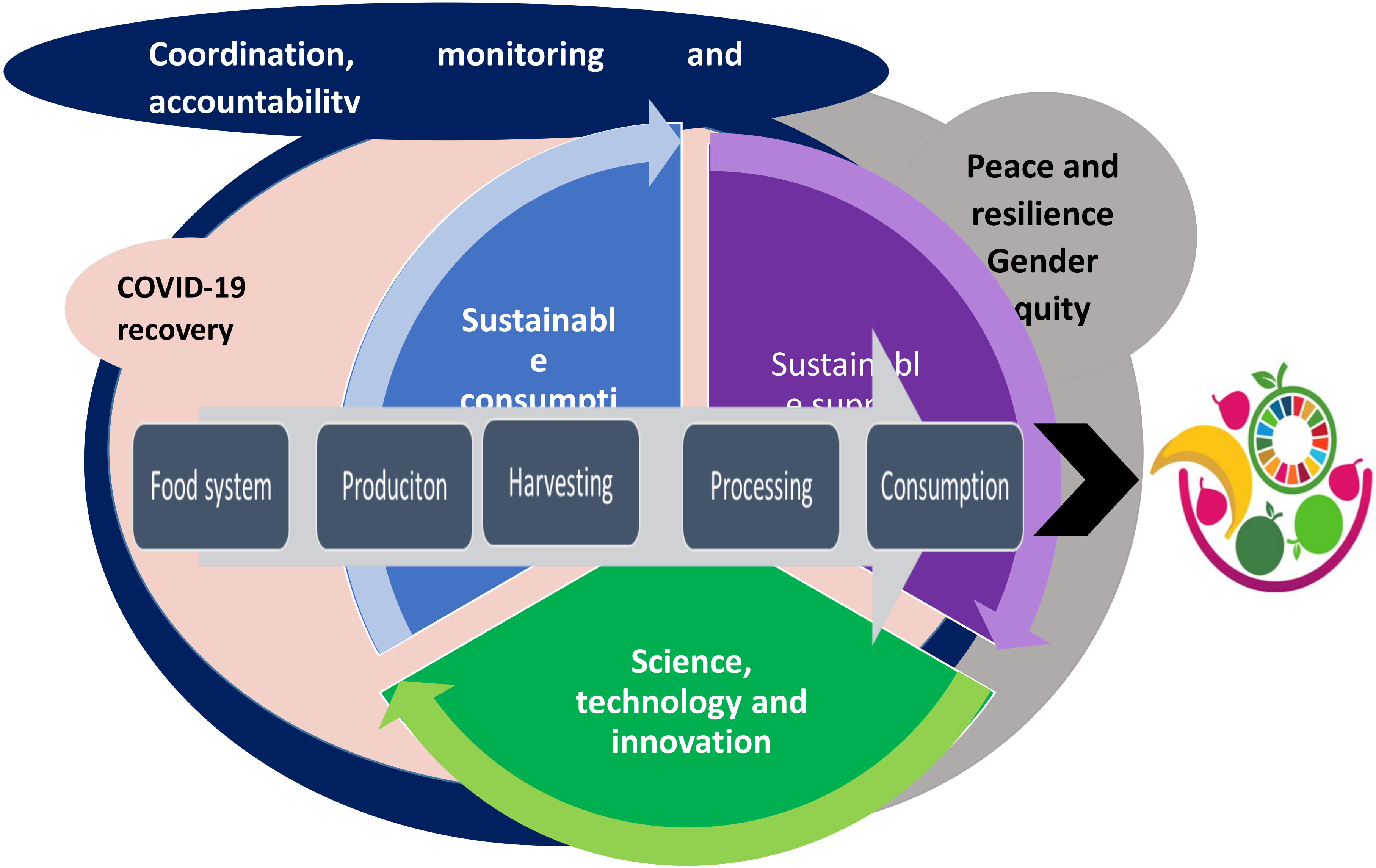
c) Climate change, land-use change and natural resources degradation

Climate change, including increases in frequency and intensity of extremes, has adversely impacted food security, with negative impacts observed on the yields of some crops (e.g., maize and wheat) and on pastoral systems in low latitude regions (IPCC, 2019). With increasing warming, the frequency, intensity and duration of heatwaves, droughts and extreme rainfall events are projected to increase in most world regions, increasingly threatening the stability of food supply (IPCC, 2019). For instance, an estimated 86% probability of losses across the world's maize breadbaskets was found with warming of 4 °C, compared to 7% probability for 2°C warming (Gaupp et al., 2020). Nutritional quality of crops will also be affected by rising atmospheric CO_2 levels (IPCC, 2019).

The global food system (from farm inputs to consumers) emits about 30% of global anthropogenic greenhouse gases (GHG), contributes to 80% of tropical deforestation and is a main driver of land degradation and desertification, water scarcity and biodiversity decline (IPCC, 2019). About a quarter of the Earth's ice-free land area is subject to human-induced degradation and about 500 million people live within areas undergoing desertification (IPCC, 2019). By 2050 land degradation and climate change could lead to a reduction of global crop yields by about 10% with strong negative impacts in India, China and sub-Saharan Africa resulting in the displacement of up to 700 million people (Cherlet et al., 2018). Around 2 billion people live within watersheds exposed to water scarcity and this number could double by 2050 (Gosling and Arnell, 2016). Future agricultural productivity in the tropics is also at risk from a deforestation-induced increase in mean temperature and the associated heat extremes and from a decline in rainfall (Lawrence and Vandecar, 2015). Over half of the tropical forests worldwide have been destroyed since the 1960s, affecting the lives of 1 billion poor people whose livelihoods depend on forests and equalling a mass extinction event if tropical deforestation continues unabated (Alroy, J., 2017).

5. Transforming food systems is key to safe and nutritious food for all

Apart from urgent action necessary to manage future population growth, changing the path of our future will demand will need to deliver structural transformation of food systems, changes in the allocation of resources and research attention to factors beyond production (CFS, 2020). This will need to be accompanied by far more concerted effort to coordinate activities, monitor progress more closely and greater accountability from all players across the food system. A global social compact (an implicit agreement among the members of a society to cooperate for social benefits) is needed to manage the demand and consumption drivers and harness science, technology and innovation to improve the sustainable production of enough food to ensure access to affordable, safe and nutritious foods for all (Figure 2). The sections below identify some of the levers for change.


Coordination, monitoring and
accountability
Peace and
resilience
Gender
quity
COVID-19
recovery
Sustainabl
e
consumpti
Sustain bl
Food system
Produciton
Harvesting
Processing
Consumption
Science,
technology and
innovation

a) Coordination, monitoring and accountability

Food security is a public good. Therefore, improved coordination, monitoring and accountability across the food system and among all stakeholders is necessary, including sharing knowledge, building capacity, better measurement, updated data, better modelling for foresight, scenarios and case studies and access to documented success stories. Advances in information technology and data science play an important role in enabling rapid assessment of situations (such as the IPC Pilot Artificial Swarm Intelligence Project), monitoring and decision making and adaptive learning. An integrative global food system model is still missing, since existing models (see Khanna and Zilberman, 2012) do not have consistent global coverage and are not designed to assess the impacts of a broad range of factors. Strengthening national policy scenarios and foresight is also necessary (Schmidt-Traub et al. 2019). Moreover, improved indicators of food systems (see SOFI, 2020) are required (see Sukhdev et al. 2018, Chaudhary et al. 2018 for examples), that could provide more holistic measures that capture the three elements of safety, nutrition and inequality.

If we are to transform food systems to ensure safe and nutritious food for all, a concerted effort is needed to develop a global compact and accountability system to drive agreed-on transformation.

To reach safe and nutritious for all and reach sustainable food systems, a concerted effort is needed to drive agreed-on transformation by strengthening coordination across sectoral policies (health and nutrition, food and agriculture, climate and environment). Integrated, science-based policies must for the base of these policies to reinforce their accountability both at national and international scales.

Rigorous global monitoring systems require global collaboration, updated information, and investment with significant returns. A task force charged with understanding global monitoring and data collection opportunities about agrifood systems, could provide a clearinghouse for the multiple (often duplicated) data held by UN agencies as well as public and private organisations. While some effort has been made to coordinate international actions to address crises, access to food requires targeted interventions for the most vulnerable. Two-way real-time digital applications to collect and disseminate information to various stakeholders and beneficiaries are needed in last mile and crises and in regions disproportionately affected by the Covid-19 pandemic food system disruptions. This could include driving supply side demand through food banks, social grants, subsidised meals, vouchers and other food assistance (including through e-commerce systems) (WFP, 2017).

b) Influencing food demand and dietary changes

There are several ways to reduce demands on the global food system, both in the short and long-term, by accelerating demographic transitions, increasing incomes, reducing food losses and waste and changing diets. Because of the strong association between female education, fertility and infant mortality, alternative education scenarios alone (assuming similar education-specific fertility and mortality levels) lead to a difference of more than one billion people in the world population sizes projected for 2050 (Lutz and Samir, 2011; Samir and Lutz, 2017).

Household food waste is proliferating in emerging economies. Global per capita food waste could double by 2050 (Barrera and Hertel, 2020). Halving food losses and waste is a target of SDG 12 that could help feed more people, benefit climate and the environment and conserve water (Kummu, et al., 2012, Searchinger et al., 2018; IPCC, 2019). This requires changes along supply chains (agricultural production, food processing, distribution/retail, restaurant food service, institutional food service, and households) through improved logistics and processing technologies, economic incentives, regulatory approaches and education campaigns (Read et al., 2020; Barrera and Hertel, 2020). Vertical integration of food chains can shorten chains to the benefit of smallholder farmers while trade can expand market opportunities. Compared to a business-as-usual scenario, a combined scenario targeting under-nourishment while also reducing over-consumption and food waste would reduce food demand by 9% in 2050 (Hasegawa et al., 2019).

Balanced diets, featuring plant-based foods, such as those based on coarse grains, legumes, fruits and vegetables, nuts and seeds, and animal-sourced food produced in resilient, sustainable and low-GHG emission systems present major opportunities for adaptation and mitigation of climate change while generating significant co-benefits in terms of human health(Springmann et al., 2018; IPCC, 2019). 'Healthy sustainable diets' can be defined by optimization procedures (Donati, et al., 2016). However, all diets have trade-offs between nutritional values and the environment and not all may be affordable for all (Headey & Alderman, 2019). Populations with a high prevalence of undernutrition and micronutrient deficiencies (Fanzo, 2019) benefit from increasing the consumption of animal-sourced products due to the bioavailability of key micronutrients (Perignon, Vieux, Soler, Masset, & Darmon, 2017). Moreover, a balance is necessary between meeting the demand for diversified, nutritious and affordable food and minimizing the time and energy to prepare meals.

Policies can create incentives for change. Urgent public policy action is needed to create incentives for creating healthy, sustainable food systems and delivering safe and nutritious foods for all are crucial instruments to manage food demand, shift consumption patterns and ensure equity through trade, agricultural research, taxes and subsidies across the food system. A wide range of well-established and relatively inexpensive policy options and interventions are available for improving nutrition at the individual level (Buckhman et al., 2020, Hawkes et al., 2020; Bhutta et al., 2008). Policies that enable healthy food environments (such as sugar taxes, educational food labelling, reducing salt, the prohibition of trans-fats and a reduction in the use of high-fructose corn syrup) are core to improving food environments and limiting the burden of non-communicable diseases. Increasing the diversity of food sources in public procurement, health insurance, financial incentives and awareness-raising campaigns, can potentially influence food demand, reduce healthcare costs, contribute to lower GHG emissions and enhance adaptive capacity.

c) Meeting sustainable food and nutrition demand for all

Nutrition outcomes in developing countries are affected by agriculture in several ways: as a source of food for household consumption and of income, through the role of food prices and agricultural policies, through the role of women's employment in agriculture for nutrition, child care and child feeding and their own nutritional and health status (Gillespie and van den Bold, 2017).

There are more than 570 million farms worldwide, most of which are small and family-operated. Over 1960-2000, average farm size decreased in most lower to middle-income countries, whereas it increased in most in high-income countries (Lowder et al., 2016). As farm sizes increases, the production of diverse nutrients and viable, multifunctional, sustainable landscapes requires efforts to maintain production diversity (Herrero et al., 2019).

Diversification in the food system (e.g., implementation of integrated production systems, broad-based genetic resources, and diets) can reduce risks from climate change (IPCC, 2019). Diversified agroecological systems can play a key role in meeting health and nutrition goals, while also reducing environment-related health risks caused by conventional agriculture through water and air pollution, and more specifically by pesticides, antibiotics and inorganic fertilizers (Frison and Clément, 2020). Compared to conventional agriculture, organic agriculture generally has a positive effect on a range of environmental factors, including above and belowground biodiversity, soil carbon stocks and soil quality and conservation, but it has weaknesses in terms of lower productivity and reduced yield stability (Knapp and van der Heijden, 2019).

Sustainable land management can bridge yield gaps and avoid deforestation, while providing climate change adaptation and mitigation and land degradation co-benefitsin croplands and pastures (Smith et al., 2020). This can be achieved by increasing soil organic carbon (Soussana et al., 2019), agroforestry, erosion and fire control, improved irrigation water and fertilizers management, heat and drought tolerant plants (Pretty et al., 2018). For livestock, sustainable options include better grazing land management, improved manure management, higher-quality feed, and use of breeds and genetic improvement (Herrero et al., 2016). Under stringent global climate change mitigation policy, risks for food security would be increased (Hasegawa et al., 2018) through competition for land between food production, bioenergy and afforestation. Nevertheless, increasing and valuing soil carbon sequestration on agricultural land would allow reducing these negative impacts by approximately two thirds (Frank et al., 2017). The large-scale deployment of bioenergy options such as afforestation, energy crops, carbon capture and storage has adverse effects for food security, but small scale projects with best practices may deliver co-benefits (Smith et al., 2020).

Increased demand for fish and seafood has threatened fisheries and sustainability of ocean resources. The aquaculture industry has emerged and increasingly fills the seafood supply gap to meet growing demand. Challenges in marine feed supply, in antibiotics use and in waste recycling need to be overcome to further develop aquaculture (Belton et. al., 2020).

Ensuring that food prices reflect real costs, including major externalities caused e.g. by climate change, land degradation and biodiversity loss is necessary to address artificial price distortions, reduce food waste, internalize the costs of externalities (including the public health impacts) and, at the same time, ensure decent incomes and wages for farmers and food system workers. Food assistance policies that do not distort market and labour incentives can meet emergency food needs and improve access to food. Trade can help improve food availability, diversify diets and smooth price volatility (MacDonald et al., 2015).

d) Harnessing science and innovation and managing risks

Food system transformation can bring about efficient and more rapid productivity growth (Fugile et al., 2020). Science should increasingly inform solutions and generate knowledge that is actionable to transform food systems and reach safe and nutritious for all (Arnott et al., 2020). Since policy agendas are largely set at national and local scales, the translation of global-scale scientific assessments into actionable knowledge at national and local scales is needed.

New and emerging technologies could be game-changers for overcoming challenges, but their development should be guided by assessing their socio-economic, ethical and environmental impacts. Evidence-based assessment is needed of the risks and benefits associated with new technologies. Research is also needed to understand the diffusion modes of traditional knowledge and social innovations that could support the conservation of common goods in more participatory, collaborative, inclusive and equitable ways.

Advances in science and technology such as genome editing (Khatodia et al., 2016), precision agriculture and digital agriculture (Basso and Antle, 2020), active packaging and blockchain technologies (Kamilaris et al., 2019), artificial intelligence and big data analysis (Wolfert et al., 2017) and whole-genome sequencing in food safety (Deng, Bakker, & Hendriksen, 2016) have the potential to meet these challenges. However, adapting these technologies to local conditions, making them accessible to farmers and retain much of the gain among consumers and the rural communities is challenging, especially for developing economies, smallholder farmers and small businesses. Therefore, investments in science-based, participatory processes to map out realistic and equitable options are needed (Basso and Antle, 2020).

The importance of agriculture in producing non-food products (biofuels, chemicals, biomaterials) and in supporting ecosystem services is increasingly recognized in the context of the bioeconomy, which targets an increased reliance on renewable sources to address climate change (Zilberman 2014). A circular bioeconomy envisions developments in industrial biotechnologies to generate co-products, by-products and waste recycling, thereby generating an overall increased input efficiency of agricultural systems producing bio-based products in diversified agroecological landscapes (Therond et al., 2017; Maina et al., 2017).

Global and regional data sharing systems based on the FAIR principles (findable, accessible, interoperable and reusable data) (Mons et al., 2017) for food security, nutrition and health, food safety and waste management, as well as agricultural, climatic and environmental impacts of food systems would greatly enhance the accountability of all stakeholders of the food systems. Gender-disaggregated data is often lacking but is essential for analysing the impacts and potential trafe-offs of various actions.

Increasingly, risk assessment tools will be needed to drive food safety policy and standards and to optimize surveillance, detection and early warning systems of zoonotic diseases (Di Marco et al., 2020) and crop diseases (Mohanty et al., 2016). Modernizing our food safety and biosecurity risk management systems is an integral part of the food system transformation required to meet food and nutrition security needs. This will require a science- and risk-based approach for production of safe food within a food systems approach.

6. Concluding messages

Action to address safety, malnutrition, poverty and inequality, as well as climate and environmental issues, through food systems transformation will undoubtedly bring large health, social, economic, ecological and development co-benefits and savings on public expenditure while supporting several interrelated SDGs. A range of priority actions to speed up progress towards international targets and scale up the solutions proposed in section 5 can be taken in the short-term, based on existing knowledge, while supporting longer, more sustainable responses with significant co-benefits. Future actions will have to be iterative, coherent, adaptive and flexible to maximise co-benefits and minimise trade-offs. Many recommended policy changes and interventions have win-win potential for food security, health and the environment. However, other choices will have adverse or unintended impacts on the interconnected drivers affecting food systems and their outcomes.

Adopting a whole-system approach in policy, research and monitoring and evaluation is crucial to manage trade-off and externalities from farm-level to national scales and across multiple sectors and agencies. Ultimately, context matters and comprehensive national action plans are crucial for setting out actions suited to the particular economic, agricultural, social and dietary preferences of the particular nation.

Adaptive learning and new knowledge must be shared globally to accelerate our capacities to meet existing and future challenges. Substantial public, private and international investment is necessary to faster progress towards the targets and recover from the set-backs of the Covid-19 pandemic. International cooperation and coordination of the food system is necessary, including the establishment of a comprehensive monitoring, evaluation and early warning system with comprehensive indicators, transparency and commitments of all stakeholders. For example, bringing all the indicators in Table 1 into one annual food system monitoring report would facilitate cooperation among UN agencies. Creating a food system compass could be based on bottom-up pathways developed at national scale to reach food systems targets supporting an ensemble of global scale and integrative food systems models. Establishing such a system will require capacity development for comprehensive foresight, scenario and predictive modelling to better understand uncertainties, trade-offs and impacts of various change pathways. More research is necessary to identify the most adequate, affordable, healthy and sustainable diets across different contexts. More frequently collected nutrition and poverty data are necessary to provide more data points for monitoring change and progress. Innovative indicators such as the affordability of adequate, nutritious and healthy diets are vital to bring the three elements of safety, nutrition and inequality together.

The costs of acting and not acting on the key drivers of diet and food system change and the impact of these changes and shits are required for effective decision making. For example, the cost of nutrition interventions is relatively low per unit compared to the long-term losses in human potential and incomes for poorer people. The cost of NCDs to the health system is significantly higher per unit that the cost of scalable interventions. Rapid reductions in anthropogenic GHG emissions across all sectors can reduce negative impacts of climate change on food systems in the long term (similar for land and for water restoration).

Research and technology advances are essential to solve critical constraints and offer many opportunities to improve productivity, food safety and reduce food losses and waste, as well as GHG emissions. Capacity-building, property rights, technology development, transfer and deployment and enabling financial mechanisms across the food system can support livelihoods and increase incomes. Greater cooperation with regard to trade could overcome constraints and barriers.

Enabling a common future with safe and nutritious food for all requires a transformation of food systems, changing both supply and demand of food in differentiated ways across world regions: increasing crop yields and livestock feed conversion efficiencies, largely through agro-ecological practices and agroforestry, deploying at scale soil carbon sequestration and agricultural greenhouse gas abatement, reducing food losses and wastes, as well as over-nourishment and changing the diets of wealthy populations. Global food systems sustainability also requires to halt the expansion of agriculture into ecosystems and to facilitate the restoration of degraded forests, wetlands and peatlands.

6. References

Alexandratos, N., & Bruinsma, J. (2012). World agriculture towards 2030/2050: the 2012 revision.

Alroy, J. (2017). Effects of habitat disturbance on tropical forest biodiversity. *Proceedings of the National Academy of Sciences*, *114*(23), 6056-6061.

Arnott James C, Katharine J Mach and Gabrielle Wong-Parodi. Editorial overview: The science of actionable knowledge Current Opinion in Environmental Sustainability 2020, 42:A1–A5

Barrera, E. L., & Hertel, T. (2020). Global food waste across the income spectrum: Implications for food prices, production and resource use. *Food Policy*, 101874

Basso, B., & Antle, J. (2020). Digital agriculture to design sustainable agricultural systems. *Nature Sustainability*, *3*(4), 254-256.

Belton, Ben, Thomas Reardon, and David Zilberman. "Sustainable commoditisation of seafood." *Nature Sustainability* (2020): 1-8.

Bhutta, A; Ahmed,T; Black RE; Cousens, S; Dewey, K; Giugliani, E; et al. (2008). What works? Interventions for maternal and child undernutrition and survival. The Lancet| volume 371, issue 9610, p417-440 DOI:https://doi.org/10.1016/S0140-6736(07)61693-6

Bukhman, G; Mocumbi, AO; Atun, R; et al. for the Lancet NCDI Poverty Commission Study Group. (2020). The Lancet NCDI Poverty Commission: bridging a gap in universal health coverage for the poorest billion. *The Lancet*; September 14, 2020 https://doi.org/10.1016/S0140-6736(20)31907-3

Chaudhary, A., Gustafson, D., & Mathys, A. (2018). Multi-indicator sustainability assessment of global food systems. *Nature communications*, *9*(1), 1-13.

Cherlet, M., Hutchinson, C., Reynolds, J., Hill, J., Sommer, S., von Maltitz, G. (Eds.), *World Atlas of Desertification*, Publication Office of the European Union, Luxembourg, 2018.

Committee on World Food Security (CFS). (2020). CFS Voluntary Guidelines on Food Systems for Nutrition (VGFSyN). Draft for Negotiations. CFS, Rome. http://www.fao.org/fileadmin/templates/cfs/Docs1920/Nutrition_Food_System/CFS_Voluntary_Guidelines_Food_Systems_Nutrition_Draft_for_Negotiations_16Mar.pdf.

Deng, X., den Bakker, H. C., & Hendriksen, R. S. (2016). Genomic epidemiology: whole-genome-sequencing–powered surveillance and outbreak investigation of foodborne bacterial pathogens. *Annual review of food science and technology*, *7*, 353-374.

Di Marco, M., Baker, M. L., Daszak, P., De Barro, P., Eskew, E. A., Godde, C. M., ... & Karesh, W. B. (2020). Opinion: Sustainable development must account for pandemic risk. *Proceedings of the National Academy of Sciences*, *117*(8), 3888-3892.

Donati, M., Menozzi, D., Zighetti, C., Rosi, A., Zinetti, A., & F, S. (2016). Towards a sustainable diet combining economic, environmental and nutritional objectives. *Appetite*, 106, 48 - 57.

Fanzo, J. (2019). Healthy and Sustainable Diets and Food Systems: the Key to Achieving Sustainable Development Goal 2? *Food Ethics*, 4, 159-174.

FAO 2018, The future of food and agriculture – Alternative pathways to 2050.

FAO, IFAD, UNICEF, WFP and WHO. (2020). *The State of Food Security and Nutrition in the World 2020*. Rome: FAO.

FAO. (2011). *Global Food Losses and Food Waste: Extent, Causes and Prevention*. Rome: FAO.

Fore, H., Dongyu, Q., Beasley, D., & Ghebreyesus, T. (2020). *Child malnutrition and COVID-19: the time to act is now.* The Lancet, 396(10250), 517-518.

Frank, S., Havlík, P., Soussana, J. F., Levesque, A., Valin, H., Wollenberg, E., ... & Smith, P. (2017). Reducing greenhouse gas emissions in agriculture without compromising food security?. *Environmental Research Letters*, *12*(10), 105004.

Frison, E., & Clément, C. (2020). The potential of diversified agroecological systems to deliver healthy outcomes: Making the link between agriculture, food systems & health. *Food Policy*, 101851.

FSIN Food Security Information Network. (2020). *2020 Global Report on Food Crises: Joint analysis for better decisions*. Rome: FSIN.

Fuglie, K., Gautam, M., Goyal, A., Maloney,WF. (2020). Harvesting Prosperity: Technology and productivity growth in agriculture. Washington, DC: World Bank. © World Bank. https://openknowledge.worldbank.org/handle/10986/32350 License: CC BY 3.0 IGO."

Gaupp, F., Hall, J., Hochrainer-Stigler, S., & Dadson, S. (2020). Changing risks of simultaneous global breadbasket failure. *Nature Climate Change*, *10*(1), 54-57.

Gerten, D., Heck, V., Jägermeyr, J., Bodirsky, B. L., Fetzer, I., Jalava, M., ... & Schellnhuber, H. J. (2020). Feeding ten billion people is possible within four terrestrial planetary boundaries. *Nature Sustainability*, *3*(3), 200-208.

Gillespie, S., & van den Bold, M. (2017). Agriculture, food systems, and nutrition: meeting the challenge. *Global Challenges*, *1*(3), 1600002.

GNR, Micha, R., Mannar, V., Afshin, A., Allemandi, L., Baker, P., Battersby, J., ... & Dolan, C. (2020). 2020 *Global nutrition report: action on equity to end malnutrition*.

Goals: Interactions, infrastructures, and institutions. *The Lancet Global Health,* 3(5):PE251-E252.

Gosling, S. N., & Arnell, N. W. (2016). A global assessment of the impact of climate change on water scarcity. *Climatic Change*, *134*(3), 371-385.

Hasegawa, T., Fujimori, S., Havlík, P., Valin, H., Bodirsky, B. L., Doelman, J. C., ... & Mason-D'Croz, D. (2018). Risk of increased food insecurity under stringent global climate change mitigation policy. *Nature Climate Change*, *8*(8), 699-703.

Hawkes, C; Ruel, MT; Salm, L, Sinclaire, B; Branca, F. (2019). Double-duty actions: seizing programme and policy opportunities to address malnutrition in all its forms. *The Lancet* volume 395, issue 10218, p142-155. DOI:https://doi.org/10.1016/S0140-6736(19)32506-1

Headey, D., & Alderman, H. (2019). The relative caloric prices of healthy and unhealthy foods differ systematically across income levels and continents. *The Journal of Nutrition*, 149(11), 2022-2033.

Headly, D., Heidkamp, R., Osendorp, S., Ruel, M., Scott, N., Flory, A., . . . Walker, N. (2020). Impacts of COVID-19 on childhood malnutrition and nutrition-related mortality. *The Lancet*, 396, 519 - 521.

Herrero, Mario, Benjamin Henderson, Petr Havlík, Philip K Thornton, Richard T Conant, Pete Smith, Stefan Wirsenius, Alexander N Hristov, Pierre Gerber, et Margaret Gill. Greenhouse gas mitigation potentials in the livestock sector. *Nature Climate Change* 6, nº 5 (2016): 452-61.

Herrero, M., Thornton, P. K., Power, B., Bogard, J. R., Remans, R., Fritz, S., ... & Watson, R. A. (2017). Farming and the geography of nutrient production for human use: a transdisciplinary analysis. *The Lancet Planetary Health*, 1(1), e33-e42.

Hertel, TW., Ramankutty, N., Baldos, ULC. (2014). Global market integration increases the likelihood that a future African Green Revolution could increase crop land use and CO2 emissions. Proceedings of the National Academy of Sciences 111: 13799–13804.

HLPE. (2020). *Food security and nutrition: building a global narrative towards 2030*. Rome: HLPE.

INFOSAN (2019). INFOSAN activity report 2018-2019. Geneva: World Health Organization and Food and Agriculture Organization of the United Nations; 2020. https://www.who.int/publications/i/item/9789240006928.

IPPC, 2019. *Climate change and land, an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems*, IPPC, www.ipcc.ch/report/srcc

Jaffee S, Henson S, Unnevehr L, Grace D, Cassou E. *The safe food imperative: accelerating progress in low- and middle-income countries*. Washington DC: International Bank for Reconstruction and Development and The World Bank; 2019 (https://openknowledge.worldbank.org/handle/10986/30568, accessed 4 February 2020).

Janssens, C., Havlík, P., Krisztin, T., Baker, J., Frank, S., Hasegawa, T., ... & Valin, H. (2020). Global hunger and climate change adaptation through international trade. *Nature Climate Change*, 1-7.

Kamilaris, A., Fonts, A., & Prenafeta-Boldύ, F. X. (2019). The rise of blockchain technology in agriculture and food supply chains. *Trends in Food Science & Technology*, *91*, 640-652.

Khanna, Madhu, and David Zilberman. "Modeling the land-use and greenhouse-gas implications of biofuels." *Climate Change Economics* 3, no. 03 (2012): 1250016.

Khatodia, S., Bhatotia, K., Passricha, N., Khurana, S. M. P., & Tuteja, N. (2016). The CRISPR/Cas genome-editing tool: application in improvement of crops. *Frontiers in plant science*, *7*, 506.

Khoury, C. K., Bjorkman, A. D., Dempewolf, H., Ramirez-Villegas, J., Guarino, L., Jarvis, A., ... & Struik, P. C. (2014). Increasing homogeneity in global food supplies and the implications for food security. *Proceedings of the National Academy of Sciences*, *111*(11), 4001-4006.

Knapp, S., & van der Heijden, M. G. (2018). A global meta-analysis of yield stability in organic and conservation agriculture. *Nature communications*, *9*(1), 1-9.

Kummu, M., de Moel, H., Porkka, M., Siebert, S., Varis, O., & PJ, W. (2012). Lost Food, Wasted Resources: Global Food Supply Chain Losses and Their Impacts on on Freshwater, Cropland, and Fertiliser Use. *Science of the Total Environment*, 438: 477–89.

Laborde, D., Martin, W., Swinnen, J., & Vos, R. (2020). COVID-19 risks to global food security. *Science*, *369*(6503), 500-502.

Lawrence, D., & Vandecar, K. (2015). Effects of tropical deforestation on climate and agriculture. *Nature climate change*, *5*(1), 27-36.

Lowder, S. K., Skoet, J., & Raney, T. (2016). The number, size, and distribution of farms, smallholder farms, and family farms worldwide. *World Development*, 87, 16-29.

Lutz, W., & Samir, K. C. (2011). Global human capital: Integrating education and population. *Science*, *333*(6042), 587-592.

MacDonald, GK., Brauman, KA., Sun, S., Carlson KM., Cassidy, ES., Gerber, JS., West PC. Rethinking Agricultural Trade Relationships in an Era of Globalization, BioScience, Volume 65, Issue 3, March 2015, Pages 275–289, https://doi.org/10.1093/biosci/biu225.

Maina, S., Kachrimanidou, V., & Koutinas, A. (2017). A roadmap towards a circular and sustainable bioeconomy through waste valorization. *Current Opinion in Green and Sustainable Chemistry*, *8*, 18-23.

Mohanty, S. P., Hughes, D. P., & Salathé, M. (2016). Using deep learning for image-based plant disease detection. *Frontiers in plant science*, *7*, 1419.

Mons, B., Neylon, C., Velterop, J., Dumontier, M., da Silva Santos, L. O. B., & Wilkinson, M. D. (2017). Cloudy, increasingly FAIR; revisiting the FAIR Data guiding principles for the European Open Science Cloud. *Information Services & Use*, *37*(1), 49-56.

Mottet, A., de Haan, C., Falcucci, A., Tempio, G., Opio, C., & Gerber, P. (2017). Livestock: On our plates or eating at our table? A new analysis of the feed/food debate. *Global Food Security*, *14*, 1-8.

NCD Risk Factor Collaboration. (2019). Rising rural body-mass index is the main driver of the global obesity epidemic in adults. *Nature*, *569*(7755), 260

Perignon, M., Vieux, F., Soler, L., Masset, G., & Darmon, N. (2017). Improving diet sustainability through evolution of food choices: Review of epidemiological studies on the environmental impact of diets. *Nutrition Reviews*, 75(1), 2-17.

Pretty, J., Benton, T. G., Bharucha, Z. P., Dicks, L. V., Flora, C. B., Godfray, H. C. J., ... & Pierzynski, G. (2018). Global assessment of agricultural system redesign for sustainable intensification. *Nature Sustainability*, *1*(8), 441-446.

Ruel, M. T., Quisumbing, A. R., & Balagamwala, M. (2018). Nutrition-sensitive agriculture: What have we learned so far? *Global Food Security*, 17, 128-153.

Samir, K. C., & Lutz, W. (2017). The human core of the shared socio-economic pathways: Population scenarios by age, sex and level of education for all countries to 2100. *Global Environmental Change*, *42*, 181-192.

Schmidt-Traub, Guido, Michael Obersteiner, and Aline Mosnier. "Fix the broken food system in three steps." (2019): 181-183. Nature.com (comment)

Searchinger, T., Waite, R., Hanson, C., & Ranganathan, J. (2018). *Creating a Sustainable Food Future: A Menu of Solutions to Feed Nearly 10 Billion People by 2050: A synthesis report*. Washington DC: World Bank.

Shafiee-Jood, M and Cai, X.(2016). Reducing Food Loss and Waste to Enhance Food Security and Environmental Sustainability. *Environmental Science & Technology* 2016 50 (16), 8432-8443. DOI: 10.1021/acs.est.6b01993.

Smith, P., Calvin, K., Nkem, J., Campbell, D., Cherubini, F., Grassi, G., ... & Nkonya, E. (2020). Which practices co-deliver food security, climate change mitigation and adaptation, and combat land degradation and desertification?. *Global change biology*, *26*(3), 1532-1575.

Soussana, J. F., Lutfalla, S., Ehrhardt, F., Rosenstock, T., Lamanna, C., Havlík, P., ... & Smith, P. (2019). Matching policy and science: Rationale for the '4 per 1000-soils for food security and climate'initiative. *Soil and Tillage Research*, *188*, 3-15.

Springmann, M., Clark, M., Mason-D'Croz, D., Wiebe, K., Bodirsky, B. L., Lassaletta, L., ... & Jonell, M. (2018). Options for keeping the food system within environmental limits. *Nature*, *562*(7728), 519-525.

Sukhdev, P. (2018). Smarter metrics will help fix our food system. *Nature*, *558*(7708), 7-8.

Therond, O., Duru, M., Roger-Estrade, J., & Richard, G. (2017). A new analytical framework of farming system and agriculture model diversities. A review. *Agronomy for Sustainable Development*, *37*(3), 21.

UNDESA United Nations Department of Economic and Social Affairs (2015). Population Facts. No 2015/1. https://www.un.org/esa/socdev/documents/youth/fact-sheets/YouthPOP.pdf

UNDESA United Nations, Department of Economic and Social Affairs, Population Division (2019). World Population Prospects 2019: Highlights (ST/ESA/SER.A/423).

UNICEF & WHO. 2019. *UNICEF-WHO Joint Low Birthweight Estimates*. [online]. [Cited 28 April 2020]. www.unicef.org/reports/UNICEF-WHO-lowbirthweight-estimates-2019; www.who.int/nutrition/publications/UNICEF-WHO-lowbirthweight-estimates-2019.

UNICEF, WHO and the World Bank. (2020). *Levels and Trends in Child Malnutrition: UNICEF / WHO / World Bank Group Joint Child Malnutrition Estimates*. Geneva and Washington DC: UNICEF, WHO and the World Bank.

van Vliet, J., Eitelberg, D. A., & Verburg, P. H. (2017). A global analysis of land take in cropland areas and production displacement from urbanisation. *Global environmental change*, *43*, 107-115.

WFP. (2017). *World Food Assistance report 2017: Taking stock and looking ahead*. Rome: WFP.

WFP (2020). COVID-19 will double number of people facing food crises unless swift action is taken. Retrieved from https://www.wfp.org/news/covid-19-will-double-number-people-facing-food-crises-unless-swift-action-taken

WHO & UNICEF. (2017*). The extension of the 2025 Maternal, Infant and Young Child nutrition targets to 2030*. Discussion paper. . Geneva, Switzerland and New York, USA.: WHO & UNICEF.

WHO (2020). Dietary recommendations: Nutritional requirements; Establishing human nutrient requirements for worldwide application. WHO, Geneva. https://www.who.int/nutrition/topics/nutrecomm/en/

WHO. (2015). *WHO estimates of the global burden of foodborne diseases: foodborne disease burden*. Geneva: WHO.

WHO (2013) Advancing food safety initiatives: strategic plan for food safety including foodborne zoonoses 2013–2022. Geneva: World Health Organization; 2013 https://apps.who.int/iris/bitstream/handle/10665/101542/9789241506281_eng.pdf;jsessionid=2CA0920F1CE46F365F5C65D9664C0A94?sequence=1

William A Masters, Yan Bai, Anna Herforth, Daniel B Sarpong, Fulgence Mishili, Joyce Kinabo, Jennifer C Coates, Measuring the Affordability of Nutritious Diets in Africa: Price Indexes for Diet Diversity and the Cost of Nutrient Adequacy, *American Journal of Agricultural Economics*, Volume 100, Issue 5, October 2018, Pages 1285–1301, https://doi.org/10.1093/ajae/aay059

Wolfert, S., Ge, L., Verdouw, C., & Bogaardt, M. J. (2017). Big data in smart farming–a review. *Agricultural Systems*, *153*, 69-80.

World Bank, 2017. An investment framework for nutrition reaching the global targets for stunting, anemia, breastfeeding, and wasting (authored by Shekar M., Kakietek J., Dayton Eberwein J. and Walters D.). Washington, DC: World Bank Group.

World Bank (2018). *Poverty and Shared Prosperity 2018: Piecing Together the Poverty Puzzle*. Washington DC.: World Bank.

Worldbank (2019), blog on food systems. https://blogs.worldbank.org/voices/do-costs-global-food-system-outweigh-its-monetary-value

Xue L., G. Liu, J. Parfitt, et al.Missing food, missing data? A critical review of global food losses and food waste data. *Environ. Sci. Technol.*, 51 (June (12)) (2017), pp. 6618-6633, 10.1021/acs.est.7b00401

Zilberman, David, Liang Lu, and Thomas Reardon. "Innovation-induced food supply chain design." *Food Policy* 83 (2019): 289-297.

Zilberman, David. "Fellows Address: The Economics of Sustainable Development." *American Journal of Agricultural Economics* 96, no. 2 (2014): 385-396.

Zuccala, E., & Horton, R. (2020). Reframing the NCD agenda: a matter of justice and equity. *The Lancet*.