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Transformations within reach:
Pathways to a sustainable and resilient world

RESILIENT FOOD SYSTEMS

Available at: **pure.iiasa.ac.at/16822**

First published in December 2020.

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Resilient Food Systems

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Suggested citation
Sperling, F., Havlík, P., Denis, M., Valin, H., Palazzo, A., Gaupp, F., Visconti, P. (2020). IIASA–ISC Consultative Science Platform: Resilient Food Systems. Thematic Report of the International Institute for Applied Systems Analysis (IIASA), Laxenburg, and the International Science Council (ISC), Paris.

Acknowledgments

The International Institute for Applied Systems Analysis (IIASA) and the International Science Council (ISC) initiated the Consultative Science Platform to explore the humanitarian and socioeconomic crisis triggered by the COVID-19 pandemic and considerations for enabling sustainable development paths during the recovery process. Focus are four themes: resilient food systems, sustainable energy, science systems and governance for sustainability. The initiative is led by Leena Srivastava (IIASA), Flavia Schlegel (ISC) and Luis Gomez Echeverri (IIASA) and guided by an advisory board under the patronage of HE Ban Ki-moon, former UN Secretary General and chaired by HE Mary Robinson, Chair of The Elders, Patron of ISC and former President of Ireland.

This report covers the resilient food system discussions and has been authored by Frank Sperling, Petr Havlík, Mathieu Denis, Hugo Valin, Amanda Palazzo, Franziska Gaupp, and Piero Visconti. It benefits from three virtual consultations held between June and September 2020, chaired by Ismail Serageldin, ISC Patron, Emeritus Librarian of Alexandria, and Founding Director of the Bibliotheca Alexandrina. Experts with diverse professional backgrounds from academia, international organizations, governments, private sector, and civil society participated in the consultation and included: Sasha Alexander, David Beckmann, James Birch, Nadereh Chamlou, Fernando Chaparro, Ruben Echeverria, Ismahane A. Elouafi, Shenggen Fan, Nina Fedoroff, Nighisty Ghezae, Oliver Greenfield, HE Ameenah Gurib-Fakim, Mario Herrero, Saleemul Huq, Daniel Kurdys, Sidney Leclercq, Martin Lees, Uma Lele, Mauricio Lopes, Michal Nachmany, Eva Ohlsson, Sheela Patel, Guy Peér, Sir Richard Roberts, Pedro Sanchez, Pauline Scheelbeek, Ben Simmons, Elena Smirnova, Barbara Stinson, Stefan Uhlenbrook, Kevin Urama, Joachim von Braun, Chris Walzer, Koko Warner, and additional input from Marcelo Inácio da Cunha in the follow-up. The writing team is most grateful to them for giving their time, sharing their individual expertise, insights and reflections, which together with insights provided by colleagues helped us to build on the background documents and presentations we prepared for this consultative process when developing this report. We recognize that many of the humanitarian and socioeconomic impacts of the pandemic are still unfolding and the scope of many response measures is still being developed. Hence the report can only provide a limited snapshot of an evolving and more complex picture. Nevertheless, we hope that the insights and perspectives shared here will offer some useful food for thought for efforts that are focused on how we can emerge from this crisis and reset the course toward a more resilient and sustainable future.

This initiative was presented at a virtual side event on 29 September 2020 as part of the 75th United Nations General Assembly (UNGA). The emerging findings of the resilient food systems theme were further discussed at a dedicated side-event on 13 October at the 2020 Borlaug Dialogue, organized by the World Food Prize Foundation. Contributions to the side event were made by Barbara Stinson (World Food Prize Foundation), Flavia Schlegel (ISC), Albert van Jaarsveld, Petr Havlík, and Taher Kahil (IIASA). Panelists were Ismail Serageldin, HE Ameenah Gurib-Fakim (former President of Mauritius), Ismahane Elouafi (ICBA), and Eric Ogunleye (AfDB), and discussions were moderated by Frank Sperling. The writing team is grateful for input from colleagues at IIASA at various stages of developing the report, including Dilek Fraisl, Steffen Fritz, Tamas Krisztin, Michaela Rossini and Shonali Pachauri, and the helpful support provided during the process by Philippa Baumgartner, Ansa Heyl, Anastasia Lijadi, David Soto Martinez, and Amela Ploskic.

Executive Summary

The global spread of COVID-19 is rapidly changing the world as we know it. The pandemic, which is causing loss of life and personal grief, as well as wreaking havoc on health and economic systems, has revealed our global interdependencies and vulnerabilities. Many of the knock-on effects of this crisis are still emerging and will continue to unfold in the coming years. Several countries continue to suffer from increasing infection numbers, while some are slowly emerging from the crisis and taking steps to restart public life and their economies.

This report is a contribution to the IIASA-ISC Consultative Science Platform, which seeks to explore the implications of the pandemic for sustainable development pathways. This report summarizes emerging perspectives for building resilient food systems in the wake of COVID-19. Its thematic scope and the recommendations have benefited from three virtual international consultations conducted between June and September 2020 (see Acknowledgments). The summary sections that follow and the main text of this report describe first our global food system and the need for transformation in general before discussing the impacts of the pandemic and exploring how the recovery process can be harnessed to build more resilient, equitable, and sustainable food systems. It is envisaged that the Consultative Platform and the report will stimulate further dialogue to help identify applied research initiatives, which strengthen the knowledge foundation for decision making.

Our global food system

Our global food system comprises multiple systems, including modern, mixed, and traditional food systems. At one end of the spectrum are modern food systems, organized by large international agribusinesses and retailing companies that often rely on complex food supply chains. At the other end are traditional food systems with their reliance on smallholder and subsistence farmers and local markets and supply chains.

Global trends emphasize production efficiency. To meet rising demands, agricultural markets are becoming more and more integrated. In our increasingly interconnected food systems, trade has become essential both for ensuring the food security of importing countries and for providing livelihoods and income opportunities for exporting countries.

The general rationale for transformation

Before the pandemic struck, food systems already faced several challenges. Due to climatic impacts, conflicts, and economic downturns, global progress in addressing malnutrition has ground to a halt in recent years. Moreover, while chronic hunger remains a pervasive problem in developing countries and particularly in sub-Saharan Africa, the prevalence of obesity and associated non-communicable diseases is on the rise globally. Agricultural activities and land use changes are also major drivers of climate change, biodiversity loss, environmental degradation, and pollution.

Deep transformations of food system architecture are needed to ensure the long-term sustainability. A combination of demand- and supply-based measures can deliver various social, economic, and social objectives. These include, inter-alia, widespread adoption of sustainable production practices, environmental conservation and regeneration, dietary shifts, reduction of food loss and waste, and improvements in economic and social justice along food supply chains.

Impacts of the COVID-19 pandemic and lockdown measures

The emergence of the COVID-19 pandemic and its associated lockdown measures have triggered humanitarian and socioeconomic impacts that threaten to unravel long-term development gains. The pandemic is considered to be one of the worst crises for the economy since the Great Depression, leading to supply and demand shocks across many economic sectors. It has caused widespread unemployment, shifts to part-time work, and loss of disposable income and purchasing power. Poverty levels are on the rise. Unless rapid action is taken, the number of lives threatened by acute levels of hunger is expected to double due to the crisis. Rising levels of food and nutritional insecurity are being observed in both developing and developed countries.

The pandemic has revealed vulnerabilities in our food systems. The impact of the pandemic on food systems is primarily felt through impacts on employment and income rather than on agricultural production. The global food supply has been robust and stock-to-utilization ratios have remained solid throughout the crisis. However, job and income losses, insufficient safety nets, and constraints on local access to food created conditions for food insecurity for many households and uncovered inequalities within and across societies. Lack of access to basic services, such as water and sanitation, and the prevalence of informal employment situations, have forced many people in developing countries to make the impossible choice between following physical distancing measures or maintaining basic income and access to food. The pandemic also uncovered the dependency of some value chains on migrant labor and brought attention to the importance that informal markets play for food access in some urban economic settings. Income loss, local price spikes, and challenges to food access have also meant consumers beginning to shift to cheaper and nutrient-poor foods. These and other factors, such as logistical disruptions, have increased food loss and the wastage of perishable food items such as fruits and vegetables, revealing weaknesses in transportation infrastructure and storage and cooling facilities, particularly in developing countries.

The impacts of the pandemic are compounded by other shocks and crises in some countries and regions. The Greater Horn of Africa, the Arabian Peninsula, and Southwest Asia have been facing one of the worst locust outbreaks in decades, which is destroying harvests and triggering food emergencies. In western Africa, the humanitarian and socioeconomic impacts of COVID-19 are superimposed on the ongoing regional food crisis. Environmental shocks observed in 2020 also include an unusually active hurricane season, heatwaves, forest fires in Australia, southeastern Asia, Siberia, and the Americas, and the thawing of permafrost and record high temperatures in the Arctic. Climate change and continuing environmental changes underline the importance of strengthening the preparedness of food systems to manage and adapt to multiple risks in our interconnected and interdependent world.

Towards Recovery: General Considerations on Opportunities and Challenges

The recovery from the global crisis triggered by COVID-19, places humanity at the crossroads towards or away from a sustainable development trajectory, depending on how we collectively decide to respond to this pandemic. The recovery process should be fully embedded in the aspirations of the Sustainable Development Goals (SDGs). However, it is important to be aware of the potential challenges and pitfalls involved in transformation toward sustainable and resilient food systems. These include:

- **The uncertainty of the timing and speed of the socioeconomic recovery.** At the time of writing, confirmed cases of COVID-19 infections and fatalities are still on the rise globally. Recent breakthroughs with vaccines being approved raise hopes of improvement in 2021, but many uncertainties remain about how rapidly vaccinations can be rolled out in countries around the world. Repeated local or more extensive lockdown measures may be necessary, which will further impact economies and impede the recovery process.
- **Risk of growing economic and technological divide.** The capacities of countries to deploy fiscal rescue packages and broad social protection measures differ greatly across the world. However, if governments prioritize their own national recovery, this will jeopardize the international cooperation needed to make the transformations necessary to achieve the SDGs and it will further widen the economic and technological gaps between and within regions.

Because of such uncertainties and constraints, it is important for the recovery to be an informed one and to be guided by a vision and a strategic narrative for a more resilient and sustainable future. The recovery is about making deliberate, informed strategic choices, bearing in mind the potential long-term consequences of the different development paths available.

Building resilient food systems: Focal areas for the recovery process

Many of the components of the transformation toward sustainable food systems were already in existence and widely recognized before the pandemic. It is understood, for example, that the transformation must be multi-sectoral in focus and embedded in a wider push toward building greener and more circular economies. However, the pandemic has also illustrated that the social, economic, and environmental pillars of sustainable development need to be founded upon resilience. As the discussions within the IIASA–ISC Consultative Platform underlined, this foundation has been weak and needs to be strengthened in supporting each of the pillars. We have identified the following focal areas for the recovery process:

1. Reorient food system architecture toward an emphasis on resilience and equity. The evolution of food systems has largely been driven by efficiency concerns. The pandemic and the associated global lockdown have revealed the interdependencies and vulnerabilities arising from this approach. The recovery process should be focused on counterbalancing concerns about efficiency with an emphasis on resilience and equity to ensure the capacity of food systems to deliver food and nutritional security to the most vulnerable.

- Reconfigure supply chains and trade dependencies based on an evaluation of their likely capacity to absorb and adapt to socioeconomic and environmental shocks
- Expand the benefits, reach, and duration of social safety nets to provide people in informal employment with a pathway to join social security structures and thereby mitigate the impact of future unemployment/crisis situations
- Promote sustainable farm models that recognize sociocultural heterogeneity and specific development and environmental contexts
- Strengthen the technical and financial support for smallholder farmers to alleviate poverty and/or enable transition to more secure livelihoods.

2. Make human and planetary health concerns an integral component of food systems. The emergence of zoonotic diseases like COVID-19 illustrate the entanglement between human and natural systems. The food system plays a critical role not only with respect to provision of basic human needs and the advancement of human welfare, but also in terms of managing the risk of epidemics and protecting Earth's life support systems. Enabling universal access to healthy diets not only has the potential to address key human health concerns like stunting in childhood, obesity, and non-communicable diseases but also reduces pressure on land and natural resources. Hence, a focus on human and planetary health concerns should be an integral part of the food system.

- Adopt ambitious biodiversity and ecosystem conservation targets to guard human and environmental health across scales and couple this to a strengthening of regulations, monitoring capacities, and enforcement mechanisms
- Accelerate the shift toward affordable, healthy, and environmentally sustainable diets, and associated production, and transfer the costs to unhealthy and unsustainable diets and production systems
- Prioritize investments in improving water access and sanitation, which contribute to food security and improved health, and at the same time provide protection for the essential agricultural and food system workforce
- Strengthen environmental regulations, monitoring capacities, and enforcement mechanisms
- Account for natural capital in decision-making processes, promote environmental stewardship through appropriate incentive schemes, and remove harmful subsidies
- Integrate environmental provisions and performance criteria into bi- and multilateral trade agreements that account for embodied climate and natural-resource footprints and environmental health risks.

3. Secure innovation, technology diffusion, and upscaling of sustainable practices. To provide healthy, nutritious diets for a growing world population, increases in agricultural production will be necessary. The global recession and the reduced fiscal space of many countries threaten to undermine progress toward closing yield gaps and the adoption of more efficient technologies and practices. The pandemic also illustrated how digital technologies can help some supply chains to rapidly adapt to the shock of the global lockdown. During the recovery process, steps need to be taken to ensure that the technological and digital divide between countries does not widen. Continuous support to developing countries is needed to strengthen innovation capacities, enable adoption of technologies, and advance the scaleup of sustainable land management practices that are appropriate to their sociocultural, economic, and environmental contexts. These actions need to be coupled with a focus on greater diversification of agricultural production and support for livelihood opportunities through appropriate education and skills development.

- Provide clear goals, targets, and regulatory mechanisms to channel the engagement of the private sector
- Strengthen the biological diversity of crops to suit diverse environmental conditions, and develop relevant new biotechnologies that meet stringent social and ecological safeguards
- Accelerate and scale up technical and financial support for sustainable land and integrated water resource management practices that can be readily adopted
- Strengthen extension services, technical assistance, and funding instruments
- Facilitate access to digital technology across supply chain, such as precision agriculture, e-commerce, blockchains for tracing foodstuffs

4. Strengthen collaboration and partnerships for transformative action. Global challenges like a pandemic or climate change require international cooperation and solutions. The COVID-19 pandemic also underlines the importance of reacting quickly to problems that exhibit non-linear behavior. This must be reflected in strengthened mandates and capacities of the multilateral institutional system for delivering coordinated responses, complemented by novel mechanisms for collaboration across national boundaries, sectors and stakeholder groups.

- Strengthen institutional coordination capacities across scales to manage multiple hazards and risks associated with exponential non-linear dynamics
- Promote mechanisms for knowledge sharing and collaboration across diverse stakeholder groups and regions.

5. Reform the science–policy interface for strategic decision making. The pandemic illustrates the value of agile, fact-based decision making. Societies are increasingly facing complex challenges, particularly with respect to food systems which, in such an interconnected world, need to be prepared for a multitude of social, economic, and environmental risk and changes. The ability to make informed cross-sectoral decisions must be strengthened, and this must be reflected in a reform of the science–policy interface. For facilitating rapid disaster response and improving near-term actions, this includes strengthening integrated early warning systems and improving incentives and capacity of science systems to carry out rapid assessments of vulnerabilities across various dimensions of the food system. For advancing strategic planning capacities, it includes assessing the medium to long-term implications of strategic decisions for sustainable development paths, integrating natural and social science perspectives.

- Advance early warning and near real-time monitoring capacities for rapidly detecting potential shocks, risks and vulnerabilities, undermining the functioning of food systems
- Incentivize collaboration between natural and social sciences to advance an integrated understanding of the biophysical constraints, environmental, economic and behavioral dynamics shaping food system architecture and levers for transformation
- Expand mechanisms for stakeholder engagement in framing narratives for co-developing resilient and sustainable food systems and support scenario analysis across geographical scales.

1 Introduction—COVID-19: New Realities for Sustainable Development

The global spread of COVID-19 is rapidly changing the world as we know it. The pandemic, which is causing loss of life and personal grief, as well as wreaking havoc on health and economic systems, has also revealed our global interdependencies and vulnerabilities. Many of the knock-on effects of the present crisis are only just starting to become visible and will continue to unfold in the coming years. While some countries are still suffering increasing infection rates, other countries are slowly emerging from the crisis, undertaking steps to restart public life and their economies.

The International Monetary Fund considers the lockdown measures triggered all over the world by the pandemic to have generated the worst economic crisis since the Great Depression, expecting the global economy to contract by at least 4.4% in 2020[1] and a slow recovery to begin in 2021 toward the economic trajectory projected prior to the epidemic (IMF 2020). The pandemic has led to supply and demand shocks in many economic sectors. Impacting developed and developing countries across the globe, the crisis has led to widespread unemployment, shifts to part-time work, and loss of disposable income and purchasing power. Many developing and emerging countries are impacted by the depreciating of their currencies and loss of remittances. Declining prices of several important commodities due to the global lockdown in the first half of 2020 have been observed (World Bank 2020a), further impacting the revenue of commodity-exporting countries.

The pandemic threatens to undermine global progress toward alleviating poverty and ensuring universal food security. Halving the incidence of extreme poverty, defined as people living on less than 1.90 USD per day, was one of the main achievements of the Millennium Development Goals (MDGs). Poverty levels fell from around 2 billion people (36% of global population) in 1990 to 740 million (10 % of global population) in 2015 (World Bank 2020b). While the number of people living in extreme poverty continued to drop further to 689 million in 2017, the World Bank (2020b) highlights that over recent years the annual rate of reduction hovers around 0.5 % (2015-2017) and is thereby lower than annual reduction of one percent observed on average over the preceding 25 years. For the first time in years, the absolute number of people living in extreme poverty levels is on the rise again in 2020. Early estimates suggest that an additional 88 million to 115 million people may suffer extreme poverty due to the pandemic, bringing the total to well over 700 million people again (World Bank 2020b). The pandemic is expected to further exacerbate the rise in food insecurity observed since 2014 (FAO 2020). The socioeconomic impacts of the pandemic are further exacerbating inequalities within and between countries. It is feared that the impacts of the pandemic could have longer-term consequences for low-income countries, substantially undermining their development prospects, unless adequate international support is provided (Gurara et al. 2020).

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[1] This reflects the updated global economic outlook for 2020 presented by the IMF in October. The IMF projected that global GDP would contract in 2020 by 3% and 4.9%, respectively, in April and June 2020.

How governments and the international community manage this recovery phase will have larger social, economic, and environmental implications. The humanitarian and socioeconomic crisis of COVID-19 and global lockdown are shifting the boundary conditions for development at a time when rapid transformations of our economies are needed to prepare for and manage global change processes.

Within this broader context, this report explores the implications of COVID-19 and the recovery process for building a more resilient and sustainable food system. The report is a contribution to the Consultative Science Platform launched by the International Institute for Applied Systems Analysis (IIASA) and the International Science Council (ISC) to examine the implications of the pandemic for various development paths. It focuses on four themes: Resilient Food Systems, Sustainable Energy, Governance, and Science Systems. Drawing on a background paper (Sperling et al. 2020), a series of consultations were held with experts from academia, the public and private sectors, and civil society between the end of May and September 2020. These, in conjunction with complementary literature reviews, helped to inform the scope of this report. Following an overview of our current food system, the report discusses the impacts of the pandemic and lockdown measures before shifting the focus from the near term to the longer term; the potential risks and opportunities in the recovery process are described and discussed; and action areas for building more resilient food systems are suggested.

2 Current food systems and the need for transformation

Our current food systems have succeeded in increasing the world's food supply at a faster pace than the rising demand of a growing and more affluent population but are confronted with a growing set of challenges and inadequacies. First, although global food demand keeps increasing, new threats to food production are arising due to climate change and, in some regions, water scarcity and land degradation. Second, the weakness of one of the pillars of our current food system, namely, the importance of nutritious food and the relationship between nutrition and health, is increasingly being recognized. Third, the current models of production of many food systems generate socioeconomic inequalities and environmental impacts that must be tackled. To meet these multiple objectives and challenges, there is a need for systems transformation. This was widely recognized before the outbreak of the pandemic. However, the pandemic laid bare the vulnerabilities and interdependencies embedded in our food systems and revealed the insufficient recognition given to resilience and equity concerns.

2.1 Our current food systems are diverse and face complex challenges

When speaking of the global food system in this report here, this is done to describe some general overarching trends, while recognizing there are a great variety of food systems. Our food system is, in fact, a system of systems, and global trends are shaped by the interactions among the various food systems at local to global scales, including synergies, complementarities, and the competition among them. The High-Level Panel of Experts (HLPE) on food security and nutrition of the World Committee on Food Security provides a categorization of food systems (Box 1). This typology includes modern, mixed, and traditional food systems (HLPE, 2017), although it is acknowledged that the boundaries between these different systems are often blurred in reality. At one end of the spectrum, modern food systems often rely on complex supply chains, organized by large international agribusinesses and retailing companies, and the application of industrial production methods, in-time supply chains, high diversity of products, strong price competition, and in some cases unequal market power along the supply chain. At the other end of the spectrum, we find traditional food systems, relying on smallholder and subsistence farmers, local markets, and supply chains, and partly or fully disconnected from international markets and products, as well as investments opportunities and farm inputs and technologies. Agriculture remains a major source of livelihood in many developing countries. The reform of food systems and development of agribusinesses are seen as major opportunities for helping end poverty on the African continent and creating a 1 trillion USD business opportunity for African economies by 2030 (World Bank 2013).

Global trends emphasize production efficiency. To meet rising demands, agricultural markets are becoming increasingly integrated. Between 2000 and 2016 the global value of trade increased threefold, reflecting changing patterns of consumption, the rising influence of emerging economies, and the growing trade in food products between developed countries (FAO 2018).

There is a gap widening between net exporting and net importing regions, with agricultural exports tending to originate from a relatively small number of countries and the distribution of imports being more widespread (FAO 2018). In increasingly interconnected food systems, trade has become essential for ensuring food security of importing countries, while providing livelihoods and income opportunities for exporting countries. In several developing countries, particularly in sub-Saharan Africa, population growth rates have outpaced agricultural productivity gains—contrary to the global picture—and a growing trade deficit in agricultural commodities is being observed.

The current global food system faces several challenges. Due to climatic impacts, conflict, and economic downturns, global progress in addressing malnutrition has ground to a halt in recent years, and at the global level, the number of people suffering hunger is again increasing slightly (FAO 2019; FAO 2020a). Prior to the outbreak of the pandemic, over 690 million[2] people were undernourished (FAO 2020a) and many more suffered from food insecurity and micronutrient deficiencies. While chronic hunger remains a pervasive problem in developing countries and particularly in sub-Saharan Africa, the prevalence of obesity and associated non-communicable diseases is on the rise globally (Ng et al 2014).

Our food systems are associated with large environmental externalities. The agriculture, forestry, and other land uses (AFOLU) sector contributes 23% to net anthropogenic greenhouse gas emissions (IPCC 2019). Agricultural activities and land use changes are major drivers of biodiversity loss and environmental degradation (Díaz et al. 2019). Agriculture has profoundly altered nutrient cycles and water and natural resource use, affecting terrestrial, freshwater, and marine ecosystems (UNEP 2019). The increasing application of nitrogen fertilizer is contributing to a rise in atmospheric concentration of nitrous oxide and thus to climate change, which calls for greater attention to mitigation options in global food systems (Tian et al. 2020). The accumulation of plastic waste in terrestrial and marine systems, requires also rethinking and innovation concerning the use of plastics in food packaging (WEF 2016).

To resolve trade-offs and strengthen synergies among the various economic, social, and environmental objectives linked to our food systems, integrated solutions are needed that combine a variety of supply- and demand-side policies and measures. Various assessments and initiatives have underlined the benefits of systems thinking, showcasing how a combination of supply- and demand-based measures, such as the improvement of agriculture and livestock productivity, upscaling of sustainable land management practices, changing behavior and habits towards healthier diets, can help resolve trade-offs and generate synergies between multiple development and environmental objectives (e.g., Smith et al. 2013; Havlík et al. 2014; FOLU 2019; IPCC 2019; Willett et al. 2019).

[2] The FAO 2020 report includes an update of the methodology used to estimate the number of undernourished people, which leads to a downward revision.

Box 1. Definition of a Food System

A food system is defined by the components needed to deliver, process, package, and consume food as well as manage its associated waste and by-products (see HLPE 2017). This includes the inputs and activities for food production, such as growing crops and livestock, the food-processing steps, storage, packaging, and transportation to markets. Various stakeholders operating along these elements are connected through the food supply chain, ultimately linking the consumer directly or indirectly to the producers**.** Food environments constitute the physical, economic, and sociocultural context of consumer engagement with the food system (HLPE, 2017), shaping their ability to access food and influencing dietary preferences. Waste and by-products generated along the food supply chain or during consumption are also important components of the food system. The structure of a food system is not static, but its components are influenced by a number of biophysical and socioeconomic drivers. Hence, the importance is increasingly recognized of focusing not only on individual elements but on all of the elements of a food system and the various feed-back processes between them, particularly in light of global environmental change (e.g., Ericksen, 2008).

2.2 Transformation is essential for sustainable development

Systems analysis is used by the scientific community to inform strategic decision making, as it helps to anticipate the complex interactions between human and natural systems and thus the challenges for sustainable development across different scales (OECD and IIASA 2020). IIASA and other research institutions have contributed to research on the conceptualization and ongoing application of the Shared Socioeconomic Pathways (SSPs), where quantified scenarios of socioeconomic trends can be used to project secondary indicators in domains related to food and land use (Popp et al. 2017; Riahi et al. 2017). Alternative projection scenarios, from the most optimistic (SSP1 "Sustainability") to the most pessimistic (SSP3 "Regional Rivalry"), allow a full set of consistent representations of the future of the agricultural and food systems to be explored (Fricko et al. 2017). For example, under SSP2, a "middle-of-the-road" scenario, population grows from 7.8 billion people today to over 9.2 billion people by 2050 and GDP per capita increases by 140%. Under SSP2, cropland would expand globally by 137 million hectares (Mha) between 2020 and 2050 and pasture by an additional 112 Mha, while agricultural GHG emissions would increase by 19% (Fricko et al. 2017).

Shaping the future development of our food systems is even more important today because new challenges need to be anticipated, as illustrated by the current pandemic**.** Among the most alarming of these threats is climate change, which undermines food security, affects the productivity of the agricultural and forestry sectors, and impacts biodiversity and ecosystem health (IPCC 2019). In a fragmented world, progressive climate change would adversely affect food security, increasing undernourishment by up to 200 million[3] (Hasegawa et al. 2018), while more adverse impacts could be expected if extreme events and ecological tipping points were to be taken into account (Gaupp et al. 2019; van Ginkel et al. 2020).

Mitigating climate change will require radical changes to our economies that also imply deep transformations for food systems. According to estimates, an achievable global emission-reduction target for agriculture alone would be 1 Gt CO_2-equivalent (Wollenberg et al. 2016). However, such mitigation policies

[3] Analysis based on the SSP3 scenario and RCP6.0, see Hasegawa et al. 2018.

need to be suitably designed to minimize potential adverse impacts on other development outcomes and to ensure a positive overall outcome (Havlík et al. 2014; Frank et al. 2016, Hasegawa et al. 2018). For example, nature-based solutions for climate change mitigation would involve large transformations of the land system as a whole, including afforestation programs, deployment of bioenergy, and soil organic carbon sequestration, all of which have consequences for agriculture and food systems (Roe et al. 2019).

A large array of climate mitigation scenarios, explored by integrated assessment models, illustrate the extent of the efforts required to mitigate climate change and the implications of those efforts for other sustainability indicators (Popp et al. 2017). Generally, more ambitious and coordinated transformations involving food and land use systems will be required to achieve the various Sustainable Development Goals (SDGs) in a concerted manner (Schmidt-Traub et al. 2019).

Research has clearly indicated a number of deep transformations required regarding food systems, with considerable focus being placed on the impact of modern models of production and how adaptations in cultivation or animal rearing practices could minimize the overall pressure on ecosystems and the environment. For instance, increasing crop yield and livestock conversion efficiency is achievable in many regions of the world and could both reduce GHG emissions and improve global food security (Valin et al. 2013). The transition in livestock production systems appears to be particularly promising (Havlík et al. 2014), as the environmental footprint of this sector is typically twice that of crops (Steinfeld et al. 2006). Technical options and structural changes can also be deployed to limit the adverse effects of GHG emissions or other local effects (Frank et al. 2018). Conservation farming practices that enhance soil organic carbon can even generate win–win solutions for food security by increasing the land carbon sink and increasing crop productivity (Frank et al. 2017).

On the demand side, reduction in meat and dairy consumption has long been identified just as crucial a transformation to mitigate non-CO_2 emissions from livestock as addressing climate impacts through land use change (Stehfest et al. 2009). However, from a human health perspective, changing meat consumption habits still forms only a marginal part of the nutrition transformation required for limiting the burden from non-communicable diseases (Afshin et al. 2019). Combining planetary and human health would therefore imply broader adjustments in food systems, and would also affect some products such as fruits, vegetable, oilseeds, and nuts; this would require more radical transformations (Willett et al. 2019), as well as some associated trade-offs in terms of water consumption or other environmental impacts (Springmann et al. 2018).

Dietary change is not the only lever on the demand side; so too is the large amount of food lost or wasted along the supply chains (FAO, 2019). Integrated assessment modeling illustrates that better use of food, particularly through reduction of food wastage and losses, would allow a significant part of food access issues to be reduced. Better food access should also build on redistribution of food within society, as access to food remains deeply uneven, mostly for reasons of economic inequality (Hasegawa et al., 2018). Overconsumption of food is also a source of inefficiency in food systems, creating a health and economic burden that requires specific policy attention (OECD 2019).

The role of trade has been much studied as a factor of stability in the food systems. For example, trade benefits have been demonstrated in the context of climate change, as some regions will lose their comparative advantages for the production of important staple crops (Leclère et al. 2014; Mosnier et al. 2014; Gouel and Laborde 2018). Research based on IIASA's Global Biosphere Management Model (GLOBIOM) suggests that trade liberalization would generally improve food security under various climate change scenarios

(Janssens et al. 2020). As discussed in later sections the role of trade in influencing the exposure and capacity to mitigate diverse multiple socioeconomic and environmental risks needs to be considered.

All the transformations described above can significantly improve global sustainability. However, integrated assessment modeling has demonstrated that sustainable pathways will require many of these levers to be combined for the world to be put on track to achieve the SDGs. For instance, in the case of biodiversity, only a combination of these levers would allow biodiversity to recover from its long-term downward trend (Leclère et al. 2020). Ten crucial transformations were identified in a report by the Food and Land Use Coalition (FOLU 2019) and sustainability pathways modelled to illustrate the required magnitude of change. These transformations cover the domains listed above, as well as overall enabling conditions, related to global and local governance, the mobilization of digital technology and the inclusiveness of society. A recent report of the Consultative Group on International Agricultural Research (CGIAR) similarly illustrated the importance of mobilizing a large number of actions to achieve the required level of food system transformation (Steiner et al. 2020). Systems analysis proved to be key in supporting the definition of the future sustainability pathways in the case of the SDGs. In a post-COVID world, however, such pathways will need to be revisited and updated, based on what the crisis taught us about our current food systems vulnerabilities and the future needs for building resilience.

3 The Impact of COVID-19 and global lockdown on food systems

3.1 Food and Nutritional Security

The agricultural system's purpose is, first and foremost, to meet an essential human need—access to safe and nutritious food for all. The pandemic is revealing the extent to which this primary function has been compromised at global and regional levels. The impacts on food systems are complex and still evolving. Preliminary insights from the literature and from consultations suggest that in the context of food systems, the pandemic has been not so much a supply crisis but predominantly a demand crisis, although different regional and local contexts need closer evaluation.

Food insecurity

The threat of acute food insecurity is on the rise. In April 2020, the Head of the World Food Program David Beasley has warned that unless rapid mitigation measures are undertaken, the world may face "multiple famines of biblical proportions," potentially doubling the number of people at risk of dying of acute hunger from 135 million to 265 million people by the end of 2020[4]. In a situation update released in November 2020, the WFP (2020) revised these numbers upwards, estimating that a total number of 271.8 million people are facing acute food insecurity due to exacerbating effects of the pandemic alongside other compounding factors. The pandemic threatens to unravel global progress toward universal food security by 2030, as stipulated in the second global goal of the SDGs.

Global and local food supply

These warnings about growing levels of food insecurity in developing and developed countries come as the outlook for global food supplies has remained largely stable and global food reserves are high. Due to good harvests in 2019 and in early 2020, stock-to-utilization ratios have been considerably higher in 2020 than during the 2007 and 2008 crisis (e.g., Headey and Fan 2008, World Bank 2020a). Primary agricultural production has not been severely affected by the crisis to date. However, the impact on the food supply may look considerably different at regional and local levels when links between producers and consumers break down due to lockdown measures and associated impacts. For example, in Africa, Latin America, and Asia supply chains rely heavily on human capital and access to local and informal markets. Hence, containment measures can represent a considerable threat to the supply of food staples and raise local food prices in these regions. Price spikes have been observed locally due to the impact of travel bans, closure of markets, and other measures taken to contain the spread of the virus, as Ali et al. (2020) highlight for example in their discussion of the situation in West Africa.

[4] https://insight.wfp.org/wfp-chief-warns-of-hunger-pandemic-as-global-food-crises-report-launched-3ee3edb38e47

Trade and supply chains

The global trade system has proved to be quite resilient to the pandemic shock, and there have been relatively limited impacts on the exchange of main commodities. Well before the COVID-19 crisis, the food price spikes episodes in 2007-2008 and 2010-2011 illustrated the threat of protectionism for global food security as well as volatilities arising from the interplay between food, energy and financial markets (e.g. Headey and Fan 2008, Tadesse et al, 2014). During the pandemic some countries have implemented specific trade restrictions[5] (e.g., Vietnam for rice, Russia for wheat), totaling 21 countries by early July 2020 (Laborde et al 2020). However, most of these restrictions have been short-lived (Laborde et al. 2020), the lessons of the 2007–2008 crisis appear to have been learned and no major disruptions in the international trade of the main commodities have been observed. The pandemic has also delayed efforts for further economic integration in Africa, as the start date for the African Continental Free Trade Area (AfCFTA), originally scheduled for 1 July 2020 had to be postponed[6].

The impacts on supply chains have been heterogeneous. In Europe, border closures revealed the dependency of food systems on migrant and seasonal labor. In the United States (USA) and Europe, the meat packing industry became a hotspot of Coronavirus infections (Wallenburg et al. 2020, Middelton et al 2020), revealing food safety and sanitation issues. It also highlights the dependency of modern food systems on highly specialized supply chains. Shutdowns of large processing plants have created bottlenecks in the meat supply, while also exacerbating food losses and waste. With the closure of some slaughterhouses and decreased demand, many animals have had to be culled without entering the food market. In the USA, the disruption of ethanol refineries has also generated a shortage of dried distiller grains which are usually used as protein ingredients in the livestock sector; other feed types have had to be substituted for these, leading to higher costs and productivity decreases.

COVID-19 as a demand shock to food systems

From a global perspective, the crisis has predominantly played out as an employment and income crisis. In May 2020 the International Labour Organization (ILO) estimated that without alternative income sources such as cash transfers by governments, the income loss from unemployment or underemployment due to the COVID pandemic could result in an increase in relative poverty for informal workers and their families of more than 21 percentage points in upper-middle-income countries, almost 52 points in high-income countries, and 56 points in low-income countries (ILO 2020).

COVID-19 and the lockdown measures have led to multiple demand shocks. Rising levels of poverty, loss of income, and physical distancing measures have rapidly changed consumer behavior. This has led to a mismatch between supply and demand. Oversupplies, especially acute in the food chain for restaurants and canteens[7] due to demand shortage during the lockdowns, as well as demand disruptions in biofuel[8] for transportation, have led to food wastage and stock increases in cereals like corn. Increases in food loss and

[5] https://www.ifpri.org/project/covid-19-food-trade-policy-tracker
[6] https://www.un.org/africarenewal/magazine/may-2020/coronavirus/implementing-africa%E2%80%99s-free-trade-pact-best-stimulus-post-covid-19-economies
[7] https://www.theguardian.com/world/2020/apr/09/us-coronavirus-outbreak-agriculture-food-supply-waste
[8] https://research.rabobank.com/far/en/sectors/grains-oilseeds/us-ethanol-recovery.html

waste have been observed across regions, particularly for perishable food groups, such as fish, fruits, and vegetables, for which (cold) storage options are limited. Furthermore, in countries like the USA, the industry is organized in ways that make it virtually impossible to reroute food produced for restaurants toward grocery stores, amplifying food losses at a time when people are lining up at food banks.

Different vulnerabilities of societal groups

While every human being is susceptible to infection by SARS-CoV-2, human and socioeconomic vulnerabilities differ considerably according to societal groups within and across countries. In particular, the impacts of the pandemic and lockdowns differ depending on age, gender, race, ethnic and religious group, income class and social status. The pre-existing physical condition is an obvious compounding factor to this vulnerability, closely interlinked with some of the inter individual differences above (Bixler et al. 2020). Specific attention is also to be paid to vulnerabilities linked to safely accessing sufficient and nutritious food. Furthermore, it is difficult to discuss the COVID-19 impacts without distinguishing the strongly differentiated situations between developed and developing countries.

Lockdowns, travel bans, loss of employment, and physical distancing measures particularly exacerbate the vulnerabilities of poor people. Overcrowded living conditions, precarious and often informal employment, and the absence of disposable income make many of the sanitary and protective measures recommended to fight the spread of COVID-19 difficult to implement in practice. Instead, poor people may be confronted with irreconcilable choices between protecting themselves from COVID-19 and seeking a basic daily income to obtain food.

The pandemic underlines the importance of having secure access to basic services. A large proportion of the global population still lacks access to safe drinking water and sanitation, and this is known to exacerbate food security challenges (FAO 2019). Chronic dehydration or exposure to water-borne pathogens exacerbate undernutrition and childhood stunting. The need to access water sources in crowded and unsanitary environments also facilitates the spread of the pandemic among poor and vulnerable people.

People employed or engaged in the trade and service of food (cashiers, food preparation and service workers, waitstaff) are among those most at risk for COVID exposure due to their physical proximity and frequent contact with others[9]. The exposure risk increases for food service employees in locations where the markets are crowded, sanitation facilities are limited, and cash is the primary form of currency. Since the start of the pandemic lockdown, several local, informal, and formal markets have been closed, either permanently or temporarily, until facilities could be retrofitted to limit the spread of COVID-19. These closures have been particularly detrimental for food systems where markets play a central role in selling and accessing foodstuffs. Markets that can implement social distancing measures, provide handwashing or hand-sanitation stations, and accept cashless payment options have been allowed to remain open in many countries, despite the lockdown measures.

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[9] https://www.visualcapitalist.com/wp-content/uploads/2020/04/covid-19-occupational-risk-scores.html

The ongoing pandemic has revealed the worsening impacts of inequalities within and across societies and the role of governments in implementing and expanding effective social safety nets. Governments have responded to the economic crisis triggered by the pandemic and have adapted social protections to increase benefits (vertical expansion), scaled up coverage (horizontal expansion) and made administrative systems more efficient to allow more of the population to join programs that offer more benefits (vertical and horizontal expansion) (Gentilini et al., 2020).

Experts have warned that social protection measures must carefully consider the underlying vulnerabilities and inequalities based on age, gender, race, ethnic and religious group, income class, and social status that exist across the population. In low- and middle-income countries, people employed in the informal sector, often women, may be excluded from social protection measures linked to formal employment (Hidrobo et al. 2020). In all countries women have been at the forefront of the crisis because of the central role they play in the family structure and also in the health and social aid sector. Much of the additional burden of care within families, due to lockdown conditions, home schooling, and support to sick family members has fallen on women according to the National Women's Law Center[10], underlining the need for social protections to include cash transfers for family care work (Hidrobo et al. 2020).

Children who depend on free or subsidized school meals to meet their daily nutritional requirements are also particularly vulnerable. The World Food Program estimates that 346 million children missed meals due to school closures at the start of the pandemic[11] (WFP 2020). In some high-income countries, such as the USA, more than half the students in primary and secondary schools are usually dependent on subsidized school meals. According to Headey et al. (2020), 6.7 million children under five years of age could face wasting due to pandemic-related income losses. Reductions in nutrition and health services resulting from lockdown measures or diversions could lead to an additional 130,000 deaths among the under-fives, with more than half of deaths concentrated in sub-Saharan Africa (Headey et al., 2020). Older people may become more susceptible to undernutrition (Margetts 2020) and food insecurity (Fernandes et al. 2018); this is further complicated by COVID which is 90 times more fatal in the 65–74 than in the 18–29 age group. Lockdowns and social distancing measures have been strictly applied for older people due to their vulnerability, but these have also led to disruptions in nutritional services.

Diets and consumption behavior

The pandemic-related lockdown measures have included the temporary closure of restaurants and school/work canteens in many countries. As a consequence, consumption of unhealthy, highly processed food has increased in several instances. Food purchasing trends in the USA, for example, show clear increases in the consumption of ultra-processed, energy-dense comfort foods such as potato chips, chocolate, and ice cream (Bhutani et al 2020). On the other hand, home confinement and gym closures are impacting structured exercise and physical activity. A study in northern Italy showed that individuals with obesity had already gained significant weight one month into the lockdown (Pellegrini et al. 2020). Adolescents from a range of countries, for example in

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[10] https://nwlc.org/resources/four-times-more-women-than-men-dropped-out-of-the-labor-force-in-september/
[11] https://cdn.wfp.org/2020/school-feeding-map/index.html

Latin America, reported reduced physical activity and shifts to the consumption of ultra-processed foods during the pandemic (Ruíz-Roso et al. 2020). Whether these changes will persist after all COVID-19 restrictions are lifted and what the impacts will be on chronic disease risks remains to be seen.

3.2 Environmental risks, impacts, and vulnerabilities

COVID-19 is symptomatic of a wider tension between human production processes and ecological balances. Our agriculture and food systems represent one of the most important interfaces between human activities and the environment. Pollution, environmental degradation, legal and illegal direct harvesting of wildlife, and climate change are impacting biodiversity and the health of ecosystems. COVID-19 has had positive and negative impacts on these drivers, as will be discussed below.

Environmental degradation and zoonotic diseases

COVID-19 is part of a growing list of zoonotic diseases that includes HIV, SARS, MERS, and Ebola, among others. The race to increase agricultural production has led to an intensification and homogenization of agricultural activities. This together with environmental changes plays in important role in the risk of zoonotic diseases emerging (Jones et al 2012). Demographic changes, urbanization, and land-use changes have pushed further into natural frontiers and have fragmented habitats. While the relationship between biodiversity and emerging diseases is complex (Allen et al. 2017), habitat degradation and fragmentation by human land-uses have broken down barriers, and together with the increase in livestock units and their concentration have allowed viruses and bacteria to spill over more easily from wildlife to domestic animals and/or humans (Johnson et al. 2020). The consumption and trade of wildlife further aid the spread of zoonotic diseases (Walzer 2020). COVID-19 hence should not be seen as a singular event but recognized as a disaster made more likely by altered human–environment interactions, and most likely the first of a series of pandemics in the years to follow unless measures are taken to reduce the encroachment of human activities into natural habitats and wildlife trade (Di Marco et al. 2020; Franklinos et al. 2020; Gibb et al. 2020).

Environmental impacts during the lockdown

The global lockdown and associated changes in human behavior are having a range of impacts on the environment. Due to reductions in transport and economic activities, global emissions are expected to drop by around 8 percent in 2020 in comparison to the preceding year (IEA 2020). Air pollution in several urban areas has been significantly reduced for a short period of time, offering a glimpse into an alternative future where improved local environmental conditions would have benefits for our quality of life. However, the extent to which these positive changes can be sustained and could lead to a transformation of human–environment interactions, once economic activities resume, is uncertain. Nevertheless, these positive, albeit temporary, effects illustrate the scope of transformation actually needed to attain positive environmental pathways. They also provide insights into what an alternative state of the environment and future could look like.

There have been several (often anecdotal) local reports that people's reduced presence and mobility has affected behavior of wild species in both urban and agricultural areas. Reduced disturbance is expected to have positive effects for sensitive species. As human activity has declined there has been evidence of wild species venturing into rural and urban areas, including parks and beaches, where they have not been seen for years. There have been only limited studies systematically assessing these reports. Manetti et al (2020) reviewing the wildlife reports during the pandemic in Italy note that reduced disturbances may have improved breeding success and niche expansion of species but have possibly also undermined the management of some invasive species and facilitated illegal wildlife hunting. Derryberry et al. (2020) report changes in bird singing characteristics in response to reduced noise levels, illustrating the rapid behavioral adaptation of some species to changes in disturbance from human activities.

Wildlife is also an important source of food and medicine in several parts of the world. Unsustainable harvesting of several species has pushed them to extinction (Scheffers et al 2019) and, according to observations on the ground, this threat has been increasing over the last few years (UNODC 2020). For instance, the use of pangolins in East Asia (and Africa) for food and traditional medicines is responsible for the dramatic decline in pangolin species, three of which are on the brink of extinction and the remaining five at medium or high risk of extinction, according to the *International Union for Conservation of Nature* (IUCN)[12]. China is now taking more aggressive steps toward addressing the wildlife trade[13], which has been responsible for the demise of several endangered species, including pangolins.

Weakening of environmental regulation, monitoring, and enforcement

Other effects of the pandemic may prove detrimental to environmental protection. In some countries there has been a pushback during the crisis against environmental regulation and conservation measures. The lockdowns have also weakened monitoring and enforcement capabilities, and public attention to environmental destruction has dwindled, resulting in immediate and tangible impacts. For example, the deforestation rate of the Amazon rainforest in April 2020 was 64% higher than in April 2019; the first three months of 2020 saw 50% higher deforestation rates than in the same period of 2019[14]. Increased logging activities have also been observed in other regions since the start of the COVID-19 pandemic, specifically in countries such as Cambodia, Colombia, Indonesia, Madagascar, and Nepal[15]. There is real concern that a prolonged recession could result in governments deregulating businesses, moving the world away from achieving environmental SDGs. This includes the risk of the EU Common Agricultural Policy (CAP) to be misaligned with the European Green Deal, specifically the ambitions of its Farms 2 Fork Strategy, and the EU Biodiversity Strategy[16]. The CAP is the single largest budget item of the EU, accounting for 40% of the European Union's budget, and influences the potential to realize the transitions highlighted here.

Ongoing environmental change: What also happened in 2020

While the world's attention is focused on the pandemic, it is worthwhile to reflect that during 2020, a number of environmental extremes were observed around the world, including forest fires in Australia[17], Southeast Asia and the Americas, heatwaves and forest fires in Siberia[18], and thawing of permafrost and record high temperatures in the Arctic. Several of these extreme events can be attributed to climate change.

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[12] IUCN SSC Pangolin Specialist Group. https://www.pangolinsg.org/
[13] https://www.reuters.com/article/us-china-environment-wildlife-idUSKBN27P35B
[14] https://edition.cnn.com/2020/05/14/americas/coronavirus-amazon-brazil-destruction-intl/index.html
[15] https://news.mongabay.com/2020/07/covid-19-lockdown-precipitates-deforestation-across-asia-and-south-america/
[16] https://foodpolicycoalition.eu/wp-content/uploads/2020/09/Open-letter-on-CAP-and-Green-Deal_final.pdf
[17] https://weather.com/science/nature/news/2020-02-26-australia-fires-burn-unprecedented-amount-of-forests
[18] https://www.worldweatherattribution.org/siberian-heatwave-of-2020-almost-impossible-without-climate-change/

The year 2020 was also the year in which all the alphabetical names for hurricanes were used up (WMO 2020). According to the WMO, which selects the hurricane names each year, 2020 is proving to be an unusually active year for hurricanes[19]. Thus, for the remainder of the hurricane season, new hurricanes are having to be named using letters from the Greek alphabet. This has happened only once before in 2005 (WMO 2020). Moreover, in the wake of the landfall of cyclone Pawan in early December 2019, exceptionally heavy precipitation favored the locust infestation in the Greater Horn of Africa, which exacerbated the food crisis in the region and compounded the impacts of the pandemic (FAO, 2020b).

These events are a reminder of our vulnerabilities to climatic variability and change alongside other ongoing environmental changes. We are on a warming curve, where the global mean temperature is now above one degree Celsius compared to preindustrial levels (WMO 2020). We are also in the midst of the sixth mass extinction (Ceballos et al. 2020). These ongoing processes, together with other environmental degradation and pollution, are eroding the Earth's life support system beyond safe limits (Rockström et al. 2009a,b, Steffen et al. 2015). Hence, COVID-19 should not be used as an argument for delaying action to address other environmental challenges. Instead, it should be recognized as a urgent wake-up call to reduce pressure on the environment and to initiate stronger, more comprehensive, and rapid efforts to enhance preparedness for changes and hazards that can no longer be avoided.

3.3 Resilience and Adaptive Capacity

The current pandemic reveals how interdependent our economies are and how the ripple effects of a shock can quickly move across sectors and political boundaries. It is also a warning that societies should be prepared for more complex risks and changes. This particularly applies in the case of food systems which are exposed to a variety of environmental and socioeconomic shocks. It requires being prepared for global scale disturbance of earth system processes, including climate change and sea level rise, as well as being able to manage local level impacts and compounding risk factors, such heat waves, droughts, and environmental degradation. Human experience to date may be an insufficient guide for managing future risks. Instead of environmental changes being dealt with incrementally, emphasis is needed on strengthening the capacity to manage a multitude of risks playing out across different spatial scales, both fast-onset events like floods and slow-onset situations like droughts. Account must be taken of the possible occurrence of tipping points in natural or social systems, where a small change could suddenly lead to large-scale impacts and shifts in the properties of a system (see Lenton et al. 2008, Milkoreit et al. 2018). Overall, a much more comprehensive analysis of the capacity of food systems to manage such risks is required. There must be a better understanding of which stakeholder groups are the most vulnerable to pandemic, environmental, and socioeconomic risks and of the interventions best suited to building their resilience.

Multiple shocks

In several cases, the impacts of the COVID-19 crisis have been exacerbated by existing vulnerabilities and additional shocks. Before the pandemic took hold, the Greater Horn of Africa, Arabian

[19] https://public.wmo.int/en/media/news/2020-hurricane-season-exhausts-regular-list-of-names

Peninsula, and southwest Asia were already facing one of the worst locust outbreaks in decades, threatening to destroy harvests and triggering food emergencies (FAO, 2020b). In western Africa, the humanitarian and socioeconomic impacts of COVID-19 have been superimposed over an ongoing regional food crisis; the combined effects of confinement, market closures, barriers to trade, and loss of income could adversely affect an additional 50 million people[20]. Countries in these regions have been forced to manage multiple simultaneous shocks and crises—economic shocks, social conflicts, climatic events and disasters, other epidemics. Disruptions in the food supply chain may also have wider knock-on effects. In general, the COVID-19 crisis has put significant strain on the humanitarian and food aid sector and increased vulnerabilities during emergencies.

Social Safety Nets

Rising levels of poverty and food insecurity have revealed the absence or weaknesses of social safety nets. Abhijit Banerjee and Esther Duflo, whose pioneering work on understanding the lives of the poor through a series of randomized field trials was recognized by the 2019 Nobel Prize in Economics, have advocated regular cash transfers to the poor in India, in the hope that a universal income can protect them from food insecurity[21]. In an overview of the impacts of the pandemic on nutrition in India, Lele et al (2020) highlight the vulnerability of informal labor force and the disproportionate impact on women, underscoring the need for expanding the reach of safety nets, including better follow-through on implementation, and embedding a strong emphasis on protecting incomes and providing livelihood security into the recovery process. COVID-19 also uncovered insufficient social protection in several developed countries, particularly in urban areas. This was illustrated, for example, by the rising number of food banks in major cities; in Amsterdam, for example, the number increased by 30% during the lockdown. In New York, 1.1 million people were also estimated to have suffered food insecurity during initial months of the lockdown, while in the United Kingdom 5 million people in households with children under 18 experienced conditions of food insecurity[22].

In many countries existing social safety nets were insufficient to absorb the socioeconomic impacts of the pandemic. This is illustrated by the rapidly growing number of countries that are expanding or introducing new social protection measures. Gentilini et al. (2020-June Revision) have found that nearly 195 countries have implemented at least some type of social protection measures estimated to reach 1.7 billion people, showing a rapid increase of such measures during the COVID-19 pandemic. Seventy percent of countries have provided cash transfers and 44% of countries have provided in-kind food/voucher schemes. However, only 13% of countries have begun implementing school feeding programs and the authors estimate that only 15% of the total measures taken relate directly to the food system[23] (Nguyen 2020). Furthermore, 93 countries have implemented waivers or postponements of utility payments and many of these waivers are ongoing. The cash transfers represent on average about 30% of the average monthly GDP per capita, and in the majority of countries they have lasted for up to three months. The US COVID-19 Relief package passed in March 2020 included an additional 15 billion USD in funding for the Supplemental Nutrition Assistance Program (SNAP), a

[20] http://www.food-security.net/en/topic/food-and-nutrition-crisis-2020/
[21] https://www.theguardian.com/commentisfree/2020/may/06/vulnerable-countries-poverty-deadly-coronavirus-crisis
[22] https://foodfoundation.org.uk/new-food-foundation-survey-five-million-people-living-in-households-with-children-have-experienced-food-insecurity-since-lockdown-started/
[23] https://www.ifpri.org/blog/policy-seminar-social-safety-nets-covid-19-response-protect-food-security-and-nutrition

program already reaching approximately 38 million people in the USA before the pandemic[24]; its coverage has been extended to a further 6 million people since the start of the pandemic[25].

The role of innovation and technology in risk management

In some cases, the impacts of the COVID-19 crisis on food systems could be reduced by innovation and other adaptive measures. For example, drones have been increasingly used for agricultural monitoring. E-commerce platforms have offered restaurants a partial adaptive response to physical distancing measures and closures. Digitization and mechanization of food systems can improve the efficiency and productivity of food systems, while helping to reduce exposure to some risks. However, given the importance of agricultural activities to livelihoods, particularly in developing country economies, it is particularly important for the adoption of new, smarter technologies not to come at the expense of employment and livelihood security, but rather to strengthen education, retraining, and skills development and to enhance other forms of social support to fight the pandemic effects and support the recovery process.

[24] https://fns-prod.azureedge.net/sites/default/files/resource-files/34SNAPmonthly-7b.pdf
[25] https://www.nytimes.com/2020/07/19/us/politics/coronavirus-food-stamps.html

4 Toward Recovery: General Considerations on Opportunities and Challenges

As discussed in Section 2, there was increasing recognition prior to COVID-19 that continuing with business as usual was no longer viable. The transformation of food and land-use systems has a central role to play in reaching the Sustainable Development Goals (SDGs) and meeting other key international policy objectives, such as the Paris Agreement on Climate Change. Changes in land use practices and dietary shifts are needed to improve food security and human health, meet environmental objectives, and strengthen the resilience of livelihoods and economic sectors. The impacts of COVID-19, discussed in Section 3, further reinforce the need for transformation of food systems. The pandemic cannot be used an argument for delaying action, as the key sustainable development challenges remain and are fundamental to long-term human well-being. Instead, the COVID-19 crisis calls for a recovery that is fully embedded in the ambition of the SDGs (see UN 2015).

We are now at the crossroads towards or away from a sustainable development trajectory, depending on how we collectively decide to respond to this pandemic. We can broadly distinguish two alternatives that embody two distinct views on how to respond to the current global disruption (see also Box 2). On the one hand, strategic decisions made during the recovery could focus on pathways to rebuilding society and the economy as we know it, that is, reverting to a business-as-usual scenario. On the other, a recovery path could be chosen to harness the disruption caused by COVID-19 and catalyze a broader transformation toward resilient and green economies. The first alternative places a single focus on recovery from the specific shock caused by COVID-19. The second is guided by a systems thinking approach to strategic decision making, seeking integrated solutions able to strengthen society's general preparedness for a variety of shocks and looming threats. It is currently unclear which of these contrasting alternatives will predominate, that is, the extent to which the international community will succeed in coupling near-term responses to COVID-19 with longer-term transformations of human systems toward greater resilience and sustainability.

The current architecture of our food systems reflects the increasingly interconnected nature of our economies and societies. Globalization has helped generate multiple benefits, but it also means we are increasingly confronted with shocks that originated in distant geographical locations and the challenge to manage complex risks that exhibit non-linear behavior. This has been illustrated during the pandemic, but it is also a crucial aspect of climate change and other global changes.

Before moving to key considerations and recommendations, it is worth highlighting some potential challenges and pitfalls involved in the transformation toward sustainable and resilient food systems.

The timing and speed of the socioeconomic recovery are uncertain. At the time of writing, the confirmed cases of COVID-19 infections and number of deaths are still on the rise globally. As of early November 2020, over 49.7 million cases and 1.2 million deaths had been recorded globally since the beginning of the pandemic (WHO 2020). There is also concern that the extent of infection in developing regions may be much higher than currently reported, given their limited healthcare capacities and testing possibilities. While China, New Zealand, and a few other countries appear to have contained the virus, recent surges in infections in several European countries following the easing of social distancing and travel restrictions over the Northern Hemisphere summer have illustrated the risk of a second wave. The international race to find a vaccine and recent approvals have nurtured hopes of vaccinations becoming globally available in 2021, but considerable distributional challenges will need to be overcome. Until then, however, repeated local or more widespread lockdown measures may be necessary, further worsening economic impacts and slowing down the recovery process. If the recession of the world economy is prolonged, economic assumptions which informed analyses of sustainable development pathways before the pandemic will need to be revisited.

Risk of growing economic and technological divide. The capacities of countries to deploy fiscal rescue packages and broad social protection measures differ greatly across the world. With governments prioritizing their own national recovery, there is a risk that lack of international cooperation will hamper the sustainability transformations needed for the SDGs and widen the economic and technological gaps between and within regions. The EU, USA, and other advanced economies have released unprecedented economic stimulus packages (Cassim et al. 2020), based on both fiscal and monetary interventions. Developing countries have only limited capacity to do the same and may also have to deal with the devaluation of their currencies, as well as loss of investments and remittances. While there is now excess liquidity in some world regions, the uncertainty relating to the course of the pandemic has impeded private-sector investments.

In light of the uncertainties and constraints outlined above, it is important that the recovery is informed and guided by the vision of a more resilient and sustainable future. The recovery is about making deliberate, informed strategic choices, taking into account the potential long-term consequences for the various development paths. At this time of crisis, countries and the international community should not call the SDGs into question but rather reaffirm their own commitment to them. The SDGs provide the available framework for international cooperation on global development at a time when multilateralism has been weakened. Hence, they should be recognized as the fundamental reference guide for a sustainable recovery.

Embedded in the SDGs are the elements for more sustainable and resilient food systems. These are focused on delivering universal food and nutritional security, promoting innovation and the expansion of sustainable practices, supporting decent jobs, equity, and creating livelihood security, reducing food loss and waste, while protecting the climate, marine and terrestrial systems. Building ownership around these elements and translating them into a coherent vision should be an integral part of the recovery process of national and regional governments and also inform international collaboration. However, the pandemic has also revealed particular aspects of food systems and of our economic systems in general, which require further attention to guide strategies and policies for the recovery. In this section, we outline focal areas for reshaping and adjusting policies and actions in the wake of COVID-19 to build more resilient food systems.

Box 2. Illustrative narratives for alternative futures

COVID-19 and the global lockdown have led to a global recession, undermined long-term development progress, and exacerbated inequalities within and across countries. As countries transition from crisis management to a focus on socioeconomic recovery, we illustrate here two contrasting narratives for future development paths, which would also have consequences for building more resilient food systems.

Disordered recovery to business as usual. Emphasis in the recovery is placed on saving and restoring existing economic structures as fast as possible without strategizing investments. Country capacity with respect to issuance of fiscal stimulus packages differs greatly: growth returns to the richest parts of the world, but development in low- and middle-income economies stalls. Greenhouse gas emissions continue to increase, as several countries dilute their national climate change targets and environmental regulations. The objectives of the Paris Agreement appear to be out of reach, and multilateral cooperation weakens as official development assistance (ODA) and investments from developed countries are reduced. Devaluation of currencies, loss of remittances, depression of prices for primary commodities, and absence of social safety nets further exacerbate the poverty and food insecurity in developing countries, while obesity levels continue to rise globally. The technological gap between developed and developing countries widens. Developing countries struggle to improve agricultural and livestock productivity, as they are also confronted with managing climate variability and change, land degradation, and other environmental changes. The multilateral system is weak, countries putting national priorities first. While some countries are thriving economically, other countries are falling behind. The world becomes divided into regional blocks with limited cooperation among them.

Resilient and sustainable futures. Fiscal stimulus packages seek to couple recovery with targeted transformation toward more equitable, circular, green, and inclusive economies. Strong emphasis is placed on strengthening social safety nets and access to basic services. International development cooperation is recognized as an essential tool to help narrow economic and technological gaps between countries. Developed countries for the first time universally meet their ODA contributions target of 0.7% of GDP in 2022 as a collective international response to the crisis and from 2025 commit to upscaling their ODA contributions to 1.2% of GDP. These commitments are coupled to fiscal and institutional reforms in developing countries toward greater accountability and transparency. Great emphasis is placed on education and training, helping to build endogenous research capacities in developing countries. A balanced approach of technological innovation and upscaling of available sustainable agricultural practices allows agricultural productivity to be improved, while also helping to regenerate degraded lands. Recognizing and rewarding farmers as stewards of ecosystem services through targeted incentive and payment schemes, coupled with strengthened regulations and enforcement mechanisms further contribute to maintaining carbon stocks and protecting biodiversity. The international push toward healthy and affordable diets, which is supported through targeted government programs and awareness campaigns, reduces the prevalence of non-communicable diseases while also reducing the pressure on land. The world is moving toward integrated collaboration and integration to address global challenges, maintaining a collective focus on SDG targets in 2030 and carbon neutrality by 2050.

5 Building resilient food systems: Focal areas for the recovery process

Many of the ingredients for the transformation toward sustainable food systems already exist and have been well-recognized before the pandemic (e.g., FOLU 2019; Willett et al. 2019). While it is understood that the transformation has to be multisectoral in focus and embedded in a wider push toward building greener and more circular economies, the pandemic has also illustrated that the social, economic, and environmental pillars of sustainable development need to be firmly anchored in resilience. As the consultations within the IIASA–ISC Consultative Platform underlined, this foundation has its weaknesses, and support for each of the pillars needs to be strengthened. Drawing on the discourse in the consultations and supplementary reviews, the following sections outline a set of general focal areas for building resilient food systems in the wake of COVID-19. Each section provides some context and concludes with a Box of summary recommendations, so-called action areas (AAs). Developing pathways toward more resilient, equitable, and sustainable food systems will require these suggestions to be developed within specific socio-cultural, economic, and environmental contexts and for the synergies and trade-offs between multiple objectives to be carefully examined.

5.1 Empowering a systemic shift toward resilience and equity

The evolution of our food system has largely been driven by a focus on boosting agricultural production and increasing its efficiency. One positive outcome has been that global increases in caloric food supply have outpaced population growth for decades, while agricultural and livestock productivity gains have limited the adverse impacts of this production increase through agricultural land expansion (Ramankutty et al. 2018).

It has also led to increasing integration of markets, the rise of internationally operating agri-businesses, long and increasingly complex supply chains and just-in-time production approaches. A growing number of countries are dependent on imports for their food security, while sometimes only a few countries dominate the market for a particular commodity. A concentration of actors on the supply or demand side can lead to harmful market power positions and create vulnerabilities. Where there is only a limited number of exporters, this can create a food security risk for importers, if trade is interrupted. Conversely, if exporters depend only on a small number of importing countries, shifts in demand can quickly affect their income. This can be particularly detrimental to developing countries where the agricultural sector is often a major source of livelihood and income.

While the impact of the pandemic on global trade in agricultural products has been limited and no global food supply crisis has occurred with stock to utilization ratios remaining high for major food staples (World Bank 2020a), the lockdown and other containment measures have put a spotlight on the inter-dependencies of countries and their different levels of exposure to supply and demand-based risks to various components of the food system (Schmidhuber et al. 2020). Lockdown measures, travel restrictions, and other logistical barriers, together with loss of income and associated behavioral changes, have led to a mismatch between supply and demand, as well as labor shortages in some agricultural sectors.

With the looming risk of future pandemics, shocks associated with climate change, and the global environmental and socioeconomic changes that are compounding local pressures, the way food systems are framed needs to change. The prevailing emphasis on efficiency, which is focused on maximizing production relative to cost, is insufficient for shaping the food system architecture in a sustainable manner so that it can meet intertwined social, economic, and environmental challenges. Efficiency must be counter-balanced by an emphasis on sustainability principles in general and a focus on equity and resilience in particular. This does not mean that economic growth and efficiency are irrelevant, but rather that greater consideration needs to be given to when this focus is warranted and who benefits from it. Moreover, not only the quantity, but also the quality of growth needs to be considered. The global food system needs to deliver universal food and nutritional security. Hence, the architecture of food systems should be guided by how well it serves this primary purpose and how it empowers the most vulnerable and marginal groups.

Building resilient food systems should be viewed as a dynamic concept rather than a static one. In general, the IPCC (2012, p. 563) defines resilience as the "ability of a system and its component parts to anticipate, absorb or recover from the effects of a hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration or improvement of its essential basic structures and functions." When considering the resilience of socio-ecological systems, which includes food systems, a central aspect to consider is the ability of the system to recover its functions and bounce back after a shock (e.g., Walker et al. 2004), but this also needs to be closely linked to considerations of the capacity of the system to adapt or transform (Folke et al. 2010), particularly where this may lead to more favorable outcomes in a world exposed to multiple shocks and long-term trends.

Ideally, an emphasis for resilience should reinforce conditions for enabling sustainable development. Resilience considerations may apply to multiple spatial and temporal scales. It is possible to imagine situations where an emphasis on local-level resilience may be at odds with larger-scale resilience and sustainability concerns, or vice versa. Hence, when resilience concepts are being operationalized, the interactions among the various components of the food system need to be kept in mind. Among the questions needing to be asked are resilience of what and for whom? Potential trade-offs between social, economic, and environmental resilience and sustainability concerns need to be addressed. Furthermore, when building resilient food systems it should be avoided that food system structures are locked-in that are unsustainable or maladaptive to trends, thereby exacerbating vulnerabilities of livelihoods and economic activities over time. Hence, resilience concepts should take into account multiple risks, be considered in their implications across scales, and include an emphasis on adaptation and transformation where this becomes necessary (Tendall et al. 2015).

The COVID-19 crisis is another crisis of the poor, underlining that resilience building and poverty alleviation efforts are intrinsically linked. Historically, economic development has always built initially on agricultural sector expansion, then shifting to sectors with a higher level of technology and added value: industry, and later services. However, many developing countries did not complete this first stage of the development as technologies and investments were imported from other countries to develop industry and services, and international trade could bridge food supply gaps where needed. The agricultural sector, often remote from international markets and offering too low profit for foreign investments, remained underdeveloped, and least developed countries remained victim of the so-called poverty trap, missing the opportunity to develop high value-added activities in their own agricultural sectors. High population growth rates, conflicts, lack of investment in education, health, and infrastructure, and the difficult climatic and environmental conditions also explain the current underdevelopment of rural areas in these countries. There is the need to establish sustainable farm business models as a source of development for smallholders by reforming land tenure systems, increasing investment in locally relevant research and development, selective technology transfer, efficient extension services, and modern information systems, in particular extending the use of mobile phones more widely in rural areas.

Building more sustainable farm systems and refocusing and improving rural livelihoods will require greater attention being paid to smallholder-related research, policies, and measures. Based on the findings of Ceres2030[26], an international research consortium assessing ways end hunger, agricultural research has neglected the needs of smallholders. Despite over 475 million of the 579 million or so farms in the world being estimated to be under two hectares in size, they are not at the core focus of research initiatives intended to improve agricultural practices[27]. Recent estimates suggest that smallholders working on less than 2 hectares of farmland produce 30-34% of the world's food while small to medium size farms (< 50 ha) contribute 62-66% (Ricciardi et al 2018). Herrero et al (2017) report similar numbers and highlight the relevance of small and medium size farms for diverse agricultural production. The diversification of agricultural practices has shown to be important in enhancing the food security of farming households, among other factors (Waha et al. 2018). Improving access to more sustainable and resilient livelihoods and practices suited to smallholder farmers through targeted technical and financial assistance should become a greater focus of both research and governance agendas, while also facilitating the transition to alternative, more secure livelihoods, where shifting economic and environmental conditions make this necessary.

The vulnerabilities associated with informal employment need to be addressed. Among the first individuals hit by the socioeconomic impacts associated with the pandemic were the daily workers without a stable contract or savings, who from one day to the next lost their source of income in the lockdown phase. In cities especially, this prevented them from purchasing food and increased their food insecurity. Systematic efforts are needed to convert daily jobs into longer-term contracts, complemented by a social security system and government support in times of crisis.

Like the health system, food systems needs to be given special status, given their centrality to meeting essential human needs and their unique relevance in terms of sustaining the Earth's life support system.

The pandemic has highlighted the need to extend comprehensive safety nets and introduce rapidly functioning social protection measures in our interconnected economies, exposed as they are to a variety of potential shocks and risks. Building on these lessons, governments and the international community should strengthen the scope and efficiency of social safety nets so that they reach the most vulnerable societal groups. To inform these efforts, the capacity of early warning systems and near-real time monitoring of economic, social, and environmental conditions should be harnessed and expanded to allow rapid detection of changing hazard exposure and shifting vulnerabilities within the population. An improved understanding of the risk exposure and vulnerabilities of societal groups needs to be coupled with facilitated access to social safety nets, simplified enrolment procedures, and reduced administrative burden for benefits claims.

The role of safety nets in reducing socioeconomic vulnerability should be considered both in the national and international contexts. To scale up safety nets, which prioritize support for basic human needs, in particular food security and good nutrition, appropriate mechanisms and financing instruments need to be put in place. In this context governments may wish to consider how targeted fiscal reform and redistribution mechanisms might play an effective role in strengthening social resilience and equity within and across countries. Because of the lack of fiscal space and capacity, particularly in the least-developed countries,

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[26] https://ceres2030.org/about/
[27] Nature (2020) editorial: https://www.nature.com/articles/d41586-020-02849-6

which are dependent on income from commodity and food imports and are hence hard hit by global economic crisis, international solidarity also needs to be strengthened to avoid a widening of the human development gap. While developed countries need to move rapidly to meet the minimum target of 0.7% of the GDP for official development assistance and to upscale associated support for food system transformation (see von Braun et al 2020), other complementary instruments should be explored to help developing countries manage risks embedded in their food systems and provide them with the fiscal space to increase access to essential social services.

Resilience of agricultural trade needs to be considered in terms of exposure to a variety of environmental and economic risks. The pandemic and global lockdown largely exerted mainly a demand shock on agricultural trade. Other risks, such as climatic extremes or pest outbreaks or crop and livestock diseases, may lead to supply shocks. Trade may also be an important factor in managing long-term changes. International trade can help buffer agricultural productivity and food security of regions against the impacts of climate change (Janssens et al. 2020). Given the multitude of global risks and compounding local risks that food systems are exposed to, greater emphasis should be placed on assessing the capacity of existing supply chains and trade patterns to withstand or adapt to variety of shocks. Looking at the situation of West Africa, Ali et al (2020) note the potential risks to food security associated with long supply chains if protectionist measures are implemented, while also recognizing the need for a balanced approach to trade in order to manage diverse portfolio of challenges to food security in the region. In general, specific attention should be given to the extent to which the current system benefits the most vulnerable countries and where the global trade system needs to be complemented by a greater emphasis on regional integration of trade or a strengthening of self-sufficiency.

Box 3. Shift towards resilience and equity – Key action areas

AA-1: Expand the benefits, reach, and duration of social safety nets and allow people employed informally a pathway to join social security structures to mitigate the impact of future unemployment/crisis situations

AA-2: Promote sustainable farm models, recognizing sociocultural heterogeneity and specific development and environmental contexts

AA-3: Strengthen the technical and financial support for smallholder farmers for poverty alleviation and/or enable transition into secure livelihoods

AA-4: Re-configure supply chains and trade dependencies, based on an evaluation of their likely capacity to absorb and adapt to socioeconomic and environmental shocks

5.2 Integrate human and planetary health perspectives

The emergence of the SARS-CoV-2 virus is a symptom of the growing pressure of human activities on natural systems. The transformation of the food system is imperative to limit the emergence of other similar and potentially even more dangerous threats in the future. This will require tackling human and environmental health as joint objectives for the future development of food systems.

Human encroachment on natural spaces, environmental destruction and degradation, loss of biodiversity, wildlife trade and consumption, combined with increases in human and livestock populations and geographical interconnectivity, facilitate the emergence and spread of zoonotic diseases. Initial broad-level assessments suggest that reducing deforestation, improving monitoring, and other measures aimed at preventing the outbreak of a pandemic, would amount to 2% of the estimated cost of the COVID-19 pandemic over a 10-year timespan (Dobson et al, 2020).

Diets are a central focus of a transition towards more sustainable food and land-use systems, as discussed in previous sections. This further illustrates the link between human and environmental health and the benefit of pursuing a more integrated approach. Shifting to healthier diets alleviates pressure on land and the need for conversion of natural ecosystems into agricultural land. However, loss of income and purchasing power as a result of the pandemic and lockdown measures may make it more difficult for households to afford healthier diets. Hence, in addition to awareness building and educational initiatives promoting healthy diets, there needs to be a focus on improving the affordability of healthy diets. Relevant policies and measures should be guided as follows:

The integration of ambitious biodiversity and ecosystem conservation targets should be deepened across policy frameworks. The post-Aichi[28] process under the Convention on Biological Diversity (CBD) will further define targets for biodiversity conservation, complementing the targets specified under SDGs 14 and 15 for protecting and restoring the marine and terrestrial environment (UN 2015), respectively. In addition, the UN Convention to Combat Desertification (UNCCD) calls on the international community to meet a land degradation neutrality target, which means that the capacity of land to provide ecosystem goods and services and ensure food security will remain stable or improve over time. With key international policy decisions on biodiversity conservation under the CBD and climate change under the UN Framework Convention on Climate Change (UNFCCC) being shifted into 2021, there is the opportunity to further integrate ambitions and shape cross cutting solutions.

The emergence of COVID-19 and other zoonotic diseases highlights the importance of biodiversity and healthy ecosystems as buffers against disease risk. The pandemic cautions us against further destruction and degradation of natural environments and loss of biodiversity. Avoiding deforestation and land use changes in tropical and other regions can reduce the risk of disease due to spillover events from wildlife to humans and/or livestock. Hence, biodiversity conservation efforts should take into account the potential to deliver multiple benefits. This is already done in research on how conservation efforts should target areas of high value for carbon storage and sequestration, a high level of biodiversity or of unique environmental quality such as species endemism, and relevance to other key ecosystem services (Jung et al. 2020). Target setting efforts require further ambition in terms of area protected as well as specificity in terms of identifying conservation hotspots to guard against pandemic, climate, and/or other environmental risks.

In addition to protecting terrestrial ecosystems, the protection of marine resources in national and international waters needs to be scaled up. Ensuring adequate management of marine protected areas is important not only for the replenishment of fish stocks and sustainable provision of protein supply from the sea, but also for mitigating and adapting to climate change, acting thereafter as an insurance policy for global environmental change (Roberts et al. 2017).

[28] The Aichi targets under the CBD, which have informed the target setting on biodiversity and conservation in the SDGs, are expiring in 2020. New targets are being defined in the process leading to the post-2020 Biodiversity Framework of the CBD.

Current commitments for the protection of biodiversity are insufficient. While over the recent decade some notable progress has been made in the protection of terrestrial and marine areas, over 78% of threatened species are inadequately protected (Maxwell et al. 2020). Hence, it is critical to move well beyond the current SDG targets of 17% and 10% of terrestrial and marine areas protected, respectively. The ambition of protecting 30% of terrestrial and marine areas by 2030 under discussion for the post-2020 Biodiversity Framework under the CBD must be seen as an interim milestone for further up-scaling of protection efforts (e.g., Wilson 2016, Maxwell et al. 2020, Jung et al. 2020).

While area-based conservation targets are an important starting point, it also matters which areas and places are protected. Further emphasis should be placed on regenerating degraded areas for restoring biodiversity. Strassburg et al (2020) identify key priority areas for regeneration across the globe. Overall, the pandemic should be a reminder of the precautionary principle, motivating us to protect more rather than less to ensure that the web of life and ecosystem goods and services are adequately safeguarded and that the risk of future pandemics through spillover events is reduced.

Increased ambition needs to be matched by appropriate implementation mechanisms, including strengthened regulations, monitoring capacities, and enforcement capacities. It is not enough just to set targets: guarantees are also needed that these ambitions will be translated into action. The pandemic has highlighted efforts to push back against environmental regulation and enforcement capacities. During the recovery process, there should be a focus on improving access to real-time data on the state of the environment, helping to strengthen public awareness, engagement of civil society, and allowing for independent verification of national policies and actions. Bi-and multilateral cooperation should provide support for strengthening environmental monitoring and enforcement capacities as part of broader programmatic engagement in agriculture and other land use activities.

To enable the shift to healthy and environmentally sustainable diets, there needs to be greater emphasis on affordability. The shift to healthy and sustainable diets should not be a luxury. Before the pandemic an estimated 3 billion people were unable to afford a healthy diet on a consistent basis (FAO 2020a). Environmental, health, and social costs are largely not reflected in most common food product prices, whereas organic, healthy food, produced in a socially responsible way is often expensive. The contraction of economies and the decline in disposable incomes during the pandemic threaten to put healthy diets further out of the reach of large parts of the global population. Awareness-building campaigns, policies and regulations, and better food labeling need to be accompanied by a greater emphasis on affordability. Governments should take into account the health, social, and environmental burden passed on to society, by identifying, testing, and implementing suitable incentive mechanisms that transfer some of the cost of healthy diets to unsustainable food products.

Shifts in demand for healthy and diversified food should be met by associated shifts in agricultural production. The emphasis on nutritional security and human health has direct implications for the types of food crops that are grown, and the demand for livestock and aquaculture, which requires an alignment of thinking about land use management (Sanchez 2020). Sanchez notes that a global shift to the EAT Lancet healthy diet recommendations to meet the needs of 10 billion people by 2050 would demand less land than currently used by the agricultural sector. Other assessments and research initiatives have further highlighted the importance of healthy diets in reducing the pressure on soils and the environment and bending the curve on biodiversity loss (FOLU 2019, Leclere 2020), illustrating the benefits of integrating human and planetary health concerns in food systems.

The focus on diets needs to be complemented by a focus on access to clean water and hygiene. The importance of sanitation and handwashing has been brought to the forefront during COVID-19. This attention should be maintained in the wake of the pandemic also to reduce the vulnerability to other diseases, particularly in developing country regions (Amegah 2020). Access to safe drinking water is a critical component of food security in general. Chronic dehydration or exposure to water-borne pathogens exacerbates the challenges of undernutrition and childhood stunting. In countries where a large share of the population lacks access to safely managed water and sanitation, food insecurity and associated health issues tend to be more profound (FAO 2019).

Water resources are critically important for food and energy security and for environmental health. Management of water resources should therefore shift from a sectoral focus to a nexus approach that would take account of the interconnectedness and interdependence of water as a resource. The shift toward more sustainable use of water for human purposes (water for energy, food, sanitation, and hygiene) needs to take into consideration the importance of improving irrigation efficiency to maximize the crop production per unit water as well as wastewater recycling as an option to respond to water demands across sectors. Within agricultural production systems, the management of water should be embedded in broader efforts to scale up climate-resilient agricultural practices and support for nature-positive food production, such as agroecology, permaculture, agroforestry systems, sustainable land management, integrated water resource management, and locally adapted precision agriculture as means to reduce GHG emissions and pollution and sustainably manage natural resources.

Natural capital needs to be accounted for in decision-making processes. The pandemic has further underlined that our food and economic systems at large are embedded in the natural system. Economic growth has long been recognized as an insufficient indicator for measuring development progress and human welfare. The emergence of green growth and green economy concepts illustrate efforts to strengthen the emphasis on the quality of growth. However, there are diverging opinions and approaches as to how economic thinking on the role of growth should be revised and reformed.

Agricultural systems are widely recognized for their central role in transforming natural environments. Zoonotic diseases like COVID-19 accentuate the importance of reassessing the economic incentive structures that influence human and environment interactions. From a governance perspective this includes improved accounting of the state of natural capital, which provides important environmental goods and services to countries, economic sectors, and human livelihoods.

National wealth accounts, which include natural capital alongside human and physical capital, can help build a more comprehensive assessment of economic and environmental sustainability. The World Bank, United Nations, and other organizations have led pioneering efforts to strengthen accounting approaches (e.g., World Bank 2011; UNU-IHP and UNEP 2012). There is an urgent need to expand such efforts and bringing them into decision-making contexts. This will not only improve the scope and measurement of natural capital, but also requires the limits to the substitutability of natural capital be recognized (Cohen et al. 2017), considering that some natural capital is complementary to other forms of capital and essential to the sustainable provisioning of ecosystem goods and services. While it is difficult to determine what the critical level of natural capital is, the SDGs and other environmental targets can offer some initial guidance on how much natural capital should be deemed essential, based on collective value judgments (Cohen et al. 2017).

In addition to revising and improving economic performance measures pertaining to environmental sustainability, incentives for environmental stewardship need to be developed. This is particularly important in the food and land use systems sectors. Reducing emissions from deforestation and degradation (REDD+) and other schemes related to payment for ecosystem services (PES) have a mixed track record. Building on lessons learned, such mechanisms should be reformed and strengthened to reward those farmers and other stakeholders who act as stewards of the environment and promote a wider adoption of sustainable land management practices.

Environmental provisions should be integrated into bi- and multilateral trade agreements, accounting for embodied climate and natural resource footprints and environmental health risks. Trade has played an important role in enabling economic growth, but it has also distanced producers and consumers and, in some cases, exported ecological footprints, environmental impacts, and polluting activities. The pandemic has had a heterogeneous impact on supply chains and trade in agricultural commodities and food products. During the recovery, there should be greater emphasis on assessing and, if necessary, restructuring supply chains and trade in terms of their capacity to absorb or adapt to multiple shocks and promote efficient and sustainable use of resources. In general, food trade can either increase or decrease the environmental impact of agriculture. This depends on whether or not the impact of a given agricultural activity is greater in the exporting than in the importing region. Trade may also drive further consumption and hence the associated production of particular food products with knock-on implications for environmental footprints.

Building on robust assessment of environmental footprints embodied in supply chains and trade, provisions in bi- and multilateral trade agreements should be strengthened to accelerate the shift to better environmental standards and practices in food systems. The more explicit inclusion of environmental footprint considerations within the rules of the World Trade Organization (WTO) would help to increase the global environmental sustainability of agricultural production.

Box 4. Integrate human and planetary health perspectives: Key Action Areas (AAs)

AA-5: Adopt ambitious biodiversity and ecosystem conservation targets to guard human and environmental health across scales, coupled with a strengthening of regulations, monitoring capacities, and enforcement mechanisms

AA-6: Accelerate the shift toward affordable, healthy, and environmentally sustainable diets and associated food production, transferring costs to unhealthy and unsustainable diets and production systems.

AA-7: Prioritize investments in improving water access and sanitation, which contributes to food security and improved health, while also providing protection for the essential agricultural and food system workforce

AA-8: Account for natural capital in decision-making processes and promote environmental stewardship through appropriate incentive schemes

AA-9: Integrate environmental provisions and performance criteria in bi- and multilateral trade agreements, accounting for embodied climate and natural resource footprints and environmental health risks

5.3 Secure innovation, technology transfer, and scale-up of sustainable practices

The pandemic has the potential to act as an accelerator for technological innovation. This is for example apparent in the medical sector where the race for a vaccine has led to a variety of approaches, including novel RNA-based vaccine candidates, while streamlining and speeding up institutional approval processes (see Kramer 2020).

Adoption and rapid scale-up of technologies also helped to buffer against some of the impacts of the pandemic on the food system. Digital technology and mechanization have helped to maintain and monitor agricultural production, adjust food supply chains, sustain transportation of agricultural inputs and products, and connect food producers and consumers. However, the general willingness and capacity to innovate in agri-food sectors is lower than in most other sectors of the economy in most countries. Much of the public agricultural research takes place in developed country regions. It is also an increasing focus of middle-income countries. However, in most developing countries the capacity of many national agricultural research systems is limited and profoundly underfunded (Beintema and Echeverria 2020). In a review of research and development in agriculture, Fuglie (2018) highlights the importance of increasing investments in enabling further growth in agricultural productivity. Fostering innovation, technological transfer, and scaleup of sustainable practices during the recovery process will be essential if we are to build more resilient food systems.

Innovation and adoption of better technologies and practices can bring large benefits in many regions across the world and throughout the entire food supply chain. Technological advancement will require continuous financial support, knowledge transfer and training, and collaborative mechanisms for developing countries, to avoid a widening technology and capacity gap between countries.

Feeding a growing and more affluent population will require increases in crop and livestock productivity and diversity. Such productivity increases have been shown necessary to decrease the pressure on land resources (e.g., Stehfest et al. 2009). In light of the threats of climate change, greater emphasis needs to be placed on genetic and trait diversification, both for plants and livestock. While there needs to be a focus on existing stable crops, further applied research is required for exploring alternative, currently under-utilized varieties (e.g., quinoa, amaranth, buckwheat, foxtail millet, finger millet), particularly in terms of their potential to raise agricultural productivity and local food security in marginal environments and facilitate the rehabilitation of degraded lands (Rodriguez et al. 2020).

There are no "silver bullets" for improving agricultural practices, both high- and low-tech solutions need to be considered. The 2020 Nobel Prize for Chemistry, awarded to Emmanuelle Charpentier and Jennifer Doudna[29], recognizes their pioneering work in gene editing, which beyond its applications in medical research opens up new avenues for agriculture and food systems (see also Doudna and Charpentier 2014), including drought-resistant crop development and other options for growing crops on marginal and degraded lands. The potential offered by their ground-breaking work is significant in a world exposed to shifting climatic conditions and increasing climate extremes. Gao (2018) comments that advances in gene editing through the CRISPR

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[29] https://www.nobelprize.org/prizes/chemistry/2020/press-release/

technology could accelerate the plant breeding process, helping to diversify plant traits to adapt to demands of a rapidly growing world population and changing environment, increasing productivity as well as resilience, but also highlights the importance of a sound regularly environment and transparency of information for engagement with the public. The promise of these technological advances needs to be weighed carefully against ecological and other risks and the access to and use of emerging technologies needs to be assessed in its broader societal impacts.

Innovation focused on opening up new and alternative food sources needs to be maintained and accelerated. The potential of alternative and novel foods in improving food and nutritional health, while reducing environmental impacts, needs to be further explored. This includes a wide variety of existing but currently underutilized feed and food options, such as seaweeds and algae (e.g., Mahadevan 2015; Torres-Tiji et al. 2020), and insects (van Huis and Ooninex 2020). Cultured meat, derived from cells grown in the laboratory can potentially be tailored to meet specific nutritional needs while also reducing the pressure on land and natural resources, but large-scale production using these is challenging (Moritz et al 2015) and questions about environmental sustainability of production need to be further explored (Sergelidis 2019). While shifts to more plant-based diets will reduce the pressure on land, cultured meat may not have an advantage over shifting from beef to poultry (Alexander et al. 2017). However, expanding the variety of future foods, ranging from plant-based options to insects and cultured meats, needs to be considered for strengthening the health and sustainability aspects of diets (Parodi et al. 2018), complemented by efforts to lessen environmental footprints associated with food loss and waste (Alexander et al. 2017; FOLU 2019).

During the recovery process, momentum in agricultural research needs to be sustained while strengthening the emphasis on contextualized solutions. As well as focusing on high tech, expanding access to readily available low-tech solutions and practices should not be overlooked when these can improve productivity and environmental sustainability. There is a wide array of sustainable land management, conservation agriculture, agroforestry practices with proven benefits for land productivity, biodiversity, and climate resilience[30]. The often predominant emphasis on global transformations needs to be complemented by elevating applied research for context-specific solutions. Here, public–private partnerships and research networks should be strengthened with a focus on improving targeted research and implementation capacities in developing countries, to facilitate the adoption of technologies and practices that are suitable for the prevailing socioeconomic and environmental conditions, but also take into account global trends and sustainability demands. Research into solutions for expanding access, plus technical and financial support for these practices, should be a priority in building a more resilient food system in the wake of COVID-19.

Advancing innovation will require the proper enabling environment for private-sector engagement, including a fresh look at public–private partnerships and interactions with the research community. During the recovery process, governments will need to send clear signals about facilitating the transition and transformation of sectors toward greater sustainability and resilience. Initiatives to translate the SDGs and corresponding targets into meaningful, actionable targets for the private sector should

[30] E.g., https://knowledge.unccd.int/topics/sustainable-land-management-slm

be reinforced and expanded. Creating a marketplace for ideas on agricultural and food systems innovation will be important to facilitate the translation of applied research into implementation.

Overall, efforts to bridge the digital and technological divide between countries should be strengthened during the recovery process. With many countries being confronted with limited fiscal space and falling investments, this will require targeted efforts and collaboration to maintain momentum for innovation and technology transfer. Strengthening the endogenous research capacities of developing countries will be key to ensuring that technological solutions and innovative practices are adopted and further adapted to local contexts.

Box 5. Innovation, technology and sustainable practices – Key action areas (AAs)

AA-10: Provide clear goals, targets, and regulatory mechanisms to channel private sector engagement

AA-11: Strengthen the biological diversity of crops, suited to diverse environmental conditions, and advance suitable biotechnologies that meet stringent social and ecological safeguards

AA-12: Accelerate and scale up technical and financial support for sustainable land and integrated water resource management practices that can readily be adopted

AA-13: Strengthening extension services, technical assistance, and funding instruments

AA-14: Facilitate access to digital technology across supply chain, such as precision agriculture, e-commerce, blockchains for tracing foodstuffs (e.g., by providing risk-transfer mechanisms to catalyze investment in innovative measures)

5.4 Catalyze change: Strengthen mechanisms for international collaboration and partnerships

Strong international institutions are necessary to coordinate policies and limit tensions between countries and regions and to articulate the multiple social, economic, and environmental interests represented by food systems internationally.

The pandemic illustrates the importance of rapid, fact-based, coordinated responses to shocks that exhibit non-linear behavior. Examples from some low- and middle-income countries show that fast responses, including closing of borders, physical distancing, or other virus-containment measures have been important in keeping infection numbers at manageable levels, while delayed action has overwhelmed sophisticated healthcare systems, even in some developed countries.

Many countries and regions had to confront the pandemic while having to manage multiple other shocks. However, the impact of the pandemic on global food security was partially buffered by robust global food supply and largely favorable climatic conditions. This was a lucky coincidence. Teleconnections in the climate system, such as those for example linked to El Nino Southern Oscillation events, can lead to adverse climatic conditions across multiple regions, which would further compound the impacts on food security of pandemics like COVID-19. Hence, early warning systems, institutional preparedness and international cooperation need to be strengthened with respect to managing multiple and diverse risks to food systems from the local to global scale. Given the complexity and teleconnections embedded in modern food systems, improved capacities for international governance, strengthened international organizations (e.g., WHO, UNEP, WTO, and bi- and multilateral development cooperation) are desirable and necessary.

The multilateral system is, however, weak and continues to lack enforcement capacities. The multilateral system was already being undermined by shifting geo-politics before COVID-19. The pandemic reinforced some of these challenges, further underlining the need for leadership and international collaboration to effectively tackle global problems (Sachs 2020). While strong and effective international institutions are important, it remains to be seen to which extent and how quickly moves toward unilateral action can be reversed in 2021 to contain the spread of the pandemic, facilitate international vaccination efforts, and enable a broader socioeconomic recovery process. It is thus important that alternative platforms and mechanisms within and across countries are developed, tested, and strengthened to maintain dialogue and foster understanding, knowledge exchange, and momentum for change. This includes city alliances, which have already proven powerful in the international climate debate, partnerships for change between civil society, public and/or private sectors, and international collaboration between regional governments. Alongside traditional actors in the food system and environmental space, a number of action-oriented knowledge and funding platforms for the transformation of the food systems are emerging, for example EAT, the Climate Land Use Alliance (CLUA), the Food Agriculture Biodiversity and Energy Consortium (FABLE), and the Food and Land Use Coalition (FOLU), which seek to bring together multiple stakeholders operating across different scales. The discussions in the context of the IIASA–ISC Consultative Science platform suggest that in addition to moving forward with the global agenda, further attention is must be focused on identifying context-specific solutions and implementation capacities, which are informed by the larger strategic and programmatic context of food system transformations.

Box 6. International Collaboration and Partnerships – Key Action Areas (AAs)

AA-15: Strengthen institutional coordination capacities across scales to manage multiple hazards and risks associated with exponential, non-linear dynamics

AA-16: Promote mechanisms for knowledge sharing and collaboration across diverse stakeholder groups and regions

5.5 From theory to action: Strengthening the science policy interface

The dynamics set in motion by COVID-19 illustrates the importance of timely access to data, coupled with the capacity to interpret, act and rapidly adapt to evolving information and facts. Our interconnected world is confronted with complex, intricate problems, multiple shocks playing out simultaneously, compounding vulnerabilities, and non-linear dynamics. The barriers between scientific disciplines must be broken down if we are to arrive at a more integrated understanding of the challenges that confront us and the solutions we need. Not only is greater collaboration across scientific disciplines called for; so too is strengthening the involvement of stakeholders, including decision makers, the private sector, civil society, and citizens at large. The challenge will be to make the scientific process more transparent and accessible at a time when it also becoming more complex.

With regard to food systems, early warning systems and monitoring capacities need to be strengthened so that emerging risks and vulnerabilities can be rapidly identified and guide appropriate interventions. As we come to better understand the global footprint of human land-use activities, a stronger integration of the natural and social sciences is needed to evaluate the interplay between the biophysical constraints and economic incentive structures and behavioral mechanisms driving the evolution of the food system. With climate change under way, advancing technologies that improve the productivity and diversity of traits of crops and livestock will need to be a key component to adapting to changing environmental conditions. The environmental, socioeconomic, and ethical implications of the technological possibilities and advances need to be carefully assessed and balanced with efforts to identify and upscale available sustainable land management practices that help to protect and sustain the environment. Scenario planning exercises, integrated assessments, and other modeling and methodological tools can help better understand the long-term consequences of strategic choices, as long as underlying assumptions are clearly communicated, and data and information are transparent.

Box 7. Science policy interface – Key action areas (AAs)

AA-17: Advance early warning and near real-time monitoring capacities to rapidly detect potential shocks, risks, and vulnerabilities that undermine the functioning of food systems

AA-18: Incentivize collaboration between natural and social sciences to advance an integrated understanding of the biophysical constraints, environmental, economic, and behavioral dynamics shaping food system architecture and levers for transformation

AA-19: Expand mechanisms for stakeholder engagement in framing narratives for co-developing resilient and sustainable food systems and support scenario analysis across geographical scales

6 Concluding Remarks

The pandemic and global lockdown have been a stark reminder of the integration of our economies, the multitude of human and environment interactions, and the vulnerabilities that arise from these interdependencies. Food systems are of critical importance for meeting basic human needs, advancing human welfare, and ensuring environmental sustainability. Many of the key levers for transformation and necessary demand- and supply-side measures have been identified and are readily available.

The prospect of a vaccine will hopefully help contain COVID-19 and allow countries to reset their economies in the near future, but it will not make us immune to the risk of future pandemics arising from the spillover events of zoonotic diseases facilitated by wildlife consumption and trade, land use change, and environmental degradation. In a changing climate, food and nutritional security are projected to get under further pressure (IPCC, 2019). Hence the rapid transition toward sustainable food systems is essential for averting risks emerging from the global food systems. The economic, social, and environmental pillars of sustainable food systems need to be anchored in a strengthened focus on resilience, centered upon serving the most vulnerable. The recovery process represents a unique opportunity to do so.

Recent research suggests that transforming energy systems to meet the objectives of the Paris Agreement would cost only a fraction of the total volume of pandemic recovery funds currently being issued (Andrijevic et al. 2020). The alternative is locking in investments during the recovery that are not viable in the long run. The centrality of food system transformations for sustainable development pathways has also been well established and recognized for its potential of generating significant economic benefits (e.g., FOLU 2019). The transformation of food systems will require upfront investments and international collaboration. For example, to meet their stated commitment of lifting 500 million people out of hunger and malnourishment, G7 countries would need to approximately double their efforts, adding 14 billion USD to their current annual spending of 12 billion USD each year from now until 2030 (von Braun et al. 2020).

Securing innovation of food systems in the wake of pandemic has been highlighted in its importance for avoiding a widening of technology and capacity gaps between countries. However, narrowly focused innovation can enable progress towards one objective while hindering or undermining progress towards another. Hence, impact pathways of innovations should be considered across entire food systems, so that synergies and trade-offs between economic, social and environmental objectives can be identified and managed, and processes be put in place that facilitate the adoption of suitable innovative technologies and practices by society (Herrero et al. 2020).

Science can help in charting the right course forward, supporting efforts to maximize synergies and minimize trade-offs between the multiple objectives that need to be served by the food system. However, food system transformation will ultimately hinge on collective value judgments, commitment, and political will to enable the required sustainability transitions. The transformation needs to be based on open access to information, transparent communication, trust in governance, and adequate recognition and support of societal needs.

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