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Toward resilient food systems after COVID-19

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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, revealed our global interdependencies and vulnerabilities. During the height of the crisis in 2020, it was estimated that the global economy contracted by 3.3% (IMF, 2021). For the first time in years, the absolute number of people living in extreme poverty level has been rising again with estimates suggesting that an additional 88 million to 115 million people in 2020 suffered extreme poverty due to the pandemic (World Bank, 2020a). The pandemic exacerbated the increases in food insecurity observed over recent years (FAO, 2020a). While in 2021 the global economy is expected to grow by 5.4%, the recovery from the recession is uneven by countries and economic output is expected to stay below the projections before the pandemic (World Bank, 2021). In this reset of economic activities, a continued emphasis on the transformation of food systems will be pivotal for setting the world onto a path toward the Sustainable Development Goals (SDGs) (UN, 2015a) and the objectives of the Paris Agreement on Climate Change (UN, 2015b).

Many of the knock-on effects of the pandemic are only starting to become visible and will continue to unfold over the coming years. This paper explores initial insights into the impacts of COVID-19 and discusses entry points for harnessing the recovery process for building more resilient and sustainable food systems. It is an outcome of the Consultative Science Platform launched by the International Institute for Applied Systems Analysis (IIASA) and the International Science Council (ISC), which explores the implications of the pandemic on various aspects of sustainable development. An initial background paper (Sperling et al., 2020a), which outlined impacts of the pandemic and framed key issues for the recovery process, formed the basis for a series of discussion rounds with experts from academia, public and private sector and civil society between May and September 2020. The final report emerging from the expert feedback and supplementary literature reviews during this process (Sperling et al., 2020b) provides the foundation for this article, which has been further updated to capture additional developments in 2021.

The paper is structured as follows. First a general overview of key characteristics of our current food systems and the case for their transformation is given, drawing particularly on insights from systems analysis and integrated assessments. Then key socioeconomic and environmental vulnerabilities of food systems, uncovered during the pandemic, are discussed. Considering the challenges and opportunities that the recovery process offers to reset humanity onto a sustainable development trajectory, this then forms the basis for exploring focal areas and entry points for action to build more resilient food systems in the process, helping to secure development gains in an increasingly inter-connected world, which is exposed to a diversity of shocks and hazards.

2. Current food systems and the need for transformation

There are a great variety of food systems. When speaking of the global food system here, this is done to describe general overarching trends. Global trends are shaped by the interactions between 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. Food systems cover all the components needed from producing to consuming foods as well as the management of waste and by-products and typologies include modern, mixed, and traditional food systems (HLPE, 2017).

At one end of the spectrum, modern food systems often rely on

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complex supply chains, organized by large international agribusinesses and retailing companies, and the application of industrial production methods, in-time production, high diversity of products, strong price competition, and in some cases unequal or market power along the supply chain (UNEP 2016, Yi et al., 2021). At the other end of the spectrum, we find traditional food systems, which are labor intensive, 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 (UNEP 2016). It is acknowledged that in reality the boundaries between these different systems are often blurred in reality (HLPE, 2017). A variety of alternative and complementary categorizations exist, including a focus on prevalent production types and methods as well as expansion into emerging or niche food system types. While there is great diversity of food systems, typologies can be helpful in delineating some key characteristics and fostering a systems thinking approach (Ericksen et al., 2010).

3. Our current food systems face complex challenges

The evolution of our food system has largely been driven by a focus on boosting agricultural production. Global trends emphasize production 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).

This development has been accompanied by an increasing integration of markets. 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 widening gap 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). A rising number of countries are dependent on imports for their food security, while sometimes only a few countries dominate the market for a particular commodity. 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 most populated African countries have become net grain importers (Hendrix, 2016).

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 livelihoods and income.

Due to climatic impacts, conflict, and economic downturns, progress in addressing malnutrition has ground to a halt in recent years, and at the global level, the number of people suffering hunger has begun to increase again (FAO, 2019; FAO, 2020a). Prior to the outbreak of the pandemic, over 690 million 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). The structure of a food system is not static, but its components are influenced by biophysical and socioeconomic drivers. It is hence important to consider potential feed-back processes between various elements of the food system, particularly in light of global environmental change (e.g. Ericksen, 2008).

Our food systems are associated with large environmental externalities. The agriculture, forestry, and other land uses (AFOLU) sector contributes around 23% to net anthropogenic greenhouse gas (GHG) emissions (IPCC, 2019). Agricultural activities and associated 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, 2019a). 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).

3.1. *Transformation is essential for sustainable development*

To resolve trade-offs and strengthen synergies among the various economic, social, and environmental objectives linked to our food systems, integrated solutions are needed. 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 toward 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).

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). Shared Socioeconomic Pathways (SSPs) represent quantified scenarios of socioeconomic trends, which 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 for the exploration of consistent representations of the future of the agricultural and food systems (Fricko et al., 2017). For example, under SSP2, a "middle-of-the-road" scenario, the global population grows from 7.8 billion people today to over 9.2 billion people by 2050, while 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). 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 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 land-use, including afforestation programs, deployment of bioenergy, and soil organic carbon sequestration, all of which have consequences for agriculture, food systems and biodiversity (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 necessary to achieve the various Sustainable Development Goals (SDGs) in a concerted manner (Schmidt-Traub et al., 2019).

A number of deep transformations of food systems are required to ensure sustainability. This includes investigating the impacts 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 and the environment by increasing crop productivity and increasing the land carbon sink (Frank et al., 2017).

On the demand side, reduction in meat and dairy consumption has long been identified just as a crucial transformation to reduce habitat loss and degradation 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). Shifts toward healthier and more environmentally friendly diets 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 addressing 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 improve the redistribution of food within society, as access to food remains deeply uneven, mostly for reasons of economic inequality (Hasegawa et al., 2018).

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). Modeling results 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, 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). A report by the Food and Land Use Coalition (FOLU, 2019) identifies ten crucial transformations, where the required magnitude of change is informed by the modeling of sustainability pathways. These transformations cover several of the domains described above, while also discussing enabling conditions, such as 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 illustrates the importance of mobilizing a number of actions to achieve the required level of food system transformation (Steiner et al., 2020).

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. Systems thinking is valuable in defining future sustainability pathways, facilitating alignment with 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 the vulnerabilities of our current food systems and the future needs for building resilience.

4. The impact of COVID-19 and global lockdown on food systems

The impacts of the pandemic exposed the fragility of the development gains made toward poverty alleviation and fighting hunger. Social, economic, and environmental vulnerabilities of our food systems became apparent during the rapidly unfolding pandemic in 2020 and the implementation of lockdown and containment measures. The following sections place primary emphasis on the vulnerabilities of food systems exposed during this period, while also highlighting some further developments during 2021. We discuss the consequences of the pandemic for food security and nutrition, illustrate how the pandemic exacerbated inequalities and socioeconomic vulnerabilities embedded in the food system, and then examine the interplay between how the emergence of pandemic has been triggered by land-use change and environmental degradation, while also compounding and being compounded by environmental changes.

4.1. Food security and nutrition

The fundamental purpose of food systems is to meet an essential human need—access to safe and nutritious food. 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. As discussed below, 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.

The pandemic is unravelling global progress toward universal food security by 2030, as stipulated in the second global goal of the SDGs. The number of undernourished people in 2020 was estimated to fall between 720 and 811 million people, which represents an increase of 4–18% compared to the global situation before the pandemic in 2019 (FAO et al., 2021).

A particular concern has been the rise in acute food insecurity. In April 2020, the Head of the World Food Program David Beasley 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.[1] By 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.

These warnings about growing levels of food insecurity in developing and developed countries came as the global outlook for food supplies remained largely stable and global food reserves were high. Due to good harvests in 2019 and in early 2020, stock-to-utilization ratios were considerably higher than during the 2007 and 2008 crisis (e.g., Headey and Fan, 2008; World Bank, 2020b). Primary agricultural production has not been severely affected by the crisis during 2020.

The global trade system proved to be quite resilient during 2020. 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., 2020). During the first wave of the pandemic some countries implemented specific trade restrictions (e.g., Vietnam for rice, Russia for wheat), totaling 21 countries by early July 2020, but most of

1 WFP concerns about the impact of the pandemic on acute hunger in 2020: https://www.wfp.org/stories/wfp-chief-warns-hunger-pandemic-global-food-crises-report-launched

these restrictions were 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.

While the impact of the pandemic on global trade in agricultural products has been limited and no global food supply crisis has occurred, the lockdown and other containment measures did 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, led to a mismatch between supply and demand, as well as labor shortages in some agricultural sectors.

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 (Waltenburg et al., 2020; Middleton et al., 2020), revealing food safety and sanitation issues. These impacts observed across several developed countries highlight 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.

In comparison to the situation on global food markets, the impact on the food supply at regional and local levels may be considerably different when links between producers and consumers break down due to lockdowns and associated containment measures. For example, supply chains of developing countries in Africa, Latin America, and Asia 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 lead to rising local food prices in these regions. Food price volatility in the past has been recognized as trigger for food insecurity, political instability and unrest, and hence flagged as a national security concern (Hendrix, 2016). In 2020, price spikes were 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.

While the FAO's Food Price Index, which serves as a global indicator of price movements of food commodities, has been declining over the first five months of 2020 and hence during the initial widespread lockdowns triggered by the pandemic, it has been steadily rising since June 2020 and in November 2021 has now reached the highest level since 2011.[2] The local effects may be profound, particularly for developing countries with the pandemic still ongoing after a year of economic decline, loss of livelihoods and savings.

Beyond the existential concerns arising from the pandemic for the incidence of poverty, food and nutritional security, the consumption behavior and nutritional health in societies was also more broadly affected. Lockdown measures during 2020 included the temporary closures of restaurants and school/work canteens in many countries and in some cases, resulting in an increase in the consumption of unhealthy, highly processed food. For example, food purchasing trends in the USA show clear increases in the consumption of ultra-processed, energy-dense comfort foods such as potato chips, chocolate, and ice cream (Bhutani and Cooper, 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 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 are longer lasting after all COVID-19 restrictions are lifted and what the impacts will be on chronic disease risks remains to be seen.

4.2. Socio-economic impacts and equity concerns

The ongoing pandemic revealed the worsening inequalities within and across societies and shone a spotlight on 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) or 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).

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-19 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). In an updated assessment released in January 2021, the ILO concluded that an equivalent of 255 million full-time jobs (based on a 48-h work week) were lost during 2020 (ILO, 2021).

While every human being is susceptible to infection by SARS-CoV-2, human and socioeconomic vulnerabilities vary considerably according to societal groups within and across countries. 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 inter-individual differences (Bixler et al., 2020).

Specific attention needs also to be paid to vulnerabilities linked to safely accessing sufficient and nutritious food. Lockdowns, travel bans, loss of employment, and physical distancing measures particularly exacerbated the vulnerabilities of poor people. Overcrowded living conditions, precarious and often informal employment, and the absence of disposable income made 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. Lack of water and sanitation access in crowded and unsanitary environments also facilitates the spread of the COVID-19 among poor and vulnerable people.

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 poor people in India, in the hope that a universal income can protect them against food insecurity.[3] In an overview of the early impacts of the pandemic on nutrition in India, Lele et al. (2020) highlight the

[2] FAO food price index: https://www.fao.org/worldfoodsituation/foodpricesindex/en/

[3] Perspective by Esther Duflo and Abhijit Banerjee on mitigating Covid19 crisis in developing countries: https://www.theguardian.com/commentisfree/2020/may/06/vulnerable-countries-poverty-deadly-coronavirus-crisis

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.

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. For example, Gentilini et al. (2020) found that in the first half of 2020 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.

The employment crisis triggered by the pandemic has affected women more significantly than men (ILO, 2021). 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,[4] underlining the need for social protections to include cash transfers for family care work (Hidrobo et al., 2020).

The lockdown measures have impacted vulnerable aged-based population groups that depend on nutritional programs for meeting their daily nutritional requirements. The World Food Program estimates that 346 million children missed meals due to school closures at the start of the pandemic[5] (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). Lockdowns and social distancing measures have been strictly applied for older people due to their vulnerability, leading to disruptions in nutritional services. In addition to the aforementioned vulnerability of children, past studies have shown that older people, even in advanced economies, may be especially susceptible to undernutrition (Margetts et al., 2003) and food insecurity (Fernandes et al., 2018).

People employed or engaged in the trade and service of food (cashiers, food preparation and service workers, waitstaff) were among those most at risk for COVID-19 exposure due to their physical proximity and frequent contact with others.[6] 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. 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.

4.3. Environmental risks, impacts, and vulnerabilities

COVID-19 is symptomatic of a wider tension between human production processes and ecological balance. 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 on biodiversity and the health of ecosystems. COVID-19 has had positive and negative impacts on these drivers, as will be discussed below.

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 other environmental changes plays in important role in the risk of emerging zoonotic diseases (Jones et al., 2013). Demographic changes, urbanization, and land-use changes have pushed further into natural frontiers and fragmented habitats (IPBES, 2019). While the relationship between biodiversity and emerging diseases is complex (Allen et al., 2017), habitat degradation 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).

The global lockdown and associated changes in human behavior during 2020 had a range of impacts on the environment. Due to reductions in transport and economic activities, recent updated estimates suggest that global emissions fell during 2020 by 5.4% in comparison to 2019 (UNEP, 2021). While profound, this is less than the drop initially projected by experts (IEA, 2020). It is also less than the 7.6% emission reductions, which are required each year over the next 10 years to meet the objectives of the Paris Agreement while sustaining economic development (UNEP, 2019b).

Other effects of the pandemic may prove detrimental to environmental protection and land-use management. A recent survey of protected area (PA) managers noted that Covid-19 had negatively impacted almost all operations, including the investigations of suspected illegal activities, training programs, research and monitoring, protection of endangered species, conservation education and outreach, regular field patrols and anti-poaching operations were reported by the majority of PA managers. The pandemic has, also drastically reduced income through tourism, for instance, in Africa, three quarter of PAs surveyed were fully or partially closed during the pandemic and tourism visitation has dwindled. This, in combination with decrease in government funding, further exacerbated the chronic underfunding and understaffing of protected areas, many of which, according to the survey are facing imminent risk of financial collapse (Waithaka et al., 2021).

The lockdowns weakened monitoring and enforcement capabilities outside protected areas and may also have diverted public attention away from the ongoing environmental destruction. This has resulted in some immediate, 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.[7] 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.[8] While COVID-19 pandemic was underway, growing fishing pressure in many Marine Protected Areas

[4] Impacts of lockdown differ by gender: https://nwlc.org/resources/four-times-more-women-than-men-dropped-out-of-the-labor-force-in-september/

[5] WFP data base for monitoring school meals during Covid-19 induced school closures: https://cdn.wfp.org/2020/school-feeding-map/index.html

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

[7] News report on higher deforestation rates in the Amazon in 2020: https://edition.cnn.com/2020/05/14/americas/coronavirus-amazon-brazil-destruction-intl/index.html

[8] Additional report on increased deforestation rates in Asia and Latin America during COVID-19 lockdown: https://news.mongabay.com/2020/07/covid-19-lockdown-precipitates-deforestation-across-asia-and-south-america/

(MPAs) was observed. Illegal fishing by supertrawlers increased substantially in marine protected areas MPAs like the Galapagos Archipelago. In many nearshore MPAs people who lost tourism livelihoods had to fall back on fishing. Lost livelihoods and uncertain food security intensified illegal extractive activities including fishing in no-take area or using illegal fishing gears (Phua et al., 2021).

There is real concern that a prolonged pandemic and economic crisis in countries could result in governments deregulating businesses, moving the world away from achieving environmental SDGs. A recent analysis found that recovery efforts in 16 of 20 major economies invested in or focused more on activities that undermine environmental protections rather than support them, at the same time the governments of at least 22 countries rolled back or weakened environmental protection policies (Golden Kroner et al., 2021).

While the world's attention is focused on the pandemic, it is worthwhile to reflect that a number of environmental extremes were observed around the world, including forest fires in Australia,[9] Southeast Asia and the Americas, heatwaves and forest fires in Siberia,[10] and thawing of permafrost and record high temperatures in the Arctic. Several of these extreme events can be attributed to climate change. 2020 was also the year in which all the alphabetical names for hurricanes were used up (WMO, 2020), signifying an exceptionally active hurricane season.

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 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.[11] 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.

5. Toward recovery: General considerations on opportunities and challenges

The transformation of food and land-use systems has a central role to play in reaching the SDGs and meeting other key international policy objectives, such as the Paris Agreement on Climate Change (UN, 2015b). 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, explored in Section 3, further reinforce the need for transformation of food systems. The pandemic cannot be used as 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, 2015a).

We are now at the crossroads toward or away from a sustainable development trajectory, depending on how we collectively decide how we want to emerge from this pandemic. For illustrative purposes, we can broadly envision two alternatives that embody distinct views on how to respond to the current global disruption (see Table 1). 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 sustainability, which is also informed by more comprehensive risk management efforts across scale. Before moving to key considerations and recommendations in section 5, it is worth also highlighting some potential challenges and pitfalls involved in the transformation process.

The timing and speed of the socioeconomic recovery are uncertain. While there were some initial signs of improvement early in 2021, global

Table 1
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.
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. This is reflected in a sustained increase of ODA contributions by developed countries to facilitate a collective international response to the crisis. These ODA 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.
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.

Source: Authors.

[9] Attribution studies on weather extremes observed in 2020:https://weather.com/science/nature/news/2020-02-26-australia-fires-burn-unprecedented-amount-of-forests

[10] https://www.worldweatherattribution.org/siberian-heatwave-of-2020-almost-impossible-without-climate-change/

[11] Food and nutrition crisis reports: http://www.food-security.net/en/topic/food-and-nutrition-crisis-2020/

infection numbers continue to be at high levels. By the end of December 2020 over 79.2 million cases of COVID-19 and over 1.7 million deaths had been reported globally since the start of the pandemic (WHO, 2020). The confirmed cases of COVID-19, which are reported on a weekly basis by WHO, peaked at close to 5 million people in early January (WHO, 2021a) and the numbers started to drop to about half this amount by mid-February before increasing again, reaching again over four million cases in early April 2021 (WHO, 2021b). This fluctuation between global drops and increases in weekly case numbers has continued throughout 2021, as situations in some countries improved only to deteriorate in others again. While China, Australia, New Zealand, and a few other countries appear to have largely contained the virus, the number of infections continue to be high in several other parts of the world. In autumn 2021, Europe is confronted with another surge of Covid-19 cases (WHO, 2021c). There is concern that the extent of infections and fatalities particularly in developing regions may be higher than reported due to limited testing and healthcare capacities, as has been explored in the Nepal (Giri and Rana, 2021). However, other factors may also be at play, such as demographics, geography, past experiences with epidemics, level of urbanization and connectivity, which been explored as arguments for explaining the comparatively and unexpectedly low Covid-19 cases numbers in most African countries (e.g. Nguimkeu and Tadadjeu, 2021; Zhang et al., 2021). As of early November 2021, the number of confirmed COVID-19 cases across the globe reached over 249 million and over 4.9 million deaths had been reported since the start of the pandemic (WHO, 2021b).

The growing number of approved vaccines in 2021 and vaccinations have nurtured hopes of containing the pandemic in the near future, but considerable distributional challenges still need to be overcome. Over 7.4 billion vaccine doses have been administered in the autumn of 2021, but only 1 out 13 people is vaccinated in low-income countries compared to 1 in 2 people in high-income countries.[12] To emerge from the pandemic a global vaccination success is needed (OECD, 2021). Until then, however, repeated local or more widespread lockdown measures may be necessary, further worsening economic impacts and slowing down the recovery process. Depending on the speed and robustness of the recovery of the world economy, economic assumptions which informed analyses of sustainable development pathways before the pandemic may 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 quickly released unprecedented economic stimulus packages (Cassim et al., 2020), based on both fiscal and monetary interventions. In 2020 the 50 largest economies committed 14.6 trillion USD in the response to COVID-19 with 1.9 trillion USD focused on long-term economic recovery (O'Callaghan and Murdock, 2021). 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. There is also a question mark behind the willingness of governments to harness the crisis to restructure their economies rather than recovering old structures which may no longer be fit to meet the challenges of changing world. According to O'Callaghan and Murdock (2021) only 18% of the longer-term recovery spending or 2.5% of the total fiscal spending announced in 2020 is specifically contributing to a green recovery. The recovery is about making deliberate, informed strategic choices, taking into account the potential long-term consequences for the various development paths. 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.

[12] Further information on the evolving Covid-19 case numbers, vaccine distribution and global access can also be found at: https://covid19.who.int/; https://data.undp.org/vaccine-equity/

6. 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., Willett et al., 2019; FOLU, 2019). The SDGs already contain key elements for more sustainable food systems. These include 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 (see UN, 2015a). However, while it is understood that the transformation must 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 more firmly anchored in resilience. As the reviews and consultative discussions within the IIASA–ISC Consultative Platform underlined, this foundation currently has its weaknesses, and support for each of the pillars needs to be strengthened.

Building resilient food systems should be viewed as a dynamic, cross-sectoral 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 over time (Folke et al., 2010), particularly where this may lead to more favorable outcomes in a world exposed to multiple shocks and long-term trends. Environmental tipping points may threaten food security and there is a need to further understand their interactions with socioeconomic characteristics of food systems (GFS, 2017). The risk of simultaneous breadbasket failures, arising from widespread adverse impacts on maize, wheat, and soybean, has been shown to increase profoundly with progressive levels of global warming and associated increases in the exposure to climatic extremes (Gaupp et al., 2019).

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. The lock-in of food system structures, which meet current demands, but are unsustainable or maladaptive to trends, should be avoided. This would ultimately exacerbate 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 IIASA-ISC consultative discussions informed two key overarching areas of emphasis, which we believe should characterize the transformation of food systems as we emerge from the pandemic. First, the recovery process should be harnessed for a fundamental, systemic shift toward greater social resilience and equity. Second, the recovery process should emphasize the integration of human health and planetary health perspectives into the food system architecture. In support of this emphasis, three intervention areas should receive particular attention to catalyze the transition toward greater resilience and sustainability of food systems: i) Advancement of innovation, technology transfer, and scale up of sustainable practices, ii) strengthened mechanisms for cross-sectoral partnerships and multilateral collaboration, and iii) an expanded science-policy interface. Table 2 presents an overview of suggested areas of emphasis and entry points for action to strengthen the resilience of food systems in the wake of COVID-19. The following subsections then describe in further detail the rationale for placing particular attention on the suggested focal areas during the recovery process. It is understood developing pathways toward more resilient, equitable, and sustainable food systems will require that these suggestions to be developed within specific socio-cultural, economic, and environmental contexts, where the synergies and trade-offs between multiple objectives need to be carefully examined.

6.1. *Empowering a systemic shift toward resilience and equity*

With the looming risk of future pandemics, shocks associated with climate change, and global environmental and socioeconomic changes 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

Table 2
Resilient food systems – Overview of suggested areas of emphasis for the recovery process.

Resilient Food Systems		
Transformative Emphasis (section)	Rationale	Selected Focal Areas
Systemic shift toward social resilience (5.1)	To buffer and secure socio-economic development gains driven by food systems against a changing risk landscape, balancing efficiency concerns with resilience, adaptive and transformative demands.	• Expand the benefits, reach, and duration of social safety nets • Provide pathways to formal employment • Promote sustainable farming models, adapted to socio-cultural contexts • Facilitate just transitions into less vulnerable livelihoods, where necessary • Reconfigure trade and supply chains, based on their absorptive and adaptive capacity to shocks
Integration of human and planetary health concerns (5.2)	To couple social, economic and environmental resilience building efforts for ensuring long-term sustainability.	• Adopt ambitious biodiversity and ecosystem conservation targets, coupled with strengthened regulations, monitoring capacities, and enforcement mechanisms • Accelerate the shift toward healthy and environmentally sustainable diets and associated food production with an emphasis on affordability • Prioritize investments in water access and sanitation for improved food security and human health • Account for natural capital in decision-making processes and promote environmental stewardship through integrated planning and appropriate incentive schemes • Integrate environmental provisions and performance criteria in bi- and multilateral trade agreements
Catalytic Intervention Areas (section)	Rationale	Selected Focal Areas
Secure innovation, technology diffusion and upscaling of sustainable practices (5.3)	To close gaps in innovation and access to sustainable technologies and practices within and across countries, directed toward reducing pressure on the natural resource base, improve risk management practices, improving processes and enabling environments.	• Provide clear goals, targets, and regulatory mechanisms to channel private sector engagement • Strengthen the biological diversity of crops, adapted to diverse environmental conditions, and advance suitable 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 readily be adopted • Strengthen extension services, technical assistance, and funding instruments • Upscale research on sustainable farm models targeting smallholders • Facilitate access to digital technology across supply chain, such as precision agriculture, e-commerce, blockchains for tracing foodstuffs • Provide risk-transfer mechanisms to catalyze investment in innovative technologies and measures
Strengthen science-policy interface (5.4)	To strengthen the foundation for fact based decision-making and enabling integrated solutions, which assess impact pathways of policy and measures across the food systems	• Advance early warning and near real-time monitoring capacities to rapidly detect potential shocks, risks, and vulnerabilities that undermine 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
Deepen cross-sectoral and multilateral collaboration (5.5)	To improve the capacity to manage multiple hazards and compounding risk factors to food systems and promote transformation pathways that account for sustainability constraints across scales.	• 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

Source: Authors, informed by IIASA-ISC consultative discussions.

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. 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.

With regards to strengthening socioeconomic resilience, 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. Improved early warning capacities, understanding of the risk exposure and vulnerabilities of societal groups need to be coupled with facilitated access to social safety nets, simplified enrolment procedures, and reduced administrative burden for benefits claims.

Building more resilient food systems will require improving the enabling conditions for sustainable farm systems, which provide fair and equitable livelihood opportunities (e.g. FOLU, 2019). This entails also considering the interlinkages across various components of the food systems, such as examining how producers and consumers are linked through value chains and considering current power imbalances, which are embedded in many food systems today (Yi et al., 2021). Helping farm systems manage and adapt to multiple environmental and socioeconomic risks will require targeted innovations in technologies and practices (as further discussed in section 5.3). Where farming livelihoods will become unsustainable over time due to climate change or other risk factors, policies and measures need to put into place to facilitate the timely transition into less vulnerable livelihoods.

The role of safety nets in reducing socioeconomic vulnerability across food system 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, 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.

The role of agricultural trade in resilience building efforts should be considered in terms of exposure to a variety of economic and environmental risks. The pandemic and global lockdown exerted mainly a demand shock on agricultural trade as discussed earlier. 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 a 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 market regional integration or a strengthening of regional self-sufficiency.

6.2. Integrate human and planetary health perspectives

Efforts aimed at strengthening socioeconomic resilience need to be complemented by a focus on ensuring environmental resilience, maintaining a viable natural resource base to deliver food security and nutrition over time. Human and planetary health perspectives should hence jointly inform the design and transformation of food systems.

Diets are a central focus of a transition toward more sustainable food and land-use systems. Beyond the need to deliver on food and nutritional security, dietary shifts are necessary to tackle the rise in obesity and non-communicable diseases, while also alleviating the pressure of a growing and more affluent population on natural resources. The recognition of the link between human and environmental health underscores the importance of pursuing a more integrated approach to diets (Willett et al., 2019).

To enable dietary shifts, there needs to be greater emphasis on affordability. 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; Leclère et al., 2020), illustrating the benefits of integrating human and planetary health concerns in food systems.

The focus on diets needs to be accompanied 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).

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.

The emergence of the SARS-CoV-2 virus is a symptom of the growing pressure of human activities on natural systems and the disruptions caused by COVID-19 illustrate the multi-dimensional threat that pandemics can hold to sustainable development (Di Marco et al., 2020). With land-use changes and consumption behavior being among major drivers of pandemic risks, food systems play a pivotal role in helping to integrate human and animal health and increasingly also broader environmental health perspectives, as demanded of the One Health concept (Destoumieux-Garzón et al., 2018). While principles and operational guidance for implementing One Health are advancing (Gruetzmacher et al., 2021; Berthe et al., 2018), a further broadening of linkages with ecological and environmental sciences is called for in guarding against zoonotic diseases but also other health risks (Humboldt-Dachroeden et al., 2020). Given the central position that food systems already occupy in their (positive or negative) impacts on the earth's life support systems, the lessons from the pandemic should provide impetus to ensure that food system accounts for the interlinkages between human and environment interactions and comprehensive risk management approaches to limit the emergence of other similar and potentially more dangerous threats in the future are advanced.

This will require better protection and management of the natural resource base, tackling human and planetary health as joint objectives for the future development of food and land-use systems. 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).

The integration of ambitious biodiversity and ecosystem conservation targets should be deepened across policy frameworks. Following the expiration of the Achi targets[13] the Convention on Biological Diversity (CBD) is currently in the process of developing a new framework, which will define new targets for biodiversity conservation. Commonly referred to as post-2020 Global Biodiversity Framework, it complement 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.[14] With on key policy decisions on biodiversity conservation under the CBD shifted into 2021 and 2022, there is the opportunity to further integrate ambitions and shape cross cutting solutions, building on and strengthening linkages to outcomes from the United Nations Food Systems Summit (UNFSS) and the 26th Conference of Parties to the UN Framework Convention on Climate Change (UNFCCC) in 2021.[15]

Current commitments for the protection of biodiversity are insufficient and need to be upscaled. 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). 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.

For biodiversity conservation but also building more resilient and sustainable food systems, the protection and sustainable management of marine resources in national and international waters demands further attention. Ensuring adequate management of marine protected areas is important 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 (Sala et al., 2021; Roberts et al., 2017).

The CBD process offers the opportunity for a bolder and more integrated environmental agenda. The first draft document of the post-2020 Global Biodiversity Framework emphasizes the need to protect biodiversity, halting and reversing extinction rates, and lists 21 targets for 2030, which combine efforts to reduce threats to biodiversity with meeting people needs and are underpinned by targets for tools to facilitate implementation (see CBD 2021). The targets include a focus on "integrated biodiversity-inclusive spatial planning" (CBD 2021, target 14). Integrating food production and biodiversity conservation targets in integrated spatial planning could resolve trade-offs between these two objectives and bring about net benefits for Nature and people (Fastré et al., 2021). In this context, the ambition of protecting 30% of terrestrial and marine areas by 2030 under discussion for the post-2020 Biodiversity Framework under the CBD needs to be strongly coupled with spatial planning for other land- and sea-uses (Fastré et al., 2021). 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.

Target setting efforts not only require further ambition in terms of area protected as well specificity in terms of identifying conservation hotspots to guard against pandemic, climate, and/or other environmental risks. While area-based conservation targets are an important starting point, it also matters which areas and places are protected. Conservation efforts should take into account the potential to deliver multiple benefits. Recent research illustrates how conservation efforts can simultaneously 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).

Ambitious strategies for nature conservation and restoration need to be accompanied by sufficient resources. Waldron et al. (2020) estimate that protecting the 30% of the planet most important for biodiversity could cost between US$103 billion per year to US$178 billion depending on the implementation scenario chosen. This is a fraction of the more than US$ 12 trillion that has been pledged for COVID-19 relief. Crucially, the direct economic benefit of protecting 30% of land and the oceans are US$64 – US$454 billion, generally outweighing the costs (Waldron et al., 2020). Increased ambition needs to be matched by appropriate implementation mechanisms, including strengthened regulations, monitoring 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

[13] The Aichi targets under the CBD, which have informed the target setting on biodiversity and conservation in the SDGs, expired in 2020. New targets are being defined in the process leading to the post-2020 Biodiversity Framework of the CBD. This process has been extended into 2021 due to the disruptions caused by the pandemic. For further detail on the state of the process, please see: https://www.cbd.int/conferences/post2020

[14] Information of land degradation neutrality target of the UNCCD: https://www.unccd.int/actions/achieving-land-degradation-neutrality

[15] Further information on UNFSS and COP26, UNFCCC: https://www.un.org/en/food-systems-summit; https://unfccc.int/conference/glasgow-climate-change-conference-october-november-2021

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.

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. 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 that the limits to the substitutability of natural capital are recognized (Hepburn 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 (Hepburn et al., 2017).

In addition to revising and improving economic performance measures pertaining to environmental sustainability, incentives for environmental stewardship need to be strengthened. 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 (e.g. Erb et al., 2009; Kastner et al., 2015). As discussed, 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.

6.3. 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 vaccines, 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. Beyond applications in medical research, advances in gene editing open up new avenues for agriculture and food systems (Doudna and Charpentier, 2014), including drought-resistant crop development and other options for growing crops on marginal and degraded lands. This groundbreaking scientific work should be considered in its potential in a world exposed to shifting climatic conditions and increasing climate extremes. Gao (2018) comments that advances in gene editing through the CRISPR Cas9 technology can help 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 regulatory environment and transparency of information for engagement with the public.

Maintaining and accelerating innovation in the wake of the pandemic is important for developing new and alternative food sources. 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 Oonincx, 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 continues to be 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 over the coming years, attention to 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.[16]

The often predominant emphasis on global transformations needs to be complemented by elevating applied research for context-specific solutions. 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, including extending the use of mobile phones more widely in rural areas. Building more sustainable farm systems, refocusing and improving rural livelihoods will require greater attention being paid to innovations in technology and practice targeting smallholders. Based on the findings of Ceres2030, 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. Recent estimates suggest that smallholders working on less than 2 ha 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 and strengthened institutional support structures 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.

Advancing innovation across food systems 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 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.

6.4. *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. This has implications not only decision-making processes, but also for the way that underlying scientific knowledge constructed. As the pandemic illustrates, 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 as society (Moradian et al., 2020, Leach et al., 2021). 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 and further integrated so that emerging biophysical and economic risks and vulnerabilities can be rapidly identified and guide appropriate interventions. Many countries and regions had to confront the pandemic while having to manage multiple other shocks. As previously discussed, the impact of the pandemic on global food security during 2020 was partially buffered by robust global food supply. 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. 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. As we have come to understand the global footprint of human 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 (OECD and IIASA, 2020), as long as underlying assumptions are clearly communicated, and data and information are transparent.

6.5. *Catalyze change: Expanding 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

[16] Knowledge resources on sustainable land management (SLM): https://knowledge.unccd.int/topics/sustainable-land-management-slm

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.

The multilateral system continues to lack enforcement capacities to effectively confront the global challenges of today and tomorrow. The multilateral system was already being undermined by growing geopolitical tensions in recent years. 2020 was characterized by trade disputes and uncertain outlook on the international momentum to address to climate change. 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. On the one hand the emergence of vaccination instilled hope in the combat against the pandemic, while the return of the United States in 2021 to the Paris Agreement may help to re-energize collective action toward more sustainable and resilient societies. The UN Food Systems Summit, and the 26th Conference of Parties of the UNFCCC, and the CBD Summit establishing the post-2020 global biodiversity framework present a window of opportunity to advance integrated solutions to addressing development and environmental challenges in support of the SDGs. Yet assessments of current recovery funding shows that only a fraction of the resources is focused a green recovery (O'Callaghan and Murdock, 2021), illustrating the uncertainty underlying the direction of the recovery, i.e. whether societies will choose to "bounce forward" or prefer to "fall back" to business as usual.

As the pandemic rages on through 2021 and access to vaccines is uneven, international solidarity continues to be tested. It is thus important that alternative platforms and mechanisms within and across countries continue to be 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 and sectors. 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 must be focused on identifying context-specific solutions and implementation capacities, which are informed by the larger strategic and programmatic rationale for food system transformations. 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.

7. Concluding remarks

The pandemic and its consequences 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.

As vaccination efforts further progress, the spread of COVID-19 will hopefully be contained and countries will be able to reset their economies in the near future. But returning to previous paradigms would 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 world under 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 to and emerging from the agriculture and food sectors. 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.

Research on transforming energy systems to meet the objectives of the Paris Agreement suggests that it 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. Currently only a fraction of the fiscal spending made available in response to the pandemic is focused on enabling a green recovery (O'Callaghan and Murdock, 2021). 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 (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). With further recovery spending to be issued, the opportunity to build in equity, sustainability and resilience concerns should not be missed.

The United Nations Food System Summit (UNFSS) has brought further attention to the importance of food and land-use systems for sustainable development. Assessments in the lead-up to UN Climate Conference in Glasgow (COP26) show that the updated Nationally Determined Contributions (NDCs) fall short in their collective ambition of aligning with emissions reductions required for a pathway toward limiting global warming to 1.5 °C or at least well below 2 °C above pre-industrial levels (e.g. UNEP, 2021). With the NDCs capturing national level targets and measures for climate change mitigation and adaptation, a recent assessment emphasized the importance of more comprehensively targeting food and land-use as an opportunity for scaling up action (FOLU, 2021). The declarations of over 130 countries to stop forest loss and degradation by 2030[17] and country coalitions forming for strengthening environmental stewardship and protecting networks of marine and coastal areas announced during COP26, should be seen as impetus for further ratcheting up ambitions at the CBD and the post-2020 Global Biodiversity Framework in particular for the protection of terrestrial and marine resources and promoting integrated solutions to tackling food and nutritional security, climate and environmental change.

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

[17] Declaration of world leaders at COP26 on forests and land-use:https://ukcop26.org/glasgow-leaders-declaration-on-forests-and-land-use/

innovation can enable progress toward one objective while hindering or undermining progress toward 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.

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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As with author list, provided in separate document.

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