Food and Agriculture Organization of the United Nations

How to feed the world in times of pandemics and climate change?

Opportunities for innovation in livestock systems

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We are One World working together for One Health and Zero Hunger.

Foreword

Livestock systems play a central role in food and nutrition security and contribute significantly to livelihoods and economic development. Investment in the transformation of livestock systems can accelerate progress in countering both climate destabilization and emerging infectious diseases while also furthering progress towards other sustainable development goals.

Global food security, economies, health, and livestock are increasingly threatened by climate extremes. The frequency of disease outbreaks – including the emergence of novel viruses and zoonotic illnesses – is expected to continue rising.

Currently more than a third of the world's population cannot afford a healthy diet and at least one in four people is without regular access to sufficient food. Hunger has been rising in the last five years. Now is the time to reverse this trend and achieve Zero Hunger. Because humankind's survival depends on access to safe and healthy diets.

As our world is facing escalating threats, we are challenged to better safeguard livelihoods and transform our agri-food systems. Agenda 2030 is there to guide us and we must act swiftly and collaboratively to achieve the Sustainable Development Goals (SDGs).

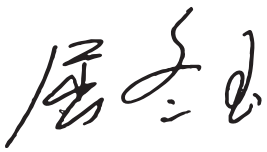
Infectious disease outbreaks and climate shocks cause disruptions that shake the bedrock of our agri-food systems. Without swift action, these challenges may have compounding effects, with even more severe consequences for food security, economic development, and global health.

Transforming our agri-food systems – in which livestock play a pivotal role – requires that we overcome historical silos and the status quo to embrace more innovative and integrative approaches. Preparedness and response work for both pandemics and climate shocks can be mainstreamed into existing programmes towards achieving a thriving global society where no one is left behind.

The crucible of COVID-19 is an opportunity to "build back better" by applying the lessons learned from emergency and rehabilitation activities of past zoonotic disease outbreaks and natural disasters to strengthen agri-food systems and economies. This means investing in sustainable, inclusive, and resilient agri-food systems for better production, better nutrition, a better environment, and better lives.

The Food and Agriculture Organization of the United Nations (FAO) supports countries to accelerate progress in achieving this vision through technology, innovation, data, and complements – strengthening governance, human capital, and institutions. FAO is working hand-in-hand with its Members towards better preparedness and resilience against threats to the health of people, animals, and the environment.

By working together, agri-food systems, livelihoods, and economies will be better protected from the adverse efffects of pandemics and climate change, and many lives can be saved; today and for generations to come.



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Executive summary

Key messages

- Globally we are only as protected as our most vulnerable members because pathogens cross borders.
- A strong evidence base is needed to better understand underlying causes of biological and environmental pressures and their interaction effects in order to identify and manage risks before they become large-scale emergencies.
- Opportunities to boost profitability through more effective livestock production practices will also help to reduce the burden of disease outbreaks and encourage innovations to make livestock production more resilient and sustainable.
- The economic case for market-based approaches and public and private investments will help to mobilize resources to deliver preparedness and response plans.
- Mainstreaming livestock production innovations into existing development programmes will help accelerate progress and boost resilience to health and climate crises for achieving global prosperity.
- Improve equity across livestock systems, ensuring the most vulnerable are protected, including smallholder farmers, pastoralists, seasonal workers, women, and youth.
- Increase the agility of livestock systems to adapt to disruptions by: improving preparedness and response plans; maintaining special transport and trade corridors; boosting feed stocks, medicine reserves, food storage, and cold chain capacity; accelerating innovation for digital and technology solutions for market access and contactless processes; maintaining fair prices and price monitoring; and ensuring emergency funds, insurance, and support services for livestock systems.
- Reduce the risk of biological threats by: coordinating within and across sectors for a One Health approach; diversifying supply chains; improving surveillance of environments and pathogens, as well as traceability of animal-source foods, connected to early warning systems; strengthening infection prevention and control measures, including reducing exposure of people and animals to pathogen reservoirs such as wildlife; improving conditions at live animal and food markets; strengthening food safety measures; observing international standards for safe and efficient food trade; and advancing infodemic management, risk communication, and community engagement for a more effective emergency response.
- Boost climate resilience by: protecting livestock from unfavourable climate conditions; using the inherent mobility of livestock to respond to variability in climate and resources; diversifying sources of protein, including exploration of alternatives less impacted by climate destabilization; and fostering livestock genetic diversity with better matching of animal traits to environmental conditions.
- Climate change mitigation efforts can be further enhanced by: optimizing production relative to greenhouse gas emissions; boosting recycling efforts, including manure management, for a circular bioeconomy with less waste; capitalizing on nature-based solutions for carbon offsets and reversing land degradation; and exploring the environmental and health benefits – and potential risks – of alternative protein sources.

Progress towards Zero Hunger must be protected from the dual challenges of pandemics and climate change. The frequency of infectious disease outbreaks – including the emergence of novel viruses and zoonotic diseases[1] – is expected to continue rising as livestock, food security, economies, and global health are increasingly threatened by a destabilizing climate (FAO, 2020a, 2020b; FAO *et al*., 2020a). At the same time, malnutrition is unacceptably high across all regions of the world. In 2019, nearly one in ten people in the world were exposed to severe levels of food insecurity (FAO *et al*., 2020b).

Now is the time to redouble efforts to achieve Zero Hunger and the Sustainable Development Goals (SDGs) by ensuring universal access to safe and healthy diets. Because good nutrition is the foundation of good health and global prosperity.

Global food systems can be better protected from the harms of infectious disease outbreaks and climate shocks, and their compounding effects on food security, economic development, and global health.

The crucible of COVID-19 is an opportunity to acknowledge vulnerabilities in order to "build back better" by applying the lessons learned from emergency and rehabilitation activities of past zoonotic disease outbreaks and natural disasters. This means investing in sustainable, inclusive, and resilient food systems for better production, better nutrition, a better environment, and better lives.

Transforming our food systems – in which livestock play pivotal roles – requires that we embrace more innovative and integrative approaches. The 13th Global Forum for Food and Agriculture (GFFA) in 2021 is seeking recommendations, guided by four questions about "How to feed the world in times of pandemics and climate change?"

1. How can food systems emerge strengthened from the COVID-19 pandemic?
2. How can the agricultural sector contribute to preventing further pandemics?
3. How can food systems become more climate-resilient?
4. How can food systems contribute to climate change mitigation better than before?

In this brief, the four questions posed by the GFFA are addressed from the perspective of livestock systems. The questions are treated separately, noting that there are compelling arguments for an integrative approach. Coordinated approaches that transcend historical silos are essential given the interconnectedness of environmental health, animal health, and public health. Preparedness and response work for both pandemics and climate shocks can be mainstreamed into existing development programmes to accelerate progress towards the SDGs.

In the following sections, which aim to answer each of these four questions, we include a brief overview of key challenges and opportunities for innovation, alongside recommendations for priority actions. These range from steps to better mitigate and monitor threats, to helpful measures for boosting resilience. Making advances in any and all of these areas will require an enabling policy environment and structural adjustments for solutions to be practical, appealing to implement, and sustainable. Policy objectives are addressed in the last section of the brief and – and corresponding considerations for implementation in support of the priority actions ar given in the Appendix. These represent a range of approaches in recognition of the complexity and diversity of livestock systems globally: incentive programmes; legal and regulatory frameworks; enforcement mechanisms; norm-setting; market and pricing adjustments; investments in research, development, and infrastructure; community engagement, and exploration of alternatives – all in a context of strengthened prevention, preparedness, and response planning.

Whilst the GFFA is addressing food systems more broadly, the focus of this brief is on livestock systems. This is because they play a central role in food and nutrition security, and contribute significantly to livelihoods and economic development. Investment in the transformation of livestock systems can therefore accelerate progress in countering both climate destabilization and emerging infectious diseases[2] while also furthering progress towards other development goals.

Thoughtful reconfiguration of livestock systems based on analyses of risks and benefits will help to address current vulnerabilities and capitalize on opportunities for innovation that will ensure better outcomes.

The Food and Agriculture Organization of the United Nations (FAO) supports countries in accelerating progress in achieving this transformation through technology, innovation, data, and by strengthening governance, human capital, and institutions.

FAO's support for countries in building **safer**, **greener**, and **more equitable** livestock systems has gained a momentum that needs to be maintained and accelerated for food security and global prosperity.

By working together, food systems, livelihoods, and economies will be better protected from the destabilizing forces of pandemics and climate change to secure healthy diets for all and a thriving global society where no one is left behind.

[1] Zoonoses are diseases that are transmitted between animals and humans.

[2] Emerging infectious diseases are those whose incidence in humans has increased in the past two decades or threatens to increase in the near future; https://www.cdc.gov/niosh/topics/emerginfectdiseases/default.html.

Situation

"Innovations for feeding a growing population may also help protect humankind from the destabilizing effects of pandemics and climate change."

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The frequency and economic impact of emerging infectious diseases is on the rise (FAO, 2020a; Jones *et al*., 2008; Smith *et al*., 2014). The COVID-19 pandemic has revealed underlying risks, fragilities, and inequities in global food systems that call for change. Whilst recovery efforts understandably focus on managing immediate risks of COVID-19 and facilitating a swift recovery, the question arises of how we can better prevent, prepare, and respond to the combined threats of climate destabilization and emerging health threats while meeting a growing demand for food. COVID-19, the disease caused by SARS-CoV-2, is one of many health crises in a long history of emerging disease outbreaks (e.g., avian influenza, severe acute respiratory syndrome (SARS), Middle East respiratory syndrome (MERS), Ebola). In recent decades, most of these outbreaks originated in animals, creating a need for strong engagement of livestock systems in "One Health" initiatives, including a greater focus on key pillars of environmental health (FAO, 2013a). Countering the destabilizing forces of pandemics and climate change through better mitigation and preparedness efforts can see livestock systems contribute to a sustainable future by becoming greener, safer, and more equitable.

Global hunger has been rising steadily since 2015 due to gaps in policy, conflict, socio-economic challenges, natural hazards, pests, and climate change (FAO *et al*., 2020b). COVID-19 has created a sharp rise in food insecurity worldwide, with disruptions to food production, supply chains, and livelihoods (FSIN and Global Network Against Food Crises, 2020; WFP, 2020). Twin challenges of a protracted pandemic and climate destabilization – among other drivers of food insecurity – must not derail progress towards safe and nutritious food for all because this is a fundamental human right and the foundation for good health and global prosperity. The goal of Zero Hunger by 2030 is a call to action for innovative transformations in food systems, including livestock.

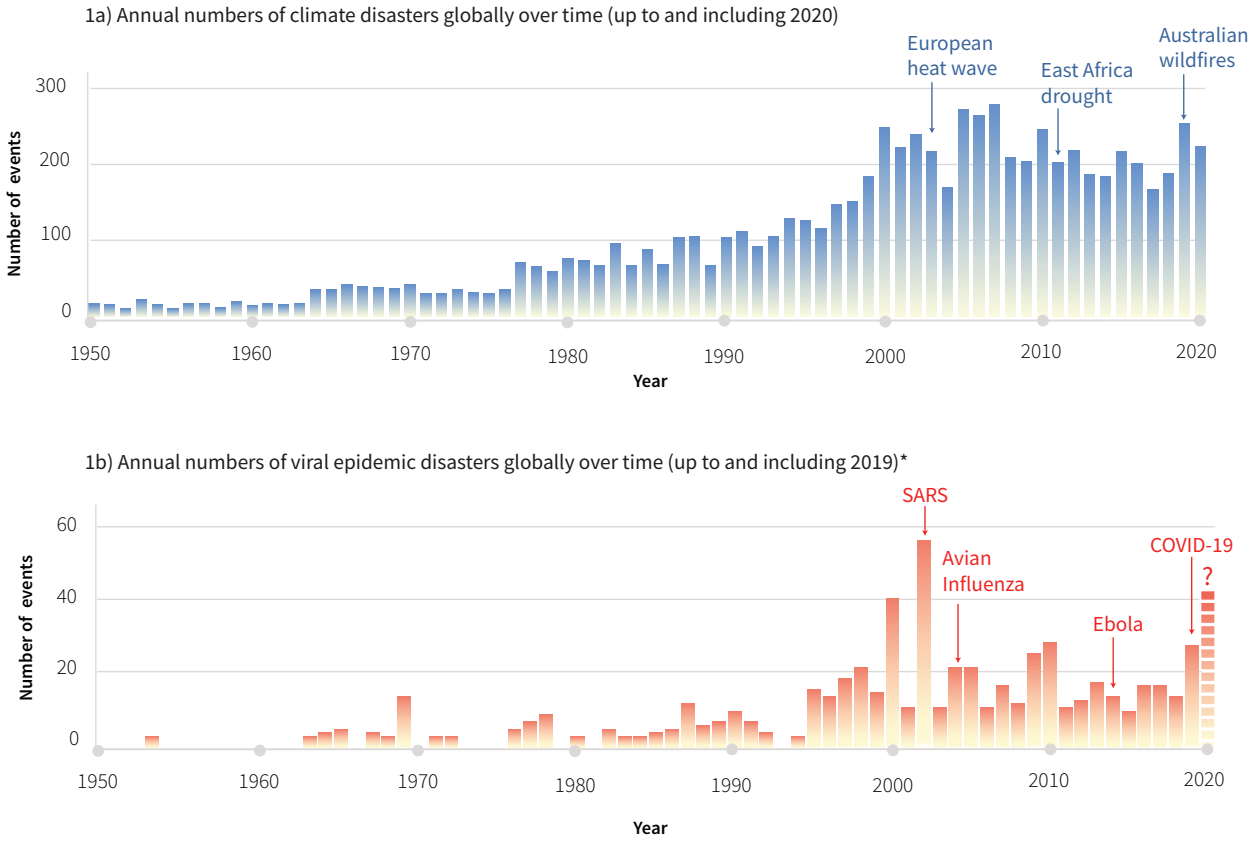
Pandemics and climate change share some characteristics – and indeed climate may alter the complex ecological relationships underlying infectious disease transmission patterns (Institute of Medicine, 2008; Wu *et al*., 2016) – suggesting that there may be common approaches for lessening their impacts on food systems. Both pandemics and climate change are systemic disruptors to food systems across the globe. The risks posed by these threats are growing rapidly as food demands drive up production in more variable and fragile environments. Whilst the drivers of both pandemics and climate change result from ongoing and gradual processes, such as deforestation, forest fragmentation, natural habitat encroachment, and greenhouse gas emissions, their impacts often take the form of sudden and unpredictable shocks, such as epidemics, floods, severe storms, heatwaves, and wildfires. Figure 1 illustrates how the number of viral epidemics and climate shocks has largely been increasing over time, culminating in the present COVID-19 pandemic and recent devastating wildfires. Both pandemics and climate change have destructive impacts on food security and nutrition, especially among vulnerable populations. The widespread nature of both these threats, and their impact on public goods, mean that individual behaviour can also have global consequences. Prevention, preparedness, and response must therefore engage all stakeholders at all levels, apply trans-disciplinary and multi-sectoral approaches, and span local, national and international coordination.

The COVID-19 pandemic provides an opportunity for governments, policy makers, and the international community to use the momentum created by the disruptive nature of this crisis to "reset" how we are feeding the world. Such recovery is not only a matter of managing risks but also acknowledging and addressing profound and complex interrelations between diseases, climate change, and other factors such as habitat destruction, land-use change, dietary imbalances, and the welfare of people and animals.

In a brief prepared for the 2018 GFFA (FAO, 2018), three broad categories of livestock systems were identified (extensive, labour-intensive, and capital-intensive) and linked to different opportunities for innovation across key domains of sustainability: food and nutrition security; livelihoods and economic growth; health[3] and

[3] Health here refers to animal health and also to human health, as it relates to animal and environmental health, in a One Health context.

Figure 1: Yearly climate disasters and viral epidemics worldwide since 1950



* The incomplete bar for 2020 indicates that data collection for the year is not yet complete but the COVID-19 pandemic includes a large number of epidemic events worldwide.

Source: EM-DAT: The Emergency Events Database – Université Catholique de Louvain (UCL) – CRED, D. Guha-Sapir – www.emdat.be, Brussels, Belgium. [Cited 6 January 2021]. These data do not provide a comprehensive representation of all disasters but rely on reporting and alignment with the selection criteria of the Emergency Events Database (EM-DAT). A disaster event is defined as including at least one of the following criteria: 10 or more human deaths, 100 or more people affected, injured, or made homeless, or a declaration by the country of a state of emergency and/or appeal for international assistance. The natural disaster indicators include meteorological (extreme temperature), hydrological (flood), climatological (wildfire and drought), and biological (viral epidemic) events. These indicators have been selected to illustrate the variability of climate and disease events and are not intended to represent a causal relationship between climate and epidemic events.

animal welfare; and climate and natural resource use. It is the great diversity of livestock systems, and the many roles they play in different contexts, that determine their contributions to these dimensions of sustainability. It also follows that diverse livestock systems present different challenges and opportunities in mitigating, preparing for, and responding to pandemic risks and climate change.

Livestock contribute substantially to global food systems, providing valuable nutritional benefits, supporting livelihoods, and strengthening the resilience of families and communities to environmental and other shocks. Recent epidemics and extreme climate events are threatening these benefits, but also open the door to new opportunities for innovation in livestock systems in pursuit of sustainable development. Priorities for development include making our livestock systems greener and safer. Unintended consequences of livestock systems include greenhouse gas emissions and zoonotic spillover events, contributing to a destabilizing climate more prone to extreme events, and disease outbreaks, respectively. COVID-19 did not emerge from livestock as far as we know, but a long history of spillover events includes an acceleration of frequency following the introduction of farming around 12 000 years ago, which brought humans and domesticated animals into closer proximity. This human-animal-environment interface, together with an increasing reliance on high stocking densities, the burgeoning use of antimicrobials, and the narrowing of gene pools, pose risks to animal welfare and global health because these conditions are conducive to the emergence and proliferation of virulence and antimicrobial resistance traits in pathogens. Another priority for development is making livestock systems more equitable by strengthening protections for human rights and well-being, particularly as inequities are further exacerbated by epidemics and climate shocks. Whilst some nodes in food systems have shown to be quite resilient in the face of the COVID-19 pandemic, others have been significantly affected. For example, many smallholder famers faced difficulties accessing markets, and personnel at some slaughterhouses and meatpacking plants have been subjected to unacceptable sanitary conditions and an elevated risk of contracting

COVID-19 (Taylor *et al*., 2020). Bottlenecks at processing plants and markets have also pushed many producers into disposing of stock, contributing to the challenge of food waste and loss on an even greater scale. At the same time, while many of the larger livestock systems might be better buffered against the worst of these impacts as a consequence of scale, they are still vulnerable to largescale disruptions wrought by disease outbreaks and climate shocks. Animal welfare is a growing challenge too given increasing densities on farms, questionable mass culling, and illegal trade in wildlife (FAO *et al*., 2020a; Marchant-Forde and Boyle, 2020). Given a wide range of challenges, stakeholders in every livestock system and operating at all scales share a common interest in seizing opportunities for positive change that will better protect food systems from disruptions.

On the question of *"How to feed the world in times of pandemics and climate change?"*, the 13th Global Forum for Food and Agriculture (GFFA) in 2021 is seeking recommendations to address four questions:

1. How can food systems emerge strengthened from the COVID-19 pandemic?
2. How can the agricultural sector contribute to preventing further pandemics?
3. How can food systems become more climate-resilient?
4. How can food systems contribute to climate change mitigation better than before?

In the following sections of this brief, the four questions posed by the GFFA are addressed separately, noting that there are compelling arguments for a concerted, integrated approach and a combination of measures. In fact, mainstreaming climate change and pandemic preparedness and response actions into existing programming for the SDGs may help to accelerate progress and boost resource use efficiency. Implementing the priority actions for each of the following four focal areas will require an enabling policy environment and structural adjustments for solutions to be practical, appealing to implement, and sustainable. Options for policy approaches in support of the priority actions are addressed in the last section of the brief and in the Appendix. Whilst the GFFA is addressing food systems more broadly, this brief focusses on food systems in which livestock, including those raised for purposes other than food – and wildlife – play important roles.

Strengthening resilience to pandemics

Livestock supply chains have been disrupted at various stages during the COVID-19 pandemic. This reveals a need for enhanced preparedness and response plans to build resilience in livestock systems to achieve greater food and nutrition security in the face of emerging threats.

Priority actions

1. Increase agility of livestock systems to adapt quickly to blunt the impact of supply chain disruptions. This includes investment in preparedness and early response plans and maintaining cold chain capacity and special transport and trade corridors.
2. Diversify supply chains to make them less dependent on small numbers of large operators across food systems to better distribute risks from disruptions while managing trade-offs for biosecurity and other sustainability domains.
3. Accelerate innovation for digital and technological solutions for better market access in emergency situations and to create more contactless steps in livestock systems.
4. Improve traceability of animal-source foods such as through blockchain technologies connected to certification and labelling schemes.
5. Strengthen and observe international standards for safe and efficient trade to ensure access to safe food.
6. Mainstream infodemic management into epidemiological response systems and strengthen community engagement and risk communication to tackle misinformation and improve access to expert recommendations for an effective emergency response.
7. Improve equity across livestock systems, ensuring the most vulnerable are protected, including smallholder farmers, pastoralists, seasonal workers, women, and youth.

Impacts of the current pandemic on livestock systems have ranged from restricting access to animal feed, breeding material, labour, and veterinary services on the input side to bottlenecks at processing plants causing some producers to dispose of stock. In some cases, this led to mass culling on farms, particularly as falling market prices exceeded costs of animal care, or fears of contracting the virus from animals reached a critical point, such as in the case of mink-associated variant strains. Blocked or delayed live animal transport has also challenged animal welfare. At the consumer level, restricted hours or closures of formal and informal markets, restaurants, and the suspension of school milk or meal programmes has exacerbated food access issues. And many of these disruptions have contributed to food loss and waste on a larger scale (Marchant-Forde and Boyle, 2020; FAO, 2020c).

However, the pandemic has also revealed the resilience of traditional, local, and extensive livestock systems that were less reliant on non-local inputs and long supply chains. The livestock sector can invest in expanding this diversity of systems across socio-economic settings to become less dependent on a small number of large operators in order to better distribute risk, while managing trade-offs given potential changes in risks for other sustainability domains such as biosecurity. In practice, this may include more diverse integration to avoid over-reliance where a single entity owns all parts of the supply chain, from farm to processing and packaging plant. This will help to ensure that when there is a breakdown of one facility, its function can more readily be replaced by another. Such diversification can be further reinforced by integrated emergency procedures within and across systems to blunt the impact of supply chain disruptions. This requires response capacity to be built through forecasting and simulation exercises (FAO, 2020d).

There is also merit in upgrading operations and safety regulations to help contain pathogens and reduce the risk of exposure to workers. It is appropriate to classify actors in the livestock food chain (input- and output-levels) as essential workers to ensure access to personal protective equipment (PPE) and other health interventions (e.g., tests and vaccines) in recognition of the vital role they play in keeping everyone fed, especially during an outbreak when good nutrition is needed to support immunity (Taylor *et al*., 2020). Such protections would apply to essential workers in other agri-food and resource extraction sectors as well (ILO and FAO, 2020). It would also be helpful for governments to consider proactively developing an emergency fund for livestock production, processing, and distribution in the event of a crisis. This may help to avoid delays for financial stimulus to help address cashflow issues given the challenges of an approvals process during an emergency (FAO, 2020e, 2020f). FAO has also called for an acceleration of digitalization to provide more "contactless" services, which are helpful in an outbreak situation (FAO, 2020e). Improving access to digital tools will help with rapid risk communication, and connecting wholesalers and suppliers directly to consumers through e-commerce platforms, as well as to service providers for the vulnerable. Such platforms may also expand direct access to consumers for producers, and need to be inclusive of smallholders (FAO and UN ECLAC, 2020; FAO, 2020f, 2020g). These approaches also require an evolution of standard setting and mechanisms for ensuring food safety and fair trade.

Governments need to collaborate to keep global agriculture and food trade open and well-functioning. The pandemic has highlighted the value of science-based internationally agreed standards for food safety and quality in order to facilitate safe and efficient trade. Having such globally agreed public goods provides a basis on which to build trade as well as to maintain it in a crisis. The importance of global food trade and its contribution to food security necessitates systems in all countries to appropriately protect human, animal, and environmental health while facilitating trade. This is particularly relevant in the context of an outbreak when adherence to expert recommendations such as hygiene and sanitation practices, PPE, distancing, quarantining, and self-isolation is needed to maintain safe and efficient food supply chains. Observance of the Codex Alimentarius Commission (CAC) international standards for food safety helps to ensure a strengthened food safety and quality dimension of food systems. The pandemic has also revealed key gaps, which new standard setting work aims to address to strengthen food systems. This includes the development of electronic certification by the Codex Committee on Food Import and Export Inspection and Certification Systems (CCFICS), addressing challenges for the regulation of burgeoning e-commerce marketplaces given greater online trade, and tackling the potential for increased food fraud (FAO and WHO, 2020). To assist in recognizing and rewarding producers investing in safer and more sustainable practices, digital technology can be used to increase the transparency and traceability of animal-source foods. Certification and labelling schemes linked through blockchain technology, and based on a One Health approach, can create permanent records documenting the history of animals and animal products, and indeed inputs such as feed, throughout the entire production cycle to enable retailers and consumers to make more informed purchasing decisions.

The COVID-19 pandemic has additionally revealed gaps in the emergency response whereby a tsunami of information and rampant misinformation and disinformation – an "infodemic" – has contributed to growing non-compliance with expert recommendations on how best to manage the outbreak within and across sectors and for civil society at large. This can lead to irrational consumer decisions with severe consequences for livestock systems. Without broad acceptance of scientific evidence and risk assessments to guide an outbreak response, the impacts are also likely to be protracted and more severe. To help improve the efficacy of outbreak responses in food systems, there is a need to integrate infodemiology and infodemic management practices into existing epidemiological surveillance, warning, and response systems (WHO, 2020a; Tangcharoensathien *et al.*, 2020). This can include a range of practices such as better tracking of harmful information, enhancing access to expert guidance, protection of stakeholder groups against harmful messages, and behaviour change initiatives to improve observance of safety measures (Gallotti *et al.*, 2020; Roozenbeek *et al.*, 2020).

There is also a challenge of the disproportionate impact of zoonoses (and climate change) on communities with the least resilience to health and economic shocks. There is a growing income disparity between rural smallholder livestock producers and large-scale livestock producers, as well as unfairly low prices for primary livestock foods and materials such as hides, skins, hair, and

wool. On top of systemic inequalities, many asmallholder farmers have been cut off from markets, and movement restrictions have disrupted transhumant systems, limiting the ability of pastoralists to feed their animals and sustain their livelihoods. Reduced mobility may also force overgrazing and increase the pressure on grassland ecosystems. Migrant workers in slaughterhouses and meatpacking plants have often either not been able to work or have been subjected to conditions conducive to a higher risk of contracting COVID-19. In low- and middle-income (LMIC) countries where medical, veterinary, and animal production services are limited and food systems are ill-equipped to prevent, detect, and respond to emerging and resurgent zoonotic diseases, smallholder farmers are particularly at risk, which may exacerbate human rights issues for women and children. The pandemic is also likely to push more children out of school and into child labour. Even before the pandemic, more than 70 percent of child labour – 108 million boys and girls worldwide – was reportedly in agricultural sectors, including livestock, fisheries, aquaculture, forestry, and crop farming (FAO, 2020h). Whilst blanket bans on the trade of wildlife species – along with the corresponding legal, regulatory, and enforcement approaches – may be considered a temporary or localised emergency measure where pathogen spillover risks are particularly high, such initiatives may not reduce the amount of illegal wildlife trade, unless there is additional support for communities to reduce their dependence on wildlife. Such initiatives will need to consider the wider context of risks versus benefits of withdrawing wildlife from the food chain given its importance for food security, cultural value, and the livelihoods of Indigenous Peoples and local communities who depend on it (FAO *et al.,* 2020a).

One of the determinants of inequality is the low intergenerational elasticity of income mobility – i.e., the probability of an individual moving out of hunger and poverty is highly determined by the socio-economic position of their parents. A policy mechanism often used to reverse this trend is to foster the labour productivity of the poorest by increasing the human capital of their children and level of access to parents' assets. Thus, while the pandemic has led to critical short-term economic losses, there is a longer-term economic cost caused by the shock that will further shrink individuals' assets and human capital. Social services are urgently needed to assist vulnerable populations in achieving a minimum standard of living. The reconstruction of wealth among vulnerable populations and their future generations means raising the level of productivity of those experiencing the greatest hardship to above the economic mean over time. The growing economic disparity in livestock systems and in food systems globally demands action to ensure inclusive development where the most vulnerable are protected.

Preventing future pandemics

Most emerging infectious diseases that afflict people are zoonoses, originating in animals and wildlife (Taylor *et al.*, 2001; Woolhouse and Gowtage-Sequeria, 2005; Jones *et al.*, 2008; IPBES, 2020; FAO *et al.*, 2020a). As demand for animal-source food rises, and development encroaches deeper into wilderness spaces, food chain dynamics are creating new opportunities for zoonotic diseases to emerge and thrive (FAO, 2013a). Collaboration within and across livestock systems – and other sectors, such as natural resources and health – to protect the health of animals, people, and the environment will help to prevent future pandemics through a strengthening of infection prevention and control measures.

Priority actions

1. Promote collaboration within and across food systems and sectors for a One Health approach at local to global levels. Ecosystem restoration, biodiversity conservation, and the health of people, livestock and the environment in tropical forest systems can go hand in hand if One Health approaches are applied to the areas of land use and forest food systems.
2. Improve animal health and welfare in all livestock systems through stronger infection prevention and control measures to reduce the risk of pathogen emergence and spread.
3. Enhance research and surveillance at the human-animal-environment interface, connected to early warning systems for zoonotic and other health threats such as antimicrobial resistance.
4. Promote the prudent use of antimicrobials in all livestock systems and throughout food systems, monitoring impacts on antimicrobial resistance.
5. Reduce exposure of people and livestock to potential pathogen reservoirs including wildlife.
6. Improve hygiene, sanitation, and operating procedures at livestock and food markets to reduce the spread of pathogens.
7. Accelerate innovation for automated steps in livestock systems to reduce human exposure to pathogens of animal origin, and vice versa.
8. Strengthen food safety measures in all livestock systems to reduce the risk of exposure to foodborne pathogens.

Pandemics are not random occurrences but result from human behaviour, including how people source and grow food, trade and consume animals, and alter environments. A special report from UN Environment Programme's Frontier Series considers "seven human-mediated factors [are] most likely driving the emergence of zoonotic diseases: 1) increasing human demand for animal protein; 2) unsustainable agricultural intensification; 3) increased use and exploitation of wildlife; 4) unsustainable utilization of natural resources accelerated by urbanization, land use change, and extractive industries; 5) increased travel and transportation; 6) changes in food supply; and 7) climate change" (UNEP and ILRI, 2020).

Impacts from zoonotic disease outbreaks and environmental change illustrate intrinsic interconnections that warrant a systems approach for study and solutions. For example, the growing demand for animal-source foods in one part of the world can drive deforestation in another. Livestock systems are increasingly complex and can have unintended adverse impacts on natural resources, and on the health and well-being of people and animals. Livestock-driven deforestation and antimicrobial over-use and mis-use – including administering antibiotics for the purpose of growth promotion – may both contribute to the emergence and spread of infectious diseases (Marshall and Levy, 2011; O'Neill, 2015; Bloomfield *et al.,* 2020; Caudell *et al.*, 2020). Therefore, livestock systems have an important role to play in sustainability initiatives and the prevention of pandemics. Given antagonistic coevolution between people and pathogens, we need to focus on reducing the risk of outbreaks, and better controlling their spread and severity. In this regard, different livestock systems face key differences in risk exposure. The current pandemic highlights the need to prepare for, prevent, detect, and respond to infectious diseases on local to global scales across all livestock systems because pathogens cross species barriers and borders.

COVID-19 was first identified in humans in December 2019, and the exact origin of those infections remains unclear, for now. There are, however, examples of transmission between humans and animals. Several animals that have been in contact with infected people, such as minks, dogs, domestic cats, lions, and tigers, have tested positive for COVID-19. This is a crucial reminder that zoonotic diseases are not spread in one direction from animals to humans but may also transmit among multiple species (OIE, 2020a, 2020b, 2020c, 2020d; FAO *et al.,* 2020a). This underscores the need for One Health collaborations within and across livestock systems and other sectors, such as environment and public health. The intrinsic linkages between the health of people, animals, and the environment warrant further research and enhanced biosecurity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and surveillance at all levels, including for "non-traditional" livestock systems, such as in mink production (FAO, 2020i).

Livestock systems can play a key role in preventing future pandemics, where early detection can significantly lower the downstream impacts of outbreaks on public health and economies. Developing monitoring and surveillance infrastructure from farm-level through the food value chain will be critical to track pathogens, connected to early warning systems. A standardization of processes for establishing new farms may be helpful, including identification and registration systems for premises and animals to tackle the challenge of uncontrolled establishment of farms with low biosecurity. We need also to track and control the use of antimicrobials (and residues) throughout livestock systems and food value chains. This must include attention to live animal markets and food markets, where boosting surveillance, as well as improving hygiene, sanitation, and operating procedures – including good record-keeping – will help to trace and contain pathogens. Implementing risk-based approaches to assess and control pathogens across food chains may further help to overcome the limitations of visual animal and animal-source food inspections and help prevent contamination to reduce the likelihood of novel disease emergence and spread (FAO, 2020j). Furthermore, restrictions and disruptions, especially in labour-intense settings, provide an opportunity for introducing automation in livestock systems in order to reduce the risk of biological threats. Innovations to increase automation in capital-intensive systems for reducing human-animal exposure to potential pathogens must be complemented with animal welfare measures and the development of alternative employment opportunities.

At the level of production, improving biosecurity measures will pay dividends as an integral way to promote livestock health and protect a farm or livestock system from the entry and spread of diseases (FAO, 2019a, 2020c, 2020k). This includes controlling who comes into contact with the animals, separating sick animals from the herd or flock, keeping animals of the same life stage together throughout the production cycle to help reduce the risk of introducing new pathogens ("all-in, all-out"), and limiting contact with multiple species, including wildlife (FAO *et al*., 2020c). The interaction between livestock and wildlife can be rather direct such as in the case of livestock living or feeding in close contact to wildlife; cattle grazing close to wild badgers or buffalo, for example, or poultry in contact with wild birds. Or contacts may be less direct, resulting from disturbance to natural areas such as forest encroachment for pasture and feed production, and habitat fragmentation, bringing forest dwellers such as bats out of their natural habitat and closer to people and their livestock (FAO, 2013a). Emerging zoonotic infectious disease risk may be especially high in forested tropical regions experiencing land-use changes where mammal species richness is also high (Allen *et al*., 2017; FAO *et al*., 2020a). In a recent white paper*, Build back better in a post-COVID-19 world – Reducing future wildlife-borne spillover of disease to humans,* and associated policy brief (FAO *et al*., 2020a, 2020c), FAO, through the Sustainable Wildlife Management (SWM) Programme partnership, explores drivers of disease spillover from

wildlife to humans, and why these zoonotic disease outbreaks can spread to become epidemics and pandemics, such as in the case of COVID-19. The white paper further explores options for preventing, detecting, and responding to future spillover events, with a special focus on priority interventions at the human–wildlife–livestock interface whilst protecting and enhancing livelihoods and food security. A particularly urgent priority is integrating into the broader One Health movement the research and interventions on land use and forest food systems, along with ecosystem restoration and biodiversity protection measures in tropical forest systems. More research is needed and policies that aim at better managing this human-animal-environment interface should also consider supporting closer disease monitoring and alternative livelihoods for communities depending on wildlife for their food security and livelihoods (FAO *et al*., 2020a).

Additional infection prevention strategies include animal welfare measures – because stress can negatively impact on immunity and viral shedding – and vaccination, which is severely underutilized, particularly in LMICs. FAO ethnographic research with livestock producers has revealed that vaccines are commonly viewed as an unnecessary luxury unless there is a serious and active local outbreak, or they are viewed as ineffective because of anecdotal experience based on problematical vaccine scheduling or dosing. Such obstacles to good management practices need to be addressed through expert- and community-led awareness and behaviour change initiatives to help tackle rising global vaccine hesitancy. There is also an urgent need to boost investment in research and development to build out the vaccine pipelines for combatting endemic zoonotic diseases and the emergence of novel pathogens. Promoting the prudent use of antimicrobials for livestock production will further help to prolong the lifespan of critically important drugs for use by animals and humans alike. Advances in immunization infrastructure for the rollout of COVID-19 vaccines might also be used to help distribute priority vaccines for animals against infectious diseases such as peste des petits ruminants (PPR).

Previous epidemics have demonstrated that a disruption to the health of livestock systems, including a lack of access to veterinary services and input supplies such as vaccines and medicines; delays in disease reporting, diagnosis and early warning; and failure of early response, have resulted in an advanced spread of disease. All of these domains represent priority areas for action.

Becoming more climate-resilient

The impacts of climate change are already evident worldwide: floods, drought, severe storms, temperature extremes, fires. These extreme events are impacting food systems, especially those serving the most vulnerable. While halting and ultimately reversing climate change is a top priority, there are many immediate opportunities to make food systems more resilient to climate change, and to strengthen the role of livestock in this endeavour. Buffering against climatic shocks and other crises is one of the important roles that livestock can play.

Priority actions

1. Strengthen resilience in livestock systems by reversing land degradation, protecting water resources, and better integrating crop, tree, and livestock systems.
2. Nurture, protect, and utilize genetic diversity across all livestock systems to maximize adaptive potential.
3. Improve preparedness for climate shocks – such as early warning systems, animal health services and capacity to maintain emergency feed stocks – and strengthen coping mechanisms such as access to blended finance, insurance against forage-scarcity and price monitoring systems linked to accessible markets in times of crisis.
4. Take advantage of the inherent mobility of livestock to adapt to climate and resource variability, by facilitating a relocation of systems to areas with more favourable climatic conditions.
5. Adapt livestock systems to protect against unfavourable climatic conditions for example improving access to shade, water, feed, or controlled conditions.
6. Diversify sources of protein, including innovations for alternative protein production pathways that are less directly impacted by climate destabilization.

Livestock systems have inherent resilience against variable and changing climates – many having evolved specifically to cope with climatic variability – and much can be done to enhance this. Mixed crop- and tree-livestock systems are the backbone of agriculture in most settings, providing food security and livelihood options for hundreds of millions of people. The interactions between crops, trees, and livestock can be managed to contribute to environmentally sustainable intensification, diversification, and risk management. There is a growing literature on the buffering capacity of mixed and diverse systems but making the most of this potential will require knowledge transfer and extension, as mixed systems can be complex to manage. The resilience of mixed systems can be strengthened by protecting water resources and biodiversity, and by better sequestering soil organic carbon through practices such as grassland management, restorative grazing, and silvo-pastoralism.

Locally-adapted animal breeds are reservoirs of genetic and phenotypic diversity because of ongoing exposure to highly variable conditions and corresponding selection pressures. This diversity is essential for maintaining the adaptive potential of livestock species in order to protect productivity and economic growth in the face of environmental changes, new or resurgent diseases, and changing market preferences. Pastoral systems, for example, are a helpful counterbalance to systems encompassing fewer breeds with less diversity in order to boost livestock resilience globally. More can be done to characterise local livestock breeds to enable environmental suitability matching – as has been done for many crops – introducing different breeds in different places with better heat tolerance or disease resistance for example. There are also opportunities to build on genetic traits conferring resilience in situ by improving the productivity of locally adapted breeds.

As climate continues to change and becomes more variable – triggering more frequent and more extreme events – strong preparedness and resilience mechanisms must protect livestock's contribution to food systems globally. This is particularly important for the most vulnerable groups. Livestock systems can be better prepared for climate-related shocks by investing in early warning systems, strengthening animal health services, improving access to feed and water, and increasing emergency feed and medicine stocks. Healthy, well-fed animals are far better able to cope with climate-related shocks. As well as being better prepared to take early action, further measures are needed to boost capacity to cope with shocks. Insurance against forage-scarcity can be achieved through index-linked insurance schemes, where the conditions leading to forage scarcity are monitored – usually through remote sensing – and, at a certain threshold, trigger payments to be made. Systems to monitor market prices can take advantage of digital technology and mobile networks to alert livestock producers of changing market values and costs of inputs such as feed. Such systems need to be coupled with mechanisms that enable rapid access to markets so that animals can be sold in a timely manner and at fair prices before they lose condition, become sick, or die.

Livestock systems are also inherently more adaptable to changing climate than crop-based systems given mobility, as opposed to being rooted in the ground. Therefore, livestock may play an increasingly important role in some areas relative to plant-based production (Thornton and Herrero, 2015). While opportunities

may exist for some households to take advantage of more conducive rangeland and cropping conditions, such changes will pose serious challenges for other households. Capitalizing on livestock mobility more strategically in times of increasing variability can happen at a number of levels. Pastoralists use livestock mobility to overcome local variability in fodder distribution. This capacity can be enhanced by ensuring that traditional transhumant routes remain open, for example, and that movements are not restricted. On a larger scale, livestock producers may also be incentivized to relocate or start-up in areas where prevailing conditions for forage, feed, and livestock production are more environmentally favourable, and where there is lower climate risk and disease pressure.

Livestock systems are also highly adaptable, meaning that in certain circumstances they can be adapted to protect against unfavourable climatic conditions. Even in grazing systems, access to shade, water, or supplementary feed, can be improved. In the more intensive systems sometimes used for dairy, beef, pigs and poultry, conditions can be increasingly controlled to protect against adverse climatic conditions. In all of these contexts, however, it is important that environmental burdens are not simply shifted through virtual resources use, where commodities consumed in one location are produced using resources from another. Investing in providing inputs from afar or in controlling conditions in the production environment will need to be carefully weighed up against increased production costs, possible energy use, and impacts on the farm, environment, and elsewhere.

In some circumstances, it may be appropriate to invest in innovations for producing animal-source foods and alternative protein sources that are less vulnerable to climate disruption because of more stable climatic conditions or because production occurs in controlled environments. This may mean a shift towards protein-rich foods that can readily be produced in controlled environments, including aquaculture, while managing trade-offs such as increasing disease pressure with increasing animal densities. In such situations, the energy needed to control the production environment can be sought from renewables such as solar, wind, or biogas. Other options are also being explored such as alternative protein sources to meat, milk, and eggs. There are considerable investments being made in this area, and there is a precedent for cultured meat already approved for human consumption, but we are a long way off from this becoming a large-scale practice, and the potential environmental, societal, and public health trade-offs are not yet adequately understood.

Contributing to climate change mitigation

Livestock systems contribute nearly 15 percent of anthropogenic greenhouse gas (GHG) emissions and commitments to the Paris Agreement cannot be met without ambitious action across all livestock systems (Gerber *et al.*, 2013; UNFCCC, 2015). There are many actions that can be taken to reduce emissions but the suitability of different approaches depends on the specifics of the livestock system. Blended approaches are likely to be more effective and sustainable.

Priority actions

1. Boost efficiency in livestock systems to optimize production relative to greenhouse gas emissions.
2. Minimize waste and losses by boosting recycling efforts, including manure management, for a circular bioeconomy.
3. Capitalize on nature-based solutions to ramp up carbon offsets. Reversing land degradation and forest encroachment for pasture and feed production are high priorities.
4. Promote low-carbon protein sources including accounting for protein alternatives to feed people and livestock whilst striving towards healthy diets for all.
5. Develop innovative behaviour changing initiatives to overcome polarization and engage stakeholders in community-led transformation that is practical and sustainable.

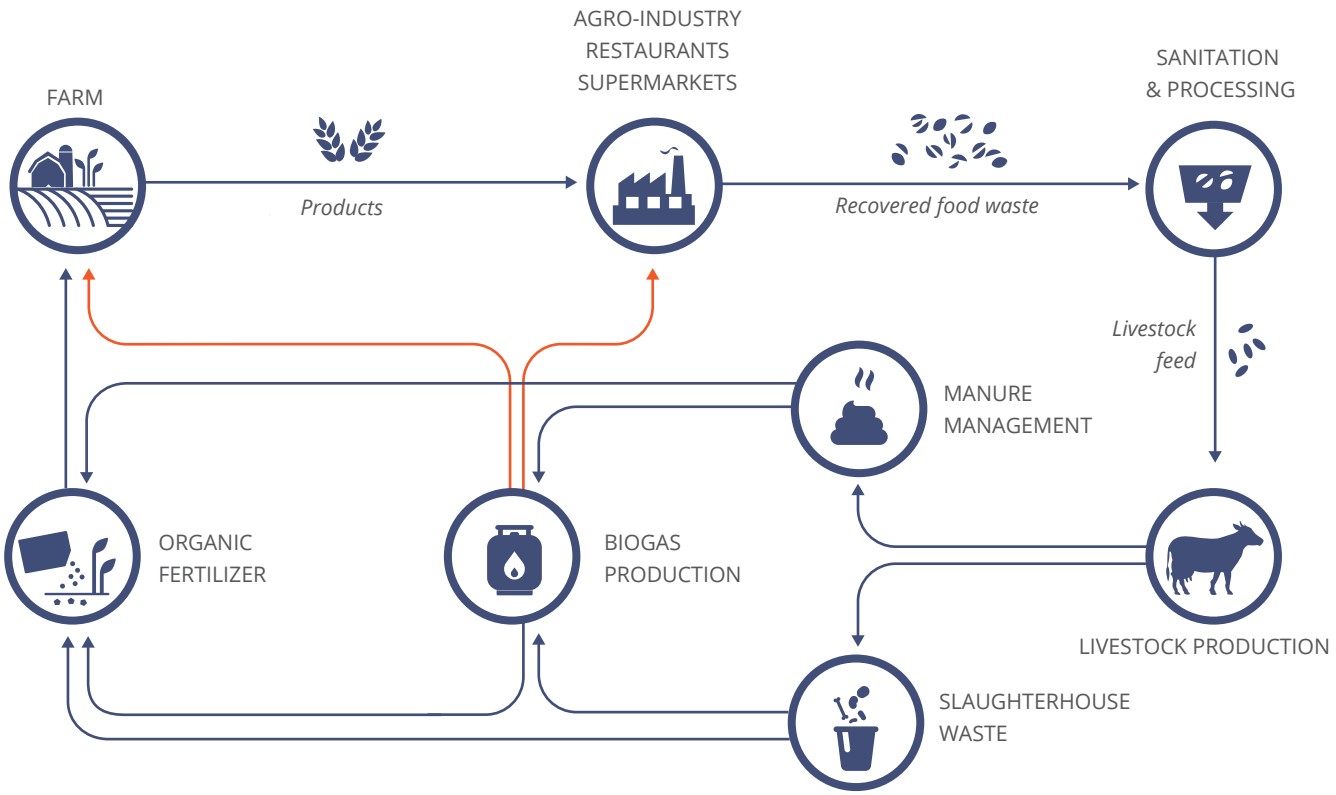
Within-system comparisons reveal large variations in GHG emissions intensities – emissions relative to the amount of animal-source food produced – so there is considerable scope for improving efficiency through broader adoption of best practices. The variability of emission intensities is greatest for ruminant species, which also generally have higher average emission intensities, but ruminants can be raised largely on land that cannot be used to produce crops (FAO, 2019b). Whilst much of this variability is due to prevailing agroecological conditions, a considerable proportion is due to differences in management practices that could be improved through various forms of intensification or innovations. In many parts of the world, improved organizational strategies and technological innovations – such as improved feeding, genetics, animal health, general husbandry, and information technology – are driving up productivity, making resource use more efficient with potential to reduce GHG emissions per unit of product.

Intensification also needs to be sustainable – avoiding negative impacts on other sustainable development objectives, particularly in relation to food and nutrition security, livelihoods, public health, animal health and welfare, and protecting other aspects of the environment.

Food systems rely on natural resources as primary inputs. There are key recycling and loss reduction mechanisms available that can be more widely implemented, and there is ample opportunity for innovations in resource re-use efficiency. Promoting a "circular bioeconomy" – as opposed to a linear process of extraction, production, use and disposal – involves recycling resources at every possible step in the systems, as well as "closing systems" to minimize the loss of resources and nutrients. Increased circularity in food systems – where waste from one process becomes a resource input for another – offers ways to increase the efficiency of food production. Globally, around 14 percent of food produced is lost between harvest and retail (FAO, 2019c) and further significant quantities are wasted at retail and consumption levels. A first priority to tackle both hunger and GHG emissions, and to enhance nutrient use efficiency, is to cut food waste and losses as far as possible in livestock systems. Food that would otherwise be lost or wasted can be put to better use. Food waste from restaurants and supermarkets or second grade grains can be valuable sources of livestock feed, as long as appropriate measures are taken to ensure feed safety. While there are considerable differences in recycling practices within and between countries, large amounts of potential feed, such as crop residues, food waste and loss, and agro-industrial by-products, are often unused when instead these could be fed to animals (Figure 2).

The Agriculture, Forestry and Other Land Use (AFOLU) sector differs from others, such as energy or transport, in that it removes carbon from the atmosphere and sequesters it, as well as emitting it. This uniquely positions the sector to offset its own emissions directly. Livestock is one component of AFOLU but is difficult to consider in isolation from the wider sector because of the many interactions and interdependencies across AFOLU components. For instance, 30 percent of all crops are grown to feed livestock (Mottet *et al.*, 2017) and most livestock are raised in combination with plants, including crop-livestock and silvo-pastoral systems. Ties between production systems have become increasingly severed in the processes of intensification, with livestock operations concentrating in areas with limited cropland on which to apply manure. However, net emissions can be further reduced by re-integrating livestock and crop (or tree) production for better recycling of nutrients. At present, only 62 percent of nitrogen in manure is returned to cropland and grassland in a useful way, globally.

Figure 2. Some of the recycling opportunities available in livestock systems towards creating a circular bioeconomy.



Note: Food recovered from waste streams in the retail, catering, agrifood and biofuel industries can be sanitized and converted into high-value, nutritious feed. The manure from livestock, and the waste from slaughterhouses, can be recycled first as biogas (and used to help fuel the agrifood industry), and then converted into organic fertilizer that can in turn be applied back to crops. Carbon savings are made at all stages of the recycling. In this scenario, improvements in manure management and adoption of lower carbon energy sources could help reduce greenhouse gas emissions by up to 25 percent and provide more than 2 million tonnes of CO_2 eq. savings from biogas production (FAO, 2013b). Feeding food waste to livestock in this way can also improve nitrogen use efficiency (and reduce nitrogen losses in feed and animal production), reduce N_2O emissions, and could release millions of hectares of agricultural land currently dedicated to feed production (Uwizeye *et al*., 2019).
Source: FAO, 2019b.

Given that agriculture is the largest direct driver of deforestation globally, accounting for 73 percent of tropical deforestation (Noriko *et al.*, 2012), halting expansion into forests for feed production and pasture is also an urgent priority and remains one of the most effective ways for livestock systems to contribute to climate change mitigation (FAO, 2020l). Vast quantities of carbon are sequestered in arable land used to produce feed, and in grazing lands on which ruminant livestock are raised. However, much carbon is unnecessarily lost from cropland and a large proportion of the world's rangelands are degraded and could capture far more carbon in soil organic matter, if restored. Regenerative forms of grazing provide much needed carbon offsets. The introduction of trees in tropical pastures on previously forested land (silvo-pastoralism) helps to stabilize productivity and generate many social, economic and environmental benefits. Regenerative grazing also contributes to improved biodiversity and water efficiency, as well as making the land more resilient to a changing and more variable climate.

Another opportunity for creating offsets is the generation of renewable energy on livestock farms. This includes using manure and other waste to generate biogas, prior to recycling as a source of nutrient replenishment, that can offset the use of energy-intensive synthetic fertilizers. There is also scope for more widespread use of the land and buildings linked to livestock farms to install solar and wind power facilities. The economics of such offsets would need to be made favourable to livestock keepers, and appropriate carbon-accounting mechanisms put in place, for the resulting emission savings to be offset against those produced by livestock.

While some segments of society are under-nourished and others over-consume, there must be a convergence on healthy, nutritious diets for all while reducing the overall contribution of livestock to GHG emissions in order to meet the 2030 Agenda for Sustainable Development. With heightened awareness, there is growing consumer interest in lower-emitting animal-source foods, such as poultry meat, and eggs, as well as aquaculture and plant-based alternative protein sources. Consumer demand drives rapid innovation, and these growing trends represent unique opportunities for non-conventional food systems. Cellular cultures, where animal proteins and whole cells are generated in bioreactors, are being rapidly developed. While it may be some time before replica meat cuts are routinely made in this way, protein

supplements, and alternatives to powdered milk, powdered eggs, and ground meat for the food industry are already on the horizon. The search for alternative protein sources is perhaps having even greater impacts in the domain of livestock feed. Biotechnological innovations are revolutionizing the way that protein can be produced and used for feeding livestock. This includes established practices like the application of synthetic amino acids, as well as newer approaches involving algal, fungal and microbial protein replacing conventional feed protein such as soy, as well as the use of insects. Some feed additives, such as seaweed, have shown considerable potential to reduce enteric methane emissions, but need to be made more widely available to farmers. As new products cross regulatory hurdles and enter the market, there will be a clear need for proper accounting to help chart the way forward for the continually evolving food system vis-à-vis health (including nutrition and food safety), food security, livelihoods, climate and other environmental goals.

Success in mitigating climate change by greening livestock systems (and other sectors) also depends on stakeholder acceptance of the science documenting these challenges and evaluating solutions. Wider implementation of social science approaches will help to overcome a growing polarization of views regarding climate solutions and animal welfare concerns. Further research can uncover key obstacles to acceptance of new initiatives, the dominant values of target stakeholder groups that may be used to better frame and target appeals, and priority entry points for stakeholder participation as early as possible in developing policies, incentives, and enforcement programmes. Together, these measures can trigger behavioural change through community-supported and community-led initiatives.

FAO in action on COVID-19 and climate change

FAO has a network on the ground in more than 150 countries. As a comparative advantage, FAO integrates diverse expertise in animal health, welfare, and livestock production; surveillance; food and feed safety; genetic resources; natural resource management and climate; forest degradation and restoration; risk communication and behaviour change; infodemic management; and support for regulatory frameworks, standards, target-setting, setting, policy approaches, multi-stakeholder engagement, and bottom-up processes of collective action.

Under new leadership, FAO is focusing its strategic framework on the four "betters": better production (prosperity); better nutrition (food); better environment (planet); and better lives (people). Tackling pandemics and climate change – ensuring a recovery that is greener, safer, and more equitable – is central to the Organization's remit. FAO's COVID-19 response and recovery programme (FAO, 2020i, 2020m, 2020n, 2020o, 2020p) – Transforming Our Food Future – has seven key elements:

1. Data for decision-making – ensuring quality data and analysis for effective policy support to food systems and zero hunger;
2. Economic inclusion and social protection to reduce poverty – COVID-19 responses for an inclusive post-pandemic economic recovery;
3. Trade and food safety standards – facilitating and accelerating food and agricultural trade during COVID-19 and beyond;
4. Boosting smallholder resilience for recovery – protecting the most vulnerable, promoting economic recovery, and enhancing risk management capacities;
5. Preventing the next zoonotic pandemic – strengthening and extending the One Health approach to avert animal-origin pandemics;
6. Food systems transformation – building back better during response and recovery;
7. Global humanitarian response plan – addressing the impacts of COVID-19 and safeguarding livelihoods in food-crisis contexts.

FAO is calling for joint global action in the form of a "Food Coalition". This will be a multi-stakeholder, multi-sectoral mechanism to support the activation of the response and recovery programme. This coalition will mobilize resources, expertise and innovation, creating a network of networks; advocate for a COVID-19 response; and promote dialogue and exchange of knowledge and expertise. Countries have already expressed interest in becoming active partners.

FAO is working closely with the World Organisation for Animal Health (OIE) and the World Health Organization (WHO) in a Tripartite initiative for One Health, and this collaborative approach extends to other partners, reference centres, academic institutions, and regional working groups for a coordinated global response to health threats, including AMR. FAO's work on zoonotic diseases is also wide ranging. FAO contributes to the SWM Programme partnership, which aims to preserve wildlife and ecosystems, whilst at the same time improving the food security and livelihoods of the people who depend on these resources, at project sites in Africa, Asia and Latin America. Based on the recommendations in this SWM White Paper (FAO *et al*., 2020a), the Programme has also begun to explore the origins of spillover of disease from wildlife to humans and why these zoonotic disease outbreaks can spread to become epidemics and pandemics, such as in the case of COVID-19. The Programme will also investigate what can be done to prevent, detect, and respond to future spillover events, FAO, in collaboration with partners, including OIE, WHO, and the International Atomic Energy Agency (IAEA), is also championing global and regional animal health programmes and strategies for priority animal diseases (FAO, 2020q).

FAO plays an essential role in supporting governments, producers, traders, and other stakeholder groups to use antimicrobials responsibly to keep antimicrobials working and to protect food and agriculture sectors from the harms of antimicrobial resistance (UN, 2019). This includes tools such as the Progressive Management Pathway for AMR (FAO PMP AMR; FAO, 2020r) to support countries in identifying actions needed for step-by-step improvements in AMR control, and the Assessment Tool for Laboratories and AMR Surveillance System (FAO ATLASS; FAO, 2020s) to assist countries in assessing their national surveillance systems and laboratory diagnostic capacity for AMR detection.

The Organization also hosts the Secretariat of the Codex Alimentarius Commission (CAC), the Commission on Genetic Resources for Food and Agriculture (CGRFA), and the International Plant Protection Convention (IPPC), supporting the work of these standard setting organizations by providing them with scientific advice and assisting in the implementation of standards through support to countries.

FAO's work on mainstreaming climate change mitigation into livestock systems spans five main categories:

1. Developing tools, methodologies, and protocols to measure emissions, as well as developing and assessing technical and policy options (FAO, 2020t, 2020u, 2020v). FAO's Global Livestock Environmental Assessment Model (GLEAM; FAO, 2020w), for example, provides a tool to assess the lifecycle emissions from livestock systems and is increasingly being used by countries to build emission inventories and to estimate the potential gains from different mitigation approaches. The Livestock Environmental Assessment and Performance (LEAP) Partnership (FAO, 2020x) is a multi-stakeholder initiative that seeks to improve the environmental sustainability of the livestock sector through harmonized assessment methods, metrics, and data.
2. Strengthening the knowledge and evidence base by developing baselines, assessments, and projections of emissions. Using the tools and approaches above, FAO provides information resources, technical documents, and policy briefs (e.g., FAO, 2020q) to guide and inform analysis and decision-making in relation to livestock and climate change. For example, briefs such as the present document and the 2018 brief on *Shaping the future of livestock* (FAO, 2018) have been developed for GFFA and briefs have been developed in support of the UNFCCC Conference of Parties (COP), such as the recent *Five practical actions towards low carbon livestock* (FAO, 2019b). In the context of UNFCCC, FAO is also supporting the Koronivia Joint Work on Agriculture, in the forms of briefs, webinars, tools, and technical support for Koronivia workshops and submissions to the UNFCCC Secretariat on specific topics (FAO, 2020y).
3. Piloting and validating technical and policy options through projects, and support for up-scaling and investments. FAO and partners work with countries on specific projects to pilot, validate, and scale technical options for adaptation and mitigation in livestock systems, also helping countries gain access to climate finance. A fundamental component of engagement in building capacity to establishing baselines, develop adaptation and mitigation plans, and in measuring, reporting and verification (MRV) of progress towards Paris Agreement commitments. In building country capacities, FAO partners with numerous technical and donor agencies, such as the Climate and Clean Air Coalition (CCAC), the Global Research Alliance for Agricultural Greenhouse Gases (GRA), the Global Environment Facility (GEF), the Adaptation Fund (AF), and the Green Climate Fund (GCF). FAO is also supporting low carbon and resilient livestock investments by providing tools and capacity development for International Funding Institutions (IFIs), such as the World Bank, the International Fund for Agricultural Development (IFAD), the International Financing Corporation (IFC), and the European Bank for Reconstruction and Development (EBRD), as well as for national development banks that report on the impact of their investments and are looking to green their livestock portfolio.
4. Convening of inter-governmental and multi-stakeholder partnerships for better integration of sustainability objectives. FAO has two key streams of discussion and engagement. First is through intergovernmental bodies such as the Committee on Agriculture (COAG), which has established a new sub-committee on livestock. FAO also contributes substantially to other intergovernmental bodies relevant to livestock systems such as the GFFA, the Commission on Livestock Development for Latin America and the Caribbean (CODEGALAC), and the Commission on Genetic Resources for Food and Agriculture (CGRFA) with its Intergovernmental Technical Working Group on Animal Genetic Resources. The second stream is through multi-stakeholder groupings, such as the Global Agenda for Sustainable Livestock (GASL; FAO, 2020z); the LEAP Partnership and the Global Soil Partnership (GSP; FAO, 2020aa), whose secretariats are hosted by FAO. These multi-stakeholder partnerships unite the public and private sectors, producers, research and academic institutions, NGOs, foundations, and community-based organizations through social movements to build consensus around issues of sustainability.
5. FAO is promoting an holistic approach considering the four dimensions of food security and nutrition: availability, access, use and utilization, and stability. This integrated approach enhances the effectiveness of actions undertaken to manage climate change by addressing the linked challenges of food security and One Health at the same time. An implication of this approach is the pursuit of "no-regret options", such as the promotion of resilient and healthy animals, which are better adapted to climate shocks and in turn contribute to mitigation of GHG emissions. This warrants coordination across sectors to enhance the effectiveness of climate change initiatives by simultaneously tackling the interlinked challenges of livestock. An example of FAO's approach is the Reducing Emissions from Deforestation and Forest Degradation (REDD+) Programme (FAO, 2020l).

FAO is committed to assisting Member States working towards low-carbon livestock, prudent antimicrobial use, enhanced surveillance, and recovering from the COVID-19 pandemic as part of achieving the 2030 Agenda for Sustainable Development and meeting the Paris Agreement targets, ensuring a recovery that is greener, safer, and more equitable.

Policy approaches

The accelerating threats of infectious disease outbreaks and climate destabilization are triggering a reconfiguration of livestock systems. This process of reconfiguration is an opportunity for addressing current vulnerabilities to better mitigate these threats and boost resilience to them. FAO's new strategic framework focuses on "accelerators" of change, including technology, innovation, data, and the strengthening of governance, human capital, and institutions. Policy and institutional measures are needed to implement the priority action areas listed above, and to drive transformation in livestock systems towards a vision of global health and prosperity (see Appendix for examples of policy approaches).

Policy approaches may be aimed at reducing risk and neutralizing threats, maximizing benefits, and exploration of alternatives as part of a broader movement to continually adapt food systems to changing conditions. Policy mechanisms may range widely from direct legal and regulatory interventions ("command-and-control"), as well as standard-setting practices, to financial instruments (e.g., pricing, taxes, tax waivers, subsidies, loan guarantees, and other incentives) and investments in infrastructure, research for development and capacity building. Together, such a range of approaches can discourage high-risk practices while incentivizing innovations for the adoption of greener, safer, and more equitable practices, thus creating an enabling environment to encourage transformation and help reduce stakeholder risk.

Regulations are already in place for animal health, welfare, production, breeding, and management of animal genetic resources, as well as for environmental pollution and food safety in many countries. Similar approaches could be introduced for reducing livestock-related GHG emissions and other environmental impacts, and for practices that specifically reduce risk of pathogen emergence and spread. In addition to legal considerations for a safe and secure food supply (FAO, 2020ab), soft law, in the form of normative guidance, can also be effective and quicker to implement.

"Pull incentives may help to generate market demand in support of shifts towards best practices. Governments, regulatory bodies, professional societies, and co-operatives can respond to consumer pressure on markets by developing and implementing certification schemes that recognise commodities that are produced in green, safe and equitable ways. This would entail benchmarking, monitoring, and evaluation to deter problematic practices and incentivize those that will help countries meet agreed targets. Subsidies counterproductive to meeting health, welfare, and environmental objectives can be replaced with cross-compliance regulation, under which conditions direct payments can be made to farmers and other food system stakeholders for reducing greenhouse gas (GHG) emissions and adopting good practices, including a suite of infection prevention and control measures. Incentives and market-based approaches, incorporating consumer concerns depend on reliable certification schemes for farms and other food system components, with rigorous traceability and appropriate labelling systems for livestock commodities at the point of sale.

It may be argued that the prices of livestock, and indeed all agricultural commodities could also be allowed to better reflect the "costs" of externalities (FAO, 2019b), such as GHG emissions, non-prudent use of antimicrobials, and other high-risk practices for which there is evidence of their role in the emergence and spread of pathogens.

Protecting global public goods such as an hospitable environment and public health will depend on both "top-down" public policy interventions and enforcement mechanisms as well as support for "bottom-up" community-led initiatives. Stakeholder assessments, including vulnerability and risk assessments, and building awareness are key to bringing about sustainable change in practices. Policies are also needed to ramp up research and development efforts in support of biosafe farming practices and low-carbon livestock.

Whichever combinations of technical and policy interventions are proposed, special attention must be paid to impacts on prices for livestock commodities – whether they arise from efficiency gains, low-cost alternatives, subsidized production or taxation – to guard against unintended consequences for livestock and other associated sectors.

Certain similarities between the disruptive effects of pandemics and climate change suggest that some interventions may simultaneously target challenges relevant to both of these stressors, pointing towards a common, coordinated approach in some areas. This is further borne out in the priority actions identified in the above sections and by examples of policy approaches provided in the Appendix. There are areas for integrative action towards prevention and preparedness for pandemics and climate change. Policies supporting such collective benefits may yield stronger outcomes and faster results and should be prioritised. Integrating climate and pandemic actions and mainstreaming these approaches into existing programmes for achieving the SDGs will also support greater resource use efficiency and broader impacts.

Call to action

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COVID-19 may be considered a reckoning as well as a call to action to immediately create and update national preparedness and response plans for pandemics, climate shocks, and other large-scale disruptions in livestock systems. Such preparations are vital towards ongoing transformation for safer, greener, and more equitable agriculture to sustainably feed the world.

FAO has the technical expertise to support the development and implementation of such plans to ensure that every Member State has risk mitigation measures and contingencies for maintaining food production and open and safe trade corridors in the event of a disaster or outbreak. FAO will host the International Platform for Digital Food and Agriculture as a means to further accelerate digital solutions for future-proofing livestock systems.

Livestock systems are highly diverse and complex, deal with living animals, and involve large numbers of stakeholders from different backgrounds and sectors worldwide. As such, livestock systems have the potential to model practical and sustainable transformation of food and agricultural systems. The pandemic has shown that stakeholders can come together in a crisis but too often these collaborations are not fully institutionalized and often discontinue after an emergency transition to the recovery and response period. The same applies to management approaches that provide valuable ecosystem services, such as grassland restoration and soil carbon sequestration with livestock systems. Evidence-based approaches and stakeholder engagement need to be up-scaled.

COVID-19 has reminded us how we are all intrinsically linked in an increasingly connected world. It has also drawn the focus away from human-caused climate change, which remains a global challenge of massive scale. COVID-19 has created an opportunity to possibly reverse the climate crisis as emissions dropped by 7 percent in 2020, according to latest number from the Global Carbon Project (Global Carbon Project, 2020). The aim to limit global temperature rise to 1.5 °C from pre-industrial levels had looked well beyond our grasp until the pandemic forced humanity to pause. Experts are calling this an historic tipping point and livestock systems can play a crucial role in guiding humanity towards a more prosperous and healthy future. This may include investing now in low-carbon livestock systems, towards future net-zero emission commitments.

Investing in the transformation of livestock systems can harness opportunities for innovation for achieving safer, greener, and more equitable development. The sooner we transform our food systems, the greater chance we have to secure a prosperous future with healthy diets for all in this lifetime and for generations to come.

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FAO Animal Health and Production http://www.fao.org/agriculture/animal-production-and-health

FAO antimicrobial resistance http://www.fao.org/antimicrobial-resistance

FAO climate change http://www.fao.org/climate-change

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Global Agenda for Sustainable Livestock (GASL) http://www.livestockdialogue.org

FAO Koronivia http://www.fao.org/climate-change/our-work/what-we-do/koronivia

FAO LEAP http://www.fao.org/partnerships/leap

FAO One Health http://www.fao.org/one-health

FAO Pastoralist Knowledge Hub http://www.fao.org/pastoralist-knowledge-hub

FAO REDD+ Reducing Emissions from Deforestation and Forest Degradation http://www.fao.org/redd

IMF Consumer Prices https://data.imf.org/?sk=4FFB52B2-3653-409A-B471-D47B46D904B5

IFPRI COVID-19 https://www.ifpri.org/covid-19

OIE COVID-19 https://www.oie.int/en/scientific-expertise/specific-information-and-recommendations/questions-and-answers-on-2019novel-coronavirus/

Sustainable Wildlife Management Programme Portal https://www.swm-programme.info

WFP data visualization https://dataviz.vam.wfp.org/

World Bank commodity prices https://www.worldbank.org/en/research/commodity-markets

Appendix

Examples of policy objectives for tackling pandemics and/or climate change to boost resilience and sustainability of livestock systems. Considerations for implementation with respect to risk reduction, benefits, and exploration of alternative options are also noted where helpful. Identifying trade-offs and synergies as part of feasibility and impact assessments will help to develop prevention, preparedness and response plans for livestock systems at the level of businesses, systems, countries, and regions. Policy objectives appear in the order of sections above answering the four GFFA questions and are grouped thematically.

Policy objectives	Pandemics	Climate disasters	Considerations for implementation
Develop and enhance preparedness and response plans for livestock systems.	✓	✓	These plans will enhance the resilience of livestock systems and would benefit from including the following: clarification of streamlined decision hierarchies for rapid response and advance forecasting and simulation exercises.
Engage livestock system stakeholders and civil society in infodemic management and behaviour change initiatives.	✓	✓	As part of wider efforts for preparedness and response planning, livestock operators can train personnel for infodemic management, risk- and crisis-communication; and community outreach. The success of stakeholder engagement largely depends on trust building exercises that need to begin well in advance of a crisis. This will help build community capacity for accessing expert guidance, managing misinformation, and promoting the acceptance and widespread use of vaccines, as well as prudent antimicrobial use, and other good practices for infection prevention and control and responses to climate disasters. This will also help to promote rational purchasing decisions and support for livestock systems. Participatory approaches from the earliest stages of policy development are also likely to yield better results.
Maintain safe and open trade corridors.	✓	✓	This will help to ensure adequate food distribution in the event of an emergency. This may include special provisions for carefully regulated travel of essential workers for livestock systems (i.e., with appropriate testing and tracing).
Invest in local livestock systems.	✓	✓	Developing local livestock systems, including training local workers, will help to provide a safety net in the event of travel and transport disruptions to international trade and personnel movements.
Diversify supply chains.	✓	✓	This will help to reduce risk and may include norm-setting, legal, and regulatory frameworks to help balance economies of scale and vertical integration against risk through support for a larger number of different/smaller operators, as well as access to tax waivers and subsidies to assist smallholder farmers and smaller-scale operators in securing market access and building resilient businesses. Ensuring a basic standard of living for all can further help to reduce risk and encourage more actors to enter into agrifood sectors, including livestock systems.
Classify operators in livestock systems as essential workers.	✓		Maintaining food production depends on ensuring that livestock operators have sufficient access to PPE and health interventions such as testing and vaccines. Providing regulatory frameworks, enforcement mechanisms, and incentives for companies to improve operating procedures and conditions will help reduce risk of exposure to potential pathogens.
Accelerate innovation for automated processes in livestock systems to reduce contact at the human-animal-environment interface.	✓		This will help to reduce the potential for inter-species transmission of pathogens in capital-intensive systems. Increasing automation will need to be balanced by new training and employment opportunities for actors in the livestock sector.
Boost cold chain capacity.	✓	✓	Cold chain storage capacity for animal-source foods is important in emergencies to reduce food loss and food waste. This may include re-distribution mechanisms so that foods from restaurants could be redirected to consumers (with appropriate food safety provisions in place), for example. Separately, better cold chain storage is needed for maintaining the integrity of veterinary medicines and vaccines to help prevent and manage outbreaks of zoonotic diseases.
Create earmarked emergency funds in advance of a crisis.	✓	✓	This will help to rapidly address cashflow issues and enable livestock system operators to maintain food production and distribution in an emergency.

Policy objectives	Pandemics	Climate disasters	Considerations for implementation
Producer support programs to help boost market competitiveness and risk mitigation schemes.	✓	✓	This will help to protect smaller, less efficient producers from poverty. Implementation may include insurance and subsidy schemes.
Target financial support to micro, small-, and medium-enterprises (MSMEs).	✓	✓	This will help protect the most vulnerable operators in livestock systems. Such support may include: guaranteeing loans for affordable interest rates; offering additional liquidity to existing clients in need of working capital financing; deploying specific COVID-19 or climate-event windows, with targeted technical assistance to attract potential investors or philanthropies willing to support SDG-aligned agrifood companies as well as those that are willing to transition towards more sustainable models; and enhancing cooperation with development finance institutions (DFIs), donors, funds, and banks (FAO, 2020ac; Global Environment Facility, 2019).
Support innovation for digital solutions.	✓	✓	Digital innovations may include e-commerce platforms to ensure wholesalers, sellers, and producers may connect directly to consumers and service providers for vulnerable people. This is particularly important in the event of disruptions to food chains for the rapid redistribution of foods and animal products to reduce loss and waste.
Strengthen regulatory and food safety mechanisms.	✓		Such measures must keep pace with burgeoning e-commerce options and international trade. Implementation may include legal frameworks and enforcement mechanisms to address food safety violations and food fraud.
Support observance of international standards.	✓		The Codex Alimentarius Commission work is ongoing to ensure food safety and efficient trade mechanisms even in the event of large-scale events such as pandemics. This includes for instance the development of electronic certification by the Codex Committee on Food Import and Export Inspection and Certification Systems (CCFICS).
Enhance tracing, certification, and labelling schemes for animal-source foods.	✓	✓	This will enable retailers and consumers to make informed purchasing decisions and support food safety measures, as well as reward livestock operators engaging in good practices for pandemic prevention, sustainability, equity, protection of children, and responsible antimicrobial use. Such approaches may rely heavily on digitalization developments using technology such as blockchain to maintain records for tracking and tracing animals and animal-source foods throughout the entire food value chain. These measures present new opportunities for profitability by meeting growing consumer interest in "climate smart" products.
Promote engagement of livestock systems in coordinated One Health initiatives.	✓		This depends on engagement from local to global levels to help mitigate and manage biological threats, and may include stronger coverage of food systems at the human-animal-environment interface in International Health Regulations (WHO, 2020b).
Improve baseline animal health and welfare.	✓	✓	Improvements in all livestock systems and countries will help to reduce the risk of disease and boost production efficiency relative to GHG emissions. This includes investing in stronger infection prevention practices from inputs to farm to table.
Support vulnerable communities in reducing dependency on wildlife trade where appropriate.			Stronger enforcement mechanisms are needed to address illegal wildlife trade. Blanket bans on the trade of wildlife species with corresponding legal, regulatory, and enforcement approaches may be considered a temporary or localised emergency measure where pathogen spillover risks are particularly high. All measures need to account for the contribution of wildlife to food security, culture and livelihoods of Indigenous Peoples and local communities, as well as national economies. Risk versus benefit assessments are needed to inform the development of support programmes to help reduce dependencies on wildlife trade (FAO *et al.,* 2020a).
Support Zero Hunger and good nutrition initiatives.	✓		This will help to boost immunity for people and livestock. This may include financial incentives for innovations in animal feed, which may boost productivity as well as immunity.
Strengthen biosecurity, hygiene, sanitation measures.	✓		This will help to reduce risks of emerging biological threats provided that infection prevention and control measures are implemented at all nodes in livestock systems, including on farms and at animal and food markets.
Strengthen surveillance within and across livestock systems.	✓	✓	Surveillance measures need to be connected to early warning systems to enable faster and more effective responses to emerging pathogens and for predicting climate stresses and disasters.
Develop improved risk-based analyses for assessing and controlling pathogens in livestock systems and along the food chain.	✓		This will help to overcome current limitations in visual inspections of animals and animal-source foods.

Policy objectives	Pandemics	Climate disasters	Considerations for implementation
Set sector-specific, local, national, regional, and global targets for AMU.	✓		Target-setting will help to motivate innovations in practice. For targets to be most useful, they are best combined with monitoring mechanisms to track usage in coordination with financial instruments for incentivization and enforcement.
Immediately phase out the routine use of highest-priority critically important antimicrobials.	✓		This will help to protect the efficacy of our most important medicines to ensure that they will work when needed most. Phasing out their routine use in livestock systems may begin with use for prophylactic and growth promotion purposes in livestock production (and for egg boosting and slowing milk spoilage). Implementation may include establishing or strengthening regulations and standards for prudent metaphylaxis under prescription and guidance of certified veterinarians or animal health workers (WHO, 2019; FAO *et al*., 2020d).
Invest in vaccine and antimicrobial research and development.	✓		This will help to build out the pipelines for prevention and treatment of microbial infections that affect livestock productivity, and the health and welfare of animals and people.
Develop ongoing learning opportunities and credentialling schemes.	✓		Ongoing learning opportunities are needed for veterinarians and community animal health workers (CAHWs) to ensure best practices. Investing in training more animal health workers will also help to address the limited access to producers in LMICs. Credentialling schemes can also improve prescription practices to increase emphasis on preventative medicine and appropriate use of antimicrobial drugs.
Support innovation of more rapid, affordable, and portable point-of-care diagnostic tools.	✓		Outbreaks can be prevented or more rapidly controlled if producers are able to get an affordable diagnosis on the farm. The high expense, geographical distance, and long wait times associated with laboratory tests are currently a barrier to many livestock producers in LMICs seeking health expert advice for sick animals, which is needed to provide an effective treatment.
Pricing adjustments to account for externalities.	✓	✓	The cost of agricultural commodities may be adjusted to account for impacts on environment and usage of limited resources.
Enable industry for technological innovations that boost productivity and resource efficiency.		✓	Such innovations may range from more efficient fertilizers, to better genetics, and information technology.
Policies promoting a circular bioeconomy.		✓	This may include benchmarks (with a monitoring and warning system) to motivate reductions in inefficiencies, and incentives for implementing mechanisms that reduce food waste and put it to better use. Implementation examples include tax rebates, grants or subsidies to help with the initial investment, interest-free loans, and infrastructural investments to connect contact points in the cycle.
Support for recycling research and development.		✓	This will support adaptation of value-chains to make more efficient use of wastes, residues and by-products, and fostering cross-sectoral collaboration to close resource loops.
Policies re-integrating livestock and plant (crops and trees) production.		✓	This will help to better recycle nutrients and energy so that global society can make full use of the biomass already generated for environmental and economic benefit. Implementation may include relocation grants and incentives for integrative production practices.
Zero-deforestation commitments from governments and companies, and increased supply chain transparency to reshape forest governance and reduce deforestation.	✓	✓	This will help to protect forests and other wild spaces for reducing exposure to potential pathogen reservoirs such as wildlife and at the same time mitigating climate change. Implementation mechanisms could include legislation against forest encroachment for pasture and feed production and land-tax breaks for silvo-pastoralism, for example.
Incentives and/or subsidies for livestock holders investing in "green" approaches.		✓	Carefully targeted subsidies will incentivize more environmentally helpful practices. Implementation may include subsidies for using manure to generate biogas, installation of solar and wind power facilities, and regenerative grazing for carbon offsets, which can also contribute to improved biodiversity and water efficiency, as well as making the land more resilient to a changing and more variable climate. Such positive externalities can be better recognized through payments for environmental services.
Exploration of alternatives.	✓	✓	Assessments of new alternatives to animal-source foods entering the market from environmental, social, and health perspectives will identify priority pathways for innovations in protein supply. Implementation will depend on enabling policies and incentives for biotechnological innovation for more sustainable food products as part of an expanding food system.

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