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THE ROLE OF SCIENCE, TECHNOLOGY AND INNOVATION FOR TRANSFORMING FOOD SYSTEMS GLOBALLY

by Robin Fears, Claudia Canales

ABSTRACT

Although much progress had been made in past decades, the prospects for food and nutrition security are now deteriorating and the converging crises of climate change and Covid-19 present major risks for nutrition and health, and challenges to the development of sustainable food systems. In 2018, the InterAcademy Partnership published a report on the scientific opportunities and challenges for food and nutrition security and agriculture based on four regional reports by academy networks in Africa, Asia, the Americas and Europe. These analyses and conclusions have now been updated as briefs to the UN Food Systems Summit. The present global brief draws on new evidence from the regions to reaffirm the continuing rapid pace of science, technology and innovation and the need to act urgently worldwide to capitalise on the new opportunities to transform food systems.

We cover issues for sustainable, healthy food systems in terms of the whole food value chain, including consumption and waste, the interconnections between agriculture and natural resources, and the objectives for developing a more balanced food production strategy (for land and sea) to deliver nutritional, social and environmental benefits. Our focus is on science and we discuss a range of transdisciplinary research opportunities that can underpin the UN FSS Action Tracks, inform the introduction of game changers, and provide core resource to stimulate innovation, inform practice and guide policy decisions. Academies of

science, with their strengths of scientific excellence, inclusiveness, diversity and capacity to link between national, regional and global levels, are continuing to support the scientific community in playing a key role to catalyse action. Our recommendations concentrate on priorities for building the science base – including the recognition of the importance of fundamental research – to generate diverse yet equitable solutions in providing sustainable, healthy diets, which are culturally sensitive and attend to the needs of vulnerable populations. We also urge better use of the transdisciplinary science base to advise policy making and suggest that this would be greatly advanced by constituting an international advisory Panel for Food and Nutrition Security with particular emphasis on sustainable food systems.

1. Introduction: The transformation of food systems

The world is not on track to meet Sustainable Development Goal (SDG) targets linked to hunger and food and nutrition security. According to FAO data (FAO, 2020), the number of hungry people has increased by 10% in the past five years and 3 billion people cannot afford a healthy diet. Some countries in Asia and Africa have made significant progress in increasing food and nutrition security alongside reducing poverty in the past decade, but others have not (EIU, 2021). The risks continue to be compounded by the impacts of population growth, urbanisation, climate and other environmental changes, market instability and economic inequality. Furthermore, the Covid-19 pandemic has exacerbated problems and imposed disproportionate effects on the economically vulnerable including marginalised groups in urban areas and smallholder farmers in rural areas (FAO, 2020; EIU, 2021). However, while there are unprecedented challenges, there are also unprecedented opportunities to capitalise on science, technology and innovation to transform food systems.

In 2018, the InterAcademy Partnership (IAP), the global network of more than 140 academies of science, engineering and medicine, published a global report on food and nutrition security and agriculture, drawing on information from four regional reports prepared by academy networks in Africa (NASAC), Asia (AASSA), the Americas (IANAS) and Europe (EASAC) and emphasising the value of taking a transdisciplinary approach. In the present Food Systems Summit Brief, we present an update on some of the issues from that global report linked to the recent assessments made in the Briefs prepared by the regional academy networks for the UN FSS.

The work of the academies has adopted an integrative food systems approach, along the value chain encompassing food processing, transport, retail, consumption and recycling, as well as agricultural production. Moreover, in the transformation of food systems towards economic, social and environmental sustainability, setting agricultural priorities must take account of climate change and pressures on other critical natural resources, particularly, water soil and energy, and the continuing need to avoid further loss in ecosystem biodiversity. Interest worldwide in the sustainability of food systems is accelerating (e.g. Global Panel, 2020; IFPRI, 2020; Food Systems Dashboard, 2020; von Braun et al., 2021).

In this Brief, that covers the opportunities and challenges for food systems in tackling malnutrition in all its forms (undernutrition, micronutrient deficiencies, overweight and obesity), we frame the contribution that science can make to local-global connectiveness of food systems: (i) to strengthen and safeguard international public goods, i.e. those goods and services that have to be provided at a scale that is beyond individual countries or that can be better achieved collectively; (ii) to understand and tackle environmental and institutional risks in an increasingly uncertain world; and (iii) to help to address the SDGs by resolving complexities of evidence-based policies and programmes and their potential conflicts.

2. REGIONAL HETEROGENEITY

Inevitably, in a summary of the global position, it is difficult to capture the diversity within and between regions relating to the challenges for food systems. The regional Briefs by the Academies have indicated the territorial dimension in analysing obstacles to food and nutrition security, emphasising specific contexts for marginalised peoples and smallholder farmers, e.g. for the Hindu Kush Himalayan region (AASSA, 2021). In Africa, although remarkable progress has been made in the last two decades in reducing extreme hunger, there are increasing pressures on food systems that require radical action (discussed in detail in NASAC, 2021). Most African Union member states are not on track to achieving the Comprehensive Africa Agricultural Development Plan goals (African Union, 2020). In the comprehensive publication on country-level data in the Americas that accompanied the regional report on food and nutrition security and agriculture (IANAS, 2017, regional update IANAS, 2021), there was detailed discussion of diversities within the region and of variation in the social determinants of food and nutrition security, e.g. related to gender. Other regional assessment finds moderate-severe food insecurity (SDG Indicator 2.1.2) across the FAO Europe-Central Asia region, varying from 6.7% in the EU to 19% in the Caucasus. Obesity throughout this region is higher than the world average[1], a challenge that has been examined by EASAC (2021).

3. AGRICULTURE-ENVIRONMENT NEXUS

IAP defines the desired outcome for food systems as access for all to a healthy and affordable diet that is environmentally sustainably produced and culturally acceptable. The IAP report in 2018 cautioned that an emphasis on increasing total factor productivity (TFP, the efficiency in use of labour, land, capital and other inputs) is not warranted if such a focus leads to reductions in environmental protection. Since then, there has been continuing interest in using research to leverage TFP for sustainable and resilient farming (e.g. Coomes et al., 2019). In particular, the paradox of productivity has been highlighted (Benton and Bailey, 2019) whereby agricultural productivity may generate food system inefficiency. That is, productivity, when leading to increasing availability of cheaper calories, may help to promote obesity although nutritional content matters as much as calories. Current global competition policies incentivise producers who can produce the most cheaply, typically with environmental damage, including biodiversity loss (Chatham House, 2021). The strategic focus of research and development, as well

[1] FAO, 2020 "Sustainable food systems and healthy diets in Europe and Central Asia." ERC/20/2, on www.fao.org/3/nc226en/nc2262n.pdf. This report discusses multiple issues for diversified and sustainable food systems, improving supply chains and reducing food loss and waste.

as production systems, should shift from staple crops with the current emphasis on production of a narrow range of calorie-intensive staple crops to a balanced strategy for crops that are of more value in terms of nutritional, social and environmental benefits, including fruit, vegetables, seeds, nuts and legumes (as food and feed, NASAC, 2021).

Reform of food systems requires decision makers to recognise the interdependence of supply-side and demand-side (including dietary change and waste reduction) actions. There must be further consideration given to strengthening coherence between global agreements, e.g. on responsible investment, and national action (Chatham House, 2021). And, the continuing food system sustainability challenge to balance production objectives for agricultural exports with satisfying domestic food and nutrition requirements is an issue for some countries (e.g. IANAS, 2021).

Current intensive agricultural production depends heavily on fertilisers, pesticides, energy, land and water with negative consequences for environmental sustainability. Changing environmental conditions and competition for key resources such as land and water provoke violence and conflict, exacerbating the vicious circle of hunger and poverty (NASAC, 2021). Discussion in the NASAC 2021 Policy Brief exemplifies some of the particular issues for managing water demand, including conservation and recycling of waste water and notes the opportunities for science, technology and innovation in new irrigation schemes. Research and innovation play a crucial role in the transformation to sustainable food systems to produce more efficiently by environmentally friendly means. The options for convergence of technological and societal innovation (including outputs from biotechnology, AI, digitalisation, and from social and cognitive sciences), exemplified later in this Brief, help to underpin the objectives for sustainable food systems.

Agro-ecology encompasses various approaches to using nature-based solutions for regenerative agriculture innovation (HLPE 2019) and systems research still needs to help strengthen the evidence base for agro-ecological (nature-based) approaches. For example, agroforestry in sub-Saharan Africa has potential to help tackle health concerns associated with lack of food and nutrition security (non-communicable diseases) and with human migration but requires additional research to characterise any increased risk from infectious disease alongside the beneficial outcomes (Rosenstock et al., 2019).

Developing diverse and resilient production systems worldwide is important in preparing for the likelihood of cumulative threats from extreme weather events by spillover across multiple food sectors on land and sea (Cottrell et al., 2019). In this context, it is relevant to note the interest in the potential of oceans for sustainable economies in addressing food security, biodiversity and climate change. One of the UK Presidency’s core themes for UN FCCC COP26 is “Nature” with objectives for sustainable land use, sustainable and resilient agriculture, and increasing ambition and awareness of the ocean’s potential. This potential is also of great importance for the UN FSS Action Track on nature-positive production. By contrast with difficulties in expanding land-based agriculture, the potential for sustainable production of fish and other seafood is increasingly recognised (Lubchenco et al., 2020; Costello et al., 2020) and brings new possibilities for local livelihoods. Fish supplies provide 19% of animal protein in African diets (Chan et al., 2018, NASAC, 2021). However, currently one-third of the world's marine fish stocks are overfished (FAO, 2020). Realising the potential of the oceans requires technological innovation and policy reform for fishery management and governance, to restore wild fish stocks, eliminate illegal and unregulated fishing, and ensure sustainable mariculture to minimise environmental impacts. Oceans can contribute to climate change mitigation as well as to improved food systems but it is important to be aware of inadvertent consequences of policy action, e.g. adoption of industrial-scale aquaculture can be associated with rapid growth in GHGs (in China, Yuan et al., 2019). Genetic improvement of fish species may help to reduce the environmental footprint of aquaculture (for example, in Africa where aquaculture has been expanding at a faster rate than in some other places, NASAC, 2021). This exemplifies a general point about seeking co-ordinated policy across sectors to avoid unintended effects and negative trade-offs. Another example is provided by poorly-designed land use policies to increase bioenergy production, driving increases in land rent with negative implications for food and nutrition security (Fujimori et al., 2019).

4. DELIVERING HEALTHY DIETS SUSTAINABLY PRODUCED UNDER CLIMATE CHANGE

An accumulating evidence base demonstrates that climate change exacerbates food insecurity in all regions by reducing crop yield and their nutritional content and by posing additional food safety risks from toxins and microbial contamination (e.g. IPCC, 2019; Park et al., 2019; Ray et al., 2019; Watts et al., 2021). Effects are most pronounced in those groups who are already vulnerable, e.g. children, because of reduced nutrient intake (Park et al., 20190 or decline in diet diversity (Niles et al., 2021). A systematic review of the literature identified climate change and violent conflict as the most consistent predictors of child malnutrition (Brown et al., 2020). By increasing the volatility of risks in the global food system, climate change may also reduce the incentive to invest (IAP, 2018), and rising heat- and humidity-induced declines in labour productivity reduce the income of subsistence farmers (Andrews et al., 2018).

Although better international integration of food trade can be a key component of climate change adaptation at the global scale, it requires sensitive implementation to benefit all regions (Janssens et al., 2020): in hunger-affected export-oriented regions, partial trade integration may exacerbate food and nutrition insecurity by increasing exports at the expense of domestic food availability. When assessing trade implications, it is also important to appreciate that climate change presents a risk to global port operations with the greatest risk projected for ports located in the Pacific Islands, Caribbean Sea, Indian Ocean, Arabian Peninsula and the African Mediterranean (Izaguirre et al., 2021).

There are twin overarching challenges for food systems: how can they adapt to climate change and, at the same time, reduce their own contribution to GHG emissions and climate change? These intertwined challenges are discussed in all the regional assessments. Multiple scientific opportunities are identified to adapt by developing climate-resilient agriculture, e.g. from the application of biosciences to breed improved crop varieties resistant to biotic and abiotic stresses, and of the social sciences to understand and influence the behaviour of farmers, manufacturers and consumers in responding to climate change (see, for example, EASAC, 2021). Combining evidence-based measures will also be essential to mitigate GHG emissions from the sector (currently contributing approximately 30% of global GHGs, Watts et al., 2021), including improved agronomic practices, reducing waste, and shifting to diets with lower carbon footprint. For example, a background paper prepared in 2020 for the SBSTA of UN FCCC COP[2] explored agronomic case studies (in South America, Asia, Africa and Europe) for managing nitrogen pollution (including the powerful GHG nitrous oxide) and improving manure management to decrease GHGs and benefit the environment. Capitalising on such research requires better connections between science and the broader community and with relevant policy processes. There is particular need to dismantle obstacles for transferability of practices and scaling up of local research results to guide decision making at national and regional levels.

One major mitigation opportunity discussed by IAP (2018) and in all the regional assessments relates to the potential to adjust dietary consumption patterns to reduce GHGs and, at the same time, gain significant potential health benefits (see Neufeld et al., 2021 for discussion of the definition of healthy diet). For example, there is evidence that reducing red meat consumption, where that is excessive, can improve population health (Willett et al., 2019; systematic review of the literature in Jarmul et al., 2020). Red meat supplies only 1% of calories worldwide, accounting for 25% of all land use emissions (Hong et al., 2021), though meat is an important source of protein, minerals and vitamins. The policies for reaching such consumption adjustments require more research to actually identify solutions. The proportion of excess deaths attributable to excess red meat consumption is highest in Europe, Eastern Mediterranean, Americas and Western Pacific (Watts et al., 2021). However, some populations consume sustainable diets that are meat-based, e.g. the Inuit Indigenous People in the Canadian Arctic: proposals for dietary change must be carefully designed, evidence-based and culturally sensitive in being adapted to circumstances and protecting nutrient supplies for the most vulnerable groups. It should also be acknowledged that the efficiency of livestock production varies according to farming system, such that conclusions, e.g., about the sustainability of pastoral cattle production may be different from those for feed-lot cattle production (Adeosogen et al., 2019; AASSA, 2021), and that livestock may be the only agricultural activity possible in dryland regions that do not support the cultivation of crops.

Although Africa accounts for the smallest regional share of total anthropogenic GHG emissions, about half of this is linked to agriculture, and is experiencing the fastest increase of all regions (Tongwane and Moeletsi, 2018; Latin America and South East Asia are also demonstrating rapid growth, Hong et al., 2021). As part of the whole systems approach, formulation of mitigation solutions must decouple increases in livestock productivity (and cereal productivity, Loon et al., 2019) from increases in GHGs. Progress is being made (e.g. in China, Cui et al., 2018; AASSA, 2021) and decoupling can be informed by better use of the research evidence available, e.g. for herd management, improving animal health, breeding new varieties (with better feed conversion and energy utilisation

[2] SBSTA 52nd Session 2020. "Improved nutrient use and manure management towards sustainable and resilient agricultural systems". FCCC/SB/2020/1.

efficiencies), improved forage provision (e.g. NASAC, 2021) and by strengthening of targeted social protection mechanisms alongside more generic recommendations for dietary change (EASAC, 2021).

There are unprecedented scientific opportunities coming within range but there are also multiple obstacles to mainstreaming climate change solutions into food system development planning. Evaluation of obstacles in India (Singh et al., 2017) highlights limited access to finance, difficulties in accessing research and education, and delays in accessing weather information. Systematic review of the literature on smallholder production systems in South Asia (Aryal et al., 2019) notes weaknesses in the institutional infrastructure to implement and disseminate available solutions: the application of science requires institutional change. At global scale, there is need for enhanced access to climate information and services for climate-resilient food security actions (WMO, 2019), e.g. to aid decisions on most suitable crops and planting times.

5. RESPONDING TO COVID-19

Climate change and Covid-19 are converging crises for health in many respects (Anon, 2021) including food and nutrition security. Observations early during the pandemic[3] indicated that production of staple food crops during critical periods (planting and harvesting) was vulnerable to interruptions in labour supply; food processing, transport and retail were also affected early on, particularly the relatively perishable, nutritionally-important, fresh fruit and vegetables (Ali et al., 2020). Subsequent comprehensive assessment of consequences for global food security (Swinner and McDermott, 2020) has evaluated how adverse effects on local practice and routines are transmitted to longer-term impacts on poverty and food systems worldwide in increasingly interconnected trade and markets. In some cases, supply disruption has been aggravated by national decisions to restrict export of food[4]. The combined effects of Covid-19 on recession and food systems disruption are particularly detrimental to the poor (Ali et al., 2020; Swinner and McDermott, 2020 include case studies in Ethiopia, China, Egypt and Myanmar; NASAC, 2021). However, in some regions, food systems proved relatively resilient (IANAS, 2021) and there are also examples of good practice in new safety net programmes, including school feeding programmes that should be more widely shared and implemented. Tackling the consequences for child malnutrition is identified as a particular priority for action (Fore et al., 2020), as is attention to gender bias whereby women are suffering more adverse effects in consequence of Covid-19-changed household and community dynamics (Swinner and McDermott, 2020). As emphasised by EASAC (2021), the pandemic has exposed the vulnerability of over-reliance on just-in-time and lean delivery systems, globalised food production and distribution based on complex value chains. Therefore, opportunities for increasing localisation of production systems should be re-examined. However, there is often a mismatch in the timescale needed to adapt to Covid-19 between the imperative for early action to protect vulnerable groups and the relatively slow policy responses (Savary et al., 2020). Capitalising on the

[3] CGIAR's response to COVID-19. www.cgiar.org/news-events/all-news/our-response-to-covid-19.
[4] International Monetary Fund "Policy responses to COVID-19". https://www.imf.org/en/Topics/imf-and-covid-19/Policy-Responses-to-COVID-19.

scientific opportunities may help to minimise this mismatch, e.g. improving food safety and reducing post-harvest losses (IAP, 2018), implementing evidence-based social protection measures and using Information and Communication Technologies for e-commerce, food supply resilience, early warning systems, and health delivery. Post-Covid-19 initiatives on novel foods, and urban and peri-urban farming systems, can also strengthen food supply chains and create new livelihoods for expanding urban populations, although it is also important to understand and manage inadvertent consequences for rural employment and the environment (Ali et al., 2020).

6. USING SCIENCE, TECHNOLOGY AND INNOVATION TO PROMOTE AND EVALUATE ACTION

Continuing with business as usual will not meet the objectives for transformative change. To reaffirm a core message from IAP (2018): there is urgent need to use currently available evidence to strengthen policies and programmes, and to invest in initiatives to gain new knowledge. Examples of what is possible are discussed extensively elsewhere (e.g. Fanzo et al., 2020; Lillford and Hermansson, 2020)[5]. It is not the purpose here to provide a detailed assessment of transdisciplinary research priorities but in Table 1 we map some onto the UN FSS Action Tracks to emphasise new opportunities coming within range and the need for science to achieve its potential. Examples are illustrative, not comprehensive, more detail on these and other research priorities are provided in IAP (2018), the regional Policy Briefs and in sections 1-4 of this global Policy brief. There are also, of course, many interactions between research streams and objectives that cannot be captured in Table 1.

[5] See also repositories of recent literature e.g. Sustainable solutions to end hunger (https://www.nature.com/collections/dhiggjeagd); Sustainable nutrition (https://www.nature.com/collections/fibbgbiebc); and Socio-technical innovation bundles for agri-food transformation (https://www.nature.com/documents/Bundles_agrifood_transformation.pdf).

Table 1. *The power of fundamental science*

UN FSS Action Track	Examples of research opportunities
1.Ensure access to safe and nutritious food for all	Clarifying scientific basis for balancing of food systems for a greater emphasis on nutrition not just calories; incentives to promote sustainable practices and products, and disincentives for foods with high environmental footprints or adverse health effects. Integration of local, regional and global scales for sustainability, including renewed emphasis on value of indigenous crops. Broad research agenda for the agriculture-environment nexus, including livestock biometrics. Plus, bio/chemical sciences to identify health value of novel foods, holistic properties of foods (interactions within complex food matrices and mixtures), and components not ordinarily considered as nutrients (such as flavonoids, probiotics, anthocyanins) (Kongerslev et al., 2017 for dairy products; Thorrez and Vandenburgh, 2019 for cultured meat; Nuffield Council on Bioethics, 2019 for ethical issues).
2.Shift to sustainable consumption patterns	Social sciences to understand demand-side issues, role of public procurement, value-driven consumption patterns (Smith et al., 2016; Cuevas et al., 2017; Eker et al., 2019; Laar et al., 2020). Using advances in food science and technology in food processing to reduce post-harvest losses (Lillford and Hermansson, 2020).
3.Boost nature-positive production	Understanding value and vulnerabilities of mixed farming systems; reduction in the use of external inputs (including antimicrobials); mapping and using soil microbiomics (Singh et al., 2020); conserving and using genetic diversity in breeding (FAO, 2019; Pironen et al., 2019). Realising the potential of the oceans (Lubchenko et al., 2020).
4.Advance equitable livelihoods	Big data capture, analysis and communication e.g. for precision agriculture (Hodson de Jaramillo et al., 2019; Basso and Antle, 2020), supporting smallholders and new livelihoods (FAO[1])
5.Build resilience to vulnerabilities, shocks and stress	Earth Observation Sciences to monitor agronomic status and guide interventions at large scale (Jain et al., 2019), linked to other technologies for crop sensors, mobile devices and remote monitoring. Development of baselines, attribution methodologies, reconciling differences in temporal and spatial scales in measurement, increasing understanding of synergies and trade-offs. Plus, the broad research agenda for tackling climate change and Covid-19 in provision of equitable services, including health care and social protection.

Several general recommendations can be made:

- There is need to increase commitment to invest in fundamental science and then connect that to applications and align with development priorities. There is also an important priority to develop improved methodologies to understand the levers of change, including the attributes of “game changers”. That is, how to attribute outcomes and impact to investments chosen and scientific or other actions undertaken.
- There are new opportunities to improve collaboration and coordination worldwide, and build partnerships between public and private sectors, NGOs and other stakeholders to co-design and conduct research. Transdisciplinary approaches should be encouraged. There is increasing entrepreneurial activity worldwide, e.g. in the Latin America region a wide range of start-up company activities include novel foods, novel production systems, and novel approaches to optimisation of water and other natural resources (IANAS, 2021). There are also considerable opportunities in Africa for action on agriculture to stimulate economic growth, reducing poverty, while also increasing food and nutrition security (Baumuller et al., 2021; NASAC, 2021).
- Training and mentoring of the next generation of researchers worldwide is essential: academies of science have a key role to encourage younger scientists.
- Obstacles, especially in LMICs, in the use and production of data and in scaling up applications must be addressed. For example, although big data/mobile-based communications bring significant benefits (e.g. IANAS, 2021; NASAC, 2021) and there are advances in using mobile technology to deliver climate services for agriculture in Africa (Dayamba et al., 2018), more should be done to increase access by small-scale farmers (Mehrabi et al., 2021). A digital inclusion agenda is needed for governments and the private sector to increase access to data-driven agriculture.
- In addition to generating excellent science, it is vital to reduce the delay in translating research outputs to innovation, public policy and practice (IAP, 2018). Time lags may arise from negative attitudes associated with perceived risks, by excessive regulatory requirements in some countries or by absence of regulation in others. This leads to fragmentation in the capture of benefits. For example, there is current heterogeneity in considering whether new plant breeding techniques – such as those based on genome editing – should be included within older legislation governing genetically modified organisms. Scientific advances are occurring worldwide, e.g. collaborative work in Colombia, Germany, France, Philippines and USA to develop rice resistant to bacterial blight (Oliva et al., 2019; IANAS, 2021). The controversy created by a situation where regulatory frameworks are disconnected from robust science is discussed by EASAC (2021). Figure 1 demonstrates the resulting incoherence that acts to deter science, innovation and competitiveness, creates non-tariff barriers to trade and undermines collective action to enhance food and

nutrition security. This may have particular adverse consequences for those already suffering malnutrition; for example, the acceptance of gene-based technologies is mixed in Africa even though there may be considerable scientific opportunities for using biotechnology in crop breeding programmes to increase resistance to biotic and abiotic stress, improve nutrient content and nitrogen use efficiency (NASAC, 2021).

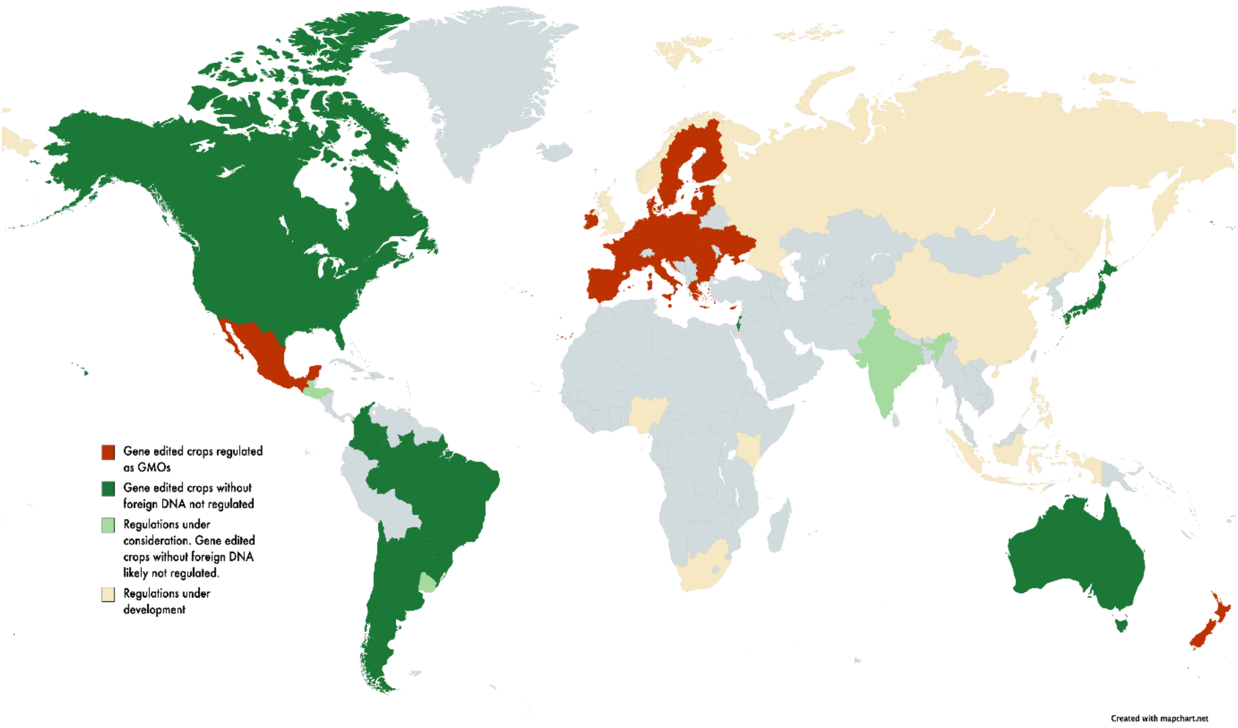

Figure 1: Variation in the regulation of genome editing for plant breeding.

7. STRENGTHENING THE CONTRIBUTION OF RESEARCH TO POLICY MAKING

Alongside action to accelerate investment in agriculture and food systems research (von Braun et al., 2020), there must be transdisciplinary integration of priorities at the science-policy interface across all relevant sectors (Fears et al., 2019), including agriculture, environment, health and social care, rural and urban development, and fiscal policy. There must also be linkage of policy at local, regional and global levels (Fears et al., 2020), while taking account of local values and circumstances and recognising the challenges for coordination. One recent example from Asia (Islam and Kieu, 2020) on developing critical mass in regional policy for climate change and food security discusses criteria for successive steps in policy planning, implementation, cooperation and legal obligation, and observes that the latter two steps often present fundamental barriers to moving from the priorities in a national development agenda to regional coherence. In the African region, the recent Joint Ministerial Declaration and Action Agenda (AU, 2020) calls upon governments to build greater productive capacity in agriculture and strengthen resilience throughout Africa's agri-food systems.

Scaling efforts for critical mass requires individual countries to recognise that their policy decisions may have impact on other countries and regions. For example, some countries export their lack of environmental sustainability by increasing food imports from elsewhere (IAP, 2018).

Academies and others within the scientific community (STCMG, 2020) have a key role in overcoming obstacles to effective policy by working together across disciplines to show the value of an inclusive approach, e.g. to the SDGs. Moreover, systematic review of the literature indicates that public support for a policy can be increased by communicating evidence of its effectiveness (Reynolds et al., 2020; Fears et al., 2020). Therefore, the work of academies to use the evidence base to inform policy development and implementation can help to provide the bridge between policy makers and the public.

Table 2. *The scientific community has a continuing role in assessing and implementing game changers to strengthen the contribution of research to policy making.*

Game changers in Action Track 1	How are academies helping to inform policy options? Examples from the regional Briefs
Changing the fundamental incentives that created the present situation	Identifying research priorities for providing diversified, sustainable, healthy diets and pricing in negative externalities; developing better connections between data sets across health, environment and economics.
Taking advantage of shifts in underlying conditions	Clarifying consequences of Covid-19 in improving systems resilience and sustainable, equitable, healthy recovery.
Recognising value of multiple organisations working on related themes	Convening and catalytic roles to help reduce barriers between countries, sectors, disciplines and encourage shared perspectives.
Avoid neglecting the obvious	Reaffirming importance of current strategies for tackling all malnutrition, including fundamental science and food science and technology in support of innovation; paying more attention to understanding the value of indigenous crops (and improving their domestication) and traditional diets (e.g. in Africa, Mabhaudi et al., 2019).
Changing mind sets so as to think in terms of systems	Food systems approach has been central to the academies work in providing evidence to policy makers and other stakeholders, and in involving those whose voice has been sometimes muted.

What are the implications for the UN FSS? UN FSS discussions have highlighted the place of "game changers" for driving transformative action and the scientific community has much to contribute in exploring the potential of game changers to underpin transformation at the science-policy interface (see AASSA, 2021). For example, a recent commentary on Action Track 1[6] identified some key precepts that can be illustrated by academies' work at regional and global levels (Table 2).

We suggest that there is an additional game changer, applicable to all Action Tracks: the development of a new international science advisory Panel on Food and Nutrition Security (IAP, 2018), with a broad remit for food systems, focused on shaping policy choices and strengthening governance mechanisms. A new Panel, recognising the new opportunities and challenges for food systems governance, could help to streamline research efficiency in its linkage to policy action and increase the legitimacy of that science advice by using robust assessment procedures (Global Panel, 2020). The impetus created by the UN FSS, requires the coordination and management of food systems by more sectors of government and stakeholders than had been the case for food security, bringing an unprecedented opportunity to develop a framework for greater transparency, accountability and sharing of knowledge. By consolidating the present myriad, fragmented, array of panels and advisory committees the proposed international advisory Panel could draw on the large scientific community already working on these topics – including academies – and should be asked to address the most pressing issues for transformative change in the face of the mounting global challenges. Food and nutrition security, particularly in high-risk groups, must be a top priority on all country's national agenda, yet many countries do not have a national security strategy in place (EIU, 2021). Furthermore, as already noted, advisory capacities, governance policies, and institutions are sometimes weak at the regional level (AASSA, 2021; NASAC, 2021). Thus, in addition to building the critical mass for evaluating complex issues at global scale, an international advisory Panel can help to drive momentum for a national food systems strategy in all countries and engender regional-level initiatives in policy development and implementation.

IAP recommends that the UN FSS now considers options for constituting a new international advisory Panel, to make best use of the rapid advances in science, technology and innovation, and to motivate evidence-based policy making at all levels. IAP and its regional academy networks are eager to be involved.

8. CONCLUSIONS

- Achieving food and nutrition security worldwide by transforming food systems remains a major challenge, compounded by recent pressures from climate change and the Covid-19 pandemic. Actions to promote food systems are relevant to multiple SDGs. It is essential to identify opportunities for synergies and trade-offs while avoiding inadvertent negative consequences, and to engage everybody, to enable change. This requires advances in complex food systems modelling.

[6] Haddad, L. 2021 "Food systems "game changers": reflections so far", on https://un-food-systems.medium.com/food-systems-game-changers-reflections-so-far-d4c8200c5663.

- Food systems are diverse and heterogeneous. Continuing research is needed to inform diverse yet equitable solutions for sustainable, healthy diets that are culturally sensitive, focusing on vulnerable groups. That calls for stronger connections between local and international research entities. The opportunities of complex and innovative remote sensing and web-based data should also be explored for this purpose.
- Greater transdisciplinarity is needed in research to progress from the current science agenda which is still too often focused on individual components of food systems or on agriculture separate from its environmental context. Social sciences research must be better integrated with other disciplines, e.g. to understand and inform consumer, farmer and manufacturer behaviours and to guide policies to deliver objectives for social justice. The development of improved methodologies for understanding attribution of impact is also a critical research priority.
- Science is a public good yet the conduct and use of basic and other research is often fragmented. There is still much to be done to build critical mass worldwide, to share skills and research infrastructure and to collaborate in agreeing and addressing research priorities and avoid unnecessary duplication. There is a continuing convening role for academies of science to facilitate exploration of opportunities and tackle obstacles to research collaboration between disciplines and between the public and private research communities.
- There are also opportunities to improve science-policy interfaces and integrate policy development at local, regional and global levels. One game changer would be to constitute an international advisory Panel on Food and Nutrition Security with new emphasis on food systems to make better use of the best science to inform, motivate and implement evidence-based policy making at all levels.

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visit **https://www.interacademies.org/**
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visit **https://sc-fss2021.**org or
contact **info@sc-fss2021.org**
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