

The Role of Science, Technology, and Innovation for Transforming Food Systems in Europe



Claudia Canales and Robin Fears

1 Introduction: The Transformation of European Food Systems

Combating malnutrition in all its forms – undernutrition, micronutrient deficiencies, overweight and obesity – is a problem faced by all countries. Recent data confirm that undernutrition and food insecurity are present in vulnerable groups in Europe (Loopstra 2018; Pollard and Booth 2019; Leij-Halfwerk et al. 2019) simultaneous with an increasing public health burden related to obesity (Pineda et al. 2018; Krzysztosek et al. 2018). There is still much to be done to ensure access to safe and nutritious food for all (UN FSS Action Track 1¹). Europe has a rich diversity of food cultures in close proximity to each other, and this diversity is mirrored in the structure of the EU farming sector: very small farms (<2 hectares) make up nearly half of the agricultural holdings, while very large farms (>100 hectares) make up just 3% of the total, but cultivate half the farmland (Kania et al. 2014). Small farms themselves differ widely, and include high-value and specialised production systems (Guiomar et al. 2018). Food has also traditionally played a central role in the EU in the shaping of individual and collective identities (Anderson et al. 2017), and it is also central in current discourses on economic, social and environmental justice and cultural recognition (e.g., Coolsaet 2016; Šūmane et al. 2018). There is large variation in food and nutrient intakes across Europe, between and within countries (Martens et al. 2019).

¹<https://www.un.org/en/food-systems-summit/action-tracks>

C. Canales (✉) · R. Fears
European Academies' Science Advisory Council's (EASAC) Biosciences Programme,
Halle, Germany
e-mail: canales.claudia@gmail.com

In 2017, EASAC published a report on food and nutrition security and agriculture in Europe as part of the InterAcademies Partnership (IAP) global project. That report followed an integrative food system approach to cover interrelated issues around resource efficiency, environmental sustainability, resilience and the public health agenda, while also addressing opportunities for local-global connectiveness and the bioeconomy. EASAC stressed that an earlier food security emphasis on agricultural production now has to be replaced by the food systems approach to encompass all of the steps in the food value chain in order to deliver accessible and affordable food for all, from growing through to processing, trading, consuming and disposing of, or recycling, waste. Food systems must include both supply-side and demand-side considerations for sustainability. Yearly food losses in the EU have been estimated at about 15% of the emissions of the entire food supply chain (Scherhauser et al. 2018). An increase in agricultural productivity would likely increase the environmental footprint without necessarily delivering healthy and nutritious diets that are accessible to all, unless embedded in a profound transformation of food systems (Benton and Bailey 2019).

One issue increasing in importance is the role of public procurement in the demand for sustainable, healthy food (Sonnichsen et al. 2020; WHO 2021): provision of sustainable, healthy diets in hospitals and other public services can help to change consumer behaviour in the longer term (EASAC and FEAM 2021). European Union interest in the sustainability of the food systems approach is increasing (e.g., SAPEA 2020) and the recent Farm-to-Fork (F2F) policy initiative covers the entire food chain, together with protection of the environment.

Much of the EASAC 2017 report focused on scientific advances in agriculture, but there was also significant attention to food science and technology, e.g., for food safety and food processing, so as to reduce food losses, extend distribution and seasonal availability, and for food fortification. The comprehensive recent work of the International Union of Food Science and Technology,² based partly on evidence presented by IAP and its regional work streams, reviewed scientific opportunities related to diverse and sustainable primary production; sustainable process and system engineering; the elimination of waste in production, distribution and consumption; and traceability and product safety (see also Lillford and Hermansson 2020). An additional issue, brought into prominence by the COVID-19 pandemic, is the potential of the improved food value chain to address poverty by increasing entrepreneurial activity and other employment (an issue that should be highlighted in UN FSS Action Track 4, Advance equitable livelihoods).

Transdisciplinary policymaking and governance are required to make food systems more nutrition-sensitive. Food and nutrition security and food sustainability must now be considered as part of formulating European dietary guidelines. Some of the research priorities are described subsequently, but there is also a need for a better definition of what a sustainable diet is and how it can be measured, so that these

²Global challenges for food science and technology, 2019, <https://iufost.org/global-challenges-and-critical-needs-2/>.

metrics form part of national surveys and inform policies and interventions to educate consumers on sustainable behaviours and diets.

Innovation is central to delivering the required transformation of food systems, and must be based on transdisciplinary science, new financing and business models, and policy development. This topic has received renewed attention recently. For example, Herrero et al. (2020) developed an inventory of innovations organised according to their position in the value chain (i.e., production, processing, packaging, distribution, consumption and waste) and their ‘readiness score’: from basic research all the way to proven implementation under real-world conditions. The dissemination and uptake of these innovations should be considered a priority, and research is urgently needed on how to make options available in current food systems with minimal disruption.

In this EASAC brief, the following sections update selected priorities from the EASAC 2017 report in order to demonstrate how science, technology and innovation can provide major contributions to the UN FSS Action Tracks. There are multiple implications for EU policy, as summarised in Fig. 1.

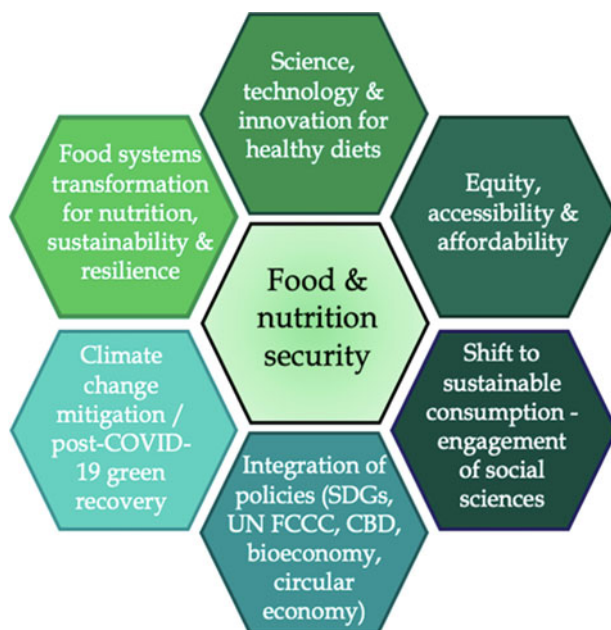


Fig. 1 Matrix of European policy objectives for food and nutrition security. Links with international policy development are particularly relevant in 2021 because of the UN FSS, as well as COP26 of the UN FCCC (Framework Convention on Climate Change) and COP15 of the UN CBD (Convention on Biological Diversity)

2 Agriculture-Environment Nexus and Agroecology in Europe

Linkage of food systems to sustainable development objectives is a core part of the integrated transformations required to attain the Sustainable Development Goals (SDGs, see GSDR 2019; Sachs et al. 2019; EASAC 2020a). Concomitantly, there is great potential for new business opportunities and economic value (WEF 2020), but also a need to understand the co-benefits and trade-offs of coupling nutritional and environmental objectives for SDGs (McElwee et al. 2020), factors that have to be taken into account in UN FSS Action tracks 2 (Shift to sustainable consumption patterns) and 3 (Boost nature-positive production) as well.

The concept of regenerative agriculture (Newton et al. 2020; Schreefel et al. 2020) embraces farming principles and practices that enhance biodiversity and ecosystem services and increase carbon capture and storage, helping to tackle climate change and improve agricultural resilience and yield. This can be viewed as a core feature of the EU's F2F strategy, but the scientific basis needs to be clarified in order to improve farming systems (Davies et al. 2020). Agroecology is an important part of regenerative agriculture innovation (HLPE 2019): scientific advances here will also help to clarify links between human and livestock health and their dependencies on the environment.

Assessing the relative contribution of different production models to sustainably delivering healthy and nutritious diets and providing important ecosystem services is an important research priority. For example, using life cycle assessments (LCAs), it was estimated that a complete switch to organic cultivation in England and Wales would lower production emissions, but also decrease yields, and the increased reliance on land use elsewhere to make up for the shortfall would result in higher emissions overall (Smith et al. 2019). However, organic agriculture can decrease the reliance on chemical inputs, improve soil carbon sequestration and soil quality, reduce the contamination of water bodies and increase biodiversity. LCAs do not accurately reflect these benefits because of their focus on the product, whereas ecosystem services from agricultural systems are not duly considered. Deploying an integrated approach requires research to quantify the economic value of ecosystems (Dasgupta 2021), as part of the improvement and standardisation of methodologies for assessing and comparing the sustainability of food systems. In addition, estimates of the levels of food production required to fulfil demand often fail to take into consideration the effects of a switch to more sustainable diets, lowered consumption patterns, and the reduction of food waste.

Research for improving the environmental assessments of production systems should include clarifying additional indicators, such as for land and soil degradation and loss of biodiversity; broadening the scope to include the provision of ecosystem services; and improving the assessment of indirect effects within a comprehensive food systems perspective, as opposed to a narrow focus on yield (van der Werf et al. 2020). Organic agriculture should also embrace innovation to improve its performance (Seufert et al. 2019; Clark 2020), and may require multiple policy

interventions to realise its potential for food system sustainability (Eyhorn et al. 2019). Effectively communicating the relative environmental footprints of different foods to consumers must also be a priority (Potter and Rööös 2021).

Diverse farming systems depend on soil structure and health. In discussing how to manage competition for land use and other resources, EASAC (2017) highlighted the critical role of soil, particularly with respect to its biological functions. A more recent EASAC assessment (2018) further emphasised the multiple roles of soil sustainability and implications for its management in informing policy development, a subject that has been relatively neglected in the EU of late. This neglect needs to be corrected. Among soil's biological functions, EASAC (2017) discussed emerging knowledge about the contribution of soil microbiomics (bacteria and fungi) to sustainable agriculture, e.g., in the strengthening of root systems and carbon sequestration. There is another link to the bioeconomy: the soil microbiome can be a resource for generating novel antibiotics and other high-value chemicals. Rapid progress continues in ascertaining the linkages between microbial diversity and ecosystem functions, including plant health under climate change, in particular, the role of soil microbial taxa in biogeochemical cycling, plant growth and carbon sequestration (Dubey et al. 2019; Wei et al. 2019).

There are continuing opportunities to link food systems and environmental objectives with bioeconomic policy: impetus and coordination has been imparted to the European Bioeconomy Strategy through the recent introduction of an EU-wide monitoring system³ for tracking the balancing of bioeconomic contributions to food and other outputs, in order to reduce environmental pressures. Systematic review of the literature suggests the need to prioritise biomass strategies to increase food production over those for animal feed or biofuels (Haines 2021). Scientific advances are bringing new opportunities to drive the bioeconomy of future foods (such as mycoproteins, algal feedstocks, cultured meat, Fanzo et al. 2020; Haines 2021).

3 Delivering Sustainable and Healthy Diets Under Climate Change

Climate change is already affecting the yield and quality of crops, with the potential for adverse consequences in terms of malnutrition (undernutrition, micronutrient deficiency, obesity, EASAC 2017). Systematic reviews of the literature have documented declines in the yields of starchy staple crops (Wang et al., 2018) and in the yields and nutritional quality of vegetables and legumes (Scheelbeek et al. 2018), fruits, nuts and seeds (Alae-Carew et al. 2020). Developing climate-resilient

³EU Bioeconomy Monitoring System, 2020, https://knowledge4policy.ec.europa.eu/bioeconomy/monitoring_en

food systems should be a core part of UN FSS Action Track 5 (Build resilience to vulnerabilities, shocks and stress).

It is important to evaluate how the agricultural sector can adapt to climate change and, at the same time, reduce its own contribution to greenhouse gas (GHG) emissions. Agriculture currently accounts for about 30% of total GHG emissions, if we include land conversion and direct, production-linked environmental costs (EASAC 2019). A key objective, therefore, for the UN FSS, when developing environment-health-climate change policies, is to simultaneously reduce both the triple burden of malnutrition and the contribution that food systems make to climate change and other environmental changes. The accumulating evidence indicates that the 1.5° and 2° C targets cannot be attained without rapid and ambitious changes to food systems (Clark et al. 2020). A combination of measures is necessary to reduce GHG emissions from agriculture, including improved agronomic practices, the reduction of waste, and an increase in sustainable consumption patterns. The evidence base indicates significant health benefits from reducing red meat consumption (where that is excessive) and increasing the use of vegetables, fruits, nuts and seeds in diets (EASAC 2019; Willett et al. 2019). The impact of changes to dietary guidelines on micronutrient intakes must be considered, especially for vulnerable groups. A recent systematic review of environmental footprints and the health effects of “sustainable diets” (Jarmul et al. 2020) concluded that, although co-benefits are not universal and some trade-offs are likely, when carefully-designed and adapted to circumstances, diets can play a pivotal role in climate change mitigation, sustainable food systems and future population health. Unfortunately, in proposing recommendations for policy solutions, issues related to the accessibility and affordability of proposed healthy and sustainable diets are often overlooked (Hirvonen et al. 2020).

Policy implications for the promotion of sustainable food systems that reward good management practices include the introduction of sustainable stewardship, food labelling and certification schemes. Current food policy in many countries concentrates more on how to protect consumer health from contaminated food than the degree to which the State should use health and environmental considerations to regulate the supply of foodstuffs (Godfray et al. 2018). Resolving this role of the State has significant implications for rebalancing consumption by introducing incentives/disincentives for carbon and biodiversity costs of populations at risk of over-consumption, while protecting vulnerable groups. At the same time, governments must consider how best to measure and monitor policy changes for their impact on food production, consumption and health.

4 Responding to COVID-19

The ongoing COVID-19 pandemic has affected all components of the food system. Long-term implications are hard to predict, as they will depend on the length and severity of the pandemic. The effects may also be compounded by shocks to production (such as drought and the interruption of seasonal labour supply for planting and harvesting), and by factors influencing the distribution, access and

affordability of food (e.g., disruptions to global food trade and food price speculations; Moran et al. 2020). To date, global supply chains continue to function in spite of isolation policies (Galanakis 2020; Moran et al. 2020), although production problems that resulted in an increase in the price of fresh and perishable products have also been reported (Coluccia et al. 2021). In Europe, there has been an increase in food wastage, partly as a result of the shutdown of restaurants, schools and other community facilities. The pandemic has affected the ability of vulnerable groups within the population to access sufficient and healthy food due to rising unemployment and enforced self-isolation, in particular, families with young children, and is exacerbating diet-related health inequalities (Power et al. 2020). Consumption-related challenges reported during lockdowns include a small increase in the intake of calories and a decrease in the intake of vitamins, minerals and plant-based protein and fatty acids, in particular, by the elderly as a group (Batlle-Bayer et al. 2020; IUFoST 2020). Combined with reduced physical exercise during lockdown, these dietary changes may increase the incidence of obesity and related NCDs. Hoarding and panic buying during pandemics, also reported, could distort the food supply chain and need to be better managed (IUFoST 2020).

Planning for a sustainable economic recovery after the pandemic provides a window of opportunity to make food systems more resilient, nutritious and environmentally sustainable, avoiding a return to business-as-usual (EASAC 2020b; Benton 2020; IUFoST 2020; Rowan and Galanakis 2020; Sarkis et al. 2020). Because the pandemic exposed the vulnerability of overreliance on just-in-time and lean delivery systems, globalised food production and distribution systems based on complex value chains should be re-examined, not only in terms of economic efficiency, but also for their environmental sustainability and climate change mitigation potential. Opportunities for the increased localisation of production systems should be explored. Research priorities also include the development of food safety measures and bioanalytical protocols for food and environmental safety along the food chain; and the development of nutritional foods to promote immune function, which may include foods for medical use by the elderly population, as well as other vulnerable groups. Further areas for innovation to capitalise on scientific opportunities comprise digitisation and the implementation of smarter logistics systems, including reverse logistics for secondary materials and waste products (IUFoST 2020; Rizou et al. 2020; Rowan et al. 2020; Sarkis et al. 2020). The generation of robust baseline data on malnutrition levels in the EU Member States remains an important knowledge gap, in particular, for vulnerable sectors of the population (EASAC 2017).

5 New Breeding Techniques: A Case Study in Science, Technology and Innovation

Improved breeding of plants and animals for agricultural production is a key component of an integrated transformation of food systems to deliver healthy and nutritious diets sustainably in the face of climate change. For plants, key target traits

for improvement include increased tolerance to drought (including soil water use efficiency), heat, and salinity, with a focus on the development of multiple traits; improved use of soil nutrients (nitrogen, phosphorous and essential elements) to reduce dependency on fertilisers; pest and disease resistance; and healthier nutrient composition (EASAC 2017, 2020c). Animal breeding priorities comprise animal health (disease resistance and stress tolerance, in particular, regarding heat); and nutrition, including strategies to mitigate enteric gut methane emissions. Achieving these objectives will require the use of the full toolbox of breeding technologies available, from conventional breeding assisted by advances in genetics and genomics, through to the use of a set of technologies collectively referred to as new breeding techniques (NBTs) and, in particular, genome editing.

Recent advances using genome editing include the development of varieties with improved nutritional content, such as high protein wheat with increased grain weight and more nutritious potatoes (Hameed et al. 2018; Zhang et al. 2018, 2020). In wheat, gene editing has also been used to derive low-gluten transgene-free plants (Sánchez-León et al. 2018). Gene editing allows for developing crop varieties with multiple resistances to biotic and abiotic stresses (e.g., in tomatoes: Saikia et al. 2020). Looking ahead, research priorities include the (re)domestication of high-nutrient stress-tolerant crops by targeting known domestication genes in established crops (e.g., for the cultivation of quinoa in Europe; López-Marqués et al. 2020; and see also van Tassel et al. 2020; Zhang et al. 2020), and the development of perennial grain crops to maximise sustained crop yields (DeHann et al. 2020).

Crops produced through genome editing techniques, including those with no foreign DNA, are regulated differently in different countries (Schmidt et al. 2020), with Europe holding the most restrictive regulatory regime. In 2018, the European Union Court of Justice ruled that crops produced by gene editing technologies are to be subjected to the same regulations as GM crops (Directive 2001/18/EC). The focus of this regulation is the process by which a crop is developed, not the breeding product, and as a result, crop varieties that are equivalent from a scientific perspective but were developed through different methods will be regulated differently (Jansson 2018). The legislation's far-reaching consequences include the stifling of innovation, since the cost of pre-market evaluations will deter investment in the technology, in particular, in the public sector and by small and medium enterprises (SMEs; Ricroch 2020; Jorasch 2020). Around 40% of SMEs and 33% of large companies ceased or reduced their gene editing-related R&D activities after the 2018 ruling (Jorasch 2020). The EU is also lagging behind in terms of generating innovation: while the United States and China have filed 872 and 858 patents for applications for gene editing applications, respectively, EU countries together have filed only 194 (Martin-Laffon et al. 2019). There has also been a very striking reduction in the number of EU countries carrying out field trials of crops improved by either GM or gene editing (Ricroch 2020). In addition, the impossibility of distinguishing between edited and naturally derived varieties makes the law unenforceable, especially if the varieties are considered legal elsewhere (Martin-Laffon et al. 2019; Schmidt et al. 2020; Zhang et al. 2020).

EASAC advised (EASAC 2020a, b, c) that it is the products of new technologies and their use, rather than the technology itself, that should be evaluated according to the scientific evidence base, and that the legal framework should be revised. The potential costs of not using a new technology, or being slow in adoption, must be acknowledged, as there is no time to lose in resolving the problems for food and nutrition security.

6 Strengthening Research and Its Uptake into Policy and Practice

The purpose of this Brief has been to address three questions: How can scientific advances help to fill knowledge gaps in delivering food and nutrition security? What does Europe need to build its research capabilities and help build global scientific capacity and partnerships? How best can science-based evidence be used to inform innovation, policy development and practice? Our recommendations are as follows.

Filling Knowledge Gaps with New Research

In the previous sections, we have exemplified how new research is of unequivocal value in addressing societal challenges. In addition to these examples, and referring back to other scientific priorities in EASAC 2017, there have been recent advances in big data handling, robotics, artificial intelligence and mobile communications for precision agriculture (Klerkx and Rose 2020; El-Gayar et al. 2020). There have also been substantial advances in the science of human gut microbiomics and linkages to diet and health. For example, methodological studies are rapidly clarifying characteristics of a healthy microbiome (Eisenstein 2020) and intervention studies have demonstrated the health value of a Mediterranean diet in older cohorts in different European countries, explained in terms of gut microbiome alterations (Ghosh et al. 2020). Advances in social science research are increasingly important to understanding determinants of inequity in food systems, mechanisms for empowerment of marginalised groups and models for entrepreneurial activity (Fanzo et al. 2020). Social science research is also helpful in evaluating specific instruments for the promotion of sustainable food in EU policy, e.g., taxation schemes, consumer cooperatives, labelling and governance initiatives (Marsden et al. 2018; SAPEA 2020).

Building the Research Enterprise

Europe has mature systems for research funding at the national and EU levels (EASAC 2017). Nonetheless, it is essential for the scientific community to continue making the case for investment in research, including fundamental science, and to recognise the value of involving other stakeholders in the design and conduct of research (SAPEA 2020). Greater inclusivity depends in part on building public confidence in science and shaping public understanding of the challenges to food and nutrition security in a changing public landscape often characterised by less

deference to authority and scientific experts (Fears et al. 2020). Strengthening research capabilities in Europe also depends on understanding the impact from the progressive loss of key skills in the EU (e.g., in plant sciences), and on reversing those losses while also developing new skills needed by the next generation of researchers (e.g., in transdisciplinary thinking). The EU also has an important role in developing global critical mass in research, e.g., by fostering research partnerships, sharing data and infrastructure, and contributing to tackling those problems that can only be addressed at the global scale. The European Commission recently launched an important initiative to assess the need for an international platform for food systems science.⁴

Translating Research Outputs

Ensuring the robustness, legitimacy and relevance of scientific evidence is vital if its impacts on innovation, policy and practice are to be realised. Overcoming obstacles in translation also depends on public confidence in science, the integration of outputs from across diverse disciplines (evidence synthesis for sustainability, Anon 2020), and the accounting of new models (e.g., for open innovation) and trade-offs between different goals, e.g., for nutrition and environment (Fears et al. 2019). Academies of science are well placed to help lead the scientific community at the science-policy interfaces. The EU already has a relatively mature science-policy interface in place, whose operational characteristics may serve as a model for other regions (Fears et al. 2019) and, currently, there is active scientific engagement in a diverse range of public policies in development, including F2F, Common Agricultural Policy and Biodiversity strategy, bioeconomy, circular economy and the European Green Deal. The F2F strategy has important and comprehensive objectives, but it remains vital to clarify and resolve governance challenges, including the tangible links to Member State action (Schebesta and Candell 2020). There is also ambiguity in defining food sustainability and, currently, a mismatch between F2F and the Common Agricultural Policy that must be resolved by developing compatible legal instruments and ensuring better coordination between the relevant Directorate-Generals (for health and agriculture). F2F highlights several controversies, e.g., on the objectives for food pack labelling, targets for pesticide use in farming, and nature-based farming solutions, all of which require a stronger evidence base. Moreover, the modelling of different scenarios for adopting the proposed F2F targets (Beckman et al. 2020) finds reductions in EU agricultural production and diminished competitiveness in both domestic and export markets. Modelling also predicted consequences for the rest of the world, driving up food prices and negatively affecting consumer budgets. While the F2F strategy is rather inward-oriented and has given little explicit attention to external effects in the rest of the world, depending on how incentives/disincentives are applied in the EU, there is a risk of pushing consumers towards the import of food produced less sustainably than in the EU. Therefore, there must be much greater

⁴https://ec.europa.eu/info/news/new-high-level-expert-group-assess-need-international-platform-food-systems-science-2021-feb-17_en

assessment of the potential consequences of the F2F proposals within the broad context of food system transformation.

The EU can also teach a cautionary lesson on the obstacles created by inflexible regulation that delays or impedes the translation of research outputs into innovation and practice. In the case study discussed previously, the EU GMO regulatory framework was found to be inflexible, disproportionate, not based on current scientific evidence and not fit for purpose. Urgent reform of the regulation of new plant (and animal) breeding techniques is essential for agricultural innovation to realise its potential in achieving SDG targets, as well as for the EU to maintain its international competitiveness and to obtain value from its public investment in research (EASAC 2020c). The current obstacles have implications beyond the EU: EU policy decisions have consequences for those lower- and middle-income countries (LMICs) who look to the EU for scientific leadership or as a market for their innovative exports.

In conclusion, the use of science and technology to transform food systems for health, nutrition, sustainable agriculture and the environment depends on progress across a transdisciplinary research agenda, but also on facilitating the use of science by stakeholders, such as farmers, manufacturers, regulators and consumers, as well as policymakers. It is time to be more ambitious in identifying, investing in, and using scientific opportunities. Academies of science stand ready to play their part in catalysing the necessary actions for food systems in transition, and at the science-policy interface.

Acknowledgements This chapter was drafted by Claudia Canales and Robin Fears, in discussion with Volker ter Meulen. We thank colleagues from EASAC, the Biosciences Steering Panel and the Working Group on FNSA (EASAC 2017) for helpful discussions and, in particular, Tim Benton, Thomas Elmqvist and Aifric O'Sullivan for making important points.

References

- Alae-Carew C, Nicoleau S, Bird FA et al (2020) The impact of environmental changes on the yield and nutritional quality of fruits, nuts and seeds: a systematic review. *Environ Res Lett* 15: 023002
- Anderseon L, Benbow HM, Manzin G (2017) Europe on a plate: food, identity and cultural diversity in contemporary Europe. Australian and New Zealand. *J Eurasian Stud* 8
- Anon (2020) Evidence synthesis for sustainability. *Nat Sustain* 3:771
- Battle-Bayer L, Aldaco R, Bala A, Puig R, Laso J, Margallo M, Vázquez-Rowe I, Antó JM, Fullana-i-Palmer P (2020) Environmental and nutritional impacts of dietary changes in Spain during the COVID-19 lockdown. *Sci Total Environ* 748:141410
- Beckman J, Ivanic M, Jelliffe JL, Baquedano FG, Scott SG (2020) Economic and food security impacts of agricultural input reduction under the European Union Green Deal's Farm to Fork and biodiversity strategies. USDA No 1473-2020-1039
- Benton TG (2020) COVID-19 and disruptions to food systems. *Agric Hum Values* 37:577–578
- Benton T, Bailey R (2019) The paradox of productivity: agricultural productivity promotes food system inefficiency. *Glob Sustain* 2:E6. <https://doi.org/10.1017/sus.2019.3>

- Clark MA, Domingo NGG, Colgan K et al (2020) Global food system emissions could preclude achieving the 1.5 °C and 2 °C climate change targets. *Science* 370:705–708
- Coluccia B, Agnusdei GP, Miglietta PP, De Leo F (2021) Effects of COVID-19 on the Italian agri-food supply and value chains. *Food Control* 107839
- Coolsaet B (2016) Towards an agroecology of knowledges: recognition, cognitive justice and farmers' autonomy in France. *J Rural Stud* 47:165–171
- Dasgupta P (2021) Final report – the economics of biodiversity: the Dasgupta review. UK HM Treasury
- Davies WJ, Ward SE, Wilson A (2020) Can crop science really help us to produce more better-quality food while reducing the world-wide environmental footprint of agriculture? *Front Agric Sci Eng* 7:28–44
- De Haan L, Larson S, López-Marqués RL, Wenkel S, Gao C, Palmgren M (2020) Roadmap for accelerated domestication of an emerging perennial grain crop. *Trends Plant Sci* 25:525–537
- Dubey A, Malla MA, Khan F et al (2019) Soil microbiome: a key player for conservation of soil health under changing climate. *Biodivers Conserv* 28:2405–2429
- EASAC (2017) Opportunities and challenges for research on food and nutrition security and agriculture in Europe
- EASAC (2018) Opportunities for soil sustainability in Europe
- EASAC (2019) The imperative of climate action to protect human health in Europe. European Academies Science Advisory Council. <https://easac.eu/publications/details/the-imperative-of-climate-action-to-protect-human-health-in-europe>
- EASAC (2020a) Towards a sustainable future: transformative change and post-COVID-19 priorities
- EASAC (2020b). How can science help to guide the European Union's green recovery after COVID-19?
- EASAC (2020c) The regulation of genome-edited plants in the European Union
- EASAC and FEAM (2021) Decarbonisation of the health care sector. In Press
- Eisenstein M (2020) The hunt for a healthy microbiome. *Nature* 577:S6–S8
- El-Gayar, O.F. and Ofori, M.Q. (2020). Disrupting agriculture: the status and prospects for AI and big data in smart agriculture. *AI and Big Data's Potential for Disruptive Innovation*. IGI Global 174–215
- Eyhorn F, Muller A, Reganold JP, Frison E, Herren HR, Lutikholt L, Mueller A, Sanders J, Scialabba NEH, Seufert V, Smith P (2019) Sustainability in global agriculture driven by organic farming. *Nat Sustain* 2:253–255
- Fanzo J, Covic N, Dobermann A et al (2020) A research vision for food systems in the 2020s: defying the status quo. *Glob Food Sec* 26:100397
- Fears R, ter Meulen V, von Braun J (2019) Editorial. Global food and nutrition security needs more and new science. *Sci Adv* 5:eaba 2946
- Fears R, Canales Holzeis C, ter Meulen V (2020) Designing inter-regional engagement to inform cohesive policy making. *Palgrave Commun* 6:107
- Galanakis CM (2020) The food systems in the era of the coronavirus (COVID-19) pandemic crisis. *Foods* 9:523
- Ghosh TS, Rampelli S, Jeffrey IB, Santoro A, Neto M et al (2020) Mediterranean diet intervention alters the gut microbiome in older people reducing frailty and improving health status: the NU-AGE 1-year dietary intervention across five European countries. *Gut* 69. <https://doi.org/10.1136/gutjnl-2019-319654>
- Global Sustainable Development Report (2019) The future is now – science for achieving sustainable development. UN, New York
- Godfray HCJ, Aveyad P, Garnett T et al (2018) Meat consumption, health and the environment. *Science* 361:eaam5324
- Guimar N, Godinho S, Pinto-Correira T, Almeida M, Bartolini F et al (2018) Typology and distribution of small farms in Europe: towards a better picture. *Land Use Policy* 75:784–798
- Haines A (2021) Health in the bioeconomy. *Lancet Planet Health* 5:e4–e5

- Hameed A, Zaidi SSEA, Shakir S, Mansoor S (2018) Applications of new breeding technologies for potato improvement. *Front Plant Sci* 9:925
- High Level Panel of Experts on Food Security and Nutrition (2019) Agroecological and other innovative approaches for sustainable agriculture and food systems that enhance food security and nutrition. In: Extract from the report: summary and recommendations. Committee on World Food Security
- Hirvonen K, Bai Y, Headey D, Masters WA (2020) Affordability of the EAT-Lancet reference diet: a global analysis. *Lancet Glob Health* 8:e59–e66
- International Union of Food Science and Technology (IUFoST) Interim Report (2020). Available at: <https://iufost.org/wp-content/uploads/2020/05/IUFoST-Interim-Report-May-2020.pdf>
- Jansson S (2018) Gene-edited plants on the plate: the ‘CRISPR cabbage story’. *Physiol Plant* 164: 396–405
- Jarmul S, Dangour AD, Green R et al (2020) Climate change mitigation through dietary change: a systematic review of empirical and modelling studies on the environmental footprints and health effects of “sustainable diets”. *Environ Res Lett* 15:123014
- Jorasch P (2020) Potential, challenges, and threats for the application of new breeding techniques by the private plant breeding sector in the EU. *Front Plant Sci* 11:1463
- Kania, J., Vinohradnik, K. and Knierm, A. (2014). AKIS in the EU: the inventory-final report Vol. II. Report of the Project PRO AKIS – Prospects for farmers’ support advisory services in the European AKIS. Krakow
- Klerkx L, Rose D (2020) Dealing with the game-changing technologies of agriculture 4.0: how do we manage diversity and responsibility in food system transition pathways? *Glob Food Sec* 24: 100347
- Krzysztożek J, Laudanska-Krzeminska I, Bronikowski M (2018) Assessment of epidemiological obesity among adults in EU countries. *Ann Agric Environ Med* 26:341–349
- Leij-Halfwerk S, Verwijs MH, van Houdt S et al (2019) Prevalence of protein-energy malnutrition risk in European older adults in community, residential and hospital settings, according to 22 malnutrition screening tools validated for use in adults > 65 years: a systematic review and meta-analysis. *Maturitas* 126:80–89
- Lillford P, Hermansson A-M (2020) Global missions and the critical needs of food science and technology. *Trends Food Sci Technol*. <https://doi.org/10.1016/j.tifs.2020.04.009>
- Loopstra R (2018) Interventions to address household food insecurity in high-income countries. *Proc Nutr Soc* 77:270–281
- López-Marqués RL, Nørrevang AF, Ache P, Moog M, Visintainer D, Wendt T, Østerberg JT, Dockter C, Jørgensen ME, Salvador AT, Hedrich R (2020) Prospects for the accelerated improvement of the resilient crop quinoa. *J Exp Bot* 71:5333–5347
- Marsden T, Hebinck P, Mathijs E (2018) Rebuilding food systems: embedding assemblages, infrastructures and reflective governance for food systems in Europe. *Food Secur* 10:1301–1309
- Martin-Laffon J, Kuntz M, Ricoch AE (2019) Worldwide CRISPR patent landscape shows strong geographical biases. *Nat Biotechnol* 37:613–620
- McElwee P, Calvin K, Campbell D et al (2020) The impact of interventions in the global land and agri-food sectors on nature’s contribution to people and the UN sustainable goals. *Glob Chang Biol* 26:4691–4721
- Mertens E, Kuijsten A, Dofkova M, Mistura L, D’Addezio L et al (2019) Geographic and socioeconomic diversity of food nutrient intakes: a comparison of four European countries. *Eur J Nutr* 58:1475–1493
- Moran D, Cossar F, Merkle M, Alexander P (2020) UK food system resilience tested by COVID-19. *Nature Food* 1:242
- Newton P, Civita N, Frankel-Goldwater L, Bartel K, Johns C (2020) What is regenerative agriculture? A review of scholar and practitioner definitions based on processes and outcomes. *Front Sustain Food Syst* 4. <https://doi.org/10.3389/fsufs.2020.577723>

- Pineda E, Sanchez-Romero LM, Brown M et al (2018) Forecasting future trends in obesity across Europe: the value of improving surveillance. *Obes Facts* 11:360–371
- Pollard CM, Booth S (2019) Food insecurity and hunger in rich countries – it is time for action against inequality. *Int J Environ Res Public Health* 16:1804
- Potter HK, Rööfs E (2021) Multi-criteria evaluation of plant-based foods—use of environmental footprint and LCA data for consumer guidance. *J Clean Prod* 280:124721
- Power M, Doherty B, Pybus K, Pickett K (2020) How COVID-19 has exposed inequalities in the UK food system: the case of UK food and poverty. *Emerald Open Research* 2
- Ricroch A (2020) The place of Europe in the new plant breeding landscape: evolution of field trials. Available at: <https://www.europeanscientist.com/en/features/the-place-of-europe-in-the-new-plant-breeding-landscape-evolution-of-field-trials>
- Rizou M, Galanakis IM, Aldawoud TM, Galanakis CM (2020) Safety of foods, food supply chain and environment within the COVID-19 pandemic. *Trends Food Sci Technol* 102:293–299
- Rowan NJ, Galanakis CM (2020) Unlocking challenges and opportunities presented by COVID-19 pandemic for cross-cutting disruption in agri-food and green deal innovations: Quo Vadis? *Sci Total Environ* 141362
- Sachs J, Schmidt-Traub G, Kroll C et al (2019) Sustainable development report. Bertelsmann Stiftung and Sustainable Solutions Network, New York
- Saikia B, Singh S, Debbarma J, Velmurugan N, Dekaboruah H, Arunkumar KP, Chikkaputtaiah C (2020) Multigene CRISPR/Cas9 genome editing of hybrid proline rich proteins (HyPRPs) for sustainable multi-stress tolerance in crops: the review of a promising approach. *Physiol Mol Biol Plants* 26:857–869
- Sánchez-León S, Gil-Humanes J, Ozuna CV, Giménez MJ, Sousa C, Voytas DF, Barro F (2018) Low-gluten, nontransgenic wheat engineered with CRISPR/Cas9. *Plant Biotechnol J* 16:902–910
- SAPEA (2020) A sustainable food system for the European Union. SAPEA Evidence Revi Report 7
- Sarkis J, Cohen MJ, Dewick P, Schröder P (2020) A brave new world: lessons from the COVID-19 pandemic for transitioning to sustainable supply and production. *Resour Conserv Recycl*
- Schebesta H, Candel JJ (2020) Game-changing potential of the EU’s farm to fork strategy. *Nat Food* 1:586–588
- Scheelbeek PFD, Bird FA, Tuomisto HL et al (2018) Effect of environmental changes on vegetable and legume yields and nutritional quality. *Proc Natl Acad Sci U S A* 115:6804–6809
- Scherhauser S, Moates G, Hartikainen H, Waldron K, Obersteiner G (2018) Environmental impacts of food waste in Europe. *Waste Manag* 77:98–113
- Schmidt SM, Belisle M, Frommer WB (2020) The evolving landscape around genome editing in agriculture: many countries have exempted or move to exempt forms of genome editing from GMO regulation of crop plants. *EMBO Rep* 21:e50680
- Schreefel L, Schultz RPO, de Boer IJM, Schrijver AP, van Zanten HHE (2020) Regenerative agriculture – the soil is the base. *Glob Food Sec* 26:100404
- Seufert V, Mehrabi Z, Gabriel D, Benton TG (2019) Current and potential contributions of organic agriculture to diversification of the food production system. In: *Agroecosystem diversity*. Academic Press, pp 435–452
- Smith LG, Kirk GJ, Jones PJ, Williams AG (2019) The greenhouse gas impacts of converting food production in England and Wales to organic methods. *Nat Commun* 10:1–10
- Sonnichsen SD, Clement J (2020) Review of green and sustainable public procurement. *J Clean Prod* 245:118901
- Šūmane S, Kunda I, Knickel K, Strauss A, Tisenkopf T et al (2018) Local and farmers’ knowledge matters! How integrating informal and formal knowledge enhances sustainable and resilient agriculture. *J Rural Stud* 59:232–241
- van der Werf HM, Knudsen MT, Cederberg C (2020) Towards better representation of organic agriculture in life cycle assessment. *Nat Sustain* 3:419–425

- van Tassel DL, Tesdell O, Schlautman B, Rubin MJ, DeHaan LR, Crews TE, Streit Krug A (2020) New food crop domestication in the age of gene editing: genetic, agronomic and cultural change remain co-evolutionarily entangled. *Front Plant Sci* 11:789
- Wang J, Vanga SK, Saxena R et al (2018) Effect of climate change on the yield of cereal crops: a review. *Climate* 6:41
- Wei Z, Gu Y, Friman VP et al (2019) Initial soil microbiome composition and function predetermine future plant health. *Sci Adv* 5:eaaw 0759
- Willett W, Rockstrom J, Loken B et al (2019) Food in the Anthropocene: the EAT-Lancet Commission on healthy diet from sustainable food systems. *Lancet* 393:447–492
- World Economic Forum (2020) The future of nature and business
- World Health Organization (2021) Action framework for developing and implementing public food procurement and service policies for a healthy diet. <https://apps.who.int/iris/bitstream/handle/10665/338525/9789240018341-eng.pdf>
- Zhang Y, Li D, Zhang D, Zhao X, Cao X, Dong L, Liu J, Chen K, Zhang H, Gao C, Wang D (2018) Analysis of the functions of Ta GW 2 homeologs in wheat grain weight and protein content traits. *Plant J* 94:857–866
- Zhang Y, Pribil M, Palmgren M, Gao C (2020) A CRISPR way for accelerating improvement of food crops. *Nature Food* 1:200–205

Open Access This chapter is licensed under the terms of the Creative Commons Attribution 4.0 International License (<http://creativecommons.org/licenses/by/4.0/>), which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license and indicate if changes were made.

The images or other third party material in this chapter are included in the chapter's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the chapter's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder.

