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# Opportunities and challenges for research on food and nutrition security and agriculture in Europe




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# EASAC

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Its mission reflects the view of academies that science is central to many aspects of modern life and that an appreciation of the scientific dimension is a pre-requisite to wise policy-making. This view already underpins the work of many academies at national level. With the growing importance of the European Union as an arena for policy, academies recognise that the scope of their advisory functions needs to extend beyond the national to cover also the European level. Here it is often the case that a trans-European grouping can be more effective than a body from a single country. The academies of Europe have therefore formed EASAC so that they can speak with a common voice with the goal of building science into policy at EU level.

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# Foreword

The InterAcademy Partnership (IAP) global network of the world's science academies brings together established regional networks of academies, forming a new collaboration to ensure that the voice of science is heard in addressing societal priorities.

Combating malnutrition in its various forms—undernutrition and micronutrient deficiencies as well as overweight and obesity—is a problem that is faced by all countries. The transformation of agricultural production towards sustainability is a global issue, connected with the global challenges of poverty reduction, employment and urbanisation. International academies of science have a substantial history of interest in these areas, for example as indicated by the InterAcademy Council publication in 2004 'Realizing the promise and potential of African agriculture'. Science has the potential to find sustainable solutions to challenges facing the global and national food systems relating to health, nutrition, agriculture, climate change, ecology and human behaviour. Science can also play a role in partnering to address important policy priorities such as competition with land use for other purposes, for example energy production, urbanisation and industrialisation with environmental connections for resource use and biodiversity. The Sustainable Development Goals adopted by the United Nations in 2015 provide a critically important policy framework for understanding and meeting the challenges but require fresh engagement by science to resolve the complexities of evidence-based policies and programmes.

There is an urgent need to build critical mass in research and innovation and to mobilise that resource in advising policymakers and other stakeholders. Academies of science worldwide are committed to engage widely to strengthen the evidence base for enhanced food and nutrition security at global, regional and national levels. In our collective Academy work, we aim to facilitate learning between regions and to show how academies of science can contribute to sharing and implementing good practice in clarifying controversial issues, developing and communicating the evidence base, and informing the choice of policy options. The current IAP initiative is innovative in bringing together regional perspectives, drawing on the best science. In this project, we utilise the convening, evidence-gathering, and analytical and advisory functions of academies to explore the manifold ways to increase food and nutrition security and to identify promising research agendas for the science communities and investment opportunities for science policy. A core part of this work is to ascertain how research within and across multiple disciplines can contribute to resolving the issues at the science–policy interface, such as evaluating and strengthening agriculture–nutrition–health linkages. Food systems are in transition and in our project design we have employed an integrative food systems approach to encompass, variously, all of the steps involved, from growing through to processing, transporting, trading, purchasing, consuming, and disposing of or recycling food waste.

Four parallel regional academy network working groups were constituted: in Africa (the Network of African Science Academies, NASAC); the Americas (the Inter-American Network of Academies of Sciences, IANAS); Asia (the Association of Academies and Societies of Sciences in Asia, AASSA); and Europe (the European Academies' Science Advisory Council, EASAC). Each had an ambitious mandate to analyse current circumstances and future projections, to share evidence, to clarify controversial points and to identify knowledge gaps. Advice on options for policy and practice at the national–regional levels was proffered to make best use of the resources available. Each working group consisted of experts from across the region who were nominated by IAP member academies and selected to provide an appropriate balance of experience and scientific expertise. The project was novel in terms of its regionally based format and its commitment to catalyse continuing interaction between and within the regions, to share learning and to support implementation of good practice.

These four regional groups worked in parallel and proceeded from a common starting point represented by the agreed IAP template of principal themes. Among the main topics to be examined were the science opportunities associated with the following.

- Ensuring sustainable food production (land and sea), sustainable diets and sustainable communities, including issues for agricultural transformation in face of increasing competition for land use.
- Promoting healthy food systems and increasing the focus on nutrition, with multiple implications for diet quality, vulnerable groups, and informed choice.
- Identifying the means to promote resilience, including resilience in ecosystems and in international markets.
- Responding to, and preparing for, climate change and other environmental and social change.

Each regional group had the responsibility to decide the relative proportion of effort to be expended on different themes and on the various elements within the integrative food systems approach, according to local needs and experience.

All four networks are now publishing their regional outputs as part of their mechanism for engaging with policymakers and stakeholders at the regional and national levels. In addition, these individual outputs will be used as a collective resource to inform the preparation of a fifth, worldwide analysis report by the IAP. This fifth report will advise on inter-regional matters, local–global connectivities and those issues at the science–policy interface that should be considered by inter-governmental institutions and other bodies with international roles and responsibilities. We intend that the IAP project will be distinctive and will add value to the large body of work already undertaken by many other groups. This distinctiveness will be pursued by capitalising on what has already been achieved in the regional work and by proceeding to explore the basis for differences in regional evaluations and conclusions. We will continue to gather insight from the integration of the wide spectrum of scientific disciplines and country/regional contexts.

This project was formulated to stimulate the four regional networks in diverse analysis and synthesis according to their own experience, traditions and established policy priorities, while, at the same time, conforming to shared academy standards for clear linkage to the evidence available. The project as a whole and in its regional parts was also underpinned by necessary quality assessment and control, particularly through peer review procedures.

We anticipated that the regions might identify different solutions to common problems—we regard the generation of this heterogeneity as a strength of the novel design of the project. We have not been disappointed in this expectation of diversity. Although the regional outputs vary in approach, content and format, all four provide highly valuable assessments. They are customised according to the particular regional circumstances but with appreciation of the international contexts and are all capable of being mapped on to the initial IAP template. This latter IAP collective phase of mapping, coordination and re-analysis is now starting. According to our interim assessment, the project is making good progress towards achieving its twin objectives of (1) catalysing national–regional discussions and action and (2) informing global analysis and decision-making.

We welcome feedback on all of our regional outputs and on how best to engage with others in broadening discussion and testing our recommendations. We also invite feedback to explore which priorities should now be emphasised at the global level, what points have been omitted but should not have been, and how new directions could be pursued.

We take this opportunity to thank the many scientific experts, including young scientists, who have contributed their time, effort and enthusiasm in our regional working groups, which have done so much to help this ambitious project to fulfil its promise to be innovative and distinctive. We thank our peer reviewers for their insight and support, and all our academies and their regional networks and our core secretariat for their sustained commitment to this IAP work. We also express our gratitude for the generous project funding provided by the German Federal Ministry of Education and Research (BMBF).

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Co-chair, IAP for Science

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Co-chair, IAP for Science and President, IAP

October 2017

# Summary

National academies of science have a long tradition of engaging widely to strengthen the evidence base to underpin the delivery of enhanced food and nutrition security at regional and national levels. EASAC, the European Academies' Science Advisory Council, has produced this report for European audiences as a contribution to a project worldwide initiated by IAP, the InterAcademy Partnership, the global network of science academies. The IAP work brings together regional perspectives in parallel from Africa, Asia, the Americas and Europe on the opportunities for the science–policy interface, identifying how research can contribute to resolving challenges for agriculture, food systems and nutrition.

Our EASAC report combines analysis of the current status in Europe with exploration of ways forward. Overconsumption of calorie-dense foods leading to overweight and obesity creates a major public health problem in Europe; but Europeans are not immune from other concerns about food and nutrition security and must also recognise the impact of their activities on the rest of the world. We define the goal of food and nutrition security as providing access for all to a healthy and affordable diet that is environmentally sustainable. We recognise the necessity to take account of diversity: in food systems and dietary intakes within and between countries, and in the variability of nutrient requirements in vulnerable groups within populations and across the individual's life cycle.

In our report we take an integrative food systems approach to cover inter-related issues for resource efficiency, environmental stability, resilience and the public health agenda, also addressing issues for local–global interconnectedness of systems. Setting priorities for increasing agricultural production through sustainable intensification must take account of pressures on other critical natural resources, particularly water, soil and energy, and the continuing need to avoid further loss in ecosystem biodiversity. Dealing with food and nutrition security must include both supply-side and demand-side issues: reducing food waste and changing to healthier consumption patterns will reduce pressure on land and other resources.

The United Nations Sustainable Development Goals and Convention on Climate Change objectives provide critically important general frameworks for meeting the challenges to food and nutrition security but mandate renewed engagement by science to clarify trade-offs among goals and address the complexities of evidence-based policies and programmes. For example, it is becoming clearer that climate change will have negative impacts on food systems in various ways, necessitating the introduction of climate-smart agriculture (such as the adoption of plant breeding innovations to cope with drought) but also that agriculture itself contributes substantially to climate change. Mitigating this contribution depends on climate-smart food systems (such as land-sparing and agronomic management practices) together with efforts to influence consumer behaviours associated with excessive agricultural greenhouse gas emissions (overconsumption of calories and high meat intake). Therefore, taking account of the accruing scientific evidence, changing dietary consumption could bring co-benefits to health and to climate change.

In our report we have focused on scientific opportunities: how the current scientific evidence base can shape understanding of challenges by the public, serve as a resource for innovation, and inform policy options, and what the research agenda should be to fill current knowledge gaps. It is urgent to continue to build critical mass in research and innovation and to mobilise that resource in advising policymakers and other stakeholders. We emphasise the vitally important role of basic research in characterising new frontiers in science and of long-term commitment to investing in research to enable, establish and evaluate innovation. This innovation must encompass social and institutional, as well as technological, innovation.

We frame our specific recommendations within the context of strategic dimensions that determine a wide range of actions in science and policy:

- The interfaces between research on the nutrition-sensitivity of food and agriculture systems and on environmental sustainability must be addressed to connect scientific knowledge on natural resources to the food value chain. The sustainable bioeconomy and circular economy provide for new overarching frameworks, going beyond traditional concepts of economic sectors.

- The focus cannot be only on populations in general but should also cover particular issues for vulnerable groups such as mothers and children, the elderly, patients and migrants. This requires systematic, longitudinal data collection to generate robust resources, together with cross-disciplinary research, encompassing economics and social sciences as well as the natural sciences, to understand vulnerable groups and the more general aspects of consumer behaviour.

- Large data sets, based on comparable and verifiable methodology, are a vital tool to support innovation throughout the food system and to prepare for risk and uncertainty. There is much to be done to fill

data gaps, to agree improved procedures for data collection, curation, analysis and sharing, while also addressing data ownership and privacy concerns.

- To contribute with evidence to options for reform of the present Common Agricultural Policy (CAP) towards devising a European Union (EU) food and nutrition policy that rewards innovation, reduces risks, focusses on public goods, takes account of the varying national interests and cultures, and contributes to benefitting the rest of the world.

- EU development assistance should be viewed broadly, to include international collaborative research; research in the EU on priorities for global food systems, their resilience and perturbations; sharing of science and technology especially related to food and nutrition security; and resolution of international governance issues of food and agriculture.

- Ensuring that regulatory and management frameworks are evidence-based, proportionate and sufficiently flexible to prepare for and enable advances in science.

Within this overall framework for European strategy development, our report identifies many opportunities to generate, connect and use research. Among specific scientific opportunities are the following.

**Nutrition, food choices and food safety**

- Understanding the drivers of dietary choices, consumer demand and how to inform and change behaviour, including acceptance of innovative foods and innovative diets.

- Tackling the perverse price incentives to consume high-calorie diets and introducing new incentives for healthy nutrition.

- Clarifying what is a sustainable, healthy diet and how to measure sustainability related to consumption.

- Exploring individual responsiveness to nutrition and the links to health.

- Promoting research interfaces between nutrition, food science and technology, the public sector and industry.

- Evaluating how to make food systems more nutrition-sensitive.

- Characterising sources of food contamination and the opportunities for reducing food safety concerns that may arise from implementation of other policy objectives (for example, the circular economy goal of recycling of waste materials).

- Compiling analytical tests to authenticate food origin and quality.

- Assessing any disconnects between the implications of the 2015 United Nations Climate Change Conference (COP21) objectives for livestock and meat consumption, and standard recommendations for consuming healthy diets.

**Plants and animals in agriculture**

- For livestock, determining how to capitalise on genomics research for food production and for animal health and welfare. This includes the rapidly advancing science of genome editing and the increasing significance of characterising genetic material conserved in gene banks.

- For the oceans, improving the knowledge base for sustainable harvest and culturing of lower trophic level marine resources and exploring the potential for biomass provision to diminish pressures on agricultural land, freshwater and fertilisers.

- For crops, progressing understanding of the genetics and metabolomics of plant product quality. This also includes capitalising on the new opportunities coming within range for the targeted modification of crops using genome editing.

- For plants as for animal science, it is important to protect wild gene pools and to continue sequencing of genetic resources to unveil the potential of genetic resources.

**Environmental sustainability**

- Evaluating climate resilience throughout food systems and transforming food systems to mitigate their global warming impact.

- Capitalising on opportunities to co-design research across disciplines to understand better the nexus food–water–other ecosystem services and to inform the better coordination of relevant policy instruments, including the CAP, Water Framework Directive and the Habitats Directive. Efforts to increase the efficiency of food systems should not focus on increasing agricultural productivity by ignoring environmental costs.

- Developing an evidence base to underpin land and water use in providing the range of private and public goods required in a sustainable way, appropriate to place.

- Regarding biofuel choices, the immediate research objectives for the next generation of biofuels include examining the potential of cellulosic raw materials.

- Research should continue to explore the value of synthetic biology and other approaches to engineer systems with improved photosynthesis. There is also continuing need for research to clarify impacts of biomass production on land use and food prices.

- For soil, expanding research to understand and quantify the potential value of soil in carbon sequestration and, hence, climate change mitigation. There is a broad research agenda to characterise other functions of soil and the soil microbiome and contribute to the bioeconomy, for example as a source of novel antibiotics. Research is also important to support cost-effective soil monitoring and management, particularly to underpin the reduced use of fertilisers and improve biodiversity.

**Waste**

- Committing to the collection of more robust data on the extent of waste in food systems and the effectiveness of interventions to reduce waste at local and regional levels.

- Ensuring the application of food science and technology and agronomy in novel approaches to processing food and reducing waste, and in informing the intersection between circular economy and bioeconomy policy objectives.

**Trade and markets**

- Increasing commitment to data collection on trade flows and prices with modelling and analysis of databases.

- Examining linkages between extreme events and price volatility, evaluating the effects of regulatory policy instruments in agricultural commodity markets and the price transmission between global commodity markets and local food systems.

- Ascertaining the science agenda for understanding the characteristics of fair trade systems, for example the non-tariff conditions associated with variation in regulatory policy, labelling or other food safety requirements.

**Innovation trends**

In each of the above-mentioned specific areas of science opportunities, the linkages between basic science and problem-solving applied science seem likely to become more closely related in the future. This is so in the fields of biosciences, digitisation, mathematics and farm precision technologies, health and behaviour, as well as in complex environmental and food system modelling. This has consequences for the redesign of the science landscape and for science teaching and the training of next-generation scientists to address food, nutrition and agriculture issues.

We emphasise the key role of agricultural sciences for European competitiveness and urge a rebalancing of commitments: to shift budget items from agricultural subsidies towards innovation in the pending reform of the CAP.

It is now important to be more ambitious in identifying and using the scientific opportunities. Our messages are aimed at European and national policymakers, member academies, the scientific community and other stakeholders. We will also use this analysis of European evidence as the regional contribution to the IAP integrated phase of the project, to develop inter-regional and global recommendations.

# 1 Introduction

## 1.1 Global challenges

Global and national food systems present increasing challenges for science communities in tackling issues for health, nutrition, agriculture, ecology and human behaviour, and for encompassing public and private sector research. The Sustainable Development Goals (SDGs) adopted by the United Nations (UN) in 2015 represent a critically important framework for tackling challenges. However, progressing the SDGs requires fresh engagement by science, including the economic and social sciences, to address the complexities of evidence-based policies and programmes.

Academies of science worldwide are committed to engage widely to strengthen the evidence base for enhanced food and nutrition security at global, regional and national levels. In this European Academies' Science Advisory Council (EASAC) report, part of a worldwide InterAcademy Partnership (IAP) project, we discuss critical issues for Europe within the context of this global project; our messages on how science can help to resolve them are aimed at European Union (EU) and national policymakers, the wider science community and other stakeholders. We emphasise that the desired outcome for food and nutrition security is access for all to a healthy and affordable diet that is environmentally sustainable. With our report, we also aim to contribute to the broader IAP project objective of facilitating learning between regions and to show how academies can contribute to sharing and implementing good practice on these vitally important topics.

There are three sets of nutrition issues that exist in parallel and are partly connected: hunger and undernutrition, micronutrient deficiencies, and overnutrition with obesity. This represents a triple burden to public health and highlights the importance of nutrition security as well as food security (Horton and Lo, 2013). Increasing numbers of people are overweight or obese and many consume calorie-dense but nutrient-poor diets. At the same time, according to the latest UN Food and Agriculture Organization (FAO) assessment (FAO, 2017), worldwide 815 million people in 2016 were chronically undernourished in terms of calorie deficit to meet energy needs to lead a healthy and active life, which is 38 million more people than the previous year (FAO, 2015). The number affected by caloric deficiency has decreased by about 20% in the past decade but an additional approximately two billion people suffer from undernutrition from micronutrient deficits. Data from the Global Hunger Index (International Food Policy Research Institute (IFPRI) *et al.*, 2016) indicate significant progress in many countries in reducing calorie deficiency but less progress on child stunting and micronutrient deficiencies.

The major global challenges for delivering food and nutrition security[1] are compounded by the pressures of the growing population (projected to reach over 9 billion by 2050 with 70% of the population in urban areas compared with 50% today), climate change, other global environmental changes, and economic inequity and instability (Pretty *et al.*, 2010; UNESCO, 2010; GOS, 2011). In addition, lack of quality and safety of diets, risk-prone food distribution systems and adverse nutrition behaviour and lifestyles, resulting in obesity, are of increasing concern, including in the EU. It is vitally important to develop food systems that are nutrition-sensitive.

Historically, global production of staple foods has increased faster than consumption, leading to reduction in prices. However, this greater supply is now slowing because of production constraints[2] together with further increase in demand because of the population growth, exacerbated by changing dietary patterns (in particular global meat consumption). A healthy diet has become more expensive, although the assessment of relative costs can be complex, as discussed subsequently. Setting priorities for increasing agricultural production must take account of pressures on other critical resources, particularly water, soil and energy, and the continuing imperative to avoid climate change and further loss in ecosystems services and biodiversity. Agriculture currently accounts for 40% of the Earth's land surface and 70% of the world's use of fresh water; the UN predicts that irrigation demands will increase by up to 100% by 2025. About 2% of calories and 15% of protein of human food is obtained from products from the sea.

Agriculture and the food system also currently account for about 30% of energy consumption, and just under one-third of greenhouse gases originate from

[1] Food security as defined by the FAO occurs 'when all people, all of the time, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life.' This definition is discussed further in this chapter and in Chapter 3.

[2] Without major technological intervention, growth in crop yields will continue to level out: globally the current rate of growth of yields of major cereal crops has slowed from 3.2% per year in 1960 to 1.5% per year in 2000 (statistics summarised by UK Global Food Security programme, www.foodsecurity.ac.uk and discussed in detail by Alston *et al.* (2014)).

agriculture and food[3]. Moreover, up to one-third of the world's food production is lost or wasted according to some estimates, it being calculated that the food wasted by the EU and North America is equivalent to the total food production of sub-Saharan Africa (Steering Committee of the EU scientific programme for Expo 2015).

Consideration of food and nutrition security must encompass both supply-side and demand-side issues. Reducing waste will reduce pressure on land and other natural resources. Therefore, achieving food and nutrition security raises important issues for resource efficiency, environmental sustainability, resilience and the public health agenda. There is urgent need for adopting an integrative food systems approach (GOS, 2011; Steering Committee of the EU scientific programme for Expo 2015), to cover the inter-related issues for resource efficiency, environmental sustainability, resilience and the public health agenda, within the context of the local–global connectedness of systems.

### 1.2 Improving the evidence base for attaining food and nutrition security

Achieving food and nutrition security, including tackling the issues for overconsumption[4], necessitates addressing the various physical, biological and socio-economic constraints that limit the ability of people to access a healthy diet (Quentin *et al.*, 2015). Poverty is a significant factor in the lack of food and nutrition security: for example, there is evidence to show that the national prevalence of stunting from malnutrition is proportional to gross domestic product (Ruel *et al.*, 2013). There may be particular problems for vulnerable groups in the population, such as mothers and children (Horton and Lo, 2013). According to the FAO, food security covers issues for food availability (is there enough?), access (can it be reached?), affordability (at a fair price), quality (is it edible?), nutrition (as part of a balanced diet) and safety (could it harm health?). Nutrition security requires adequate food, hygiene, health and social care.

Taking the food systems' view, the challenge is to provide the world's growing population with a sufficient, sustainable, secure supply of safe, nutritious and affordable high-quality food using less land with lower inputs and in the context of global climate change and declining natural resources: this requires better understanding of the trade-offs between different policy actions. We note that a food systems' view requires clear definition of the sub-systems under consideration, to avoid vague conceptualisation. A system whose boundaries, external forces and internal functional relationships are not well defined is not a meaningful framework.

Tackling the food systems' challenges requires new knowledge from the natural and social sciences[5] as a resource for innovation and for informing policy options across a very broad front. Scientific knowledge is a global public good, provided by a wide range of research institutions, supported by a wide range of funders. There is need to give increased prominence to all the elements necessary in a global research agenda to improve food and nutrition security (Haddad *et al.*, 2016)[6]. As discussed in detail elsewhere (e.g. von Braun and Kalkuhl, 2015; Steering Committee of the EU scientific programme for Expo 2015), collective engagement is essential to clarify the knowledge gaps and priorities and to improve policy and science interaction. Enhancing the science–policy interface for food and nutrition security requires improving efforts to reflect the diversity of international science insights, to exchange and coordinate between disciplines and individual research efforts, to promote transparency in synthesis and assessment of new knowledge and to increase the legitimacy of assessments and recommendations to governments and society (von Braun and Kalkuhl, 2015).

### 1.3 Food and nutrition security and sustainable development

It is necessary to do more to understand what makes a healthy and sustainable diet and how it may be produced and accessed. The magnitude of the challenge for the global and EU food systems is such that action is needed throughout the system: moderating demand, reducing waste, improving governance, as well as producing more food (Dogliotti *et al.*, 2014). Every country is co-dependent to a greater or lesser degree on local production and global trade. In addition to production and trade flows, knowledge and science information flows are of growing importance. Understanding this interconnectedness between local

[3] Taking into account also the consequences of land use change. In 2012 the EU-28 agricultural activities directly generated carbon dioxide equivalent to about 10% of total greenhouse gas emissions, ranging from 2.5% for Malta to 31% for Ireland (data published July 2015 on http://ec.europa.eu/eurostat/statistics-explained/index.php/File:Greenhouse_gas_emissions,_by_country,_2012.png). The energy required to ensure food supply in the EU amounted to about one-quarter of the EU's energy consumption (in 2013; Monforti-Ferranto and Pascua, 2015). The share of renewable energy in the food sector is relatively small (7%) compared with its part in the overall energy mix (15%).

[4] The term 'overconsumption' has been used in a variety of ways in research and there is further need to generate a clear and consistent definition (Hakansson, 2014).

[5] Relevant science can be defined as 'the pursuit and application of knowledge and understanding of the natural and social world following a systematic methodology based on evidence' (www.sciencecouncil.org).

[6] The work of Haddad and co-authors draws on a major recent study by the Global Panel on Agriculture and Food Systems for Nutrition, *Food systems and diets: facing the challenges of the 21st century*, available at http://www.glopan.org/foresight.

and global systems directs attention to a wide range of issues for trade networks, land use, climate change and the health–nutrition–sustainability relationships. The necessary actions will require implementation of diverse policy initiatives and transition to a new economic system in which a central issue is the internalising of current externalities, for example allocating economic value to environmental impacts of food systems (Ehrlich and Harte, 2015).

As part of the wider considerations for local–global interconnectedness in food systems, the effects on food production must be achieved with less impact on the environment (German *et al.*, 2016): sustainable intensification to enhance the efficiency of inputs and land use. Which mechanisms are chosen for delivering sustainable intensification has numerous implications: for example, for biodiversity and ecosystem services, relationship to nutritional quality and animal welfare (Godfray and Garnett, 2014). Throughout the present report, environmental issues will be discussed in relation to agriculture, with regard to climate change, use of water and energy, soil health, opportunities for reducing waste and for introducing precision agriculture. It is vitally important to take this integrated view to tackle cross-cutting issues and identify opportunities for cross-disciplinarity without losing the essential science focus.

The links between food and nutrition security and sustainable development are embedded in the SDGs[7] with a necessarily close relationship between different SDGs in support of food and nutrition security[8]. SDG2 (end hunger, achieve food security and improved nutrition, and promote sustainable agriculture) is closely connected with SDG1 (poverty alleviation), SDG3 (ensure healthy lives), SDG5 (gender equality), SDG6 (water), SDG7 (energy), SDG 12 (sustainable consumption and production), SDG13 (climate change) and SDG15 (land use and management). When building on this close connectivity, there is more to do to ensure that the focus on nutrition is well integrated in pursuit of the SDGs, with specific, quantifiable targets (Anon, 2014). It is essential for food and nutrition security policy at the regional and global levels to be integrated across areas in a multi-sectoral approach and for there to be policy integration at the different levels of governance within and between countries (Holzapfel and James, 2016). The Global Nutrition Report (2016)[9] provides comprehensive analysis of the critical issues at the country and region levels, with a call to action for political decision-makers that requires more investment and better allocation, better data and sharing good practice to tackle malnutrition in all its forms.

### 1.4 Obesity

At the same time as billions suffer food deficiencies because of lack of calories and nutrients, significant numbers worldwide are overweight or obese and, again, this is often associated with low income. Lifestyles and excess consumption of food or over-reliance on energy-dense, nutrient-poor foods increases personal health burdens and public health impacts, being a risk factor, for example, for the non-communicable diseases (NCDs), diabetes, heart disease and cancer. Overconsumption of calories can co-exist with malnutrition in terms of essential micronutrients.

A study of body mass index trends between 1975 and 2014 confirmed that there are now more obese than underweight people in the world (NCD Risk Factor Collaboration, 2016). However, the respective public health burdens of overweight and hunger/micronutrient deficiencies should not be quantified only in terms of numbers affected, and it is necessary to explore in much more detail the relative effects on morbidity, longevity, lifetime social costs and inter-generational aspects. The problems are also not equivalent in the sense that there is less robust scientific evidence for interventions to tackle obesity (Aveyard *et al.*, 2016) compared with the body of knowledge on how to tackle hunger and micronutrient deficiencies.

Although it is critically important not to concentrate attention on obesity at the expense of the continuing recognition of the substantial burden of undernutrition in an unequal world (Smith, 2016), the marked rise in obesity in the EU is a significant challenge to the public health research and policy agenda. The latest data from Eurostat[10] indicate that 16% of the EU population are obese (body mass index greater than 30), with national figures ranging from Romania (9%) and Italy (11%) to Hungary (21%), Latvia (21%) and Malta (26%). Slightly more than half of EU adults (52%) are considered overweight. EU food strategy has, hitherto, given relatively little attention to obesity, and this needs to be reformed as part of the construction of an EU food policy[11].

The over-abundance of calorie-dense foods and less access (through price) to nutrient-dense foods is a major

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[7] For example, as discussed in the report by IFPRI (2016), describing how food systems can contribute to meeting SDGs.
[8] For example, as discussed by the FAO in 2016, on http://www.fao.org/3/a-i5499e.pdf.
[9] The IFPRI Global Nutrition Report is funded by the Gates Foundation, European Commission, CGIAR and several individual national government agencies: www.globalnutritionreport.org/the-report.
[10] http://ec.europa.eu/eurostat/documents/2995521/7700898/3-20102016-BP-EN.pdf/c26b037b-d5f3-4c05-89c1-00bf0b98d646.
[11] Recent analysis of overconsumption at the Member State level recommends that interventions must be evaluated within a wider consumption strategy that integrates biological, economic, physical and social drivers of overconsumption ("Overconsumption and influences on diet", Global Food Security Insight August 2016, on https://www.foodsecurity.ac.uk/blog/eyeing-up-intake-an-insight-on-overconsumption-and-diet/).

issue for Europe. Overconsumption is a challenge for the efficiency of land use as well as for health. Tackling obesity and overweight has implications for the whole of food systems, including agriculture, and for personal behaviour: for both policy development and the research agenda, as will be discussed subsequently.

### 1.5 The situation on food and nutrition security in Europe

The EU is also not immune from other concerns about food and nutrition security, and food systems have to become better integrated as a pillar of the EU's bioeconomy. The proportion of EU households unable to afford access to the minimum amount generally recommended in dietary guidelines has increased since 2010, after having declined over the period 2005–2010, and reports from UK, Greek, Spanish and French charities indicate rises in the number of people seeking emergency food support (Loopstra *et al.*, 2015). However, the Global Hunger Index (IFPRI *et al.*, 2016) shows significant reductions in the hunger index for several eastern European countries over the period 1992–2016.

Further analysis of the broader issues in regional and country assessment for food and nutrition security across Europe can be found elsewhere[12], and more detail is also provided in section 3.1. It is pertinent to emphasise that, because the EU imports much of its food and animal feed, it is vulnerable to anything that affects exports from the producing countries. Moreover, the EU has a responsibility to ensure that measures taken to satisfy domestic food and nutrition security objectives do not create additional problems for other regions in terms of their use of land, water and other resources (for example, fertiliser (Nesme *et al.*, 2016)). Thus in terms of the local–global connectedness (section 1.3) for producing a healthy, sustainable diet, it is imperative to consider both the local issues for Europe and what European actions (in research, agriculture and other policy sectors) can do in global development. The interconnections between regions are complex. The contribution of food insecurity in triggering societal insecurity globally (Koren and Bagozzi, 2016) has multiple implications for the EU if civil unrest outside the EU then leads to increased migration to the EU[13].

### 1.6 IAP and EASAC

The IAP is the global network of more than 130 science academies aiming to harness the power, authority and credibility of its member academies and to access their combined scientific talent. Recent structural changes[14] have resulted in a new integrated organisation by merging what was the InterAcademy Panel together with the InterAcademy Medical Panel and InterAcademy Council.

Many national science academies have a tradition of responsibility in ensuring that the collective voice of science is heard in major policy debates. By engaging with its four regional academy networks (for Africa, the Americas, Asia, and Europe), IAP now has the capacity to advise on the science dimensions of policy-making at the global level and across disciplines. Many member academies and the regional academy networks have previously conducted their own studies in areas relevant to food and nutrition security. In November 2014, the IAP Board and Executive Committee agreed that this was a vitally important topic with which to pioneer a new series of IAP projects.

The IAP project will produce four regional reports together with a global synthesis that highlights the similarities and differences between the regions, explores inter-regional issues, providing advice and recommendations for implementation at global, regional and national levels, customised according to local circumstances and strategic needs. Thus, this IAP activity combines twin goals of delivering strong consensus messages at the global level, with clarification of the scientific basis of current disparities in policy expectations, objectives and options in the different regions of the world. The IAP project was initiated with a meeting at the German National Academy of Sciences Leopoldina in June 2015, bringing together experts to advise where work by IAP and its regional academy networks might add value to the considerable volume of work already conducted by many other scientists in seeking to inform policymakers. Collective discussion following this initial step helped to develop a common, agreed template to inform and guide all four regional Working Groups (summarised in Box 1 with further details elaborated in Appendix 1). Necessary components of this shared template are to understand regional characteristics, to delineate the significant opportunities and challenges where science can help to inform policy-making and serve as a resource for innovation, to address the impact of the cross-cutting determinants of the various priorities, and to advise on how to mobilise scientific resource.

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[12] The Economist Intelligence Unit 2014, 'Food security in focus: Europe 2014' on http://foodsecurityindex.eiu.com; FAO regional office for Europe (with a main focus on the Caucasus) on www.fao.org/3/a-i4649e.pdf. Eurostat statistics on the EU food chain, 'Farm to fork', from 2011, are on http://ec.europa.eu/eurostat/en/web/products-press-releases/-/5-22062011-BP.

[13] For example, drought in Syria may have helped to trigger the civil unrest and conflict that displaced populations (Kelley *et al.*, 2015) and promoted migration to the EU.

[14] www.interacademies.net/News/PressReleases/29843.aspx.

**Box 1 Summary of IAP template questions**

1. What are key elements to cover in describing national/regional characteristics for food and nutrition security and agriculture (FNSA)?
2. What are major challenges/opportunities for FNSA and future projections for the region?
3. What are strengths and weaknesses of science and technology at national/regional level?
4. What are the prospects for innovation to improve agriculture, at the farm scale?
5. What are the prospects for increasing efficiency of food systems?
6. What are the public health and nutrition issues with regard to impact of dietary change on food demand and health?
7. What is the competition for arable land use?
8. What are other major environmental issues associated with FNSA, at the landscape scale?
9. What may be the impact of national/regional regulatory frameworks and other sectoral–inter-sectoral public policies on FNSA?
10. What are some of the implications for inter-regional/global levels?

See Appendix 1 for further details.

EASAC is formed by the national science academies of the EU Member States, and its Council is composed of experienced scientists nominated one each by the EU national science academies, by Academia Europaea and by ALLEA (ALL European Academies, the European Federation of Academies of Sciences and Humanities). The national science academies of Norway and Switzerland are also represented. Functioning as the European arm of the IAP project, EASAC in this report represents all of Europe, not only the EU countries.

EASAC has significant previous experience in working on areas relevant to the present project and some of our work is briefly summarised in Appendix 2. EASAC constituted an expert Working Group formed from member academy nominations and other invited experts (Appendix 3) to identify and clarify the critical issues for Europe within the overall project defined by IAP.

### 1.7 Objectives and scope of this EASAC report

EASAC key messages and recommendations in this report are aimed at EU and national policymakers, member academies, others in the science community and other stakeholders. We also continue to engage with colleagues in the other regional networks to share evidence, key issues and evaluation. Our ambitions are to explore and clarify where there is consensus on key questions and to advise where further assessment of the issues is required with particular regard to (1) facilitating the translation of scientific advances into applications for societal benefit and into informing the choice of policy options; (2) identifying where there are particular scientific opportunities for inter- and trans-disciplinary research throughout food systems, building on the strengths in individual disciplines; and (3) emphasising that what happens in the EU often has significant international ramifications. We highlight the importance of basic research in helping to characterise new frontiers in science and of the long-term commitment to research that is often required (for example, to assess new crops or other innovation). We also acknowledge and discuss the continuing roles of academies: in clarifying and auditing the achievements of research (including the objectives of enhanced cooperation and reduction of unnecessary competition), in building an enduring scientific capacity to deliver, in engaging with other national and international organisations, and in assessing of inter-country and inter-regional issues.

We recognise, of course, that there may be considerable diversity in agriculture and food systems across Europe and that country-specific approaches are often vitally important. Our report does not provide a country-by-country analysis of the situation for food and nutrition security in Europe because the statistics and assessment are available elsewhere (Box 2 and see also footnote 12). Other relevant analysis at the country level will be cited where appropriate throughout our report. Where there is diversity within a country or across a region, we note the importance of devising frameworks to learn from that diversity.

There is much still to be done to fill knowledge gaps. What is a diverse, sustainable and nutritious diet? How do individuals respond to nutrients and what drives nutrition behaviour? How can food waste, and concomitant waste of natural resources, be reduced? How can changes in consumer demand, particularly to reduce overconsumption, be incentivised? How can climate resilience be fostered? How should land and marine resources be best utilised to avoid the negative effects of agriculture on the environment? How could yields be increased and what role should the biosciences play? And how do we connect these questions towards achieving sustainable healthy diets for all? Research and innovation have already contributed very significantly to food and nutrition security but it is important to be more ambitious in identifying and using the scientific opportunities.

Our starting point is that the research and innovation capabilities of the EU can do much to answer some of these questions, with resultant global as well as EU impact. But this will only happen if it is appreciated that capitalising on scientific opportunity is something that should pervade EU policy widely and not just a matter for those involved in funding and prioritising

**Box 2 European country assessments**

Detailed statistics on EU land cover and land use are provided by Eurostat, http://ec.europa.eu/eurostat/statistics-explained/index.php/LUCAS_-_Land_use_and_land_cover_survey.

Comprehensive data and analysis on agricultural statistics and indicators in the EU are provided by DG Agriculture and Rural Development, http://ec.europa.eu/agriculture/statistics. The evaluation includes agricultural data for each Member State and farm economy assessment, rural development indicators and agricultural trade statistics. Since 1966, the Farm Structure Survey has provided harmonised data on the structure of European farms. As part of the *Strategy for Agricultural Statistics 2020 and Beyond*, the European Commission is proposing a new approach for integrated farm statistics, in line with FAO's programme for agricultural censuses, to create a more coherent, flexible and interlinked system of agricultural statistics that will serve as a resource to inform policy[15]. There are further opportunities to align and integrate agricultural statistics with the EU Statistics on Income and Living Conditions (EU-SILC, see later) and Organisation for Economic Co-operation and Development (OECD) health data[16].

There has been significant analysis of the impact of EU membership on new Member States. For example, work by the FAO Regional Office for Europe and Central Asia (Csaki and Jambor, 2009) provided a comprehensive assessment of the diverse effects of EU membership on arable land use, agricultural labour and agriculture as a contributor to gross domestic product. This evaluation concluded that those new Member States with consolidated farm structure adjusted faster and more effectively to the demand of the EU enlarged markets compared with those countries undergoing land reform and farm restructuring processes.

Key characteristics of Member State diversity continue to be subject to research supported by the European Commission. For example, the Diversifood Horizon 2020 project is examining the diversity of cultivated plants within the various European ecosystems, www.diversifood.eu.

Regarding Europe as a geographical area, the FAO Regional Office provides extensive data on diversity in its analysis of Europe (with particular focus on parts of Eastern Europe and the Caucasus). The latest regional overview of food insecurity in Europe and central Asia (published 2017, evaluating the status in 2016, http://www.fao.org/publications/rofi-euca/en) draws on the FAO experience of the past 23 years to conclude that sustained economic growth is key to ensuring food security in the region. For the population of most countries in the region, the burden of overweight and obesity in terms of disability-adjusted labour years now far exceeds that from undernutrition. Policies aimed specifically at malnutrition that are judged from this FAO assessment to have worked in the region include food fortification with vitamins and minerals; food reformulation to reduce salt, saturated fats and sugar; fiscal measures such as taxes on soft drinks and sugary foods; public health and nutrition information campaigns to increase public awareness; and nutrition labelling to increase consumer awareness.

the research agenda. For example, as discussed in subsequent chapters, there are highly relevant intersections of the research agenda with Common Agricultural Policy (CAP) and rural development policy reform; with current progress of the Circular Economy Package, and with the establishment of the bioeconomy; for considering the priorities for food aid within EU borders as well as part of external development policy; and with the regulation and implementation of emerging technologies and social innovation. Although the EU has the long-standing CAP, it does not have a common food and nutrition policy. Whether it would be desirable to have such a policy content is an institutional and policy research matter to be explored.

Moreover, science in food, nutrition and agriculture needs to be communicated well and in understandable ways, and science must interact with society at large, including the media and the education system. We recognise, of course, that this is a complex mix for policy formulation and that many of the relevant issues are already being addressed by other advisory groups. We discuss some of this other work in Chapter 2: it is the aim of EASAC and IAP to add value to what is already being achieved by other groups. Later chapters in our report review critical issues for food and nutrition security in Europe, in particular the efficiency of food systems, the relationships between diet and health, the opportunities for innovation, and the implications for sustainable development.

[15] European Parliamentary Research Service, PE 599.399, April 2017, http://www.europarl.europa.eu/RegData/etudes/ATAG/2017/599399/EPRS_ATA(2017)599399_EN.pdf.
[16] One initiative to capitalise on new developments in understanding dietary habits and the nutritional status of population groups in tackling the challenges of nutrition monitoring is the 2017 conference organised by the German Federal Research Institute of Nutrition and Food, https://www.mri.bund.de/en/about-us/events/max-rubner-conference/2017/.

# 2 Science and policy context

Tackling food and nutrition security issues requires strong commitment by policymakers, but also robust scientific knowledge as noted in Chapter 1, and transparent public debate on mechanisms, trade-offs and risks.

Among the relevant national and EU policies that determine the broad strategic environment for FNSA are the following.

- Policies that affect technological or other innovation in food systems (e.g. to reduce waste, introduce new raw materials) and farming (e.g. pesticide use, antibiotic use, organic farming) and more broadly (e.g. bioeconomy).
- Policies that build human resources (e.g. education and training, attracting young people to work in food systems and research).
- CAP and other policies that help to redesign the whole agricultural economy (e.g. land use, other rural development, recycling, production in the internal market).
- Health policies, including access to health care.
- Social policies, including access to food.
- Policies to promote consumption of sustainable, healthy food and to regulate food safety.
- Policies on climate and energy use, water availability and quality, habitats and biodiversity.
- Policies that mediate the relationship between the EU and the rest of the world (e.g. trade agreements, and development aid).

In addition to ensuring that scientific evidence can inform policy options in specific areas, it is also necessary to use the scientific opportunities to build better policy interconnections and coherence (GOS, 2011), reducing current operational disconnects between different policy areas (see, for example, EASAC 2013a) and resolving conflicts between the goals of different policy initiatives, at both regional and global levels. This is a task for the EU as well as the Member States because many of the policy areas for which the European institutions have responsibility are relevant to food and nutrition security, including agriculture, aquaculture, development, trade, food safety, consumer health, environmental protection, industry, public sector research and innovation. Equally it is necessary to mobilise scientific resource and use the evidence base to evaluate whether current policy interventions are effective: that is, what works?

The various groups that have a role to develop policy and to advise on the scientific contribution to policy-making have been described elsewhere (von Braun and Kalkuhl, 2015; Steering Committee of the EU scientific programme for Expo 2015) and will not be comprehensively assessed again here, although it is important to emphasise the point that there needs to be better alignment between the disparate groups. It is relevant to note that significant inputs to EU strategy are made by groups that have a broader international scope, for example the G20 group[17], non-governmental organisations[18] and the private sector[19]. In this context, it is important also to emphasise the point that all scientific inputs must be subject to appropriate peer review and that the policy users of research outputs must be aware of the potential influence of vested interests. The European Commission emphasises that the private sector needs to be involved in driving solutions for a healthy sustainable diet, but in the EU both corporate investment in research and development and the uptake of innovation by the food sector have been relatively low by comparison with international competitors. It is also relevant to remember that European Commission-initiated research funding, such as Horizon 2020, is only a small proportion of the total research funding in the EU: it is necessary to take account of Member State actions and the role of European Commission initiatives in ensuring collaboration between national research programmes.

A full coverage of all relevant research is beyond the scope of our report. We confine the remainder of this chapter to exemplifying some relevant activities in the EU where advisory activity draws on scientific opportunity to evaluate issues for FNSA. In aggregate, this constitutes part of the accumulating evidence base on which our report will build.

## 2.1 Joint Research Centre

The Joint Research Centre (JRC) has covered a wide range of relevant topics[20] including: precision agriculture

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[17] G20 Food Security and Nutrition Framework.
[18] Oxfam report 'Growing a Better Future' 2011, http://policy-practice.oxfam.org.uk/publications/growing-a-better-future-food-justice-in-a-resource-constrained-world-132373.
[19] For example, www.nestlefoundation.org.
[20] The breadth of JRC work is reviewed in their annual report, https://ec.europa.eu/jrc/sites/default/files/jrc_ar_2014_en.pdf. Further details on JRC work on agriculture and food security are on https://ec.europa.eu/jrc/en/research-topic/global-food-security.

(and its potential role in the CAP); crop yields; issues for fisheries; nutrition (e.g. in promoting healthy ageing); and public procurement (e.g. in national school food policies and their role in reducing childhood obesity). Among the major recent JRC activities are the following.

1. Forecasting trends in the EU's agricultural commodities for the next ten years, highlighting tensions between achieving the three objectives for food security, environmental protection and climate action[21].
2. Foresight report to guide future EU policies for global food security[22].

## 2.2 European Parliament

The Science and Technology Options Assessment (STOA) Panel commissioned a very large project 'Feeding the 10 billion', which will be discussed where appropriate in subsequent sections. Since then, a briefing from the European Parliamentary Research Service (EPRS; Lerch *et al.*, 2015) described EU commitments to food security outside the EU as a strategic priority for EU development policy. These EU activities have been welcomed by the European Parliament, which also emphasises the importance of policy coherence, in particular between policies for energy, trade, rural development and agriculture.

The European Parliament Agriculture Committee (COMAGRI) is also very active concerning many of the issues raised in this EASAC report. For example, their report[23] on '*Technological solutions for sustainable agriculture*' emphasises the importance of precision farming, use of big data, genetic diversity, precision breeding, skills development and research funding, making the point that innovation and sustainability are mutually supportive rather than competing policy objectives. However, in the European Parliament plenary vote in June 2016, much of the proposal made by the Agriculture Committee to develop supportive and enabling political and regulatory framework for plant breeding and crop protection innovation was not backed by other parliamentarians[24].

## 2.3 EU-funded research and innovation initiatives

The European Commission continues to be very active in supporting research groups. For example, the Framework Programme (FP) 7 project FoodSecure[25], with a strong emphasis on policy research, promotes interdisciplinary work to explore the future of global food and nutrition security, and has helped to inform the EU research–policy interface. Other FP 7 projects will be cited in our subsequent chapters and it is noteworthy that other EU support is also available, for example from cohesion (regional) funds.

Horizon 2020 includes a significant agenda for agricultural research and the bioeconomy in support of food security and sustainable agriculture covering, for example, food consumption, behaviour and diets; phenotyping and genotyping of crop plants to improve health, yields and climate adaptability; animal health and the control of infectious diseases; crop harvesting, storage and distribution; life-cycle analysis to cut waste; environmental impacts of agricultural practices and their effects on landscapes; sustainable, competitive multi-functional agriculture and rural development, including forestry; fisheries management and aquaculture; second-generation biofuels and other bio-based products and processes.

### *2.3.1 Joint programming initiatives*

Horizon 2020 also continues commitment to partnership approaches to research and innovation. The Standing Committee on Agricultural Research (SCAR)[26] promotes coordination between Member States with the support of the European Commission, for example in initiating the two Joint Programming Initiatives (JPIs) on Agriculture, Food Security and Climate Change (FACCE) and A Healthy Diet for a Healthy Life (HDHL). Detail on these two, centrally important JPIs is in Appendix 4.

### *2.3.2 ERA-NETs*

Providing support to coordinate Member State research funding is also the main objective of the European Research Area Network (ERA-NET) scheme and there are now 30 ERA-NETs in the bioeconomy sector. Relevant agricultural topics range from animal health to biodiversity and biomass. For example, the ICT-Agri[27] ERA-NET combines information and communication technologies, robotics and agricultural research as part of precision farming (see also section 6.5).

The EU continues its broad commitment to bioeconomy policy in various ways that include objectives for

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[21] 'Medium-term prospects for EU agricultural markets and income 2015-2025', https://ec.europa.eu/agriculture/markets-and-prices/medium-term-outlook_en.
[22] 'Global food security 2030 – assessing trends in view of guiding future EU policies', https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/global-food-security-2030-assessing-trends-view-guiding-future-eu-policies.
[23] 2015/2225(INI) on http://www.europarl.europa.eu/sides/getDoc.do?pubRef=-//EP//TEXT+REPORT+A8-2016-0174+0+DOC+XML+V0//EN.
[24] www.seedquest.com, news item 8 June 2016.
[25] FoodSecure 2012–2017; details of the research–policy interface are on www.foodsecure.eu/NewsDetail.aspx?id=54.
[26] https://ec.europa.eu/research/scar/index.cfm.
[27] www.ict-agri.eu.

resilient/resource-efficient value chains, environment-smart and climate-smart primary production, a competitive food industry, and healthy and safe food and diets for all[28]. Furthermore, bioeconomy policy instruments have been reviewed recently by the EPRS[29]. There is further discussion of the bioeconomy in Chapter 7.

#### *2.3.3 European Innovation Partnership*

The European Innovation Partnership on Agricultural Productivity and Sustainability (EIP Agri[30]), aims to foster technological, organisational and social innovation by building links between research and those who use it—farmers, businesses, non-governmental organisations—in support of strengthening innovation in rural development in the CAP.

The European Institute of Innovation and Technology activity on food (EIT Food)[31] is also an important initiative, a consortium of 50 partners from the public and private sectors in 13 countries, addressing issues for consumer trust, healthier nutrition, sustainability, and education in food systems, with the aim of developing food entrepreneurship and innovation.

#### *2.3.4 European Technology Platforms*

European Technology Platforms (ETPs) are designed to support EU competitiveness and reduce fragmentation in research and development. Again, there are a wide range of ETPs aiming to refine Strategic Research Agendas for the bioeconomy. These include Plants for the Future (see also section 6.3); FABRE-TP (sustainable farm-animal breeding); Food for Life; ETPGAH (global animal health); Suschem (sustainable chemistry); FTP (forest-based sector); Manufacture (agriculture engineering); EATiP (aquaculture); EBTP (biofuels); and BECOTEPS (bioeconomy coordination).

### 2.4 Expo 2015

Expo 2015 was an important recent EU initiative focusing on food and nutrition security. This initiative and the resultant report (Steering Committee of the EU scientific programme for Expo 2015) aimed to stimulate debate across a wide variety of issues for global food and nutrition security, and the role of EU research and innovation in meeting the challenges identified. A main message from this work, covering demand-side as well as supply-side issues, is that there is considerable scope for further progress in many areas: to grow more food, reduce environmental impact, eat more healthily, reduce waste and ensure food systems are more equitable. In addition to clarifying priorities for specific research topics (Table 1), there are broad recommendations for more systems thinking, better engagement with the public, inculcating social and technological innovation, and a proposal for an International Panel on Food and Nutrition Security. Subsequently, it has been discussed (von Braun and Birner, 2016) how an international advisory panel could work in support of a new global platform to improve governance for agricultural development and food and nutrition security.

Table 1 summarises the research challenges highlighted by Expo 2015 together with other conclusions for research gap filling published by other major inquiries. Many of these recommendations from different sources converge, and will recur in the next chapters.

### 2.5 Food 2030

Following Expo 2015, the European Commission announced the major Food 2030 initiative (DG Research and Innovation, 2016), a policy framework to better *structure, connect* and *scale up* European research and innovation for food and nutrition security in a global context: *structuring*, by convening relevant EU services, Member States and stakeholders for aligning research and innovation programmes and leveraging funding; *connecting*, by adopting a whole food chain approach, including connections of land and sea; *scaling up*, by boosting new approaches, investment, education, skills and capacities. A meeting in October 2016, organised to bring together many key stakeholders from the policy and research communities[32], reviewed topics spanning the relationships between agriculture, food and health. These included personalised nutrition, connecting health and nutrition data, the role of precision agriculture, preparedness for climate change, and microbiomes. Additionally, there were more general debates on building better connections between research and practice, and between different policy-making departments. The meeting also provided initial details of the inception of the International Bioeconomy Forum in 2017, designed to be a multilateral network to mobilise research and innovation coalitions, for example on the microbiome.

### 2.6 Scenarios

Various groups have constructed scenarios for future developments in food and nutrition security: these

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[28] http://ec.europa.eu/research/bioeconomy/index.cfm?pg=policy&lib=foodsec. The Bioeconomy Observatory set up to assess progress and impact is managed by JRC, https://biobs.jrc.ec.europa.eu.
[29] EPRS January 2017 'Bioeconomy: challenges and opportunities'.
[30] http://ec.europa.eu/eip/agriculture.
[31] https://eit.europa.eu/eit-community/eit-food.
[32] http://ec.europa.eu/research/conferences/2016/food2030/pdf/food2030_agenda.pdf.

***Table 1 Science and technology dimensions of policy issues: foresight and horizon-scanning to identify broad themes for filling research gaps in food and nutrition security***

| Source | Research priority areas |
|---|---|
| Pretty *et al.*, 2010 | *Natural resources*, for example climate, water, energy, soil, biodiversity, ecosystem services and conservation<br>*Agronomic practices*, for example crop productivity, genetic improvement, pests and diseases management, livestock<br>*Agricultural development*, for example social capital, gender and extension services, livelihoods, governance and economics<br>*Markets and consumption*, for example food supply chains, prices, trade, dietary patterns and health |
| Parker *et al.*, 2014 | *Feeding a larger and wealthier global population sustainably and equitably*, for example improving production and reducing waste, increasing efficiency of use of resource inputs, dietary choice, governance frameworks<br>*Climate change adaptation practices*, for example agriculture<br>*Multi-functional land use planning*, for example balancing competing demands for food, energy and environment |
| Steering Committee of the EU scientific programme for Expo 2015 | *Improve public health thro*ugh nutrition: healthy and sustainable consumption<br>*Increase food safety and quality*<br>*Reduce losses and waste*: more efficient food chains<br>*Manage land for all ecosystem services*: sustainable rural development<br>*Increase agricultural outputs sustainably*: sustainable intensification<br>*Understand food markets*: in an increasingly globalised food system<br>*Increase equity in the food system* |

include the FAO, JRC, STOA, World Economic Forum, IFPRI and the FoodSecure FP7[25] project. Some of these are described in further detail elsewhere in our report, and a policy paper by the Rural Investment Support for Europe (RISE) Foundation (2017) is a recent attempt to identify reform options for the CAP, including a stronger nutritional focus (see Chapter 8). In developing scenarios, it is important to capture both the relatively predictable changes (such as population growth) and the critical uncertainties (including disruptive technologies, migration flows). Many of these scenarios indicate that it will be important to increase agricultural production; for example the FAO estimates that a 70% increase in global food production is needed by 2050. However, we recognise that other scenarios put less emphasis on increasing production, rather emphasising the need to take a food systems approach that also encompasses demand-side issues (and a focus on quality in terms of nutrition) and takes greater account of environmental intersections.

For example, the World Economic Forum[33] has described four scenarios for global food systems in terms of a matrix of market dynamics and demand shifts:

- Unchecked consumption—with high environmental costs.
- Open-source sustainability—highly linked markets and resources, efficient consumption and increased cooperation and innovation.
- Survival of the richest—with increasing societal disconnects.
- Local is the new global—where import-dependent regions are vulnerable.

Comparison of scenarios may be particularly helpful when revealing scientific opportunities and challenges; that is, what should the research agenda be to help understand and influence the most likely trajectories? In the following chapters, we explore what the issues are for the research agenda driven by the various expectations from different scenarios, given our emphasis on the desired outcome for food and nutrition security to improve access to healthy, sustainable food. It is not the purpose of the present report to duplicate analysis and synthesis that has already been done very well by other groups in devising a comprehensive programme of work for the research agenda. Instead, in the next chapters we focus on certain critical issues to build on this work done previously and to explore how scientific opportunity can best be used in pursuit of EU priorities for innovation and policy formulation for food and nutrition security.

[33] World Economic Forum, January 2017, www.weforum.org/whitepapers/shaping-the-future-of-global-food-systems-a-scenarios-analysis.

# 3 Food and nutrition security in Europe: the present situation, challenges and opportunities, science and technology strengths

## 3.1 What are the key issues in defining and characterising food and nutrition security?

As observed in Chapter 1, the countries of the EU are not immune from problems of food and nutrition security, and increasingly there are overconsumption challenges to face.

The FAO work previously cited has provided an important global conceptual framework with its emphasis on food availability and access and stability of the food system. The EASAC Working Group examined how to expand the FAO conceptual framework to be particularly relevant to Europe, to do the following.

- Pay more attention to the health dimensions.
- Include excess consumption as well as hunger/undernutrition.
- Cover demand-side as well as supply-side issues, with their implications for behavioural change.
- Take account of the COP21 discussions and decisions, and the implications for land use.
- Evaluate the relationship between agriculture and environmental resources within a broader socio-economic context.
- Address dynamics and volatility in food systems.

An extended conceptual framework is envisaged as in Figure 1.

The EU is a net exporter in the category food, drinks and tobacco, moving from a small trade deficit in 2011 to a small trade surplus in 2016[34].

In the view of the EASAC Working Group, the current information base on food and nutrition security in Europe is not sufficiently strong and is a constraint for related research. For example, in Europe unlike the USA, there are no time-series of surveys that identify prevalence of food deficiencies at household level. It is also important to do more to understand how

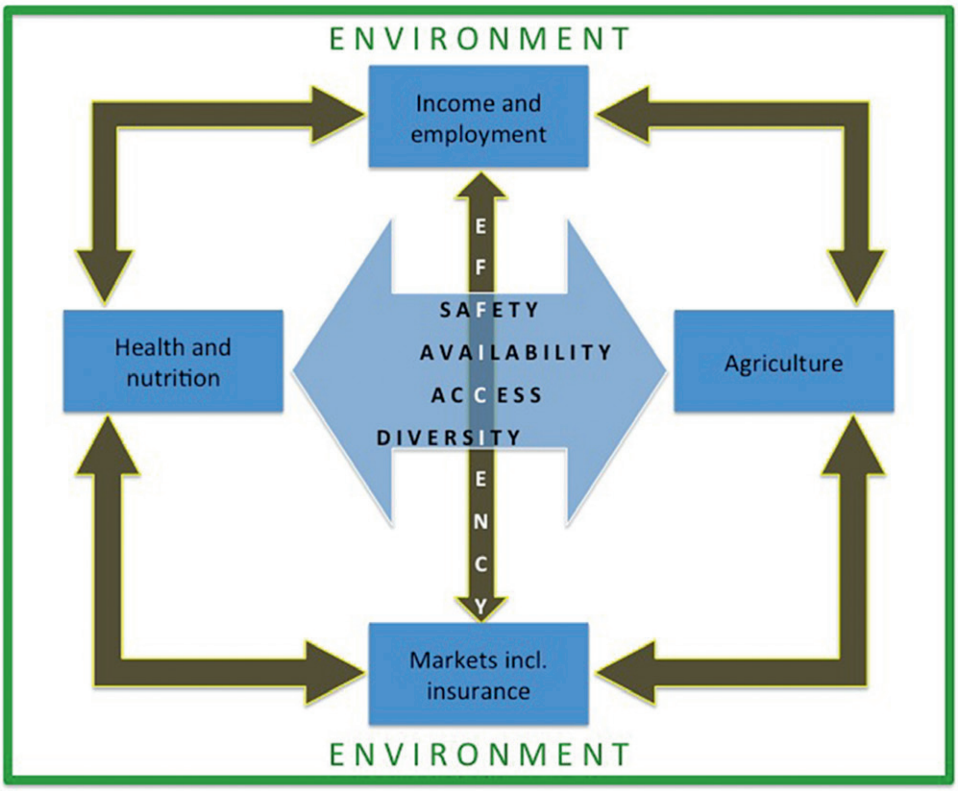


*Figure 1 An aggregate conceptual framework for research on food, nutrition and agriculture within the food systems context (von Braun, 2017).*

[34] Agri-food trade statistics are on https://ec.europa.eu/agriculture/trade-analysis/statistics_en.

nutritional status may vary during the lifespan and the implications for health. For example, research on European adolescents (Moreno *et al.*, 2014) illustrates the value of cross-sectional research in population groups to link nutrition status, lifestyle behaviour and health.

The limited data that are available from Eurostat show that half of low-income households in the newer Member States of the EU struggle in their access to food (Eurostat, 2012)[35]. In addition to the rising incidence of overweight (more than half of the adult EU population) and obesity[9] documented in section 1.4, there is clinical evidence of rising nutritional deficiencies in EU countries, and food insecurity is also associated with deteriorating mental health, inability to manage chronic disease and worse child health (Loopstra *et al.*, 2015). Recent analysis from the ULYSSES project (see section 4.4), has begun to clarify how food price increases in the EU have affected food consumption and purchasing habits. There are significant differences in the level of food deprivation across the EU with the severest impacts observed for poorer households in Romania, Lithuania, Bulgaria, Malta, Poland, Slovakia and Estonia (see also studies on Slovakia and Romania in the FoodSecure Project[25]).

Research using macrodata for FAO (Capacci *et al.*, 2013) has mapped undernutrition, overnutrition and micronutrient deficiencies across the European geographical region and explored the association with socio-economic determinants and the translation into health and economic burden. Among European countries where undernutrition persists and co-exists with prevalent micronutrient deficiencies and relatively high level of overnutrition were Albania, Armenia, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Macedonia, Moldova, Montenegro, Romania, Serbia and Ukraine. However, these data are based on the year 2010 or earlier.

Problems also certainly exist elsewhere in the EU, and the food price spike in 2007/8 had greatest impact on the poorest households. In the UK, data in 2014 suggest that, of those aged 15 or over, 10% were food insecure and 4.5% experienced a severe level of food insecurity, although this was on the basis of a relatively limited survey (Taylor and Loopstra, 2016). Another recent UK study by the All Party Parliamentary Group on Hunger[36] identified a significant proportion of children starting school underweight but also noted that there is need to collect better data to make a comprehensive assessment.

With regard to better data collection, the EASAC Working Group noted that, in addition to collecting robust statistics at the country level, it is urgent to assess the prevalence of malnutrition in potentially vulnerable groups, for example migrants, the homeless and the elderly (Michel, 2014), pregnant women and infants, and hospitalised patients (Khalatbari-Soltani and Marques-Vidal, 2016). These impacts are often poorly quantified, the information currently available is often outdated and, in consequence, attempts to fortify food to combat micronutrient deficiencies are often not strongly evidence-based.

Thus, the EU must make greater efforts to collect data to monitor malnutrition in Member States (Table 1)[37], complementing Eurostat surveys, and must act on the implications, with particular attention to vulnerable population groups. New systematic efforts—extending to overconsumption—can build on the work of EU-funded projects such as FoodSecure[25], which is pioneering ways to map undernutrition/malnutrition data to income level. Opportunities for gathering nutrition data in the EU, collected in real time, on the basis of personalised nutrition information and smart-phone-based 'citizen science', should be explored but need a robust analytical framework. Going beyond traditional data collection, 'big data' on nutrition and related health issues may play increasingly important roles for identifying causal linkages between food system functioning and human consumption. EU policymakers also need to appreciate that better data collection is likely to elicit greater demand for food assistance for EU citizens or the introduction of other forms of safety net in social care policy. At present, there seems to be an assumption by European Commission services that food assistance is only a matter for the development aid budget for regions outside the EU.

## 3.2 What are the new challenges?

Broad drivers of change influence the context in which scientific and political systems are aiming to study and deliver food and nutrition security (Box 3).

In subsequent chapters of this report we review many of these issues in further detail.

[35] Based on the question, 'Can your household afford a meal with meat, chicken, fish (or vegetarian equivalent) every second day?'.
[36] https://feedingbritain.com. Other evidence is provided in the UK parliamentary House of Commons analysis indicating that the number of children under 5 years old who were anaemic (in 2011) was at the highest level for 20 years.
[37] For example, the US Food Environment Atlas (https://www.ers.usda.gov/data-products/food-environment-atlas/) aims to assemble statistics on food environment indicators (such as restaurant and store proximity, food prices, food and nutrition assistance programmes) and support research to identify causal relationships and effective policy interventions on food choices and diet quality.

**Box 3 Drivers of change impacting on food and nutrition security**

*Demographic transformation*—including population growth, urbanisation[38], migration, rural ageing.

*Behavioural change*—in food consumption and lifestyles, for example resulting in obesity and NCDs.

*Transformation of food systems*—new value chains, for example increase role of processed food and supermarkets, lead to greater integration of food systems with labour, energy, finance and commodity markets. Innovation may revolutionise food systems but the effects may be unevenly distributed.

*Environmental change*—increased scarcities of natural resources (e.g. water, soil, biodiversity) and risks of climate changes (e.g. impact from extreme weather events and on pests and diseases).

Sources: Pollock *et al.*, 2008; GOS, 2011; von Braun and Kalkuhl, 2015; and Working Group discussion.

## 3.3 Climate change: impacts, adaptation and mitigation

Up to 70% of the EU's food imports come from developing world areas that will be particularly vulnerable to climate change[39]. There will also probably be significant effects of climate change on food production, most but not all negative, and waste within Europe, on food systems more generally, and on the choice of crops for bioenergy production as well as for food production. The impact of climate change on agricultural productivity (taken in conjunction with other effects on water resources) has been identified as a global risk[40]. Recent empirical analysis of global changes demonstrates that increasing temperatures are associated with migration flows from countries that base a large part of their economies on agriculture and can be attributed to crop yield losses (Cai *et al.*, 2016). In particular, climate-induced migration enlarges the flow in already established migration routes—suggesting that this will be a continuing challenge for the EU.

Modelling of global and regional health effects accruing from future food production under climate change (Springmann *et al.*, 2016a) predicts that in absolute terms most climate-related deaths would occur in Southeast Asia although several European countries may be significantly affected. In this modelling exercise, adoption of climate-stabilisation pathways would reduce the number of climate-related deaths with the degree of impact depending on stringency. As part of the overall impact of climate change effects on agriculture, extreme weather events may have significant consequences for food security globally and in Europe (EASAC, 2013b; Chavez *et al.*, 2015; Lesk *et al.*, 2016)[41]. Modelling of climate change impacts on European agriculture is an active research area: for example, MACSUR[42] is a knowledge hub within the JPI FACCE (Chapter 2), covering modelling of crops, livestock and socio-economic aspects.

To help adapt to the global effects of climate change, the introduction of climate-smart agriculture has been proposed, for example in World Bank Analysis[43], and there is now a range of EU options (Schiermeier, 2015). For example, there are scientific opportunities in plant breeding coming within range (see section 6.3), to construct crops adaptable to reduced water supplies (including local, orphan crops). An agenda for addressing gaps in agriculture climate adaptation research must also include the social sciences, for example to understand farmer behaviour (Davidson, 2016), because climate-smart agriculture requires coordinated actions by farmers, researchers, the private sector, civil society and policymakers to identify and introduce climate-resilient pathways (Lipper *et al.*, 2014).

The EASAC Working Group emphasised the importance of viewing the impacts broadly: there is need to develop climate-resilient food systems that requires action on, for example, food stores and transport, market transparency, infrastructure, cold chains and siting of food processing plants, as well as in agriculture (Wheeler and von Braun, 2013). And, in addition to considering how climate change will affect agricultural productivity and how to cope with change, it is also

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[38] Issues for urbanisation, the future of agriculture and food security have been reviewed in detail elsewhere (for example, Richards *et al.*, 2016). Discussion at the Food 2030 event in October 2016 noted the importance of integrating food systems, including urban farming, with other systems (energy, transport, health, water and waste) in cities. There may be various opportunities for 'zero-acreage' urban farming (Thomaier *et al.*, 2015) although there may also be significant challenges, for example with pollution (Meharg, 2016).
[39] Oxfam, 2014.
[40] World Economic Forum Report, 2016.
[41] Also discussed in 'Extreme weather and resilience of the global food system' 2015, the Final Project Report from the UK-US Taskforce on Extreme Weather and Global Food System Resilience, The Global Food Security programme, UK.
[42] Modelling European Agriculture with Climate Change for Food Security, www.macsur.eu.
[43] http://pubdocs.worldbank.org/en/677331460056382875/WBG-Climate-Change-Action-Plan-public-version.pdf.

vitally important to appreciate that agriculture itself contributes substantially to climate change and to agree what to do about that contribution.

In 2015, two major global initiatives came to fruition with the capacity profoundly to affect future strategies for FNSA. One was the UN adoption of SDGs (Chapter 1), the other was the outcomes of the United Nations Framework Convention on Climate Change[44] meeting in Paris, COP21, with the objective of limiting greenhouse gas (GHG) emissions to 1.5% above pre-industrial levels. Currently, agri-food origin accounts for 30% of GHG emissions (carbon dioxide, methane, nitrous oxide), about half of this sum attributed to production and half to land conversion[3]. Livestock are a major source of agricultural GHG emissions and, if current trends continue, it was recognised that food production alone will reach, if not exceed, the global targets for total GHGs (Bajzelj *et al.*, 2014). COP21 will be transformational and the ambitious COP21 goals bring much nearer the time when food alone would utilise the entire carbon budget now assigned (Benton and Bajzelj, 2016)[45].

Climate-smart agriculture cannot by itself meet the GHG emission goals although GHG emissions from global agriculture can be mitigated to a limited extent by land-sparing—increasing agricultural yields by sustainable intensification—thereby reducing farmland area required and by actively restoring natural habitats on land spared (Lamb *et al.*, 2016; and the CGIAR Research Program on Climate Change, Agriculture and Food Security[46]). There may also be opportunities to introduce feed additives to reduce methane production during ruminant digestion and share good practice in manure management methods and grazing practices[47]. However, in the view of the EASAC Working Group, there is also great need to act to reduce waste and to introduce demand-side strategies—that is, to tackle overconsumption and to change dietary habits in a way that will reduce GHG emissions—as part of the systems-based approach to provide food and nutrition security sustainably (Tilman and Clark, 2014).

As well as contributing to climate change mitigation and other environmental benefits (such as less deforestation (Erb *et al.*, 2016)), adjusting consumption patterns will also bring public health benefits in those populations that already consume large amounts of food from animal sources (see also Chapter 5). Global meat and dairy consumption needs to be modified to avoid overconsumption (Friel *et al.*, 2009; Chatham House, 2015), while enabling better distribution for developing countries. For example, a 30% fall in adult consumption of saturated fat from animal sources was estimated to be able to reduce heart disease by 15% in the UK (Friel *et al.*, 2009). Total calories should also be reduced where there is excess consumption, and combined with the efforts to reduce waste (see section 4.1). One estimate (Springmann *et al.*, 2016b) suggested that adoption of World Health Organization guidance on healthy diets could reduce global mortality by up to 10% and food-related GHG emissions by up to 70% by 2050. Changing consumption may, therefore, bring co-benefits to health and to GHG emissions: these co-benefits are being monitored and tracked as one indicator of the impacts of climate change on health in a major recent initiative (Watts *et al.*, 2017).

The Danish Council of Ethics[48] has called for a tax on red meat to modify consumption and mitigate climate change, and it is conceivable that CAP-induced infrastructural reform could reduce animal farming subsidies to discourage meat consumption through higher prices[47]. However, it is a complicated task to elucidate the potential macroeconomic and other consequences of a tax on meat (Smith, 2014; Springmann *et al.*, 2017) and to differentiate between the impacts of different types of meat (Schader *et al.*, 2015). Moreover, the impact of food taxes is likely to be greatest on those with lowest income, exacerbating the costs of consuming a healthy diet. The current European evidence for comparing the relative costs of diets is mixed and depends on methodology. For example, on the basis of a comparison of shopping baskets, higher nutritional quality is more expensive (Thiele, 2014), but if a healthier diet also involves eating less, then the cost may not be higher (Ryden *et al.*, 2008).

More work is required to clarify whether there is a disconnect between achieving COP21 objectives, in terms of reducing meat and dairy consumption, and the standard advice for consuming a healthy diet commensurate with the targets embedded in the SDGs.

### 3.4 What is needed to mobilise national/regional scientific capacity to address the challenges?

Much is already being achieved in clarifying and pursuing the research agenda (Chapter 2) but the current research landscape is fragmented and there are gaps in the translation of research outputs to innovation

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[44] UNFCCC, www.unfccc.int.

[45] It is relevant to note that the EU Directive on National Emissions Ceilings intends to cap agricultural emissions harmful to the environment. This links to the direct effect of emissions on human health as well as the GHGs (i.e. it includes ammonia and particulate matter as well as carbon dioxide, methane and nitrogen oxides). This Directive is currently in the trialogue stage of discussion between the European Parliament, Council of Ministers and European Commission but it has been controversial and may be dropped in consequence of the EU Better Regulation Initiative.

[46] CCAF, 'Agricultural cutbacks needed to meet climate targets', https://ccafs.cgiar.org, May 2016, and link to Wollenberg *et al.* (2016).

[47] EPRS (Van Woensel and Tarlton) February 2017, 'What if animal farming were not so bad for the environment?' PE 598.619.

[48] www.etiskraad.dk/english, April 2016.

and in the policy take-up. There is urgent need to take account of the disparate outputs from the various initiatives to synthesise the evidence base and to deploy that new knowledge for innovation and to advise policy development. Cross-sectoral EU policy initiatives (e.g. for the bioeconomy and circular economy) must now take into account global objectives set in the SDGs and COP21 commitments. By analogy with the case made for organising evidence for environmental management (Dicks *et al.*, 2014), so for food and nutrition security, recognition of the hierarchy of evidence available in a shared European research knowledge base is likely to promote efficient use of decision-support systems. There is also a critical need to develop new options for public–private partnership to shape and implement research priorities (Haddad *et al.*, 2016).

The scientific community can play a central role in new approaches to policy and regulatory coherence, in particular (1) to challenge current dogmas in food and nutrition security, and this mandates further attention to the problems posed by overconsumption; (2) to ensure that Europe's domestic requirement are pursued in the context of improving food and nutrition security globally; (3) to develop nutrition-sensitive policies more generally, not just nutrition-sensitive agriculture; (4) to reconcile current priorities with the interests of future generations; and (5) to encourage interdisciplinary system-wide approaches to mitigate trade-offs in different parts of the food system (e.g. agricultural policies increasing production of calorie-rich but nutrient-poor foods leading to externalised costs on health and environment).

As discussed in Chapter 2, Food 2030 is a major EU initiative to identify the long-term research and innovation agenda and mobilise the scientific community. The mechanisms proposed to attain Food 2030 priorities for reducing hunger and malnutrition, building a resilient primary production system, implementing sustainability and promoting innovation are to be based on four pillars (DG Research and Innovation, 2016):

- Research breakthroughs—capitalising on the transformational powers of, for example, information and communications technologies (ICT), big data and by trans-disciplinary integration of social sciences and humanities with the other sciences.
- Open innovation—supporting and facilitating linkages between current initiatives, e.g. EIPs, JPIs, Technology Platforms and fostering synergies between different funding sources, public and private.
- Open science—improving research infrastructure and data access, fostering researcher mobility, science education and strengthening science–policy–society interfaces.
- Open to the world—building on existing multilateral dialogue e.g. EU-African Union on FNSA, and seeking new international collaborations.

There is much still to be done to obtain stakeholder engagement in Food 2030 and to clarify how added value can be achieved for this broad new strategy. EASAC Working Group discussion focused on one particular aspect: the contribution by big and open data to agricultural systems innovation. In addition to their potential value in innovation, open data are important for effecting policy transparency and accountability and for the improved strategic assessment of decision-making.

In agriculture, open data are becoming increasingly integrated across different activities (e.g. crop science, animal science, food science, economics) and from diverse sources (e.g. remote sensing, social media, phenotyping, 'omics technologies (see further discussion in sections 6.5 and 6.6) There are also still problems in finding and extracting relevant data from heterogeneous data sets. The FP7-funded project SemaGrow[49] is using the agricultural data ecosystem as a test bed for its technologies to develop a robust and flexible infrastructure that enables federated access to distributed data sources. Pilot work in SemaGrow has revealed that metadata sets are not always complete and unambiguous. It is not always clear what is present in the data set because of problems relating to different vocabularies in use. Progress in Food 2030 open/big data objectives will depend on generating good quality metadata and on resolving issues with different vocabularies and ontologies as well as progress in methods for contextualisation: that is, bringing the new evidence into the policy-making process.

At the global level, the need for coherence in policy and infrastructure to deal with openness in a big-data world has been reviewed by Science International (an initiative bringing together major science organisations worldwide, including IAP), which is supporting the progression of a global accord on guiding principles on open access to big data[50]. The importance of creating this global coordination and coherence is exemplified

[49] www.semagrow.eu.
[50] www.interacademies.net/News/PressReleases/29194.aspx.

**Box 4 Principal themes emerging in the UK Food Futures Panel**

*Animal welfare*—participants would be unwilling to compromise on welfare standards, because of moral obligations to animals but also because livestock reared in good conditions tasted better.

*Food waste*—participants expressed concern about waste at all stages in the food system, from producers to retailers to consumers.

*Food education*—participants recognised the need to solve problems of food-related disease and food waste, and supported for the proposition to educate to change diets to reduce resource use, but tended to see the priority to educate children and future generations, not themselves.

*Food technology*—participants mostly agreed that innovation in the food system would contribute to food security, but while technological solutions were seen as more easily scalable, they tended to be trusted less than social innovations such as behaviour change. Participants were more willing to accept technological solutions for solving the problems 'other people' experience, for example consumers in developing countries.

*Environment*—many participants were concerned about the impact that potential solutions to food security might have on the environment. However, in trade-offs they tended to prioritise social, economic or animal welfare interests above environmental concerns.

by the contribution that big data sets could make to analysing and achieving the SDGs.

At a time when the private sector is increasingly active in collecting big data, for example in precision agriculture settings (see section 6.5), it becomes ever more important to identify mechanisms to ensure public sector access to critical information.

### 3.5 Societal acceptability

Public consultation on the research recommendations in the Expo 2015 report demonstrated that there was broad consensus on the place of research in achieving global food security and on the necessity to adopt new approaches, for example more trans- and interdisciplinary research and systems thinking. Most respondents to the Expo 2015 consultation also agreed that there must be better mechanisms for facilitating uptake of research outputs in innovative products and services (reducing times to scale up and to market) and in advising evidence-based policy. Among the research themes that received particular support in the consultation were food systems research, collaborative EU–international agricultural research, biosciences, food science and the use of social sciences to understand consumer behaviour. A cross-cutting issue that emerged strongly in this public consultation (mentioned in different contexts ranging across nutrition and food consumption, food safety, microbial diversity, food losses and food production sustainability) was the importance of collecting, processing, analysing, sharing and accessing data (see sections 3.4 and 6.6).

There have been many public consultations by the European Commission and Member States on attitudes to specific technologies associated with agriculture and food security. In the present section we focus on two more general surveys to provide a broader context for the subsequent sections.

As part of the Eurobarometer series of public polls, DG Agriculture and Rural Development in 2012 examined European attitudes towards food security, food quality and the countryside (European Commission, 2012). Results from this survey indicated that EU citizens are concerned about global food security but expressed lower levels of concern about the ability of EU Member States to meet the food requirements of their own populations. There were, however, substantial differences between countries in this regard: for example, 94% of respondents in Greece were concerned about national food production by contrast with only 11% of those surveyed in Denmark and the Netherlands. A large majority of respondents agreed that the EU should help countries outside the EU to produce more food and that the EU should itself produce more food in order both to meet rising demand in the EU and to reduce dependency on imports.

Further insight into public attitudes to food security in one Member State has been provided by the recent UK Food Futures Panel (2016) of members of the public brought together by the Global Food Security Programme of the UK's major public funders of research. In confirmation of the Eurobarometer findings, the Food Futures Panel members perceived food security as an important issue but one that is relevant at present more to developing countries than to their own country. Five major themes recurred in this public consultation (Box 4).

These recurrent public interests map quite well onto the priorities identified in earlier UK horizon-scanning by experts with an interest in the science and policy interface (Parker *et al.*, 2014; see Table 1). As discussed elsewhere in our report, more should be done on the 'science of people behaviour' to understand consumer attitudes, for example the perception of risks as more important than benefits and the basing of behaviour on short-term responses and impulses, not more considered reflection. It is vital to build further public engagement on the issues associated with food and nutrition security.

# 4 Prospects for increasing efficiency of food systems sustainably and equitably

Issues for improving access to healthy, sustainable food have to be considered within the wider context that includes the societal and environmental dimensions (German *et al.*, 2016), and the economic levers for change (Haddad *et al.*, 2016). They must be regarded as part of a broader integrated food and nutrition strategy that also covers issues for processing and packaging (with implications for food safety and food science); for reducing waste; for markets, with the implications for consumer access, choice and affordability; and for the impacts on health and well-being. As noted in Chapters 1 and 3, a systems-based view has to be taken on how to provide food and nutrition security sustainably, and policymakers are beginning to see the necessity for moving from agricultural policy to a more coordinated food policy[51]. Attempts to manage effectively this complex food system brings additional challenges for defining and monitoring priorities and implications for interdisciplinary and participatory research agendas (Whitfield *et al.*, 2015; Haddad *et al.*, 2016). There is also a substantial role for modelling[52] food supply capacity and food chain innovation, combining the sustainable development objectives with social innovation.

A report from the International Resource Panel[53] of the UN Environment Programme in 2016 calls for global resource-smart food systems to incorporate changes in the way food is grown, harvested, processed, traded, transported, stored, sold and consumed. The UN Environment Programme report provides detail on a wide range of specific actions needed, including those to reduce food loss and waste, to move away from resource-intensive products and to promote the research and innovation agenda. These topics were also considered by the EASAC Working Group, as described in the following sections.

## 4.1 Reducing waste in a more efficient food chain

As observed in Chapter 1, it has been estimated that about a third of the world's food grown is lost or wasted, and this embeds a huge amount of energy, water and land resources[54]. SDG 12.3 aims to halve per capita food waste. However, the Working Group was concerned that the evidence base for documenting and quantifying food waste is not sufficiently robust overall, although there is some good evidence available[54] and there are important priorities for the EU research agenda to evaluate in detail losses throughout the food system, and to inform the options for the circular economy policy[55]. There is also a place for better studies to determine the effects of waste intervention measures at local and regional levels. In addition, Europe as a big importer of food should be concerned about post-harvest losses in the rest of the world and the implications of those for the European research agenda. Waste should not only be assessed in biophysical terms, but also in terms of economic costs, and costs of waste prevention must be part of the research and innovation agenda in this field.

In much of the EU, as in the USA, a large proportion of waste is likely to be accounted for later in the food system—by retailers, in the home, restaurants and institutional settings. A commentary published by the US National Academy of Medicine (Yiannas, 2016) presents the perspective of a large food retailer who is now trying to minimise waste. Their actions include instituting faster distribution channels (to lengthen effective shelf life), donating unsold food to food banks, adoption of uniform information on expiry date in labelling and provision of consumer information. In the EU, confusing 'best before dates' on food labels are thought to contribute significantly to food waste and may threaten implementation of the circular economy strategy[56].

A quantitative study of EU consumer food waste and associated loss of natural resources (water and nitrogen) required for its production (Vanham *et al.*, 2015) found that almost 80% is avoidable food waste, that is edible waste not consumed. Analysis of the food product groups wasted showed that meat accounts for the highest amounts of water and nitrogen resources lost.

[51] For example, as discussed in the 2015 WRR-Report no. 93 from the Netherlands Scientific Council for Government Policy, https://english.wrr.nl/publications/reports/2016/12/13/towards-a-food-policy.
[52] Exemplified in the FP7 project 'Food planning and innovation for sustainable metropolitan regions' (www.foodmetres.eu), which models regional capacity in Berlin, Ljubljana, London, Milan and Rotterdam. Issues for urban food security more broadly are addressed in the Milan Urban Food Policy Pact, a legacy of Expo 2015, which aims to develop an international protocol to engage world cities in developing food systems based on the principles of sustainability and social justice, www.foodpolicymilano.org/en/urban-food-policy-pact-2. See also footnote 33.
[53] 'Shifts towards resource-smart food systems', International Resource Panel UNEP, May 2016, at http://www.unep.org/resourcepanel.
[54] Analysis from World Resources Institute, www.wri.org.
[55] A recent EASAC report (2016) on the circular economy emphasises the importance of identifying appropriate indicators as an essential part of policy, http://www.easac.eu/home/reports-and-statements/detail-view/article/circular-eco-1.html.
[56] For example this significant source of waste in the UK may prevent accomplishment of the Scottish government objectives to reduce food waste by one-third by 2015, https://www.euractiv.com/topics/food-waste/ 25 February 2016.

More must be done to quantify and evaluate waste (for example in terms of calories/nutrients wasted rather than weight of food) and the scientific community has a responsibility to recommend approaches to evaluating and reducing waste. The FAO Technical Platform on the Measurement and Reduction of Food Loss and Waste[57] reviews actions by various countries and recently discussed the relevance of the EU action plan on the circular economy.

The EU Waste Directive stipulates that by 2025 no biodegradable waste (including food waste) should be sent to landfills, but progress in Member States towards this target is highly variable. For the EU in aggregate, approximately 40% of municipal waste is still sent to landfill sites. Furthermore, other EU legislation prevents resource-efficient use of food waste[58]. For example, it remains illegal to use the majority of food waste as animal feed because of historical concerns about disease. It has been suggested that the EU can do better in learning from the experience of countries such as South Korea, Japan and Taiwan, who are operating safe recycling of more than one-third of their food waste as animal feed (zu Ermgassen *et al.*, 2016).

Recommendations on how to reduce waste post-harvest and by consumers and the food service sector from the perspective of one Member State were discussed in detail elsewhere (GOS, 2011). A very comprehensive analysis has also been made by STOA for the European Parliament (STOA, 2013). A recent initiative by the ENVI committee of the European Parliament[59] proposes various measures to cut EU food waste in half by 2030, including clarification of labelling instructions for 'best before' and 'use by' dates.

The relevant recommendations from the research agenda identified in Expo 2015 cover a very wide range that includes developing better knowledge about where food is wasted throughout supply chains; improving genetics for enhanced food storage; creating smarter logistics across the food system; options for enhancing public understanding of quality assurance and improving predictions to align supply and demand; developing recovery and recycling technologies, new products from food industry residues and other innovation to improve efficiency throughout supply chains.

New forms of food packaging can be expected to reduce both food waste (by extending shelf life and quality) and packaging waste (if produced from biological waste). The examples of FP7 projects in footnote 60 illustrate how applications in the bioeconomy are also compatible with the objectives of the circular economy to increase recycling and reduce waste. There is a continuing need for additional research on waste in the food chain, for example the waste that results from supply contracts between farmers and retailers and the implications of consumer behaviour and choice[61].

### 4.2 Food safety

Food security requires ensuring safety from infection and contamination of the food produced, traded and consumed (Chan, 2014). More than 200 diseases are spread through food, and contaminated food can cause long-term health problems, particularly for vulnerable groups, for example the newborn and patients with special dietary needs. The World Health Organisation describes how resolving problems for food safety involves multi-sectoral and multidisciplinary research[62].

Food-related risks are diverse, encompassing toxicity (harmful for everybody) and intolerance (dangerous only for vulnerable groups). The international institutions (WHO, FAO) have a global role in recognising and defining threats as well as disseminating knowledge about food safety. The Codex Alimentarius established by the FAO[63] gives guidelines and codes about the safety of foods and for labelling and nutrient standards. Recent Codex standards include nutrition labelling (CAC/GL 2); salmonella and salmonellosis, frequently reported foodborne diseases (CAC/GL 87); food safety emergency description (CAC/GL 19), which deals with accidental or intentional risks to public health

[57] http://www.fao.org/platform-food-loss-waste.
[58] The EU Platform on Food Losses and Food Waste has also now been initiated with action proposed within the Circular Economy Strategy to support achievement of the SDG 12.3 target (https://ec.europa.eu/food/safety/food_waste/eu_actions/eu-platform_en).
[59] *Initiative on resource efficiency: reducing food waste, improving food safety'* Report 2016/2223 (INI) adopted by ENVI committee April 2017.
[60] For example, the work of the FP7-funded ISA-PACK (A flexible, sustainable, active and intelligent packaging technology platform) with objectives to reduce wastage, increase shelf life and improve food safety, www.isapack.eu. Other FP7-funded work, e.g. WHEYLAYER 2, www.wheylayer.eu, aims to reduce food waste by using whey-derived biopolymer, a by-product of cheese production. There is also substantial research activity on other ways to channel food waste and food by-products into animal feed, e.g. the FP7-funded NOSHAN project, www.noshan.eu, converting food by-products such as olive pomace and rapeseed press cake into feed for piglets and broiler chickens and constructing a food waste database.
[61] For example, the FP7 project FUSIONS (Food use for social innovation by optimising waste prevention strategies, http://www.eu-fusions.org) emphasises informational tools including public awareness campaigns and marketing standards. This project estimated that the current food waste levels for the EU-28 is equivalent to 20% of all food produced in the EU. The Horizon 2020 project REFRESH (Resource efficient food and drink for the entire supply chain, www.eu-refresh.org) also covers the whole supply chain, asking the business community to participate in testing new approaches to reduce food waste.
[62] http://www.who.int/features/factfiles/food_safety/facts/en/index9.html.
[63] http://www.fao.org/fao-who-codexalimentarius/codex-home/en/.

that require urgent actions; control of foodborne parasites (CAC/GL 88); specification for food additives and flavourings (CAC/MISC 5); as well as mycotoxin contamination in cereals (CAC/RCP 51). These protocols are regularly amended and revised, and they include recommendations based on good agricultural practices and good manufacturing practices.

The major activities to minimise long-standing threats to food safety should be synchronised with actions, including risk assessment, on newer threats and consumers' worries (Banati, 2011). These may include the introduction of trans-fats into food, food additives, food fortification and supplements, antibiotics, hormones (not allowed in EU animal production), probiotics, novel foods and technologies (Augustin *et al.*, 2016). For example, new technologies to treat food (such as high pressure, pulsed electric field, cool plasma, ultraviolet irradiation, and ultrasound) have been used to improve shelf life but there is a lack of studies examining the influence of these processes on nutritional properties or on the interaction between food components that may affect health (Augustin *et al.*, 2016).

The European Food Safety Authority (EFSA) has the responsibility on behalf of the EU to advise the European Commission about the development of food standards, issues for food additives and monitoring and risk assessment for food safety; these cover both contamination of the food chain and deliberately introduced micro-organisms and chemicals. The recent finalisation of the EFSA strategy up to 2020[64] denotes objectives for wider engagement in the process of scientific assessment; widening the evidence base and optimising access to its data, building scientific assessment capacity; and preparing for future risk assessment challenges. EASAC welcomes the opportunity to continue engaging with EFSA, and our Working Group highlighted several key points, as follows.

### *Bacteria and antimicrobial resistance*

Food contamination takes place in many parts of the food chain and has been extensively studied in EU-funded projects[65]. At the farm level, bacterial contamination can be introduced from the intestine during slaughter of animals, from irrigation of fruit and vegetables with contaminated water and during egg laying. Some harmful bacteria are becoming resistant to antibiotics. Antibiotic-resistant bacteria in food-producing animals may contribute to increased infection in patients. Among the greatest problems are those related to methicillin-resistant *Staphylococcus aureus*, vancomycin-resistant enterococci and extended-spectrum β-lactamases. Issues for antibiotic use in agriculture and the substantial problem of rising antibiotic resistance in the EU have been discussed in previous work by EASAC (2014a) with recommendations for decreasing antibiotic use on the farm. Recent evidence from the Netherlands (SWAB, the Dutch Foundation of the Working Party on Antibiotic Policy, 2016) showed that it was possible to reduce total antibiotic use in farm animals by nearly 60% (from 2007 to 2015) and the farm use of antibiotics that are most important for human health care by 99% (since 2011). This reduction in antibiotic use was associated with decreasing antibiotic resistance levels.

### *Viruses*

Food can be contaminated by viruses at source, principally through sewage pollution of the environment, or in association with food processing through inadequate hygiene practices of operatives or systems. Many different food products, including vegetables, shellfish and a great variety of ready-to-eat foods, could be contaminated in foodborne infections.

Noroviruses cause the majority of acute infectious non-bacterial gastroenteritis and are recognised as a prominent cause of foodborne outbreaks worldwide. Noroviruses are very infectious and highly stable in the environment. According to EFSA data, noroviruses isolated from food are the next most common cause of food contamination in the EU after salmonellosis. Food contamination by noroviruses can occur during all stages of food production, both in primary production and during further processing. A common cause of noroviral infection is bivalve molluscs as they are able to accumulate norovirus particles by water filtration.

### *Microbial toxins*

These can be a problem for EU food safety systems (neonates and small children may be particularly at risk) and the EU can also help in tackling global issues, for example for aflatoxin contamination of crops[66]. Changing climate is a major driver of the increasing contamination of maize, peanut and tree nut with *Aspergillus* species. Globally, there may also be increasing marine toxins arising from climate effects

[64] EFSA Strategy 2020 – Trusted science for safe food, April 2016, on http://www.efsa.europa.eu/en/corporate/pub/strategy2020.
[65] For example, the FP7-funded RESFOOD, http://www.resfood.eu, research on new biosensing methods for rapid monitoring of bacteria and water used in agriculture.
[66] As discussed in the Food 2030 event in October 2016, there is need for further engagement in research EU–Africa–Asia on aflatoxins and food safety and this collaboration could proceed under the aegis of DG Development's Platform on agricultural research.

on algal bloom formation or migration of potentially contaminated species, which bring new requirements for food monitoring and for research to understand mechanisms involved.

#### *Food fortification*

There is significant research still to be done to understand the health and safety impacts of food fortification. For example, human studies demonstrate both positive and negative effects of fortifying food and beverages with polyphenols. The mechanisms responsible for the influence of polyphenols on reproductive health and pregnancy are being elucidated but further research to understand the physiological roles and potential clinical value of food with polyphenol should be undertaken.

#### *Biogenic amines*

Another continuing topic in food safety research relates to the presence of biogenic amines. These (histamine, tyramine, cadaverine and putrescine) occur in many foods, especially in fermented foods, wine and seafood products. They are thermo-stable and so are not inactivated by heat treatment during food processing. Further research studies on biogenic amines need to be interdisciplinary with the cooperation of food technologists, clinicians and dieticians to design safe diets for vulnerable groups that include neonates, the elderly and patients with gastrointestinal diseases.

#### *Other chemical contaminants*

Research is also needed on the impact of chemical contaminants, whether by penetration from packaging materials or by accumulation from the environment: to understand sources of food contamination, potential for additive effects from combinations of chemicals (and their degradation products), to assess toxicology, estimate human exposure and calculate tolerable daily intake. For example, the impact of perfluorinated compounds in the diet has been controversial[67]. As discussed in the Food 2030 event in October 2016, there is an increasing priority to consider the issues for contaminants alongside efforts to increase recycling of waste: linking food system objectives for recycling, the circular economy and food safety.

#### *Food allergy*

World Allergy Organization statistics[68] indicate that up to 30 million people in the EU and 500 million worldwide suffer from food allergies: the eight most common allergenic foods[69] account for 90% of food allergic reactions. This has implications for food science and technology in producing low-immunogenic food products, for food labelling policies and for ensuring the integrity of food supply chains.

#### *Authentication of origin and quality*

There is also an increasing need for authentication of the integrity of the food supply chain[70]. Recent scandals in the EU (for example, horse meat labelled as bovine) and worldwide (for example, the presence of fox-derived protein in meat claimed to be of donkey origin in China) raise issues for labelling but there are concomitant concerns for food safety. Biomarkers have been developed to enable traceability throughout the food chain (Raspor, 2005) and, for the most part, there is now a range of analytical tests available that can be applied to measure natural or synthetic contaminants that can adulterate food. Nonetheless, there are continuing diagnostic challenges to tackle, for example, the emergence of synthetic steroids and growth promoters that may not be detected by conventional methods, indicating the need for a more comprehensive approach to food surveillance. This more comprehensive approach necessitates better communication between national and EU regulatory authorities, producers and retailers, and a continuing commitment by academia-industry collaboration to develop sensitive, point-of-production and on-site rapid monitoring. The EU Official Controls Regulation, adopted in 2017[71], is an important initiative to reinforce a system for integrated rules for all the agri-food chain, to cover safety and quality and address fraud issues.

Improved engagement with the public is essential in tackling these topics and others: for example, the safety of weight loss products and other dietary supplements and the implications of changing expiry dates on product labels. Public sector and private sector research and innovation activities should also be better aligned (see next section).

## 4.3 Food science and technology

Achieving food safety and quality, and food and nutrition security more generally, requires widespread adoption of best practices in food manufacture and the distribution of safe, stable foodstuffs. This is dependent on skills in food science and technology, and innovation in food processing, storage and distribution. There is significant interest in promoting cohesion between food science and technology and nutrition (Raspor,

[67] See also the FP7 project Perfood, http://cordis.europa.eu/result/rcn/55843_en.html.
[68] www.worldallergy.org.
[69] Milk, eggs, fish, crustacean shellfish, tree nuts, peanuts, wheat, soybean.
[70] Personal communication from Richard O'Kennedy, EASAC Biosciences Steering Panel.
[71] https://ec.europa.eu/food/safety/official_controls/review_en.

2009). Food science and technology have a key role in responding to the growing obesity and NCD challenge. Energy-dense foods are cheaper than nutrient-rich foods, which implies that healthier diets are likely to have to come—at least in part—from reformulating commodity crop-rich foods to enhance nutrient content.

There is considerable concern that, because of the understandable focus on agriculture for sustainability and on human biology for diet and health, skills in food science and engineering are being marginalised. Yet it is these skills that enable agricultural produce to be converted to appropriate foods and there is danger in the public sector assuming that the responsibility resides in the private sector. The Global Visions report from the International Academy of Food Science and Technology[72] was published in 2014 following a global mapping exercise of how regions and countries include food science and technology in their strategies to deal with post-farm-gate practices in delivering food and nutrition security.

It was found that in Europe not all countries have clearly identified strategies for food science and technology, there are discrepancies between the recognition of the challenges for food and nutrition security and support for food science and technology, and often there are no clear links between overall strategies or coordination of ministries connected to food science and technology. The problem of fragmentation and poor coordination at the ministerial level must be solved to form a coherent strategy for food science and technology. Other stakeholders, from technology platforms, industry and the public, need to be involved in formulating that strategy and help reshape the multidisciplinary science base.

An update of the Global Vision report presented at the Food Summit meeting in Dublin in August 2016 showed that food science and technology is starting to increase in importance in national food and health strategies. Several countries and regions and the European Commission are now developing food strategies that include all stakeholders. It is crucial to deliver acceptable and high-quality foods from new materials, which necessarily implies the need for innovative food processing, storage and distribution. Food science and technology is essential when addressing several of the SDGs, for example in adapting to new raw materials to decrease the burden on the climate. New varieties of crops will also need a much higher flexibility of production chains. Lack of other resources will require new smart processing technologies with less consumption of water and energy and a circular economy approach that can make use of side-streams of the food industry, and reduce waste. The emphasis on health and a deeper knowledge of the impact of diets for a healthier life will also involve food science and technology in innovative developments of healthier food products that are attractive to customers (see also Chapter 5). We can also foresee innovations such as smart packaging materials that interact with the consumer with regard to content and product quality, and with new methods to enhance shelf life and traceability (see also sections 4.1 and 4.2).

The EU priorities were presented and discussed at the Food 2030 initiative in Brussels in October 2016. These priorities are, to a large extent, in agreement with the priorities of the Food Knowledge and Innovation Community[73], established in 2017. The overall objective is to focus on the food supply chain to tackle economic and societal challenges (including the imperative to increase resilience in supply chains to climate risk) by doing the following.

- Overcoming the existing level of fragmentation and improving sustainability and traceability in all parts of the food supply chain.
- Deploying innovative technologies, processes and knowledge to increase sustainable food production, reduce waste and promote health.
- Focusing on consumer-driven market strategies and innovation to benefit health and quality of life.
- Addressing the current shortage of skills and human resources.
- Mobilising investment and long-term commitment from the business sector.

The agenda of research priorities linking food science and food technology to food waste (section 4.1) and food safety (section 4.2) objectives was also discussed in Expo 2015. This agenda encompasses smarter food production (including use of sensors and methods to enhance traceability); improving risk assessment and management strategies for complex whole foods (including identifying allergenicity risks); options for innovation in food safety regulations and labels that minimise waste and enhance safety by promoting consumer understanding; supporting social science research, better to understand consumer values for quality and environmental standards.

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[72] http://globalvisions.iufost.org (Hermansson and Lillford, 2016).
[73] The Food Knowledge and Innovation Community is a partnership established by the European Institute of Technology and is the biggest European food project to date with a budget of more than 100 M euros over 7 years, and expected to have significant impact on the European food system. On https://eit.europa.eu/activities/innovation-communities

## 4.4 Understanding markets and their instability in an increasingly globalised food system

Trade creates connections between different regions of the world such that production—and its impacts—is separated from consumption. The separation between world producers and consumers will probably expand, making world food systems rely ever more intensely on international trade (although other scenarios are possible, as indicated by the World Economic Forum work[33] discussed in Chapter 2). In principle, markets can allow more efficient allocation of resources (that is, where resource inputs confer the greatest advantage) and enable sharing of the burden of supply shocks, so reducing price volatility (Steering Committee of the EU scientific programme for Expo 2015). Recent literature shows that trade flows are increasingly more resilient and exhibit ample capacity to change. For instance, Sartori and Schiavo (2015) conclude that '*the structure of international trade has evolved in a way that makes the benefits from the dissipation of shocks through the network outweigh the potential costs of shock propagation and magnification, at least from a systemic point of view*'. However, other research concludes that there is a systemic risk associated with a wider trade network (see, for example, Puma *et al.*, 2015) and, following the financial and food price crises of 2007–2008, market instability, and the implications of price volatility for food insecurity, have been a topic of major concern to agricultural economists and to policymakers.

The issues have been studied in detail in the FP7-funded ULYSSES project[74], and comprehensive analysis and conclusions have been published (Garrido *et al.*, 2016). Excessive price volatility can pose serious risks to food security in developing countries and poorer households anywhere (see section 3.1) but some level of volatility is the normal reaction of markets to information and expectations. In general, though, poorer households are much more vulnerable to higher food prices than to more volatile prices. Evidence shows that instability is agricultural commodity-specific and it is difficult to generalise for the major crops. Usually, there is a relationship between change in crop prices and food product prices, for example a 1% increase in wheat price transmits into 0.3% increase in bread price. However, in urban areas where there may be competition between supermarkets, differing pricing policies may confound the interpretation of the impact of national changes in market stability on households. Research with supermarket large datasets shows that value chains are extremely dynamic (McCorriston, 2015).

Although market fundamentals are the primary causes of price volatility, on a global scale it is clear that food market instability cannot be managed by agricultural policy alone. That is, there are significant intersections with monetary policy and financial fundamentals (money supply, interest rates and exchange rates). Global projections predict that an increasing proportion of countries will depend on food supplies from abroad such that their populations will be increasingly dependent on international food markets (Puma *et al.*, 2015). Moreover, an increasing homogeneity in global food supplies, with ever-greater reliance on a limited number of staple commodities, may be associated with loss of resilience to perturbations, introducing systemic risk for an increasingly monolithic food system. Policymakers need to recognise, therefore, that there is a pivotal role for the World Trade Organization to manage globalisation in food markets and the associated issues for water and land resources, and the potential environmental barriers to trade. With regard to projections for specific impact, most models predict only small changes in agricultural prices globally in consequence of climate change but this finding is controversial and, in particular, the potential effect of extreme weather events on future volatility deserves much more assessment. The increasing reliance of international markets on a small number of commodities brings concerns that multiple commodity failure as a consequence of extreme weather events would generate greater market instability. A case can be made, therefore, for crop diversification in Europe to build in more resilience if imports are reduced in such an eventuality.

Analysis (Garrido *et al.*, 2016) also suggests that biofuel policies contribute to higher volatility spillovers from the oil market to key agricultural products. In episodes of amplified volatility, the impact of oil price volatility on agricultural markets, which are already experiencing higher price levels and uncertainty, may exacerbate the situation. Issues for bioenergy production are considered further in section 7.1, but we emphasise that the situation is complex, and will be influenced by recent EU initiatives on land use and bioenergy production and by the strategic interventions of other groups such as OPEC.

There are options available for more specific regulation of agricultural commodities but the EASAC Working Group concluded that state intervention should be kept to the minimum possible. The food price volatility experienced in 2007–2008 was probably exacerbated by application of export bans, and these should be avoided (for example as discussed in GOS, 2011 and the Global Food Security report cited previously[41], which highlights numerous trade-reducing policy interventions), unless there are serious prospective domestic food crises.

[74] http://www.fp7-ulysses.eu; see, for example, their Policy Briefing number 04 (March 2015) 'Analysis of material and food deprivation in the EU under food price volatility and rise' (and the discussion in section 3.1 of this EASAC report).

Other recommendations to improve governance of food markets and develop roles for the World Trade Organization, from the perspective of one EU Member State, have been presented in detail elsewhere (GOS, 2011). The comprehensive discussion by Pretty *et al.* (2010, as input to GOS, 2011) covers a range of policy research questions for food supply chains, prices, markets and trade to help design mechanisms and instruments to minimise or alleviate the effects of market failure. The EASAC Working Group emphasised science issues linking trade with regulation, standards and with food safety, and advised that the nuances and difficulties of implementing adequately resilient mechanisms should not be underestimated.

Whatever policy framework is considered, it is vital that improved data collection and focused research inform global governance[75] and regulatory actions for risk management. In consequence of lessons learnt, markets are now operating more transparently, exemplified by the Agricultural Market Information System[76], established at the request of the G20 agriculture ministers. The World Bank and others are also now creating early warning systems, based on improved modelling, to render markets more predictable. These and other initiatives may reduce the chances of a new food crisis, similar to 2007–2008, but do not eliminate the possibility that market tensions would evolve into periods of intense instability.

The research agenda should consider new modelling and analysis, making use of the massive databases, with a view to gathering evidence about how markets work, how shocks occur and propagate, and what effects are likely to evolve as a result. Other research priorities identified in Expo 2015 include understanding the role of EU production in global markets and assessing the balance of economic, environmental and social effects of foreign direct investment in land and other production assets within and outside Europe.

Further comprehensive analysis of food price volatility and its implications was published recently (Kalkuhl *et al.*, 2016). Among the general implications for policymakers identified in this work are the following.

- Considering options to reduce excessive volatility—including open trade, flexible bioenergy policies, grain reserves and regulation of commodity markets.
- Introduction and extension of social protection and nutrition policies to alleviate chronic and acute undernutrition.
- Opportunities for re-designing international institutional arrangements and institutions for food security to address failures in collective action.

Taking account of Kalkuhl *et al.* (2016) and points made in the previous paragraphs, the EASAC Working Group summarised that the policy actions require progress in several research areas:

- To examine linkages between extreme events and excessive volatility with social and human welfare.
- To facilitate modelling of cooperation in food security.
- To analyse the effects of regulatory policy instruments in agricultural commodity markets.
- To analyse network and trade flow data, with a view to understand how trade evolves, what natural resources underpin it and how transportation and logistics affect the flow of calories and proteins around the world.
- To understand expectations of the value of information.
- To underpin integration of risk and volatility into models with longer time horizons.
- To understand price transmission between global commodity prices and local food systems—price and availability—and from this to food intakes.

The EASAC Working Group also discussed how the issue of price volatility should be better incorporated into the CAP farmers' strategy, to support policy interventions to manage, rather than prevent, price volatility[77]. Approximately 40% of the EU budget is currently expended on the CAP[78] (although this is anticipated to continue to decline), 50% of farmers' profit comes from the CAP subsidy and it is increasingly important for the CAP budget to be used effectively in a central role for EU food and nutrition security.

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[75] Issues for global governance were not addressed directly by the Working Group and come more within the remit of the IAP global phase of this work. However, relevant issues have been described in detail elsewhere, for example Howard (2016).
[76] www.amis-outlook.org.
[77] The role of the CAP is also being addressed in the work of the European Parliamentary committee on agriculture (COMAGRI), 'Draft report on CAP tools to reduce price volatility in agricultural markets' 2016/2034(INI), on http://www.europarl.europa.eu/sides/getDoc.do?type=REPORT&reference=A8-2016-0339&language=EN.
[78] Thirty-nine per cent in 2014 (data from April 2016) on http://ec.europa.eu/agriculture/sites/agriculture/files/cap-post-2013/graphs/graph1_en.pdf.

# 5 Nutrition, consumption patterns and public health

## 5.1 Policy opportunities

As noted in Chapter 3, European countries can be classified in broad terms with regard to their respective burdens of over- and undernutrition (Capacci *et al.*, 2013). The Rome Declaration on Nutrition[79] following the 2nd International Conference on Nutrition in 2014 observes how malnutrition has many forms and commits countries to increase investments in food systems to prevent all forms of malnutrition, particularly undernutrition in women and children, as well as reverse the trend in obesity. In the EU, there are other sub-groups, for example the elderly and those on lower income, who may be particularly at risk. The importance of taking a multidisciplinary approach to consumption has been noted previously[11]. There is a significant research agenda associated with developing better understanding on what constitutes a healthy diet (Haddad *et al.*, 2016). It is becoming clearer that the characteristics of a healthy diet will change over a lifetime with particular needs, for example in pregnancy, the elderly and in vulnerable groups. It is important to take account of the diverse exogenous and endogenous factors influencing individual variation (for example, the impact of the immune system), and knowledge of diversity is critically important in providing a foundation for personalised nutrition, which is adjusting diet to the requirements of the individual.

Poor nutrition is a pivotal factor in the global burden of disease but nutrition is not taught adequately in many medical schools and nutrition policy lags behind nutrition science[80]. Food systems are critical determinants of nutrition yet the conceptual framework informing policymakers is relatively underdeveloped. Multi-sectoral policy-making and governance is urgently required to make agriculture and food systems more nutrition-sensitive[81]. Food and agriculture are important thematic areas for embedding health-related indicators in the SDGs (Dora *et al.*, 2015). In the EU, the CAP aims are primarily economic such that food-related health—with the exception of food safety—has been accorded low priority in the CAP hitherto (Kanter *et al.*, 2014). For example, recent reform objectives of the CAP to lower the commodity price of sugar have potential to increase sugar consumption, particularly among lowest socio-economic groups, with deleterious health consequences (Aguirre *et al.*, 2015). However, recent initiatives in some Member States to introduce sugar taxes—for example on sugar-sweetened beverages—may increase consumer costs, while the commodity price is reduced. The very high value of improved nutrition to societies should be supported by policy alignments to create compatibility between nutrition and economic goals for farmers and food processors (Pinstrup-Anderson, 2013). These may include financial incentives and disincentives[82]. To reiterate, it is essential to better align public sector and private sector research and innovation objectives, for example to reduce added sugar in food, to tackle obesity and the associated NCDs (Edwards *et al.*, 2016).

It is essential to pay more attention to consumer perspectives and, in particular, to the position of vulnerable groups, so that the agenda for social care must also be integrated into the policy needs. Social practice theories are also bringing new perspectives to food consumption studies because they allow for a consideration of drivers and barriers to help understanding of consumption as related to everyday life (see, for example, Sahakian, 2015). That is, food consumption patterns are apprehended as habitual and based on routines. While much work has been done on drivers and barriers in relation to individual behaviours, there is still a lack of understanding regarding the complex cumulative effects of social learning and social mimicking processes. An understanding of social practice is necessary in efforts to inform consumer practices.

Stimulating public awareness of food-system-related health issues may help to inform both future CAP change and the procurement of healthy food by public institutions (e.g. schools and hospitals) to serve the needs of those most at risk (Freudenberg, 2016). It is equally essential for dietary guidance to take account of the imperative for food system sustainability (Tilman and Clark, 2014; and see section 3.3), including the recent

[79] www.fao.org/about/meetings/icn/2/en.
[80] D Mozzaffarian, 'A global perspective in preventing cardiovascular disease from discovery to policy'. Presentation to 'At the limits: cardiology, diabetes and nephrology', http://www.atthelimits.org/multimedia/cdnatl-2016 and discussed by Horton (2016).
[81] It should be noted, however, that currently there is significant diversity between Member States and between political groupings in views on EU intervention on nutrition and food choice. This is exemplified with regard to issues of whether EU institutions should do more to regulate nutrition and food choice on trans-fats, food additives, level of sugar and provision of healthy foods to schools, in analysis of voting by members of the European parliament (*What is there in your dish? Regulation of nutrition choice divides EU policymakers,* Vote Watch Europe 24 March 2017, www.votewatch.eu).
[82] The WHO recently called for governments to introduce subsidies for fruit and vegetables, with taxation of unhealthy foods, particularly sugary drinks. Its recommendations are based on systematic reviews of the evidence of fiscal interventions for improving diets and preventing NCDs (Anon. 2016a).

recognition of the issues for ensuring COP21-objective compliance. Recent US guidelines have begun to incorporate food systems sustainability as part of dietary guidance (Merrigan *et al.*, 2015).

Coherent linkage of pathways and policies between food systems and health requires research on value chains, determinants of consumer demand and behavioural change, on diversification of agricultural production (Picchioni *et al.*, 2016) and on understanding the economic externalities of individual choices and government choices about diets (Haddad *et al.*, 2016). Diet quality can often be measured in terms of diet diversity: it can be argued that research underpinning the objective to make staple grains more nutrient-rich should continue (Herforth *et al.*, 2015) but there must also be additional emphasis in the research agenda on identifying non-staple nutrient-rich foods (together with establishing procedures for their marketing and reduction of post-harvest loss), and potential barriers and facilitators to increase consumption of these foods.

### 5.2 Scientific frontiers in nutrition

The EASAC Working Group discussed how the relationship between food and health is complex and subject to influences by the environment, genetics, family and society, and the microbiota. New technologies, including genomics, proteomics, metabolomics and integrated systems approaches help to characterise phenotypes more precisely, underpin the development of new dietary biomarkers and elucidate nutrient–gene interactions. New technologies also help to promote the consumer focus, for example in using smart phone applications and wearable technologies for monitoring. By automating data collection (and reducing bias) and by providing feedback, such technologies may help to inform and change behaviour. New technologies in the household, for example smart refrigerators, may also help to monitor and manage and, thereby, reduce food waste. Much of this new science depends on collecting, analysing and sharing big data sets. This brings issues for standardised measurements and protocols, and provides a basis for the advent of personalised nutrition (O'Donovan *et al.*, 2016).

Metabolic phenotyping, a concept that stemmed from the introduction of metabolomics in nutrition research is central to the emerging model of personalised nutrition. It is expected that classifying individuals on the basis of their metabolic phenotype and tailoring dietary advice to different groups of individuals will improve the

***Table 2 EU projects on new scientific opportunities in nutrition, part of the JPI HDHL***

| Project name/website | Project objectives |
|---|---|
| Determinants of Diet and Physical Activity (DEDIPAC) Knowledge hub (www.dedipac.eu) | Studying determinants of dietary behaviour, physical and sedentary behaviours |
| FOODBALL (www.foodmetabolome.org) | Identifying and quantifying dietary markers using metabolomics |
| ENPADASI (www.enpadasi.eu) | Standardised framework for nutritional phenotype assessment and data sharing |
| Nutri-iCOG (www.healthydietforhealthylife.eu) | Research to address interrelation of diet and cognitive function |
| Intestinal Microbiomics (www.healthydietforhealthylife.eu) | Studying effects of diets on human intestinal microbiota and impact on human health |

efficacy of interventions and help to motivate behaviour change. Results from the FP7-funded Food4me study suggest that personalised nutrition advice produces larger, more appropriate changes in dietary behaviour compared with conventional methods (Celis-Morales *et al.*, 2016). There is also evidence to show that self-monitoring can help to change behaviour, at least in the short-term, although the evidence is not always from randomised control trials. The potential for users of self-collected data to inform primary health-care provision remains to be established in most health systems. Similarly, the issues for quality control in self-monitoring remain to be evaluated by many regulators. However, it is anticipated that personalised nutrition and self-monitoring delivered through smart technologies will not only help educate consumers on nutrition–health linkages but also provide an incentive to change eating behaviours towards more sustainable consumption patterns.

In Europe, the JPI HDHL was initiated to capitalise on scientific frontiers in nutrition and related disciplines by combining and coordinating research efforts of Member States to address major societal challenges. Various relevant projects are now proceeding as part of the JPI HDHL (Table 2 and see also Appendix 4)[83]. For example, ENPADASI will deliver an open-access research infrastructure that will help overcome some of

[83] There are many other research studies underway on relevant topics. For example, the FP7-funded project PERFORMANCE is examining personalised food delivery in vulnerable groups, such as elderly people with dysphagia in nursing homes. Food enriched with specific nutrients according to patient's need (and the composition is adjusted by feedback from monitoring the patient's status) is delivered by three-dimensional printing technology.

the challenges for personalised nutrition research and facilitate standardised data collection methodologies, sustainable data storage and complex data analysis. Other noteworthy projects include Nutri-COG and Intestinal Microbiomics as they highlight two critical themes and integrate new technologies within the context of personalised nutrition for health. Nutri-COG combines three defined research questions targeting different aspects of the interplay between nutrition and cognitive function including the interactions between diet, cognition and stress, the relation between dietary bioactives and cognitive ageing, and the influence of specific nutritional components on mitochondrial function, brain plasticity and brain development. To add to these already complex questions, research has begun to investigate bi-directional relationships between gut microbiota and the central nervous system, suggesting a role in the regulation of anxiety, aggression, mood and cognition (Bauer *et al.*, 2016). Hence, the emerging concept of the gut–brain axis. However, this is just one aspect of intestinal microbiomics, where there is increasing evidence for communication mechanisms between the gut microbiota and distant organs in physiology and disease (Schroeder and Backhed, 2016). Other examples include links with postnatal growth (Chu and Aagard, 2016; Du Toit, 2016) and obesity (Sonnenburg and Backhed, 2016). The observation that certain microbial species can counteract the impoverishing effects of undernutrition or influence the central nervous system raises the possibility that microbiota could be used as a therapeutic intervention to restore healthy growth and development. The JPI HDHL Intestinal Microbiomics programme combines six projects with the underlying objective of determining the functional effects of diet on human intestinal microbiota and the impact of diet-related variations in the intestinal microbiota on health and/or on chronic disease.

It is not possible in this report to document all the relevant scientific frontiers. But it is noteworthy that innovative research is also underway to bring together health and environmental impacts into life-cycle assessments, on the basis of different indicators (see, for example, Dooren *et al.*, 2014). One recent initiative, the Combined Nutritional and Environmental Life Cycle Assessment (CONE-LCA) proposes the use of the metric of disability-adjusted life years to uncover human exposure to particulate materials and chemicals as well as nutritional impacts (Stylianou *et al.*, 2015).

The EASAC Working Group discussed a broad agenda for food and nutrition research (Box 5).

**Box 5 Understanding and acting to improve food and nutrition security in Europe**

*How to measure European food consumption and nutrition security?*
Includes assessment of anthropometrics, diet diversity, hunger
Focus on gaps in knowledge, for example regions, income groups, age groups, migrants
How will new technologies help, for example self-monitoring?
Adapting global standards to be relevant to European populations

*What is needed to better understand food consumption and behaviour?*
Social psychology, risk behaviour
Neurobiology and economics
Social/ecological incentives
Microbiome-brain linkages
Understanding and influencing diet trends

*How to change behaviour towards sustainable, healthy food consumption?*
Instruments of public policy, for example labelling, pricing, regulation
Societal movements—influencing food trends
Ensuring sustainability of cultural dietary heritage
Food environments

*How to measure and influence sustainability related to food consumption and nutrition security?*
Social, economic and environmental aspects (e.g. GHGs, water, soil)
External effects, i.e. outside Europe
Improving throughout value chain, for example labelling and traceability
Capitalising on big data, for example monitoring health

*What is potential consumer demand for innovative, sustainable foods?*
Meat substitutes, algae, insects etc
Recycling farm to fork and gut, and back again
Scope for global exchange of innovation

*How to address food safety and authenticity scares?*
Are European food systems becoming more risky (see also section 4.2)?
Do food scares lead to more waste?

See also Expo 2015 and Food 2030 for discussion of research priorities including issues for vulnerable groups.

### 5.3 Innovative foods and innovative, sustainable diets

Currently, between 70% and 80% of food innovations introduced in Europe are thought to fail. This is wasted investment and a missed opportunity to develop new solutions to tackle health problems. There is a significant research agenda to gain better understanding of consumer needs and preferences for innovative foods and innovative diets (Box 5)[84]. While innovation can come about through the development of new food products there is also ample room for innovation at the level of 'systems of provision': that is, encompassing food processing and access as well as production. Forms of Community Supported Agriculture (Goodman *et al.*, 2012) might, therefore, qualify as innovations.

Significant opportunities are emerging for responsible research and innovation, based on collective engagement between business, public sector researchers, policymakers and the public, to align the innovative process and its outcomes with the values, needs and expectations of society (Steering Committee of the EU scientific programme for Expo 2015). There are already good examples of innovative partnerships (Chapter 2); however, as the Expo 2015 discussion noted, some of the innovation requirements have implications for institutional, political or social innovation and this mandates wider stakeholder engagement. The broader infrastructure for innovation also depends on processing, analysing, sharing and accessing large amounts of data (see sections 3.4 and 6.6). Additional research issues arise for developing the metrics to measure what is a sustainable diet, how to integrate these metrics into dietary surveys, and how to inform consumers on sustainable behaviour and diets. Consumers are attracted by price, so the challenge becomes how to ensure competitive prices for healthy foods, while also incorporating nutrition goals and sustainability objectives, and adequately rewarding farmers and others in food systems.

[84] The FP7-funded project CONNECT4ACTION, www.connect4action.eu, has developed a tool box to help food companies communicate the benefits of their innovations, including training modules for public and private sector professionals.

# 6 Opportunities for innovation in agriculture: sustainable intensification at the farm scale

## 6.1 What are the prospects for innovation to improve agronomic practice?

As discussed by EASAC previously (EASAC, 2012a, 2013a, 2014b), innovative agriculture for sustainable intensification requires the deployment of all available approaches, traditional and novel, building on existing achievements for good agronomic practice.

A mix of policy instruments is required to facilitate the development and implementation of innovative farming systems—applying equally to organic agriculture (Reganold and Wachter, 2016) as to other approaches described in the following sections—to produce sufficient, high-quality food, to enhance the natural resource base, to be financially viable and to contribute to the well-being of farmers and their communities. A mix of policy instruments is needed to overcome multiple obstacles: lack of appropriate knowledge (e.g. by supporting research and increasing transparency throughout the food chain), financial (e.g. by investment in infrastructure and elimination of perverse incentives) and legal (e.g. to enable competition and trade) (Reganold and Wachter, 2016). With further regard to organic farming, it is worth noting that there are challenges to face in reducing the current yield gap between organic and conventional agriculture (see later).

We emphasise throughout our report the importance of taking a comprehensive approach to the issues for sustainable production, encompassing, for example, improved crop varieties, integrated crop protection, soil fertility and water management, with reduction of external inputs, namely the production ecological approach (van Ittersum and Rabbinge, 1997). The value of other ecosystem services in underpinning agriculture is discussed in previous EASAC work (Appendix 2) and key research questions to explore the agro-ecosystem have been identified (Table 1). These issues are also discussed in detail elsewhere[85] and a recent Erasmus project describes various approaches to agro-ecology in EU Member States[86].

New technologies should be evaluated according to the scientific evidence base (EASAC, 2013a). Decisions about the acceptability of new technologies must be made in the context of evaluating competing risks (GOS, 2011). The potential costs of not using a new technology, or being too slow in adoption, must also be taken into account: there is no time to lose in resolving the problems for food and nutrition security.

We do not now repeat the comprehensive discussion of the research agenda for filling gaps in knowledge relating to agronomic practice (e.g. Table 1), but in the following sections select some key themes addressed in EASAC Working Group discussion. The new technologies that we discuss in plant and animal breeding are examples of what is becoming possible: we do not attempt to be comprehensive here and other research advances in plant and animal breeding, for example, are covered in the sources we cite.

## 6.2 Meat from land

Advances in animal agriculture have depended on research and development and there is a continuing need to capitalise on scientific opportunity to respond to the growing challenges, for example, the needs to improve animal health and welfare and to address climate change (see section 3.3).

The history of livestock in agriculture has moved from selective breeding for an observed phenotype (starting with initial efforts for domestication) to marker-assisted breeding, aided by reading the genome and genome-wide association studies. Genome-based selection has been of the greatest importance in cattle breeding worldwide and can be expected to revolutionise the breeding of other farm animals (Meuwissen *et al.*, 2016). Technologies such as next-generation sequencing are becoming ever more efficient and affordable. For example, it is a stated goal to reduce drug treatment in animal husbandry and this requires breeding of more robust populations as well as improved diagnostics and targeted treatments. High-throughput sequencing can gather genetic, transcriptomic and epigenetic information from the animal and from invading pathogens (microbiome and virome) (Raszek *et al.*, 2016). Understanding of host–pathogen interactions and identification of genes that could protect against disease, or that are used by the pathogen to infect the host, will support breeding programmes and enable development of diagnostics and treatments. Gaining an understanding of the relationship between genotype and phenotype (for example for heat or stress resistance (Kaushik *et al.*, 2016; Nguyen *et al.*, 2016)) of individual animals helps provide the knowledge base for future farming. It also provides

[85] For example in the FAO work on ecosystem services and biodiversity, www.fao.org/ecosystem-services-biodiversity.
[86] 2017 Euro Educates project in Austria, France, Italy, Lithuania and Slovakia, www.euroeducates.eu/medias/files/oep-o1-synthesis-of-national-reports-en-17-03-22.pdf.

essential information to improve breeds by genetic modifications (see below).

The EASAC Working Group noted the importance of maintaining animal genetic material banks to conserve information on both domesticated species and their wild counterparts. The FAO has advised that the cost of establishing gene banks for animals is high by comparison with crop gene banks and has concluded that animal gene banks would serve primarily as a back-up to the self-sustained maintenance of breeds in the production systems where they were developed[87]. The European Gene Bank Network for Animal Genetic Resources, EUGENA, is beginning to coordinate and improve existing gene banks in several European countries (Hiemstra *et al.*, 2014).

The genomic sequences of most major livestock species have been generated and it is now feasible to precisely 'rewrite' selected parts, ranging from a single nucleotide to whole chromosomes. For the past 20 years, targeted gene modification of large animals has been able to be accomplished with the help of somatic cell transfer. However, genetic modification of food animals remains controversial in the EU, partly because of the ethical issues and welfare concerns (Box 4). The main driver of research on genetically modified animals has been biomedical research, to develop animal models of human disease or for xenotransplantation. Currently, the only genetically modified animal commercially produced for food (in the USA) is the Food and Drug Administration-approved genetically modified salmon, with the trait of increased growth, although there is significant other research on genetically modified animals continuing, for example to develop cattle resistant to mastitis and chickens resistant to avian influenza (Wall *et al.*, 2005; Lyall *et al.*, 2011).

The prospects for innovation are changing rapidly, however, in consequence of recent research advances in genome editing. The foundations of this technology were laid 20 years ago with zinc finger nucleases, and the field developed further using TALENs (transcription activator-like effector nucleases) and has markedly grown with the advent of CRISPR–Cas9 (clustered regularly interspersed short palindromic repeats–CRISPR associated), first reported in 2012. Genome editing can now be accomplished more easily and precisely with few, if any, off-target effects and with the addition of no foreign DNA into the modified animal. Genome editing in pigs is currently being used to introduce disease resistance (e.g. protection from African swine fever and the porcine reproductive and respiratory syndrome virus (Lillico *et al.*, 2013; Whitworth *et al.*, 2016; Burkard *et al.*, 2017)), and to increase muscle mass (by mutation of the myostatin gene (Proudfoot *et al.*, 2015)). Research is also being undertaken to develop a trypanosomiasis-resistant cow. Besides conferring disease resistance, other welfare issues are also being addressed, for example avoiding the need to dehorn cattle by generation of hornless animals (Carlson *et al.*, 2016), avoiding the castration of male piglets to prevent boar taint (Fahrenkrug, 2016) and by understanding gene functions involved in sex regulation and fertility in chickens (Taylor *et al.*, 2017).

Science and governance issues for genome editing across a wide range of applications including animals in agriculture are currently being addressed in a separate EASAC (2017) project on genome editing (see also section 6.3) and will not be reviewed in detail here. It is reasonable to conclude, however, that there is a case for considering genome editing in animals as part of the toolbox for improving agricultural productivity if animal welfare[88] and ethics issues are resolved.

There are, of course, other controversial issues with ethical dimensions in animal science, for example the use of growth promoting feed additives and the irradiation of meat to kill potential pathogens as well as the more general issues for animal breeding, welfare and husbandry. These controversies are discussed in the comprehensive US National Research Council report on animal science research in food security and sustainability (Committee on Considerations for the Future of Animal Science Research, 2015). The report, like this EASAC report, draws on underlying assumptions:

- Global demand for animal protein consumption is increasing, although there is uncertainty about its future trajectory.

- Restricted resources and environmental changes will drive complex discussion on agriculture with implications for the research agenda.

- Rapid advances in fundamental biosciences research, together with knowledge from the social sciences and economics provides significant opportunity to capitalise on investment in animal science research and innovation.

- There must be greater communication between researchers and the public.

The National Research Council report proposes some general research priorities for animal science, which include the following.

- Production orientation, for example understanding animal nutrient metabolism.

[87] https://www.rfp-europe.org/fileadmin/SITE_ERFP/AdHoc/May2012/ERFP_AdHoc-exsitu_May2012_present-FAO.pdf.
[88] For a broader discussion of global animal welfare issues, see the FAO legislative study by Vapnek and Chapman (2010).

- Systems orientation, for example alternative animal feed ingredients from human food waste.
- Animal welfare, for example alternatives to antibiotic use.
- Climate change—adapting agricultural animals to the effects of climate change and better understanding of GHG emissions from animal agriculture (on a systemic as well as per capita basis).

Additional perspective on the issues for livestock production is provided by the Animal Task Force, the European public–private platform[89], which regards animal production as the key in a sustainable circular bioeconomy. Their research and innovation White Paper in 2013, observing that the animal products sector contributes €130 billion annually to Europe's economy, being about 50% of total agricultural activity, highlighted various research priorities for example for efficient animal production and feed chains as part of smart agriculture, and the role of the microbiome in animal and human health.

In Europe there are increasing possibilities to use alternative meat sources[90], for example insects, and substitute sources such as cell-cultured meat and alternative proteins. These new possibilities will not be discussed in detail here but they should form part of the Food 2030 agenda[32]. It may also be the case that alternative sources, for example cultured meat *in vitro*, will have lower environmental impact than livestock and this potential must also be examined as part of the research agenda to characterise the scientific opportunity.

The role of the livestock sector in GHG mitigation is a major issue. While change to livestock management practices (e.g. sustainable intensification of production, reduction of GHG emissions as manure, carbon sequestration on grazing land) could contribute to GHG mitigation (Herrero, 2016), more significant adjustments will require changing the demand for livestock products (see section 3.3). However, consumption of meat is also an important consideration for a healthy as well as sustainable diet, as discussed previously in our report and in recent literature[91]. The implications of reducing meat consumption on human health and on land use continue to be an important topic for the science agenda. For example, in understanding the impact of diets of different composition on children's development and learning, and in clarifying the impact of different feed conversion efficiencies in different animal species on land use.

### 6.3 Food and biomass from the sea

Many other groups have discussed issues associated with the contribution that fish make to food and nutrition security, for example the World Bank report (2013) with FAO and IFPRI. Current fishery practice seems to have reached an upper limit and the growth in ocean food production is now because of marine aquaculture (FAO, 2016).

The recent report by EASAC and the JRC, '*Marine sustainability in an age of changing oceans and seas*' (EASAC and JRC 2016) was delivered as a response to the increased focus on coherent marine and maritime governance in the EU, as well as globally. This study looked at several key aspects for sustainable development in changing oceans and seas (fisheries management, biodiversity conservation and marine environmental protection) and considered important scientific challenges in addressing these issues. Compared with agriculture, the present role of the ocean as a food provider for the human population is relatively small, and future food and nutrition security was not addressed specifically in the report. However, the report does address some issues that have relevance for future food and nutrition security, and these are briefly summarised below.

The EASAC and JRC (2016) report argues that, compared with land, the marine environment appears under-utilised as a food provider for the human population. The rationale for this claim is that the global marine harvest contributes only 2% to human food calories (Duarte *et al.*, 2009), significantly more (perhaps up to 15%) in terms of protein, while the global annual primary (i.e. photosynthetic) production is roughly equally distributed between land and the ocean (Field *et al.*, 1998). Expressed as a percentage of the oceanic primary production, the world capture fisheries catch is below 0.05% according to the report. This ecological efficiency is at least one order of magnitude lower than for the human food produced in agriculture. A main challenge for marine food harvest/production is therefore to increase this efficiency in a sustainable way.

Despite the relatively low yield from the oceans, unsustainable exploitation and overfishing has

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[89] www.animaltaskforce.eu.
[90] For example, a major new leadership initiative was launched in 2016 by the French Government on new sources of protein; see http://agriculture.gouv.fr/faire-de-la-france-un-leader-mondial-des-proteines.
[91] For example, a recent long-term cohort study (with some participants followed up for as long as 32 years) demonstrated that eating more protein from plant sources is associated with lower risk of death and animal protein is associated with higher risk of death in people with at least one lifestyle risk factor such as smoking or being overweight (Song *et al.*, 2016).

become a serious concern for many stocks and regions worldwide. Over the past decades the world capture fisheries catch has levelled off at a quantity slightly below 100 million tonnes per year (FAO, 2016). Bringing current fisheries exploitation to sustainable levels by ending overfishing has therefore become an important management objective. However, successful protection and conservation of today's exploited stocks alone is not likely to increase tomorrow's fishery harvest. Thus, such action alone is, along with a further increase in the demand for food, likely to diminish the role of the ocean as a food provider for the human population.

The EASAC and JRC (2016) report points out that the debate around overfishing gives the strong impression that the ocean as such is overexploited as source for human food. Over-exploitation is indeed true for a large number of fish stocks, but the exploited fish stocks represent only a minor fraction of the total marine biomass and production. Current fishery practice is based on a long tradition of hunting predators high up in the food chain, and the average trophic level of the global fishery catch corresponds to, in a terrestrial setting, that of wolf-eaters (Duarte *et al.*, 2009). Exploitation high up in the food chain involves a substantial loss of biomass, around 90% for each trophic level. In combination with the demand of a growing human population, overfishing appears to be an inevitable consequence of practise of fishing on high trophic levels. In contrast, agriculture targets primarily the first (plants) and the second (herbivores) trophic levels, and the ecological efficiency of the land-based food production is therefore much higher than in today's fisheries.

On the other hand, the human utilisation and pressure on land is considered to be much higher than for the ocean (Vitousek *et al.*, 1986; Pauly and Christensen 1995). Since the ecological efficiency of agriculture is already relatively high it might be harder to increase this further on land than in the ocean. Also, agriculture occupies a substantial part of available land areas and shortage of water is an increasing concern in many regions (see section 7.2). Water shortage is of no concern in the production of marine biomass. Also, below the euphotic zone, which range from a few metres in coastal waters to around 100 metres depth in the oligotrophic subtropical gyres, there is a huge natural reservoir of dissolved nutrients (e.g. phosphate, which might become a future constraint in agriculture). Consequently, the ceilings for increased food production appear more severe on land than in the ocean (Duarte *et al.*, 2009), and attention to increased utilisation of marine living resources in the near future will probably increase.

The EASAC and JRC (2016) report notes two ways forward to increase the role of the ocean as a sustainable food provider for the human population: (1) by directing capture fisheries towards lower trophic levels in the marine food chain than in today's fisheries; and (2) by developing ecologically efficient marine aquaculture (mariculture).

To redirect fishing pressure from higher to lower trophic levels involves several technological (lower trophic species tend to be smaller than higher trophic level species) as well as management challenges, but more urgent is the need to extend the knowledge base. Compared with the land, there is a severe lack of direct observations of marine living resources. Major biotas and biomass components of the ocean, such as krill, copepods and mesopelagic fishes, are still unknown. For example, it remains uncertain whether the global fish biomass (including the non-harvested mesopelagic fishes) is 1 billion, 10 billion or even more than 10 billion tons (Irigoien *et al.*, 2014). Consequently, the knowledge base required for a sustainable harvest of lower trophic level resources needs to be developed.

An increased role of the oceans as human food provider must obviously involve aquaculture, and aquaculture production makes up an increasingly larger part of food provided from the ocean (FAO (2016) and Figure 2). Aquaculture is also in freshwater, but mariculture is the largest activity today. Although domestication of marine plants and animals lags agriculture by thousands of years, there has been an unprecedented growth in marine domestication during the past 100 years (Duarte *et al.*, 2009), which provides an important foundation for mariculture innovations in the coming years. Such innovations should include (Duarte *et al.*, 2009; EASAC and JRC 2016) developments to (1) close the production cycle to abandon its current dependence on fish oil

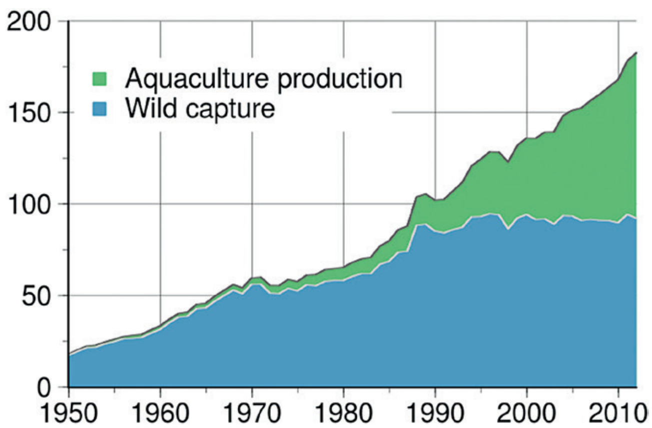


*Figure 2 Global total wild fish capture and aquaculture production in millions of tonnes, as reported by the FAO*[92].

[92] Attribution: By Con-struct - FishStat database, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=30159916.

and fish meal derived from forage fisheries catches, (2) enhance the production of edible macroalgae and filter-feeder organisms (e.g. herbivores), (3) minimise environmental impacts, and (4) increase integration with food production on land, such as transferring water-intensive (owing to freshwater shortage on land) components of the human diet (i.e. production of animal protein) to the ocean.

The present EASAC Working Group supported these recommendations for the oceans, improving the knowledge base for sustainable harvest and culturing of lower trophic marine resources, and emphasises the importance of research to integrate strategy for marine and terrestrial scientific opportunities where possible. The EASAC Working Group also emphasised the potential for marine aquaculture in biomass production (for example algae) for biofuels, thereby diminishing pressures on agricultural land, freshwater and fertilisers (see also Chapter 7).

### 6.4 Plant science

Plant sciences have contributed, and can do much more in contributing, to intensified crop productivity and to sustainable agriculture by developing new plant cultivars, increasing the efficiency of plant nutrition and offering new perspectives for pest and pathogen control. Plant breeding aims to develop new cultivars with higher yield potential, enhanced abiotic (drought, salt, water logging and aluminium stress) and biotic (pests and pathogens) stress tolerance and resistance, altered phenological development and improved quality (food and feed). Furthermore, cultivars used in organic farming have to meet additional requirements such as enhanced pest and pathogen resistances and elevated nutrient use efficiency and better competitiveness against weeds because of the avoidance of chemical plant protection, herbicides and mineral fertilisers. If organic farming and other specific farming practices (such as conservation agriculture) are to be made more competitive, then there is need for more research into these systems, with regard to the breeding of particular cultivars.

The scientific opportunities have to be better integrated in the social, environmental, economic and political contexts (Ingram and Porter, 2015). An analysis initiated and supported by the ETP 'Plants for the Future' portrays the economic, social and environmental value of plant breeding in the EU over the past 15 years (Noleppa, 2016). According to this comprehensive analysis, plant breeding innovation has contributed approximately three-quarters of the overall productivity in EU arable farming, has generated significant social welfare gain in terms of gross domestic product and farming jobs and income, and has helped to save land resources (with beneficial consequences for preserving EU natural habitats and sparing further land use outside the EU for EU imports). These various gains are predicted by the ETP to continue in the next 15 years if plant-sciences-based innovation continues but, as we discussed in previous sections, the implications of continuing yield growth have to be assessed in terms of the food chain as a whole and the consequences for public health and the environment.

Cell and tissue culture techniques (e.g. doubled haploid production) are frequently used in plant breeding today. Even a new crop, triticale, has been created by hybridising two old crop species and is now grown all over Europe. In the past decades, plant breeding has been revolutionised by biotechnology, including genetic modification. DNA-based technology has been used in selection, initially with molecular markers that are now routinely used in marker-assisted selection. Recently, genome-wide selection methods have been introduced as a result of immense progress in sequencing (next-generation sequencing) and genotyping technology (single nucleotide polymorphism chip arrays). Those techniques enable early selection by genotype, avoiding time-consuming and laborious phenotypic selection in the greenhouse or in the field and/or shifting the time point of selection to early generations. Moreover, the selection intensity has been markedly increased. Genomic selection is increasingly used in plant breeding, starting with commercial crops such as corn, soybean and rice. It is foreseeable that genomic selection will be implemented in all major breeding programmes (Lin *et al.*, 2014). Interestingly, these applications of biotechnology have been largely disregarded by the public whereas genetic modification (resulting in genetically modified organisms (GMOs)) has attracted high public awareness since its inception 30 years ago.

GMO technology has steadily advanced, resulting in new scientific opportunities. 'Traditional' methods using heavily criticised antibiotic or herbicide resistance markers have been replaced by new methods which result in marker-free GMOs. Studies have demonstrated that genetically modified plants are as safe as plants grown by conventional methods (discussed in detail in EASAC, 2013a). It has been suggested that transgenic plants (carrying genes from other species) should be distinguished from cisgenic ones (which do not carry an alien gene) in regulatory terms (Schouten and Jacobsen, 2008). Currently, the same complex regulatory machinery applies to cisgenic and transgenic plants although cisgenic plants have been bred that could have a high value to European agriculture, such as a potato variety with enhanced resistance to late blight (Haesaert *et al.*, 2015). Recent research is aiming at new production systems where genetically engineered plants respond to the application of chemical compounds in the field. In this way, the farmer can control the onset of flowering of a field crop depending on favourable weather conditions (Izawa *et al.*, 2016).

In the past 3 years, a new technology has been introduced that enables precise modification of a target gene without leaving any transgenes or unwanted genetic modification in the genome (see also section 6.2.1 for the application of genome editing in animal science). As noted previously, the term 'genome editing' summarises several techniques based on enzymes that are directed to a certain sequence in the genome, of which the CRISPR–Cas system has gained the highest importance (Hille and Charpentier, 2016; Schaben and Edwards, 2017). It has been applied in model (such as *Arabidopsis thaliana*) and crop plants (Paul and Qi, 2016). Genome editing has the potential to replace mutagenesis by irradiation or chemical treatment, which has been frequently used in breeding for 70 years. While mutagenesis is highly inefficient, resulting in many thousands of (unknown) mutations, of which only one or a few yield the desired phenotype, the CRISPR–Cas system is precise and efficient in a way that only one or a few nucleotides are altered. Although this technology has only been in use since 2012, there are numerous publications describing the application of genome editing to alter agriculturally important traits, for example bread wheat with high resistance to powdery mildew by simultaneous knock-out of three susceptibility genes (Wang *et al.*, 2014), and maize hybrids with drought tolerance (Shi *et al.*, 2017). Broader research infrastructure and other priorities to capitalise on the advances accruing from genome editing include efforts to connect genotype and phenotype information, model behaviour of gene networks, and development of databases to integrate and analyse information (Schaben and Edwards, 2017). EASAC recently completed a project on genome editing which discusses the scientific and regulatory issues in detail[93]. That report concluded that (1) if a product of genome editing does not contain foreign DNA, it should not fall within the scope of GMO legislation and (2) the EU should aim to regulate the trait and/or product, rather than the technology used in generating that product.

Previous EASAC work has reviewed a wide range of issues for the scientific opportunities in plant breeding and our recommendations cover the conservation and use of plant genetic resources in conventional breeding (EASAC, 2012a) through to resolving current problems surrounding genetically modified crops in the EU (EASAC, 2013a) and capitalising on new plant breeding techniques (EASAC 2015a) (see Appendix 2).

The US National Academies of Science, Engineering and Medicine recently published a very comprehensive study of genetically engineered (GE) crops with regard to past experiences and prospects (National Academies, 2016). This study covered agronomic and environmental effects, human health effects ('*no differences have been found that implicate a higher risk to human health and safety from* these *GE foods than from their non-GE counterparts*'), social and economic effects and the regulatory prospects. This study, in observing that the process-based approach to regulation has become less technically defensible as the old approaches to genetic engineering become less novel and the emerging processes fail to fit old categories of genetic engineering, supports the previous findings of EASAC (2013a, 2015a). We concur with their final recommendation: '*In determining whether a new plant variety should be subject to premarket government approval for safety, regulators should focus on the extent to which the novel characteristics of the plant variety (both intended and unintended) are likely to pose a risk to human health or the environment, the extent of uncertainty regarding the severity of potential harm, and the potential for exposure, regardless of the process by which the novel plant variety was bred.*'

Many of the other recommendations in our previous EASAC work also remain relevant. For example, with regard to conservation of plant genetic resources, recent analysis (Castaneda-Alvarez *et al.*, 2016) confirms the EASAC (2012a) conclusion that plant diversity in gene banks is often poorly represented by crop wild relatives and that systematic effort is warranted to improve the conservation and availability of crop wild relatives for use in plant breeding. The most critical collecting gaps include the Mediterranean and Western and Southern Europe. In the future, seed banks will be exploited in a completely different way. As tens of thousands of accessions from major crops (such as maize, rice barley) are currently sequenced, this information will be used to identify new genotypes that cannot be found by traditional phenotypic screening. Moreover, gene bank collections should be completed by as yet under-represented or unexploited (potential) crop species. There are several plant species that could have a great potential for domestication in European agriculture (Osterberg *et al.*, 2017), for example quinoa (*Chenopodium quinoa* Willd.), an old South American crop with high stress tolerance. The seeds have a high nutritional quality which is the reason for their increasing consumption as a healthy food (Cirad, 2015). The quinoa reference genome has now been ascertained (Jarvis *et al.*, 2017) and, building on this greater understanding of genetic diversity, research priorities should include breeding quinoa varieties to adapt crops to European day length and seasonal changes, so providing another example of where the research agenda has to consider the interconnections between agriculture, nutrition and ecology. The benefits of crop rotation compared with monoculture also merit further research assessment.

[93] This EASAC project on Genome Editing (2017) also covers issues for gene drive, an approach to tackling pests and diseases that may have application in agriculture as well as in human health.

The EU plant sciences sector has been very active in contributing to strategic discussions to support innovation in agriculture and horticulture. A detailed action plan has been published by the ETP[94], with recommendations covering research, education and innovation in the plant sector.

One question discussed by the EASAC Working Group was whether plant scientists had paid enough attention to understanding and modifying root systems, particularly with regard to the objective of augmenting carbon sequestration in soils. This should be part of the broader research agenda for understanding plant–soil microbiome interactions (also relevant for other considerations of water efficiency and nutrient uptake efficiency). Attempts to increase the stock of organic carbon in soil and, hence, mitigate climate change[95] may also have implications for crop planting patterns. Further research to develop the evidence base is warranted to assess whether this approach can be deployed at sufficient scale (Anderson and Peters, 2016) and would be economically viable and efficient compared with other proposed measures of climate change mitigation. Comparison of the impacts of different negative emissions technologies requires more assessment of biophysical limits and economic costs (Smith *et al.*, 2015); these and other strategies for climate change mitigation should also be subject to health impact assessment. For soil carbon sequestration, it should also be appreciated that the gain in improving soil quality could perhaps be at least as important as the effect on GHG levels (see also section 7.3).

### 6.5 Biosecurity

Agricultural biosecurity is a term that has several interpretations. It can mean the protection of countries against natural outbreaks of pests and diseases[96]; the growing threats and scientific opportunities in this context are comprehensively described elsewhere (Waage and Mumford, 2008) and were covered in the EASAC report on plant health (2014b) and in more recent work focusing on the neonicotinoids (EASAC, 2015b). The present EASAC Working Group emphasised that declining interest of industry in developing novel chemical herbicides, fungicides and insecticides because of the difficulties in obtaining authorisation, together with withdrawal of some previously authorised chemicals from the market, creates problems (EASAC 2013a, 2014b). In the absence of new chemical options, the answer must include new breeding approaches to confer pest and disease resistance (Scott *et al.*, 2016) as part of agro-ecological solutions. The role of antibiotics in protecting animals from infectious disease is discussed in section 4.2: breeding for improved pest and disease resistance has, again, to be part of the solution to limit antibiotics on the farm.

There is an additional dimension to biosecurity, however, relating to the defence against the deliberate introduction of pests and diseases as an act of terrorism, criminality or other malicious intent. These issues for plant health were considered by IAP as part of a review of science and technology developments that have implications for the UN Biological and Toxin Weapons Convention[97]. The FP7-funded project Plantfoodsec[98] has identified priority pest and pathogens for research and regulatory policy. Plantfoodsec has also initiated a virtual centre of competence on plant and food security to enhance preparedness, responsiveness and recovery capabilities in the event of intentional or unintentional biosecurity threats to EU agriculture. This virtual competence also covers issues for foodborne pathogens as a threat from deliberate food contamination (see section 4.2).

### 6.6 Precision agriculture

The introduction and development of precision agriculture is important to improve the cost-effectiveness of agriculture and, by increasing efficiency, to minimise waste and to reduce potential impacts on the wider environment. The term 'precision agriculture' is used to cover heterologous technologies and practices, and as there is no common definition of what precision agriculture is, so there are no reliable data on uptake by European farmers (STOA, 2015). Nonetheless, a range of technologies underpinning precision agriculture to improve farming efficiency includes the advances in animal and plant breeding described previously but also other technologies outside molecular biology that can contribute to a more precise and/or localised production (STOA 2015; Bhunnoo, 2016). These include, for example:

- Autonomous agricultural machinery, including robotics for weed control and crop harvesting.

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[94] www.plantetp.org.
[95] For example, as proposed in the '4 per 1000' initiative for soil carbon sequestration (increasing the quantity of carbon contained in soils by 0.4% per year is said to be able to halt the annual increase of carbon dioxide in the atmosphere). This initiative was supported by the French Government in the 2016 G20 Summit as part of the soils for food security and climate programme. See http://4p1000.org and Chabbi *et al.* (2017) for further details.
[96] As exemplified by international initiatives to prevent spreading of diseases such as wheat stem rust: http://globalrust.org, http://wheatrust.org and http://www.fao.org/agriculture/crops/thematic-sitemap/theme/pests/wrdgp/en.
[97] 'The Biological and Toxin Weapons Convention: Implications of advances in science and technology', 2015 https://royalsociety.org/topics-policy/projects/biological-toxin-weapons-convention.
[98] www.plantfoodsec.eu and see Gullino *et al.* (2017).

- Three-dimensional printing for production of chemicals on the farm.

- Aquaponics, combining hydroponics with fish farming.

- Use of smart phones (hyperspectral imaging) to detect plant pests and diseases and fish pests in aquaculture.

- Satellite positioning systems (see section 6.6), remote sensing by drones combined with other diagnostics/application systems, connecting data to assess soil and crop conditions and to deliver tailored amounts of water, pesticides or fertiliser. Satellites and algorithms can now also predict weather patterns further in advance, enabling more precise sowing and plant care regimens.

- Advances in handling big data (see also section 6.6).

Potential implications, for example for ICT systems for smart farming management software and for various commercial companies in the agriculture sector, currently undergoing a spate of mergers/takeovers, are discussed elsewhere[99].

The ongoing STOA work on precision agriculture (2015) aims to clarify some of the issues for understanding technology and societal drivers and the positions of stakeholder groups. There are already substantial EU initiatives to bring more coherence to the research agenda, for example ICT-Agri ERA-NET (see Chapter 2); and the STOA paper emphasises complementary needs, for example to develop a skilled workforce in the farming sector, which requires research to understand the drivers of farmer uptake of new technologies and practices. The STOA paper also recommends more work to understand the implications of multiple EU legislative pathways, which variously include the CAP, European Innovation Partnerships, Circular Economy Package and a variety of directives/regulations governing agricultural and aerial vehicles, water use, pesticide use and the digital single market. These recommendations are discussed further in a recent EPRS briefing[100] in the context of anticipatory policy-making to include modifying CAP for 2021–2027 and to promote research and development for cutting-edge sustainable technologies in agriculture.

In EASAC Working Group discussion, several other cross-cutting issues were raised for precision agriculture, one being that it is capital intensive and so needs to be deployed at scale, thereby increasing the differential between the economics of big and small farms and further homogenising the landscape. However, while some technologies in precision agriculture may foster homogeneity, if smart farming is really smart it should have the potential to accommodate heterogeneity. Other issues include how best to train scientists in new technologies and retain them in the EU in the face of considerable international competition for their services; how to ensure farmer ownership of farm data and avoid industry dominance in closed systems; how to share data for research and innovation in safe and secure ways to enable the experimental function; how to protect against hacking and system breakdown; and how to respond to challenges where there may be considerable uncertainty in the scenarios envisaged, for example the impact of climate change on the spread of infectious disease in animals and plants.

It was also recognised as highly important to introduce precision biology and engineering where appropriate in other aspects of the food system. Many other processes in the food chain can be improved, in particular reduction in waste, better storage and packaging, supply chains, transport infrastructure, food formulation, food retail environments and marketing, and food outlet planning and access. Space does not allow full consideration of these important issues although some have been introduced briefly in previous sections (in Chapter 4) and it is recognised that progress in many of these areas depends on the collection and sharing of large data sets (see next section).

### 6.7 Digitalisation and use of big data in agriculture and food chains

Digital technologies can rapidly transform a sector or a way of doing business, for example the advance of online shopping or apps for reserving taxi rides. Digital technologies to date for agriculture, food systems and food security have not had such a disruptive character. In the past years, expectations have been raised around the likely impact of digitalisation on agriculture, food systems and food security, through a range of developments termed data revolution, big data, data science, precision farming, open data, data ecosystems and smart farming. For example, the UN released a report 'A World that counts' on the data revolution for measuring the advancement towards the SDGs[101], while McKinsey[102] highlighted the big wins in digitising the food chain in an analytical blog post, entitled 'How big data will revolutionise the global food chain'. The network Global Open Data for Agriculture

[99] 'The future of agriculture', The Economist Technology Quarterly, June 2016, on www.economist.com/technology-quarterly/2016-06-09/factory-fresh.
[100] EPRS PE 598.628, March 2017 '*What if intensification of farming could enhance biodiversity?*'.
[101] http://www.undatarevolution.org/report/.
[102] http://www.mckinsey.com/business-functions/digital-mckinsey/our-insights/how-big-data-will-revolutionize-the-global-food-chain.

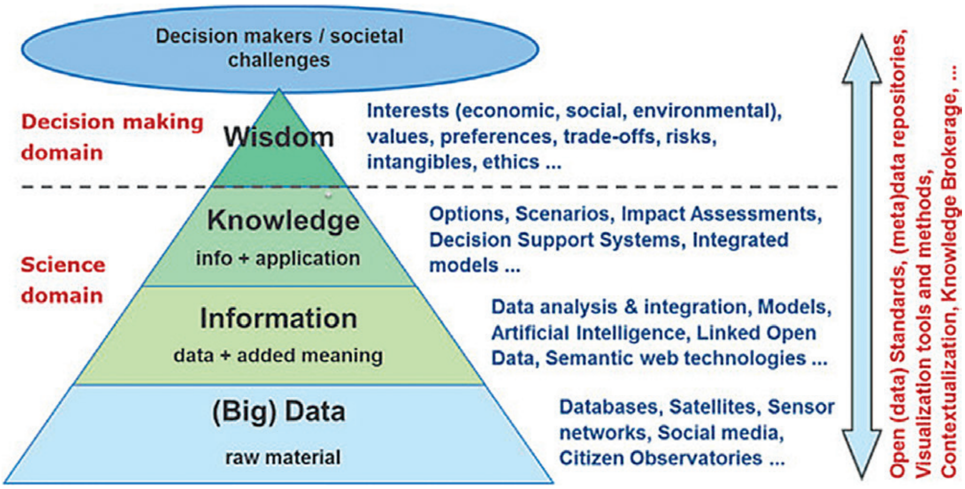


*Figure 3 Hierarchy of data–information–knowledge–wisdom, from big data to decision-making for societal challenges, taken from Lokers et al. (2016).*

and Nutrition[103] is advocating more open data to fight hunger. Thus, these separate technology developments drive the digitisation of the agriculture and food systems by (1) collecting more data through sensors, track and trace, crowd sourcing and mobile technologies; (2) sharing the data more widely through open data in data ecosystems and Internet of Things; and (3) evaluating the data with powerful techniques through big data analytics. Ultimately, this should lead to improved design and decision-making of those in policy, business and farming, and by consumers (see Figure 3).

Regarding the new methods of data collection, the EU has invested significantly in new satellites through the Copernicus programme[104], generating open data with different bandwidths and sensors at fine spatial and temporal resolution. These can be combined with drones (or unmanned aerial vehicles) and sensors on farm machinery for near- and close-sensing, enabling the development of precision farming solutions (see also section 6.5). Similar trends can be observed in food chains where sensors and precision techniques can be used to track produce from farm to fork, and rapidly identify and respond to food safety concerns, or provide an enhanced consumer experience.

Beyond the collection of data through new methods, the sharing and validation of data are crucial aspects to enable advances in science and innovation towards sustainable agriculture and food security. Initiatives such as GODAN, AgGateWay[105] and the FAIR principles (Wilkinson *et al.*, 2016) focus on the sharing of data across the food chain according to common standards and protocols to enable data analysis. A lack of data sharing could easily block further advancement as crucial relationships cannot be further explored and understood. Data ownership and privacy concerns will need to be addressed for the agriculture and food security domain.

With the situation changing from data sparse to data rich (or even data overflow), new analytical techniques are required, to capture the amount (volume), speed of acquisition (velocity), uncertainty and reliability (value or veracity) and cross-disciplinary and space–time linkages (variety), together describing the '4 V's' of big data. Big data is defined as a term encompassing the use of techniques to capture, process, analyse and visualise potentially large datasets in a reasonable timeframe (NESSI, 2012). Big data technologies have not been applied extensively to date in agriculture and food systems[106], and will have to deal with the variety and veracity of challenges of big data (Lokers *et al.*, 2016). While retaining what is valuable from previous methodologies, a break from traditional analytical methods is required to create a next generation of analytics for agricultural and food systems using collaborative and open methods of development.

[103] www.godan.info.
[104] http://www.copernicus.eu/.
[105] www.aggateway.org.
[106] '9 billion bowls', Thomson Reuters Report, 2015 on http://reports.thomsonreuters.com/9billionbowls describes a wide range of examples where big data are essential to make connections to build innovative solutions for food security. In addition to uses in weather forecasting, pest and disease surveillance, monitoring trends in food prices and links to civil unrest (as discussed elsewhere in this EASAC report), the Thomson Reuters review covers issues for the EFSA European Food Consumption Database, to identify and help reduce the risk of contaminated food, particularly among vulnerable populations, and the use of legal documentation data as the basis of developing an inventory of land rights.

# 7 What are key issues for managing competition for land use and other resources for sustainable rural development at the landscape scale?

Horizon scanning exercises (see, for example, Table 1) have identified significant science and technology challenges in multi-functional land use planning. The challenges include, for example (Parker *et al.*, 2014), assessing the validity and usability of different approaches to valuing ecosystem services; developing scenarios for balancing food, energy, water and environment objectives; and evaluating approaches to trade-offs between ecosystem services in resource allocation discussions and conflict resolution, and improving the ability to analyse risk and opportunity in such decisions.

Most European land is in a managed state, and most land management is performed by farmers and foresters who provide a range of environmental services in addition to the food and fuel that they provide through markets. Because there are very few spontaneously occurring markets for environmental services, under-provision of environmental services is an example of market failure and suggestions have been made for EU action to provide appropriate conditions and incentives for public environmental services (RISE, 2009).

Globally, the agricultural demand for land drives conversion of natural habitats. Approximately 40% of ice-free land is already covered by crops or used to raise livestock. Conversions of land for agriculture are estimated to account for 80% of deforestation, and about 50% of terrestrial species assessed by the International Union for Conservation of Nature as threatened are negatively affected by agriculture (Tanentzap *et al.*, 2015). Other environmental impacts are related to excessive chemical use in agriculture, for example nitrogen and phosphorus: in the EU, Directive 676 of 1991 on nitrate pollution obliges Member States to monitor nitrate levels and develop action plans for fertilisers[107]. Recently, a report from RISE (2016) reviewed the opportunities for nutrient recovery and re-use of nitrogen and phosphorus lost in animal manure, sewage waste and food industry waste (see also section 4.1).

Different parts of the world are aiming to reconcile the conflict between agriculture and wild nature in various ways. There is need for coordinated action to conserve the land most sensitive to agricultural activities, with evidence-based policies that internalise the environmental cost of agriculture (Tanentzap *et al.*, 2015): dedicating high-quality habitats to nature conservation while encouraging sustainable intensification on existing farmland. Europe is a matrix of habitats, somewhere where biodiversity is best conserved by land sharing and in other places by land-sparing.

Among the scientific priorities discussed in Expo 2015 for balancing environmental services are research activities to facilitate the following.

- Building decision-support tools for optimising land use, specific to place and at appropriate scale.
- Implementing decisions at community/country/regional levels.
- Identifying thresholds beyond which environmental services decline rapidly.
- Developing a stronger evidence base to underpin EU policy instruments, in particular the CAP, Rural Development Policy and the Water Framework Directive.

Other new initiatives are also aiming to develop integrated pathways for achieving sustainable development and attaining the SDGs[108]. Comprehensive discussion of all these issues is beyond the scope of the present report. However, we emphasise the importance of the continuing discussions about the EU bioeconomy (see also Chapter 2). The bioeconomy is relevant to many industry sectors including chemical, pharmaceutical, paper and paper products, textiles, other materials as well as the energy sector. The EU adopted a bioeconomy strategy in 2012, to address the production of renewable biological resources and their conversion into vital bio-based products and bioenergy. In 2014, the EU Council adopted regulation 560/2014 to establish a Biobased Industries Joint Undertaking public–private partnership. In June 2017, the Bio-based Industries Consortium published a strategic innovation and research agenda[109]. The planned updating of the

[107] In addition, the revision of the Fertilisers Regulation aims to promote innovative products and practices to reduce waste and help agriculture contribute to the circular economy, http://ec.europa.eu/smart-regulation/roadmaps/docs/2012_grow_001_fertilisers_en.pdf.
[108] For example, 'The world in 2050: pathways towards a sustainable future', International Institute for Applied Systems Analysis 2015 www.iiasa.ac.at/web/home/about/news/150312-World-in-2050.html.
[109] This agenda describes various actions to develop innovative bio-based products and accelerate market uptake, including the integration of new feedstocks such as aquatic-based sources and biowaste, http://biconsortium.eu/about/our-vision-strategy/sira.

EU bioeconomy strategy provides an opportunity for new political impetus and orientation[110].

In the following sections, we focus on three priorities for resource use: the impact of bioenergy production, the intersection of food and water resources, and the critical role of soil, particularly with regard to its biological functions. Broadly there is need for developing a land use strategy based on evidence to optimise land use for the multiple ecosystem services.

### 7.1 Bioenergy production

Bioenergy production may compete with the food sector, either directly if food commodities are used as the energy source, or indirectly if bioenergy crops are cultivated on soil that would otherwise be used for food production. Transport biofuels are currently the fastest growing bioenergy sector globally even though they represent only about 4% of total road transport fuel and 7% of total bioenergy consumption today. According to OECD and FAO analysis, by 2025 22% of global sugarcane and 11% of global coarse grain production is expected to be used to produce ethanol. Lignocellulose-based ethanol is projected to account for less than 1% of world ethanol production. Biodiesel is projected to consume 12% of global vegetable oil production.

In the EU, the biofuels policy had been determined by the 2009 Renewable Energy Directive, which states that renewable fuels should increase to 10% of total transport fuel use by 2020 on an energy-equivalent basis, and by the Fuel Quality Directive, which requires fuel producers to reduce the GHG intensity of transport fuels by 6% by 2020. These Directives were amended in 2015 by the 'Indirect Land Use Changes' Directive, which introduces a 7% cap on renewable energy in the transport sector coming from food and feed crops[111]: there is currently great interest in determining the potential impacts of this proposal and the November 2016 package of proposals for a clean energy transition. The EASAC report on forests discusses these issues further (see later in this section and footnote 115).

The proportion of global cropland used for biofuels is currently about 2%. Growth in biofuel production has been accompanied by increased output of high-protein animal feed co-products from common biofuel processes, but these co-products are often ignored in models of the economic and environmental impacts of biofuel production. For example, rapeseed is approximately 40% oil and 60% meal, so that taking account of the use of co-products for animal feed will be expected to mitigate significantly the estimated consequences for land use, GHG production and chemical inputs of biodiesel production (Popp *et al.*, 2014). The potential use of these co-products for human food consumption should also be considered as part of the research agenda. The EU remains the centre of global biodiesel production but low oil prices and poor margins continue to challenge biofuel producers in Europe. Under current market conditions it is unlikely that the 7% cap will be reached in the EU by 2020.

A recent comprehensive, quantitative modelling study[112] has assessed the impacts of indirect land use change of conventional and advanced biofuels consumed in the EU. This study explored whether increasing EU demand for ethanol from sugar/starch crops/cellulosic biomass can be met with low impact on land use change and without impact on food prices, and assessed the likely relative impact of other biofuel feedstocks and the potential for use of abandoned land. The conclusion was that the EU was still adopting an undifferentiated approach to biofuels—ignoring differing impacts of different feedstocks—which was leading to suppression of innovative products that could contribute to climate change mitigation, while supporting biofuels that were harmful.

In an earlier EASAC report on biofuels (EASAC, 2012b)[113], the competition of crops between food and fuel was highlighted as a significant issue and the policy actions announced at that time, to be taken by the EU to restrict food-based biofuel production, were welcomed. It was also noted that second-generation biofuels based on inedible parts of plants, including straw, wood and waste streams, and third-generation biofuels based on algae, show promise. Currently, algae feedstocks for fuel products are not economically competitive with fossil fuels and there are also important issues to consider for co-products of biofuel production for the bioeconomy. In most cases the anticipated improvements inherent in future-generation biofuels remain to be demonstrated and substantial investment in research and development is still required, but there have been some advances, for example in establishing networks to share testing facilities to trial next-generation biofuel feedstocks[114].

A more recent EASAC project, exploring the potential for scientific breakthroughs in energy supply and consumption with a long-term perspective (Bengtsson

[110] http://ec.europa.eu/research/bioeconomy. A recent review of the status of the EU Bioeconomy is the JRC's 2016 report, https://publications.europa.eu/en/publication-detail/-/publication/b3a3b800-4f18-11e7-a5ca-01aa75ed71a1/language-en/format-PDF.
[111] http://ec.europa.eu/energy/en/topics/renewable-energy/biofuels/land-use-change.
[112] GLOBIOM model, www.globiom-iluc.eu.
[113] The EASAC Programme on Energy is described in further detail at www.easac.eu/energy/energy-at-easac.html.
[114] BRISK, the European Research Infrastructure for Biomass conversion, http://brisk.eu.com.

*et al.*, 2016), has provided detailed discussion of the research challenges and possibilities to increase biomass and biofuel production sustainably with a particular focus on the value of synthetic biology to engineer biological systems to improve photosynthesis (Aro, 2016).

The Working Group in the present EASAC project discussed how an important step in increasing biofuel production sustainably is the competitive production of biofuels from (hemi)-cellulose on under-utilised marginal land. Perennial crops and woody energy crops typically have higher yields than grain and vegetable crops used for current biofuels. In addition, it is expected that EU biodiesel production will increase from waste vegetable oil and tallow.

The Working Group also examined some of the broader issues for bio-based non-food production (i.e. all bioenergy, not just biofuels) in the EU and the impacts on the rest of the world. It was agreed that there are still numerous bioenergy research issues to clarify and resolve: for evaluating the impact on land use, impact on producer price development and the likely implications of the market introduction of advanced technologies, and to explore further the complex relationship between bioenergy expansion and agricultural commodity price increases. Limited land could mean that Europe cannot grow enough biomass to meet its own future demands. Increasing European imports are likely to lead to international disputes because of competing demands on land use and because of lack of agreement on what constitutes sustainable biomass. Calls for international agreement on key biomass sustainability criteria (Bosch *et al.*, 2015) must incorporate social as well as environmental and economic factors. Integrated policies for land use, energy and water management are needed. Some of the issues for biomass are considered further in an EASAC project on forestry[115], which highlights potential conflicts with biodiversity in the competition for land use. Research on bioenergy should be performed in conjunction with other renewable energy sources, such as solar and wind, to capitalise on synergies.

### 7.2 Food security, agriculture and water

In Chapter 1 it was observed that agriculture (including biofuels and other products of the bioeconomy) accounts for the greater proportion of freshwater used. The EASAC Working Group examined issues both for the impact of water on agriculture (see section 3.3 in the context of climate change) and the impact of agriculture on water. In many areas of the world, this water use is unsustainable and the global issues for improving water productivity and sustainability have been comprehensively described (see, for example, Morison *et al.*, 2008). The severe water shortages in recent years in Mediterranean countries have been associated with decreasing crop yields. A new Partnership on Research in Innovation in the Mediterranean Area (PRIMA, 2018–2028)[116] will aim to develop solutions for more sustainable management of water and agro-food systems.

A focus on water for food security and nutrition was provided in World Water Week in 2015. As part of those discussions, a report was published by the High Level Panel of Experts of the UN Committee on World Food Security[117] covering the multiple linkages between water and food security, the need to manage water scarcities in agriculture and food systems, and the challenges for inclusive water governance (including social and human rights issues). However, there was little specific focus on nutrition.

A recent G20 paper examines some of the issues for the food–water–energy nexus and the need for policy coherence to contribute to re-designing the global governance of agriculture and food (Gulati *et al.*, 2017). The EASAC Working Group also emphasised that, in contrast to agriculture, water is not a constraint in mariculture (section 6.3): the challenge is to combine agri- and mari-culture in ways to minimise environmental impacts.

In the EU, agriculture is a significant source of water pollution (nutrients, particulate matter and biocide pollution) and the European Water Framework Directive[118] recognised this in requiring restoration of water to good ecological quality. Many of the issues for Europe have been comprehensively described in earlier literature (Moss, 2008). More recent work at the Member State level in identifying evidence gaps and potential solutions focused on agriculture impacts on water quality, water availability and on water use in imports. The findings (Box 6) are judged to be broadly applicable across Europe.

### 7.3 Soil science

Agricultural yields are limited by soil conditions. Because Europe can import from elsewhere, European net food availability is not currently much affected by local soil conditions but global food security is jeopardised by increasing land degradation. Soil degradation is the

115 'Sustainability and multi-functionality in Europe's forests', see http://www.easac.eu/fileadmin/images/Europe_s_Forests/EASAC_workshop_note_brussels_final.pdf.
116 http://ec.europa.eu/research/environment/index.cfm?pg=prima; www.prima4med.org.
117 'Water for food security and nutrition' on www.fao.org/cfs/cfs-hlpe.
118 http://ec.europa.eu/environment/water/water-framework/index_en.html.

**Box 6 Water and farming**

**Key findings**
Extreme weather events (flooding and drought) will increasingly influence agriculture's water impacts.

Water quality and demand issues are long-term issues. There is an important nexus between food, water and other ecosystem services.

Many of the challenges involved in managing for outcomes of water and food security are inherently trans-disciplinary and require collaboration between multiple areas of expertise.

The availability of products sourced by retailers and others in the supply chain from overseas will shift in the future because of climate changes. This poses risks for EU supply chains.

**Recommendations**
There is need to develop further long-term planning for changes in water usage and water availability, both in Europe and overseas supply chains. This must include managing for extreme weather.

Several relevant policy instruments in the EU, including CAP, the Water Framework Directive and the Habitats Directive are not always well aligned. They need to be better translated into consistent advice for land and water management.

There are opportunities to facilitate knowledge exchange and co-design of research across disciplines. Generating modelling capacity allows choices to be explicitly explored.

Farmers should be further empowered to make informed decisions about water usage: this empowerment can come from building peer-to-peer networks between farmers, and with other stakeholders in water and the environment.

Fostering consumer understanding may also help to manage the food-water-environment nexus.

Adapted from 'Facing the future together. Report from the farming and water action group', on www.foodsecurity.ac.uk.

diminishing capacity of the soil to provide ecosystem goods and services as desired by its stakeholders. Soil degradation is caused by improper use by humans (usually for agriculture, pastoral, industrial or urban purposes), may be exacerbated by climate change, and encompasses physical, chemical and biological degradation. Further loss of productive soils will amplify price volatility. Although the availability of food on the European scale would not be strongly affected by decline in soil productivity, it can affect local agricultural producers and thus endanger traditional regional activities. For example, accelerated soil erosion in vineyards on steep slopes can decrease both the productivity and quality of vines (Agata *et al.*, 2015).

Soil health (Kibblewhite *et al.*, 2008) can be defined as the continued capacity of soil to function as a vital living system, within ecosystem and land use boundaries, to sustain biological productivity, promote the quality of air and water environments, and maintain plant, animal and human health. Soil health directly affects the production function of agroecosystems, as well as other soil-related ecosystem services (Robinson and Lebron, 2010) that may include the regulation of nutrient and hydrological cycling, biodiversity maintenance and some others (Robinson *et al.*, 2013). The potential of soil to mitigate GHG emissions has been comprehensively reviewed recently (see section 6.3 and Paustian *et al.*, 2016).

An FAO report (Intergovernmental Technical Panel on Soils, 2015), with input from the JRC[119] on the assessment of soils in Europe, documents current soil resources, the drivers of change, likely impacts and proposed responses. The biggest problems identified for geographical Europe (including Eurasia) were soil sealing (covering of land by housing, roads etc), soil salinisation and soil contamination, particularly from petroleum hydrocarbons, pesticides, heavy metals and overuse of nitrogen and phosphorus fertilisers in parts of the region. Soil nutrient losses through leaching into ground- and surface-water are a major problem in many parts of Europe leading to surface-water eutrophication, loss of soil fertility and public health issues through the reduction of drinking water quality. Substantial amounts of nitrogen are also lost into the air through the process of denitrification, which includes the production of the major GHG nitrous oxide ($N_2O$). Appropriate soil management practices need to be developed to enhance nutrient use efficiency by crops.

A report for the Dutch government (Udo de Haes, 2012) on mineral micronutrients in soil (and food and feed) provides wide-ranging recommendations for policymakers in the EU and its Member States and for the farming sector. Among their recommendations for research and development are the better evaluation of mineral micronutrient availability and the extent to which agricultural needs can be met by

119 Further information on JRC work on soil protection and related issues is on https://ec.europa.eu/jrc/en/research-topic/soil-protection.

fertilising with mined micronutrients, and support for technological innovation for more efficient utilisation of micronutrients.

Soil problems are directly related to issues with food safety (see section 4.2) and food quality (e.g. balance of micronutrients) (Oliver and Gregory, 2015). There are multiple implications for soil biodiversity in providing benefits to human health (Wall *et al.*, 2015).

There have been recent advances in ecological genomics where soil fertility and soil ecosystems are measured by DNA sequencing. The EASAC Working Group noted that an important part of the research agenda is to increase effort further to evaluate the biological properties of soils in terms of understanding the bacteria and fungi present[120]. Such research has hitherto sometimes tended to concentrate on symbiotic relationships; but there are also other significant opportunities for research on the soil microbiome for the bioeconomy, for example for new microbial sources of chemical leads to novel pharmaceutical agents[121] or other high-value chemicals as well as for a broad range of objectives in agricultural sustainability, such as strengthening root systems and carbon sequestration (section 6.3).

In addition to these scientific opportunities, the challenges for soil scientists in supporting resilient and sustainable soil management and delivering ecosystem services include the following.

- Development and introduction of practices and technologies for cost-effective soil management, including reduced use of nitrogen and phosphorus fertilisers (for example, by the alternative use of clover cover in crop rotation). Studies have shown that organic agriculture has positive effects on soil health but, as noted earlier, there is need for research to reduce the yield gap to benefit from the positive effects of this farming practice.

- Improved observation systems for monitoring of soil chemical and biological contaminants.

- Development and introduction of techniques for soil re-carbonisation, restoration and remediation.

Issues of soil health and soil degradation need to be a higher political priority. The European Commission tried for nearly a decade to develop an EU strategy and governance framework for soil protection, including a Soil Framework Directive proposal, but this was withdrawn in 2014 (Montanarella, 2015). It is likely that soil health will become increasingly important in food and nutrition security. EASAC has recently started a project to focus on soil sustainability within its environment programme[122].

[120] Recent innovation includes the introduction of a soil microbiome testing kit that uses genetic sequencing to identify and quantify disease-causing organisms (affecting strawberry and lettuce) as an aid to farmers before planting (Anon, 2016b).
[121] The potential value of soil microbes in antibiotic discovery that could help to tackle the current slowdown in antibiotic innovation was discussed in the EASAC Statement (2014a).
[122] http://www.easac.eu/environment/current-projects.html.

# 8 Conclusions and recommendations

In this report, EASAC takes a systems approach to food and nutrition security, assessing the issues both horizontally (that is, i.e. food systems–climate–other environmental resources) and vertically (agriculture–nutrition–health). Many of the policy instruments we have described relate to the EU, but as a contributor to the IAP project's global scope, our report covers relevant issues for geographical Europe, not just the EU.

Agricultural productivity is often taken for granted by European citizens. It should not be, but we do not base our recommendations on a single set of assumptions about the future, in particular an imperative to produce more food. Rather, we call for action throughout the food system. In our view, and as stated at the beginning of the report, the desired outcome for food and nutrition security is access for all to a healthy diet that is environmentally sustainable in the long-term. Subsequent chapters have explored what, collectively, we need to investigate to produce and access a healthy, sustainable diet. Currently, the over-abundance of calorie-dense foods and less access to nutrient-dense foods is a major public health issue for Europe.

In this report, we have also placed great emphasis on local–global interconnections. The overconsumption in Europe has implications for the rest of the world but it is also the case that European research and innovation can contribute significantly to addressing global issues. Therefore, in addition to our focus on European food systems and local needs, we have noted issues for the interaction between European agricultural production, consumption and the global food system, and between EU domestic policy and international development assistance.

We have concentrated on scientific opportunities, namely (1) how the current scientific evidence base can shape opinion, serve as a resource for innovation, and inform policy options, and (2) what the research agenda should be to fill current knowledge gaps. It is urgent to continue to build critical mass in research and innovation and to mobilise that resource in advising policymakers and other stakeholders. We reiterate that this will only happen if it is appreciated that capitalising on the scientific opportunities is something that should pervade EU and other policy-making more widely. It is not just a matter for those involved in funding and prioritising the research agenda. Nonetheless, we emphasise the important role of basic research in characterising new frontiers in science and of long-term commitment to investing in research to assess innovation. This innovation must encompass social and institutional, as well as technological, innovation.

There are several strategic aspects to take into account in providing a framework for detailed recommendations. Drawing on the discourse in previous chapters, these strategic dimensions indicate the following.

- The interfaces between research on the nutrition-sensitivity of food and agriculture systems and on environmental sustainability must be addressed to connect scientific knowledge on natural resources to the food value chain. One major priority is to generate and use better knowledge about climate-smart adaptation and mitigation in food systems. Another priority is to ensure that progress in food and nutrition security capitalises on other actions for the bioeconomy.

- The focus cannot be only on populations but should also cover specific issues for vulnerable groups such as mothers and children, the elderly, patients and migrants. It is important to improve and share the evidence base, accompanied by the appropriate analytical framework to document food and nutrition security in Europe. This requires attending to systematic, longitudinal data collection to generate robust resource, together with cross-disciplinary research, encompassing economics and social sciences as well as the natural sciences, to understand vulnerable groups and the more general aspects of consumer behaviour.

- Large data sets are a vital tool to support innovation throughout the food system and to prepare for risk and uncertainty. There is much to be done to fill data gaps, to agree improved procedures for data collection, curation, analysis and sharing, while also addressing data ownership and privacy concerns.

- The research agenda should include generation of evidence to inform EU food and nutrition policy and governance structures. EASAC endorses the view that the EU should move from the present CAP towards food and nutrition policy that rewards innovation (Box 7), takes account of the varying national interests and cultures and contributes to benefitting the rest of the world. Agricultural sciences are important for European competitiveness and we urge rebalancing of priorities—shifting budget items from agricultural subsidies towards innovation—in the pending CAP reform.

- EU development assistance should be viewed broadly, to include: international collaborative research; research in the EU on priorities that include global food systems, their resilience and

**Box 7 What is in prospect for reform of the CAP?**

The CAP is the oldest EU policy; the latest version was introduced for the period 2014–2020.

The CAP aims to improve agricultural productivity and to ensure that farmers can make a reasonable living[123]. The EU has focused on reforming the CAP for employment creation (e.g. promoting local jobs, supporting young farmers). The ageing population in agriculture is a major challenge: according to a recent Eurostat survey, 30% of EU farms are managed by people older than 65 years, with a further 37% managed by those aged 55–64 years.

DG Agriculture and Rural Development consulted the public in 2013 (European Commission, 2014) to seek views on agriculture and the CAP, comparing responses with those received in previous Eurobarometer surveys. Among the main findings were that Europeans attach increasing importance to agriculture and a majority support key elements of the CAP for developing rural areas and supporting young farmers.

It had been expected that a reformed CAP would offer various instruments aimed at supporting both biodiversity and farming (Altmayer, 2016) but the European Parliament has expressed concerns at the biodiversity loss and called on the European Commission to assess the effectiveness of CAP measures taken to date.

In the wider context, of access to a sustainable healthy diet, many have suggested that CAP needs to be used more as an instrument to help tackle the challenges for global food and nutrition security and climate change as well as the stewardship of natural resources[124]. A case can be made to reform the CAP to obtain greater societal returns for the large current public investment in the farming sector: in particular, to use a higher proportion of the spending on CAP to reward food systems innovation. As CAP has paid little attention to nutrition and related health outcomes, these objectives must also be integrated within policy: it is important to prioritise the research that can help to evaluate different policy options.

A recent report from RISE (2017) emphasises that the present CAP gives excessive weight to inefficient, ineffective and inequitable direct payments, and needs significant reform. This reform must take account of the SDGs, and COP21 conclusions, to underpin a durable production system that is resilient in the long term and to address the challenges for the entire food system. According to the RISE analysis, policy changes are needed particularly in land management and risk management.

perturbations; technology transfer; and resolution of international governance issues.

Within this overall framework for strategy development, we have identified in our previous chapters a wide range of specific actions for scientific inquiry to generate, use and connect research. Many of these research topics are inter-related and broad advances in science can underpin many different fields of inquiry, for example microbiomics is bringing within range greater understanding of microbiome diversity and functions in humans, farm animals, soil and oceans. The following priorities are selected to illustrate the range of scientific opportunities covered in previous chapters:

### Nutrition, food choices and food safety

- Understanding the drivers of dietary choices, consumer demand and how to inform and change behaviour, including acceptance of innovative foods and innovative diets.
- Tackling the perverse cost incentives to consume high-calorie diets and introducing new incentives for healthy nutrition.
- Clarifying what is a sustainable, healthy diet and how to measure sustainability related to consumption. Efficiency in delivery of a healthy diet should be measured in terms of nutritional outcomes, that is incorporating issues for access and consumption.
- Exploring individual responsiveness to nutrition and the links to health.
- Promoting research interfaces between nutrition, food science and technology, the public sector and industry.
- Evaluating how to make food systems more nutrition-sensitive.
- Characterising sources of food contamination and the opportunities for reducing food safety concerns that may arise from other policy objectives (for example, the recycling of waste materials).
- Compiling analytical tests to authenticate food origin and quality.
- Assessing any disconnects between the implications of the COP21 objectives for livestock and meat consumption, and standard recommendations for consuming healthy diets.

[123] http://ec.europa.eu/agriculture/cap-post-2013_en.http.
[124] For example, an EPRS briefing, based on extensive discussion of previous CAP reforms and the options for a post 2020 CAP identifies major challenges for agriculture and the rural economy in terms of food security, climate change, price volatility and territorial cohesion (EPRS PE 595.845 *CAP policy instruments: issues and challenges for EU agricultural policy).*

**Plants and animals in agriculture**

- For livestock, determining how to capitalise on genomics research for food production and for animal health. This includes the rapidly advancing science of genome editing and the increasing significance of characterising genetic material conserved in gene banks.

- For the oceans, improving the knowledge base for sustainable harvest and culturing of lower trophic level marine resources and exploring the potential for biomass provision to diminish pressures on agricultural land, freshwater and fertilisers.

- For crops, progressing understanding of the genetics and metabolomics of plant product quality. This also includes capitalising on the new opportunities coming within range for the targeted modification of crops using genome editing. For all applications of genome editing in agriculture, it is important for the EU to develop proportionate evidence-based regulatory policy that has the flexibility to cover future scientific developments and does not deter innovation.

- For plants as for animal science, it is important to protect wild gene pools and to continue sequencing of genetic resources to unveil the potential of genetic resources. New breeding approaches, making use of the genomic knowledge, can also support the introduction into European agriculture of new crops with improved nutritional properties.

**Environmental sustainability**

- Evaluating climate resilience throughout food systems and transforming food systems to mitigate their global warming impact. This includes developing technologies to render food systems more independent of climate change.

- Capitalising on opportunities to co-design research across disciplines to understand better the nexus food–water–other ecosystem services and to inform the better coordination of relevant policy instruments, including CAP, Water Framework Directive and the Habitats Directive. Efforts to increase the efficiency of food systems should not focus on increasing agricultural productivity by ignoring environmental costs.

- Developing an evidence base to underpin land and water use in providing the range of private and public goods required in a sustainable way, appropriate to place.

- Regarding biofuel choices, the immediate research objectives for the next generation of biofuels include examining the potential of cellulosic raw materials.

- Research should continue to explore the value of synthetic biology and other approaches to engineer systems with improved photosynthesis. There is also continuing need for research to clarify impacts of biomass production on land use and food prices.

- For soil, expanding research to understand and quantify the potential value of soil in carbon sequestration and, hence, climate change mitigation. There is a broad research agenda to characterise other functions of the soil microbiome and contribute to the bioeconomy, for example as a source of novel antibiotics. Research is also important to support cost-effective soil monitoring and management, particularly to underpin the reduced use of fertilisers.

**Waste**

- Committing to the collection of more robust data on the extent of waste in food systems and the effectiveness of interventions to reduce waste at local and regional levels.

- Ensuring the application of food science and technology in novel approaches to processing food and reducing waste, and in informing the intersection between circular economy and bioeconomy policy objectives.

**Trade and markets**

- Increasing commitment to data collection on trade flows and prices with modelling and analysis of databases.

- Examining linkages between extreme events and price volatility, evaluating the effects of regulatory policy instruments in agricultural commodity markets and the price transmission between global commodity markets and local food systems.

- Ascertaining the science agenda for understanding the characteristics of fair trade systems, for example the non-tariff conditions associated with variation in regulatory policy, labelling or other food safety requirements.

# Appendix 1 IAP core template for project on FNSA

- The overall goal for the IAP project is to show how science can be engaged to promote and support food and nutrition security. This goal encompasses both (1) the better use of the scientific evidence already available to inform policy options and stimulate innovation, and (2) the identification of knowledge gaps to advise on research priorities to fill those gaps and improve the evidence base for public policy and resource for innovation.
- Thus, the criterion for identifying which particular topics to cover is primarily 'scientific opportunity' within the context of the IAP project objective to add value to work already done by others.
- The initial collective scoping work of the four regional academy networks has been synthesised into the following 10 questions (see below) and there will be many linkages between these top-level themes.
- The 10 top-level questions are intended, as the shared starting point, to help inform the framework for each regional academy network Working Group. This does not mean that each regional output needs to conform to a uniform structural format but rather that the issues raised and key messages delivered from all four Working Groups can be subsequently mapped onto the agreed top-level themes, to serve as the resource for the IAP global-level phase.
- Individual bullet points listed within each of the 10 themes are not intended to be comprehensive or mandatory but illustrative of some specific issues that may be addressed. There will, of course, be others according to the particular evidence reviewed and expertise employed within each region.

**1 What are key elements to cover in describing national/regional characteristics for FNSA?**

- Definitions and conceptual framework for FNSA including: how they are measured, links with health, and covering demand-side as well as supply-side issues to assess overall current 'fitness for purpose' and clarify boundaries for framing the themes.
- Including status and standards for population groups (variation within region, demographic, vulnerable).
- Covering excess consumption as well as undernutrition.

**2 What are major challenges/opportunities for FNSA and future projections for the region?**

- Climate change (impact of climate change on FNSA and contribution by agriculture to climate change).
- Population growth, urbanisation, migration.
- Supply instabilities and others (e.g. political, economic, financial).
- Ensuring sustainability (environmental, economic, social), and building resilience to extreme events (e.g. to address increasing systemic risk from interruption of increasingly homogenous food supplies).
- Agriculture and food in the bioeconomy.
- Scenario building.

**3 What are strengths and weaknesses of science and technology at national/regional level?**

- Relevant cutting-edge capabilities, including social sciences, inter- and trans-disciplinary research, modelling.
- Opportunities and challenges for research systems in context of tackling major vulnerabilities in FNSA; relative contributions from public and private sectors.
- Handling and using big data in food and nutrition science/open data opportunities.
- Issues for mobilising science and deploying outputs from research advances, addressing innovation gaps and ensuring next generation of researchers, farmers, etc.

- Science–policy interfaces. Sharing science within the region.
- External (indirect) effects: impact of research and innovation in the region on areas outside the region.

**4 What are the prospects for innovation to improve agriculture (e.g. next 25 years) at the farm scale?**

- Issues for societal acceptability.
- Plants (e.g. plant breeding, ensuring genetic diversity).
- Animals (e.g. advent of genome editing).
- Tackling pests and diseases.
- Food safety issues.
- Agronomic practices (e.g. precision agriculture).
- Not just terrestrial—also use of aquaculture/marine resources, developing market potential while avoiding over-exploitation and depletion of genetic diversity.

**5 What are the prospects for increasing efficiency of food systems?**

- Understanding the agricultural/food value chain and institutional frameworks to characterise issues for the integrative food system.
- Issues for food utilisation and minimising waste (including during harvesting, processing, consumption stages).
- Tackling governance/market/trade issues to ensure affordable food and minimise market instability.
- Food science issues. Food retail issues.

**6 What are the public health and nutrition issues, particularly with regard to impact of dietary change on food demand and health?**

- Characterising current trends in health related to issues for FNS.
- Issues for expected changes in consumption patterns (and implications for food importation); understanding and incentivising behavioural change, emerging personalised nutrition.
- Innovative foods and new food sources.
- Food safety issues.
- Promoting nutrition-sensitive agriculture to provide healthy and sustainable diet with connected issues for resource use and food prices.

**7 What is the competition for arable land use?**

- Impacts of urbanisation (including issues for agricultural labour force and new opportunities in urban agriculture as well as issues for available arable land).
- Bioenergy and other bioeconomy products.
- Multi-functional land use - goals for biodiversity and ecosystem services.
- Potential for expanding arable land availability (e.g. from marginal land).
- Implications of forestry trends.
- Also competition for resources with regard to marine sustainability.

**8 What are other major environmental issues associated with FNSA at the landscape scale?**

- Contribution of agriculture to climate change.
- Intersections with other natural resource inputs (water, energy, soil health) and fertilisers/other chemicals. Irrigation issues in multi-use water systems. Waste water.
- Balancing goals for sustainable development and FNSA.

**9 What may be the impact of national/regional regulatory frameworks and other sectoral/inter-sectoral public policies on FNSA?**

- Policies that foster technological innovation.
- Policies that build human resources (e.g. education, gender, equity).
- Policies that redesign whole agricultural ecology (land use, bioeconomy, etc).
- Policies to promote consumption of healthy food.
- Issues for policy coherence.

**10 What are some of the implications for inter-regional/global levels?**

- Link with global objectives, for example SDGs and COP21: issues for their scientific underpinning and resolution of conflicting goals.
- Wider impact of national/regional policy instruments, for example trade, development policies.
- International collaboration in FNSA research and research spillovers.
- International FNSA science governance infrastructure and science advisory mechanisms.

# Appendix 2 Relevant previous EASAC publications, 2012–2016

**Marine sustainability in an age of changing oceans and seas, 2016**

Describes how the oceans are crucial for global food security, human health and regulation of climate. With regard to the objective of an increased and sustainable ocean harvest, the report recommends the following.

- The Common Fisheries Policy is used to bring current fisheries exploitation to sustainable levels.
- There is greater commitment to policy development and knowledge building on how to improve the ecological efficiency of ocean harvest. This includes exploiting the potential for ecologically efficient aquaculture and sustainable seafood from species groups from the lower levels in marine food webs.

**New breeding techniques, 2015**

Emphasises the critical importance of supporting innovation in plant breeding and this Statement recommends the following.

- EU policy development for agricultural innovation should be transparent, proportionate and fully informed by the advancing scientific evidence and experience worldwide.
- It is timely to resolve current legislative uncertainties, that is to clarify that when products of breeding techniques do not contain foreign DNA they do not fall within the scope of GMO legislation.
- The EU should aim to regulate the specific agricultural trait and/or product, not the technology.

**Ecosystem services, agriculture and neonicotinoids, 2015**

There is increasing evidence that widespread use of neonicotinoids has severe effects on a range of organisms that provide ecosystem services such as pollination and natural pest control, as well as biodiversity. Public and political attention has focused on whether honey bee colonies are being affected by neonicotinoids, but other pollinators—including bumble bees, solitary bees, hoverflies, butterflies and moths—have generally declined across Europe as honey bee colony numbers have fluctuated. All pesticides involve a balancing act between the desired effect on food production and the inevitable risks of collateral damage to non-target species and the environment. In the case of the neonicotinoids, the increase in scientific understanding over the past 2 years suggests that the current balance requires reassessment.

**Antimicrobial drug discovery: greater steps ahead, 2014**

Continuing progress in the treatment of many infections is threatened by the growing resistance of pathogens to antimicrobial drugs. In part, the problem is caused by inappropriate use of antibiotics in agriculture. There is urgent need to develop critical mass to support and generate good new scientific leads to antibiotic innovation, to dismantle bureaucratic obstacles in drug discovery and development, and to ensure that innovation can be sustained in the longer term. Among the scientific opportunities is the potential to discover novel leads from soil samples, particularly when using novel conditions to culture hitherto unculturable micro-organisms.

Key issues addressed in this EASAC Statement are also covered in the publication ‘Antimicrobial innovation: combining commitment, creativity and coherence’ (van der Meer *et al.*, 2014).

**Risks to plant health: EU priorities for tackling emerging plant pests and diseases, 2014**

The introduction and spread of pests and diseases among food crops and other plant species in forestry, horticulture and natural habitats has significant consequences for sustainable agriculture, environmental protection and ecosystem services. The reform of plant health legislation to prevent and control the cross-border entry and spread of threats is important but there is need to do more to raise awareness to tackle the wider issues. The broad recommendations in this Statement cover priorities for the following.

- Improving surveillance systems, including new forms of monitoring and better sharing of data.
- Research and training, for example elucidating characteristics of pests and disease, their vectors and hosts, and attending to skill shortages in critical disciplines, including plant taxonomy and pathology.

- Innovation, including new durable control approaches to overcome current limitations of pesticides and breeding improved plants, durably resistant to biotic stresses.

Key issues in this EASAC Statement are also covered in Fears *et al.* (2014).

**Trends in extreme weather events in Europe: implications for national and EU adaptation strategies, 2013**

Europe is suffering a rising number of extreme weather events, from unprecedented heat waves and drought to record-breaking flood, wind storms and freezes. Changes in extreme weather are expected to affect agricultural productivity. Although agriculture has considerable adaptive capacity, investment is needed which will add to the costs of agricultural production. Such investment demands careful planning and understanding of the future conditions to ensure that plant breeding programmes, for example, are well targeted to increase resilience.

**Planting the future: opportunities and challenges for using crop genetic improvement technologies for sustainable agriculture, 2013**

The production of more food, more sustainably, requires the development of crops that can make better use of limited resources. Agricultural innovation can capitalise on the rapid pace of advance in functional genomic research but the EU has fallen behind in its adoption of technology compared with many other regions of the world. Concerns have been expressed that a time-consuming and expensive regulatory framework in the EU, compounded by politicisation of decision-making by Member States and coupled with other policy inconsistencies has tended to act as an impediment to agricultural innovation.

**The current status of biofuels in the EU, their environmental impacts and future prospects, 2012**

The EU Renewable Energy Directive set ambitious targets for the use of renewable energy including for the road transport sector. It is expected that renewable energy for the 2020 targets will come primarily from biomass in the form of biofuels and that the dominant production route for biofuels will still be through the use of edible parts of plants ('first generation' biofuels). There is concern about this use of biomass for biofuels and about the arrangements for ensuring that such fuels provide a real climate benefit while not harming the wider environment.

**Plant genetic resources for food and agriculture, 2012**

Making better use of plant genetic resources is a very important part of the necessary response to the challenges for agriculture. Such resources include traditional crop varieties and their wild relatives, modern cultivars, breeding lines and genetic stocks. The conservation and use—in molecular plant breeding—of plant genetic diversity should be an important concern for Europe and further action on conservation is urgently needed, particularly with respect to neglected and underused crops and crop wild relatives. Scientific priorities include the clarification of fundamental aspects of plant biology, improving conservation science, mobilising diversity to enhance sustainable productivity increases and deploying diversity in production systems.

# Appendix 3 Working Group composition and timetable

The report was prepared by consultation with a Working Group of experts acting in an individual capacity and nominated by member academies of EASAC or invited by the Co-chairs:

Joachim von Braun and Volker ter Meulen (Co-chairs, Germany)
Dag Lorents Aksnes (Norway)
Tim Benton (UK)
Alberto Garrido (Spain)
Charles Godfray (UK)
Anne-Marie Hermansson (Sweden)
Sander Janssen (the Netherlands)
Christian Jung (Germany)
Pavel Krasilnikov (Russia)
Aifric O'Sullivan (Ireland)
Jozsef Popp (Hungary)
Angelika Schnieke (Germany)
Barbara Wroblewska (Poland)
Claudia Canales (Norway) and Robin Fears (UK) (scientific secretariat)

The Working Group met in April 2016 (Brussels) together with external guests Anna Winkvist (Sweden, in place of Anne-Marie Hermansson), and Karen Fabbri (DG Research and Innovation) and Thierry Negre (JRC), to seek perspectives from the European Commission. A second meeting of the Working Group took place in Brussels in October 2016.

EASAC thanks the Working Group members for their insight, commitment and support, and thanks members of the Biosciences Steering Panel for their advice and guidance.

# Appendix 4 The JPIs FACCE and HDHL

The FACCE-JPI was established in 2010 with the aim of building an integrated European research base addressing the interconnected challenges of sustainable agriculture, food security and impacts of climate change. It brings together 22 countries, with links outside the EU, with a trans-disciplinary approach encompassing economic and social aspects in addition to scientific ones. The FACCE-JPI strategic research agenda was originally drafted in 2012 and revised in 2015 after the launch of the 17 SDGs to increase efficiency in attaining food security for all and to better integrate the social and ecological dimensions of sustainability. The agenda defines five core themes, describing for each theme the main research issues, research priorities and ongoing FACCE-JPI actions. In addition, cross-cutting priorities across themes are also highlighted, such as the importance of big data for food security and the impact of urbanisation.

**FACCE-JPI core themes**

1. Sustainable food security under climate change. This theme has an integrated food systems perspective with an emphasis on modelling, benchmarking and policy research. Aspects include identifying key vulnerabilities of the European food system to climate change and identifying policy options to increase resilience of European food systems under climate change. One of the FACCE-JPI actions addressing CR1 is MACSUR (Modelling European Agriculture with Climate Change for Food Security (www.macsur.eu)), which brings together 265 researchers in 70 institutions from 18 countries.

2. Environmentally sustainable growth and intensification of agricultural systems under current and future climate and resource availability. The scope of this theme includes establishing improved farm management and intensification practices; benchmarking efficiencies of resource use (water, land, nitrogen, energy) across Europe under diverse genotype × environment (including climate) × management combinations; improving crop and animal health management; breeding higher efficiency seeds and breeds (i.e. producing more with less inputs); and fostering knowledge-based innovations in information technology in agriculture. A priority is identifying crop and animals yield potentials and yield gaps across regions in Europe under current and future climate scenarios.

3. Assessing and reducing trade-offs between food production, biodiversity and ecosystem services. The scope of this theme is to provide new approaches to the increased use of functional biodiversity in agricultural systems, and for assessing and valuing biodiversity and ecosystem goods and services. It also aims to develop approaches for increasing synergies and reducing trade-offs between agriculture and ecosystem services in a variable environment. Analysing incentives and barriers to enhancing biodiversity and ecosystem services (including in soils and water) is also a research goal. This is particularly critical for the implementation of the SDG agenda at the global scale, as European decisions on agriculture and trade affect the realisation of the SDGs in other countries.

4. Adaptation to climate change throughout the whole food chain, including market repercussions. The scope of this theme includes determining adaptation options to climate change and increased climatic variability throughout the whole food chain, including market repercussions; adapting seeds and breeds through conventional and modern breeding and biotechnology; improved management practices for land use; water in agriculture; soil management; and adapting markets, institutions and insurance mechanisms.

5. Greenhouse gas mitigation: nitrous oxide and methane mitigation in the agriculture and forestry sector, carbon sequestration, fossil fuel substitution and mitigating GHG emissions induced by indirect land use change. Included are measures that contribute to reductions and removals of GHG emissions; development of cost-effective monitoring and verification methodologies of field, animal and farm scale GHG budgets; mitigation measures focusing on soil carbon sequestration in crop and pastoral soils and on nitrogen cycles.

While FACCE-JPI is an EU initiative, it recognises the global dimensions of food security and mitigation of climate change, and the strong links between local, regional and global food markets. Europe's role in international markets and its impacts on price volatility and global food security are identified as research priorities. The need for establishing the impacts of agricultural commodity trade patterns on biodiversity and ecosystem services outside Europe is also identified, including matters pertaining to land use and food security in Africa. Several FACCE-JPI actions also comprise the participation of countries of the Belmont Forum (Australia, Brazil, India, Japan, South Africa and the USA). FACCE-JPIs actions had mobilised €120 million by the end of 2015, with new actions underway with an additional investment of €50 million.

The Healthy Diet for a Healthy Life (HDHL) JPI is primarily aimed at improving understanding of the food–health relationship and to translate this knowledge into programmes, products, tools and services that enable consumers from Europe and beyond to live a healthy life. HDHL stems from the implication of poor diet, lifestyle choices and obesity as key determinants for many chronic diseases, such as cardiovascular diseases, type 2 diabetes and cancer.

The HDHL Strategic Research Agenda, now updated in a second edition, defines three research pillars that cover the determinants of (1) diet and physical activity, (2) diet and food production and (3) diet in the context of diet-related chronic diseases. The document also describes the primary initiatives for two periods (for 2012–2014 and for 2015–2019), current research activities and horizontal issues.

1. **Determinants of diet and physical activity.** The aim is to understand the most effective ways of improving public health through interventions targeting diet and physical activity and to understand the bottlenecks preventing consumers from choosing a healthy lifestyle. Since European populations are very diverse, improving our understanding of the impact of individual, social, economic, cultural, biological and other factors affecting diet and physical activity is also a priority.

The primary research initiative for 2012–2014 was to establish a European trans-disciplinary research network on determinants of dietary and physical activity behaviours, and their relation to best practice implementation strategies for long-term changes. Research challenges include collecting and using harmonised data tools, and harmonising existing knowledge relevant to diet and health. Solving these challenges requires the invention, integration and standardisation of monitoring systems, terminology, databases and measures about research on biological, ecological, psychological, sociological, economic and socio-economic determinants of food choice and physical activity.

The Determinants of Diet and Physical Activity (DEDIPAC) Knowledge Hub was established in response to these challenges to improve the understanding of determinants of dietary, physical activity and sedentary behaviours. It consists of a multidisciplinary consortium of scientists from 68 research centres in 12 countries across Europe[125].

The primary research initiative for 2015–2019 was to create pan-European programmes on the biological, social, economic, health and behavioural determinants of diet, food choice and physical activity.

2. **Diet and food production: developing healthy, high-quality, safe and sustainable foods.** The aim is to encourage farmers and the food industry to produce and to market foods with a healthier improved nutritional content, and to stimulate consumers to select foods that fit into a healthy diet and that are also safe, sustainable and affordable. An additional objective is to provide insights into the barriers and facilitators for the agricultural and food industries to develop sustainable foods that will also benefit human nutrition.

The primary research initiative for 2012–2014 comprised setting up a roadmap initiative for biomarkers of nutrition and health; designing strategies and initiating research activities addressing health claims; and exploring new methodologies or emerging biomarkers in consumer sub-groups (target groups) and individuals at risk; and reducing food spoilage. This has resulted in the launch of two projects[126]:

(1) The Food Biomarkers Alliance[127] (FOODBALL) is an initiative aimed at identifying and quantifying dietary biomarkers in different European population groups to improve the capabilities of nutritional assessment and research. The consortium includes 20 research organisations from 9 European countries plus Canada and New Zealand.

(2) MIRDIET aims to find new genetic biomarkers (circulating microRNAs) in the human body to serve as indicators of the impact of dietary intake on health.

The primary research initiative for 2015–2019 is to initiate programmes (including ERA-NETs) on comprehensive analyses of the metabolic fate of food components in human physiology with a strong emphasis on different population groups, including the elderly.

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125 https://www.dedipac.eu/.
126 http://www.healthydietforhealthylife.eu/index.php/news/135-launch-projects-joint-action-biomarkers-in-nutrition-and-health.
127 http://foodmetabolome.org/.

3. **Diet-related chronic diseases.** Effective nutrition and lifestyle-based strategies are needed to optimise human health and reduce the risk, or delay the onset, of diet-related diseases. These strategies require research on obesity and its causes; the association between neurological processes and metabolic disorders; maternal and infant nutrition; osteoporosis and malnutrition in the elderly; micronutrient deficiencies; the role of the gut indigenous microbiota; and cognitive development and decline.

The primary initiative for 2012–2014 was to establish a European Nutrition Phenotype Assessment and Data Sharing Initiative providing a standardised framework for human intervention studies on food and health, and their phenotypic outcomes with an open-access reference database. It resulted in the establishment of the Joint Action European Nutritional Phenotype Assessment and Data Sharing Initiative[128] (ENPADASI) with the aim of developing a standardised framework for human intervention studies on food and health and their health outcomes with an open-access reference database.

The primary initiative for 2015–2019 seeks to expand and foster existing prospective diet-related cohort studies, merge them into open access nutritional databases and initiate new pan-European prospective studies on diet-health relationships, including new markers of health derived from comparative phenotype analysis.

In terms of horizontal issues, the primary goal for 2020 and beyond is the full integration of the research areas. A European Nutrition and Food Research Institute will be established, organised in a virtual network to improve scientific collaboration and communication across national borders. Federated national hubs will be focusing on specific research sub-themes. This initiative also seeks to improve education, training and scientific career perspectives in the food, nutrition, lifestyle and health areas, and communication, knowledge and technology transfer. The strategic objectives outlined will be executed through a series of implementation plans that will be developed by the management board and guided by the advice of the scientific and stakeholder advisory boards. The first implementation plan (2014–2015) of the JPI HDHL was launched in March 2014.

Together, the JPIs HDHL and JPI FACCE cover the whole food and health system from farm to fork.

[128] http://www.healthydietforhealthylife.eu/index.php/enpadasi.

# Abbreviations

| | |
|---|---|
| ALLEA | All European Academies |
| CAP | Common Agricultural Policy |
| CGIAR | Consultative Group for International Agricultural Research |
| COMAGRI | Agriculture Committee (European Parliament) |
| COP | Conference of the Parties to the 1992 United Nations Framework Convention on Climate Change |
| CRISPR–Cas | Clustered Regularly Interspersed Short Palindromic Repeats–CRISPR Associated |
| DG | Directorate-General (European Commission) |
| EASAC | European Academies’ Science Advisory Council |
| EFSA | European Food Safety Authority |
| EPRS | European Parliamentary Research Service |
| ERA-NET | European Research Area Network |
| ETP | European Technology Platform |
| EUGENA | European Gene Bank Network for Animal genetic resources |
| FAO | Food and Agriculture Organization (UN) |
| FDA | Food and Drug Administration (USA) |
| FNSA | Food and Nutrition Security and Agriculture |
| GHG | Greenhouse Gas |
| GMO | Genetically Modified Organism |
| GODAN | Global Open Data for Agriculture and Nutrition |
| HDHL | A Healthy Diet for a Healthy Life |
| IAP | InterAcademy Partnership |
| ICT | Information and Communications Technologies |
| IFPRI | International Food Policy Research Institute |
| JPI | Joint Programming Initiative |
| JRC | Joint Research Centre (European Commission) |
| NCD | Non-Communicable Disease |
| NRC | National Research Council (US) |
| OECD | Organisation for Economic Co-operation and Development |
| OPEC | Organization of the Petroleum Exporting Countries |
| RISE | Rural Investment Support for Europe |
| SCAR | EU Standing Committee for Agriculture Research |
| SDG | Sustainable Development Goal |
| STOA | Science and Technology Options Assessment (European Parliament) |
| TALENs | Transcription Activator-Like Effector Nucleases |

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