European Commission

Resilience and transformation

Report of the 5th SCAR Foresight Exercise Expert Group
Natural resources and food systems: Transitions towards a 'safe and just' operating space

Independent Expert Report

Research and Innovation

RESILIENCE AND TRANSFORMATION
Report of the 5th SCAR Foresight Exercise Expert Group - Natural resources and food systems: Transitions towards a 'safe and just' operating space

European Commission
Directorate-General for Research and Innovation
Directorate C – Healthy Planet
Unit C5 - Ecological and Social Transitions
Contact Liutauras Guobys
Email Liutauras.Guobys@ec.europa.eu
Unit C2 - Bioeconomy & Food Systems
Contact: Hans-Jörg Lutzeyer
Email: Hans-Joerg.Lutzeyer@ec.europa.eu
RTD-PUBLICATIONS@ec.europa.eu
European Commission
1049 Brussels

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2020

Directorate-General for Research and Innovation
Healthy Planet

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The European Commission's Standing Committee on Agricultural Research organised this special report by a group of independent experts. The views expressed are the collective work of the group, and do not necessarily reflect those of any individuals, of SCAR or of the European Commission.

The 5th SCAR Foresight Exercise Expert Group members:

Gianluca Brunori (Chair), Richard L. Hudson (Rapporteur), Andràs Baldí, Stefano Bisoffi, Kerstin Cuhls, Johanna Kohl, Sébastien Treyer, Lilia Ahrné, Jessica Aschemann Witzel, Fabrice De Clerck, Jessica Duncan, Henning Otte Hansen, Begoña Ruiz and Grzegorz Siebielec.

In addition, the Expert Group wishes to thank for their advice and guidance the members of the SCAR Foresight Group: Elke Saggau (Chair), Stefano Grando, Vivi Hunnicke Nielsen, Egizio Valceschini, Matthew Clarke, Cathy Plasman and, from the European Commission, Liutauras Guobys and Hans-Jörg Lutzeyer.

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FOREWORD

RESEARCH, INNOVATION AND A BETTER, GREENER EUROPE

"Build back better": That is a promise made across the European Union, as we work together to rebound from the COVID-19 pandemic and its devastating consequences. But "better" has many implications. Better solidarity and cohesion, better stewardship of our natural resources, better responses to the multi-pronged challenges of climate change and biodiversity loss, better distribution of wealth and opportunities across society and – the subject of this report – better diet, better health, better livelihoods and better opportunities for all in the vital, complex system by which we produce, process, distribute and consume food. In other words, how to transition our natural resources and food systems to a "safe and just operating space".

For that, research and innovation are prerequisites. In our Horizon Europe programme, 35% of the budget will be dedicated to tackling climate change. We will catalyse a wide range of projects, partnerships and missions to find new solutions for agriculture, the bioeconomy, and the blue economy. We make advances on sustainable healthy diets, food production, and digital platforms for agriculture and food systems. Through our revitalised European Research Area and synergies with other EU and member state programmes, we will set out a coordinated and inclusive programme for change. These efforts will contribute to the European Green Deal, through which Europe will become the first decarbonised continent. They will provide a powerful engine of knowledge, ideas and innovations to speed our recovery from the COVID-19 pandemic.

These are ambitious targets. But, with the vast reservoirs of talent available to us in our universities, research centres, innovative start-ups and businesses, they are targets we can achieve by working together.

Our efforts today will ensure that our recovery is green, secure and inclusive; that our children and grandchildren enjoy a clean and healthy planet; that our ecosystems are resilient and our economy globally competitive. From the farmer, fisher and forester to the factory, shop, restaurant and home, I am confident the vital EU food and agriculture sectors will play their part in making our society strong, just, safe – and caring.

Foresight studies of the Standing Committee on Agricultural Research (SCAR) have been the starting point of many research and innovation initiatives in the European Research Area – co-created and co-owned by the European Commission and Member States.

It is my expectation that the recommendations of this 5th SCAR Foresight report will lead to similar discussions and take-up on European and national level. The report spells out how research and innovation in three specific fields – diet, diversity and circularity – can help speed social and economic progress, and Europe's recovery from the COVID-19 pandemic. This provides concrete advice to decision makers (EU member states and associated countries, and EU institutions) and an important contribution to the strategic planning process of research policymaking and coordination activities.

Finally, I would like to thank the 5th SCAR Foresight exercise expert group, led by Professor Gianluca Brunori for the foresight report and the SCAR Foresight Group chaired by Dr Elke Saggau for their efforts in the exercise and in particular for the SCAR Foresight reflection paper at the end of this publication.

Mariya Gabriel
European Commissioner for Innovation,
Research, Culture, Education and Youth

EXECUTIVE SUMMARY

For years, we have had repeated warnings of trouble ahead: climate change, loss of biodiversity, mounting social inequality and, yes, pandemics. So many warnings that we can tire of them, like a driver confused by too many road signs and flashing lights at once. But in 2020, with pandemic warnings becoming all too real, we have seen the price of inattention. It is time to change.

We believe that change must start from knowledge – from research and innovation. In the food and agriculture sector, the topic of this report, our knowledge of the problems has been growing steadily. We know that about 8% of the world's population is undernourished to various degrees, while another 39% are overweight or obese. We know that we are losing biodiversity on the planet at an alarming rate, and that food and agriculture is responsible for 70% of freshwater withdrawals and up to 30% of greenhouse gas emissions[2]. And, of course, we know that the entire food chain from farm, forest and fishery to factory, shop and home is essential with revenues of more than €2.25 trillion in the European Union. Growing, providing and consuming food are among the most basic of human activities. So, if we want to improve Europe and the world, it is a good place to start.

But to make change happen, what knowledge do we need and how to use it? That is the subject of this report. Our aim is to show, to the European Commission, the EU member states and associated countries, where current trends are pointing on diet, farming, environment and related domains. From there, we analyse how we can get to a better world, focusing on three main routes, or transitions: improving diet and nutrition, increasing circularity in the food system, and restoring lost biodiversity. In broad terms, we show how research and innovation can help us devise better policies, and help us "build back better" after the pandemic. More knowledge

and better policies in these three transitions will lead to a more resilient EU and global food system – one capable of feeding and employing billions in normal times, and adjusting quickly to whatever disasters, natural or human, may arise in future. To achieve this, the EU's Horizon Europe programme for research and innovation will be a powerful tool – particularly when coordinated with the even larger R&I efforts of the 27 EU member states combined.

Our group, comprised of six specialists in foresight processes and eight in various sectors of the agriculture and food system, was convened in late 2018 to analyse the best available knowledge in the scientific literature and in workshops with other experts. It was initiated under the European Commission's Standing Committee on Agricultural Research, or SCAR, founded in 1974 by EU Council regulation to advise the member states and Commission. Our focus: How to get to "a safe and just operating space" for society, through better management of natural resources and food systems? The phrase can be associated with the United Nation's Sustainable Development Goals. These 17 targets – such as clean water, good health, a just society – express our common human expectations. Of course, humanity is far from achieving any of them. But, between our social goals and the constraints of the planet, we imagine there to be a safe place for humankind to prosper. What is it? How do we get there?

To start answering those questions, look at where we are today. Based on research by many others published to date, we can see several specific ways in which we have gone too far in polluting the planet, squandering natural resources or mismanaging society. Within the EU – better off than much of the world, one must add – we are under-performing on several social measures, such as income equality, education, healthy life expectancy and nutrition. If we look at our impact on land, water and air, we are far past the boundaries we would need to observe to become sustainable. Our farming methods are, for instance, injecting about seven times as much nitrogen, chiefly as fertiliser, into the environment as would be compatible with a sustainable ecosystem[3].

The COVID-19 crisis has underscored the urgency, and inter-relatedness, of all these problems. Though EU member-states did in the end show some solidarity in the crisis, it was not the immediate reflex – and globally the divisive politics of *us vs. them* have predominated. Already-huge inequalities of income, education, location, race and gender were laid bare. In the agri-food sector, the initial images of empty supermarket shelves and panic hoarding frightened many. More important, however, are the potential longer-term impacts, both negative and positive, on how consumers shop for food, what they choose and where they consume it. As the OECD put it early on in the crisis: "enough food is available globally, but COVID-19 is disrupting supply and demand in complex ways." And this was from one global crisis. Even before the pandemic, the Food and Agriculture Organisation estimated, developing countries were, annually, suffering on average 260 natural disasters killing 54,000 and costing $27 billion.

TARGETS FOR A SAFER, FAIRER PLANET BY 2050

Clearly, we need a fairer, more resilient and more rational way of managing our affairs, in food as elsewhere. To simplify matters, we have devised a list of targets, related directly or indirectly to food and agriculture and to the Sustainable Development Goals, that we believe must be met by Europe by 2050 if we are to sustain human and other life indefinitely, and maintain a fair and safe society. The table below summarises them, and how far away we are today from achieving them. Hitting these targets will require action on many fronts, as outlined in this report.

TARGET FOR EU+	BOUNDARY	EXPLANATION
Zero CO_2-equivalent net emissions by 2050	Climate change	In 2017 net emissions of agriculture were 80.9 million tonnes. The European Green Deal pledges net-zero overall greenhouse gas emissions by 2050.
Restore the level of biodiversity extant in 2000	Biosphere integrity	Biodiversity level is defined here as the remaining mean number of original species, relative to their number in pristine or primary ecosystems. The index for Europe was 0.45 for 2000 (base year), and is forecast to decline to 0.33 in 2050.
2/3 of Europe's land needs ecosystem restoration	Land-system change	Land-system change is accelerating due to human interventions, mainly intensive farming, and expansion of urban and built-up areas.
Keep freshwater use at recent level	Freshwater use	Researchers estimate that humanity is currently consuming freshwater at 65% of the limit for sustainability.
Reduce phosphorous by 81% in 2050, and nitrogen by 86%.	Biogeochemical flows	Recent data suggest the gross phosphate balance in 2013 to 2015 was 1.2 kg/ha, and nitrogen was 49 kg/ha.
Reduce pesticides by 75% in 2050	Novel entities: pesticides, antibiotics, plastic	The EU Farm to Fork strategy plans a 50% cut by 2030. The European Green Deal pledges to "reduce significantly" the use of pesticides.
Health	Normal weight (BMI-Body Mass Index: 18.5-25)	Across the globe, more than 2 billion people are overweight or obese. Within the EU-27, the numbers are overweight (BMI>25) 2017: 51.8%, and obese (BMI>30) 2017: 14.9%.

TARGET FOR EU+	BOUNDARY	EXPLANATION
No gender discrimination	Social equity	Current gender pay gap in the EU-27: 15.0
All animals treated according to stringent welfare standards	Good stewardship	No systematic EU-wide data are available on this indicator of our social attitudes towards environmental stewardship.
Fair income for farmers	Social equality	Income in the farming sector is generally low and below what can be achieved in other sectors in the economy (on average only 40% of average wages in the EU-28 economy).
Access to Internet for all in rural areas	Technology access	In the EU-28, 62% of the rural population has Internet access, compared to 75% of the urban population

GETTING THERE (1): HEALTHY, SUSTAINABLE DIETS FOR ALL

The first of three major areas for change, or transition, is in what we eat: we must provide healthy, sustainable diets for all. That, we are not doing today, even within Europe. Compared to the rest of the world, the extent of undernourishment in the European population is about a fourth what it is globally. But over-nourishment is a serious problem: more than half the adult European population is overweight, and about one-sixth is obese. We eat 2.5 to 3 times as much meat as recommended by dieticians, posing extra risk of cardiovascular, intestinal and other disease. We eat too much potato and other starches, and not enough vegetables, fruits, legumes, nuts or seeds.

The reasons are complex. For the past 25 years, food prices in Europe have risen faster than retail price inflation, making it harder for poorer families to choose often-costlier healthy foods. As cities grow ever larger, the bulk of the population grows more distant from, and ignorant of, the source of their food. A global food industry both follows and influences consumer tastes for starchier or sweeter foods. And we are all shaped by our communities, our sense of identity. Whether we eat burgers or pulses, drink soda or water, is a statement of who we are or want to be. If we do nothing to change, at the current rate at which the European population is ageing, we will soon face massive rates of chronic disease overburdening our healthcare systems. And all along, our poor food choices are damaging the planet. Within the agricultural sector, animal production is by far the largest source of greenhouse gas emissions, while growing staples is responsible for the lion's share of nitrogen and phosphorous application. What we eat is inextricably linked to our environmental impact.

Changing all this will require a monumental effort, overcoming many in-built barriers – of industry structure, consumer preference, social organisation. Technological innovations, particularly when coupled with scientific advances in social and organisational arrangements, can be game-changers. The ever-growing city, and urban food strategies, can provide a ground-level tool for change. Emerging social trends will help: already, awareness of global warming has led millions to change their habits. In fact, if people just ate the way nutritionists recommend – the low-meat, high-vegetable Mediterranean diet is an example – many dietary and environmental problems would diminish.

RESEARCH TOPICS FOR SUSTAINABLE AND HEALTHY DIETS FOR ALL – A SOCIAL IMPERATIVE

- Developing agriculture, fishery and forestry methods that result in more diverse and nutritious diets
- Developing new, sustainable foods, food production and processing models, and food quality criteria
- Analysing and monitoring the environmental and social impact of what we eat
- Designing better urban food environments for choosing and buying healthier, sustainable foods
- Education, communication, 'nudging' consumers to eat sustainably and healthily

Of course, all this requires a push from government – on several fronts at once. Change must begin with better **information** for consumers, producers and others on how to make diets healthier and more sustainable; it exists today, but is not sufficiently accessible. Specific measures to change social norms can include **awareness-raising and education,** as well as **regulation of advertising**. Public policies, such as **fiscal and procurement measures**, will also influence our food habits; action by cities and local authorities will be at least as important as national efforts. **Technological change** – healthy foods, digital innovation and artificial intelligence, bio- and genetic technology, consumer technologies (such as 'apps' measuring body status and giving dietary recommendations)- can transform our food habits and diets. But we will need multi-stakeholder dialogues to steer that new technology towards equitable access to healthy, nutritious and sustainable food. Ensuring **fair competition** between companies is also critical, so that incumbents do not prevent innovative entrants from shifting the market towards new, better food habits. Lastly, we will need to develop further the **social welfare** system to ensure that access for all to nutritious and sustainable food is equitable and just, even if prices do not continue on a downward trend.

GETTING THERE (2): TOWARDS A 'CIRCULAR' FOOD SUPPLY

Among the biggest problems with our agri-food systems are the huge volume of resources that are either wasted or under-used. The FAO estimates about a third of the food produced for human consumption each year gets lost or wasted, worth nearly $1 trillion – and just half of that would be enough to feed all the undernourished people in the world.

We need a new way of thinking. The circular economy is the term the EU and many other governments have now targeted: to stop wasteful practices, design circularity into all products from the start, create cascading supply chains linking the output of one process to the input of another. The Commission's recent Circular Economy Action Plan is a step in the right direction. In tandem, many now advocate "agroecology", to take better advantage of the way different parts of the agroecosystem naturally interact. For instance, with regenerative agriculture methods, farmers work to improve the soil biota naturally, paying more attention to crop rotation, organic fertilisers, crop cover and clever combination of plants. Among farmers, greater access to and knowledge of digital technologies is needed, to reduce food lost in the field, connect with new types of customers, and manage more efficiently. Change will require investment; and some form of public assistance may be needed. Industry must optimise food factories to minimise energy and water use, while finding new uses for side-streams of production.

RESEARCH TOPICS FOR A CIRCULAR BIOECONOMY – A ROAD TO SUSTAINABILITY

'Strong sustainability' in farming

- Developing methods to 'close the loop' in agriculture, forestry and aquaculture, so waste is reduced and circularity achieved
- 'Regenerative' agriculture, harnessing natural methods to improve soil health, sustainability, diversity and productivity
- Strategies for radical reduction of antibiotics and synthetic pesticide and fertiliser in farming
- Ways to make farming, fishing and forestry more viable economically – and resilient
- New services for rural and agricultural communities that enhance their well-being

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Shaping a bio-based circular economy

- New logistic and digital infrastructures for circularity
- New ways to get industries or regions working together for circularity
- Carbon-neutral technologies for biorefineries
- New materials, bioplastics, waste conversion techniques and other basic tools
- New ways to govern a circular economy, and the trade-offs required
- Devising new business models to get people to use and support circular food practices
- Identifying and managing competing values and visions among stakeholders

And people must change. We are trapped in our lifestyles – the habits of work, play, and food preparation. Just how volatile that really is was dramatised in the pandemic: that so many could switch so quickly to online shopping, new supply sources and new habits should give hope. But, crises aside, change will not happen unaided by government. Better labelling systems, for gathering and presenting information about the origins and handling of food, would steer people to more sustainable, low-waste and low-packed options. Pushing more city dwellers to recycle will matter. And innovation will be vital. Across the EU, hundreds of entrepreneurs have started new businesses to tackle some aspect of circularity – from recycling coffee grounds into fertiliser for mushrooms, to apps helping eco-conscious city-dwellers find un-used restaurant food. They are young buds – but with local and national support, they may grow into great forces for circularity.

To overcome the many obstacles to change, new policies are needed. To begin with, the broad principles of **circularity, cascading and carrying capacity** should be applied to the whole bioeconomy systems, from production to consumption. We applaud the European Commission's efforts to do just this, with its Green Deal and recently published strategies for the circular economy, biodiversity and "Farm to Fork"- but these will require **long-term vision and persistence**, by a whole system of actors. Further, many policy areas are involved – economy, health, work and wages, digitalisation, fiscal - not only agricultural policy. This necessitates an emphasis on **policy coherence**. Change could be sped up if policy makers took greater advantage of some **favourable trends**: for instance, because of the pandemic, all citizens – including producers, processors, retailers and consumers – have become more aware that food and food chains are important and vulnerable. Mounting climate concerns are also a good lever for action. Looking at a more granular level: making the bioeconomy circular necessitates that different supply chains connect with one another, particularly at regional scale. So a critical

policy lever is **support to networks** of enterprises and of a variety of stakeholders through physical and information infrastructures. At the same time, fair prices in all parts of the chain are necessary; and for that **true cost accounting** (externalities due to waste, extended producer responsibility, environmental impact of transport, infrastructures and more) through new fiscal policies would prod entrepreneurs to adopt more circular models. For change, we will also have to **overcome high initial investment costs**, through fiscal instruments, subsidies for access to credit, or other public support mechanisms. Lastly, better **information and traceability** – to know where each product comes from, and what its environmental cost is – are key levers for the circular economy to become real.

GETTING THERE (3): TOWARDS GREATER DIVERSITY

In recent years, the very idea of diversity – in nature, society, regions and the economy – has become endangered. In nature, by 2016 about 9% of all domesticated breeds of mammal used for food or agriculture had vanished from the earth, and another 1 million species of plant and animal face extinction, according to the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES). Diversity matters. It provides alternatives, and resilience in a system. Socially, diversity promotes creativity and new ideas. It avoids a too-cyclical economy, in which all sectors could rise and fall together. In food and agriculture, diversity enables a varied and balanced diet, and provides a form of insurance against natural or human disasters. But the reasons for our declining diversity are many. Consumers, in part influenced by the food industry, often opt for energy rich foods and, out of the 14,000 edible plant species available, generally use only 150 to 200 of them and get 60% of calories from just three: rice, maize and wheat. Government is also part of the problem. In many parts of the world, the way subsidies are distributed skews market dynamics towards bigger, specialised producers.

To become more resilient, we must move towards greater diversity in agriculture, food and society generally. As we manage the pandemic, we must "build back better" – as advocated in the Commission's recent Biodiversity Strategy. This can start on the farm, where many trials are underway that show promise. For instance, a study in the UK found leaving just 8% of farmland wild actually boosted crop yields in the remainder. The EU's Green Deal and Biodiversity Strategy are important steps in this regard.

Research topics for diversifying agriculture and food systems – a key to resilience

- Diverse farming and food production systems, sustainable food processing models
- Diversifying food retail channels, for a greener, resilient system
- Supporting the role of small farms and fishers in a diversified food system
- Interdisciplinary research to boost resilience and long-term stability in agriculture and food systems, and to reduce vulnerability to shocks.
- Monitoring, measuring and disseminating knowledge about ecosystem services. This would include digital tools that encourage citizen science

In the end, the right formula will be a mix of measures, by public and private sector, by individuals and groups. The specific steps required begin with **knowledge-intensive innovation** (including in digital and genomic technologies); we need new ideas, better understanding, easier solutions to promote the ecological functioning of agricultural systems. As part of this, farmers could be encouraged to deliver more **ecosystem services**, and the role of ecosystem services as sources of well-being for all should be stressed. Also, to enable farmers to invest in on-farm diversification of products and services, it is necessary to build more **diverse supply chains and markets**. Today's **production strategies**, often based on massification, specialisation and economies of scale, should be progressively replaced by business strategies based on diversity and economies of scope. **Environmental policies (regulations and norms, fiscal incentives**) are necessary to ensure that larger food processing companies can consider this a credible option. We need greater coherence among climate, agriculture and social welfare policies. The public purse will be needed: **a potential cost of diversity is redundancy, and that has an upfront cost for which public support will be needed.** Lastly, we would need to encourage **a wider view of the purpose of a company,** to make it more "mission led": adding to the usual profit objective the goals of social and environmental responsibility. This would permit biodiversity conservation policies based partly on voluntary business commitments.

THE ROLE OF RESEARCH AND INNOVATION

To effect these changes, research and innovation are powerful tools – not just to understand problems and find solutions, but also to guide policy makers and enlist wide public support.

How? As we have seen in the COVID-19 pandemic, in which epidemiologists and virologists have been thrust into prominence, knowledge has a kind of power. It feeds into the different steps of policy making. It shows how one set of policies affects another; for instance, how changes in agricultural policy affect health policy, or trade affects sustainability. It helps evaluate the impact of any policy, potential or actual. And it can help reframe the way a problem is viewed. For instance, in the past decade, the entire policy debate over the costs and benefits of biofuels was, thanks to further research, reframed into a broader context of the bioeconomy – permitting action. Getting action generally requires that kind of long-term approach, with the obstacles and trade-offs to change openly discussed among all parties. It also requires "strategic niche management," in which policies are shaped to nurture little innovations that could revolutionise the way we farm or consume but, without support, would never scale up. Yet getting change is not about a bunch of scientists pushing advice on politicians; rather, we need to build consensus on the evidence and its policy implications among all parties involved – farmers, consumers, companies, politicians and more. Good examples of such "consensus frameworks" are the IPBES and the International Panel on Climate Change, which have succeeded in drawing high-profile attention to the results of research, and thereby catalysing action. Within the EU, the FOOD 2030 research and innovation approach, launched in 2016 by the Commission, applies a systemic approach to four overarching priorities: Nutrition for sustainable and healthy diets, climate-smart and environmentally sustainable food systems, circular and resource-efficient food systems, and innovation and empowerment of communities. Such a strategy could be considered a corner-stone of food system transformation.

Looking across the wide range of inter-related problems of food and agriculture, we have identified some cross-cutting research themes that need special attention in designing EU or national programmes. Research and innovation that can provide solutions to these issues will have broad impact:

- **Food, well-being and society.** How what we eat and how we grow it shapes our identities and well-being – and can speed or block change
- **Social innovation.** New businesses, partnerships and services to help change happen.
- **Agro-ecology.** How farming methods interact with the environment, and how to get a better, greener outcome.
- **Digital transformation of the bioeconomy.** New tools, services and policies in digital technologies that can support change and speed up some of the processes.
- **Foresight**. New study methods to track and understand how major trends and technologies could shape our future – how to prepare for different futures in an uncertain world.

- **Coping with disaster.** Understanding how shocks hit some people and regions worse than others, and how best to prepare for the unknown.

- **Finance for transition.** How financial markets, debt, subsidies and investment shape the way we produce and consume food, and how to bend those factors to support rather than block change.

These broad themes sketch out a transformative research agenda, to be implemented in synergy with long-term policy strategies. To be transformative but fair and socially compatible, research must be responsible; more work is needed in promoting the Commission's responsible research and innovation criteria. Further, the research agenda must be designed to have impact from the start. It must be open, so that all interested parties and sources of knowledge can interact freely – and at present, the way universities conduct most research in specialised departments is one obstacle that the Commission can help overcome. And finally, transformative research must be collaborative – not just with other researchers, but also with the farmers, producers, consumers and other communities affected. We need new and better ways of ensuring this kind of broad collaboration, and digital technologies will be important for that.

Implementing such a research agenda requires the capacity to do so: the right programmes, tools, networks, partnerships and projects. The EU has been exceptionally creative over the years of its Framework Programmes in devising new ways to get Europeans working together. A great deal more creativity will be needed now if we are to achieve the three transitions. We have identified several areas in which more capacity-building is still required:

- **Science-Policy-Society interfaces.** Put plainly, these are groups of experts and stakeholders that gather and communicate scientific evidence to policymakers – so that action becomes possible. With as complex a field as food and agriculture, we need more and better interfaces.

- **Partnerships.** The EU's Framework Programmes have long supported research and innovation partnerships of various stripes. We urge creating a partnership landscape with synergies among the different groups, and broader partnerships to unite science, farming and communities.

- **Long-term R&I networks.** The duration of most EU research networks is too short for the long-term nature of the UN Sustainable Development Goals. Find a way to make them match.

- **International collaboration.** Global R&D cooperation is vital for food and agriculture research, but will be difficult after the COVID-19 waves. The EU must find new, flexible tools to promote it.

- **New types of collaborative projects.** For research to be transformative, it must involve all stakeholders in society and be quite inter-disciplinary. Horizon Europe should invite more experiments in engagement, and other EU programmes should amplify the successful models.

- **Manage the silos.** Duplicative or contradictory policies are a common feature of food and agriculture work as rival ministries, agencies or regions fail to coordinate their work. Again, greater coherence among policy areas is needed, and potential cross-sector trade-offs should be evaluated before taking decisions. Creation of an EU food policy could force more cooperation.

We also note that SCAR, the body that initiated this work, has an important role in coordinating research agendas among the member states and the Commission. This will become vital as the Commission aims to strengthen the European Research Area, permitting researchers and ideas to flow more freely across the EU.

The COVID-19 crisis has shown that institutions we thought sound could wobble. It underscored the importance of resilience, if we are to withstand future shocks. In the food and agriculture sector, moving towards the "safe and just operating space" we all seek for humanity and the planet will require focusing attention on the limits we have already passed, and the major changes we must make to remain adaptive. Research and innovation are vital tools in this generation-defining project.

CHAPTER I: INTRODUCTION

'Protecting our planet and our shared environment is our generation's defining task. It is an urgent moral, human and political obligation .... Those who act first and fastest will be the ones who grasp the opportunities from the ecological transition.'
- Ursula von der Leyen, President, European Commission[4]

Picture this:

> *Around a dinner table, a family are hosting their neighbours – some elderly, some young, and all in reasonably good health. On the table is a varied spread of fresh asparagus salad, home-baked rye bread and a bean casserole. Some of the food was purchased that morning at a local farmers' market; some came directly from the apartment block's communal roof-top garden; and some – a bit of wine and coffee – came from elsewhere in the EU and the world. The menu is diverse, in both ingredients and source. When the group finishes, everybody clears their plates into a waste-recycling bin for later collection. They are all moderately comfortable in income, fairly well educated, enjoy a decent work-life balance with equal opportunity by gender and ethnic origin. They are not particularly angry with or about anybody else – the norm in their growing but liveable city. The weather is fine, the air clear....*

Clearly fiction, that account. Even before the COVID-19 crisis began, there were already many European citizens whose circumstances were nothing like that. And since the crisis, we have all seen just how fragile our economies, our societies, really are. Due to one invisible pest, we saw millions of people sick, many dying, trillions of euros lost or squandered, and countless assumptions about the way the economy works, our institutions function or our communities interact thrown into question. Today healthcare, transport, energy, technology, social services – all look, to varying degrees, not quite so straightforward and reliable as they once seemed. Before the crisis, we knew we must change – to slow climate change, reduce social inequalities, protect life on earth – but it just seemed so expensive and complicated. Now, we see that change is not a choice: it is thrust upon us, whether we are willing or not.

Take one area, the subject of this report: food and agriculture. At the start of the crisis, millions wondered how secure their food supplies really were. For city dwellers, there was the shock of seeing restaurants shut and long queues at food markets. In the country, there was the outrage of having to leave crops in the field or pour milk down the drain, as local labour shortages developed and the supply chain from farm to market broke in unexpected places. Longstanding problems of the countryside, with its often older and more fragile population, became more

visible. The international trade in food, so vast and powerful an economic force, hiccupped as some governments tried to block exports and commodity prices jumped. And we saw nutrition indirectly factors into the crisis, too: those with multiple morbidities – some diet-related, such as diabetes, heart disease and obesity – have had higher risk of COVID-19 complications and death. But since the early days of the crisis, a strange sense of normalcy has spread with no clear idea of when or how the health, social and economic repercussions will end. But already, in the food sector, the impact can be forecast. As many as 130 million extra people around the globe may, as 2020 ends, be on the brink of starvation, the World Food Programme estimated.[5] What we, in the industrialised world, all took for granted in the way our food and agriculture systems worked suddenly seemed not quite so obvious.

But even before this crisis, we were not doing well. Pre-COVID, about 820 million people in the world were undernourished,[6] yet at the same time more than 2 billion – that is 2.5 times as many – were overweight or obese.[7] In some countries (for instance, France and Ireland) bad diet and consequent diabetes, circulatory and other ailments had become the second-biggest cause of death, after tobacco.[8] Even in good times, we waste about a third of the world's food production: 30% of cereals, 35% of fish, the Food and Agriculture Organisation estimates[9] – and other research[10] suggests that wastage may be even greater. And the climate warms. The environment degrades. Species vanish. Of course, we worry about it all now more than before. Wildfires, heat waves and hurricanes were already alarming; pandemics are terrifying. Yet still, governments this year have found it difficult to work together, for the common good. As a species, *homo sapiens* is still stuck not agreeing on what to do, when and how.

And that – what to do, by whom, when and how – is the subject of this report, at least in one big policy area: research on food and natural resources. Our aim is to show, to the European Commission and the EU member states, where current trends are pointing on diet, farming, environment and related domains. From there, we analyse how we can get to a better world, focusing on three main routes, or transitions. And we show how research and innovation can help us devise better policies, and open exciting opportunities for change in both food production and consumption.

Why look at this sector of the economy, with so many other challenges to hand? Because it is a surprisingly big part of the world's overall problems. Agriculture is responsible for 70% of freshwater withdrawals.[11] It produces up to 30% of global greenhouse gas emissions;[12] and just one part of it, livestock, bears the greatest responsibility.[13] Of course, food, fisheries and agriculture industries are also essential. Combined with biofuels and biomaterials, this sector is a big part of the EU economy with revenues of €2.26 trillion in 2015.[14] And its jobs are vital, especially now as we struggle to recover from the worst global recession since the 1930s. But unintended costs – bad diets and health, pollution and resource consumption, waste and biodiversity loss – are beyond counting. The missed opportunities are vast: oceans and waterways are by the far the largest ecosystem on the planet, yet in some ways (over-fishing)

we exploit with abandon, and in other ways (algae and krill) we ignore potential. And, as if that were not enough to spur action, the food chain vulnerabilities exposed by the pandemic demand greater wisdom from us all.

And why, within the food and agriculture sector, do we look specifically at research and innovation? For starters, COVID-19 has taught us all a lot about the value of good information and advice. Science has the duty to find and tell the facts as they are, even if they seem bad news. And research leads to innovations – cleaner farming methods, more effective recycling systems, better land and water management, healthier foods, and ultimately a fairer distribution of resources across society. Research also leads to new jobs, and preparing the workforce for jobs of the future. New knowledge, new innovations, new jobs. And from those, new policies. There must be a straighter line between what we know and what we do.

To achieve this, the EU's Horizon Europe programme for research and innovation will be a powerful tool – particularly when coordinated with the even larger R&I effort of the 27 EU member states combined. Our group, comprised of six specialists in foresight processes and eight in various sectors of the food system, was convened in late 2018 to analyse the best available knowledge in the scientific literature and in workshops with other experts. It was initiated under the European Commission's Standing Committee on Agricultural Research, or SCAR, founded in 1974 by EU Council regulation to advise the member states and Commission. For SCAR, its Foresight Group feeds into EU strategic planning in this area and initiates special studies such as ours. There have been four such expert foresight reports since 2007[15] – looking at the challenges facing agriculture overall; resilience and crisis in agriculture and food systems; resource scarcities; and the bioeconomy. Each has led to new EU initiatives to address the issues raised.

This report takes a somewhat broader view, reflecting the mounting urgency of our food, agriculture, environmental and health problems. Our focus: How to get to "a safe and just operating space" for society, through better management of natural resources and food systems?[16] This means justice and safety for all – from farmers and fishers to consumers and communities, and within the natural boundaries of our planet. The phrase stems from prior research around the United Nation's Sustainable Development Goals. These 17 targets – such as clean water, good health, a just society – express our common human expectations. Of course, humanity is far from achieving any of them. But, between our social goals and the constraints of the planet, we imagine there to be a safe place for humankind to prosper. What is it? How do we get there?

3 pathways to a 'safe and just operating space'

To answer those questions, in our workshops and research we focused on ways to achieve three main goals:

1. How to ensure nutritious, healthy and sustainable food for all?

2. How to set up full circularity of food and agriculture systems?

3. How to restore diversity in our food, farm and social systems?

The processes by which we achieve these three goals are all inter-related. Each implies a complex series of changes, or "transitions" in the language of foresight studies: changes by companies, farmers, consumers, policy makers and others working together can be driving forces for system-level transitions. And these transitions will be difficult. There are good reasons why the world is today the way it is: history, economics, politics, human behaviour and more. But by examining in detail what could block or speed these necessary changes, we can chart some possible paths towards the "safe and just operating space." From there, we can assess where research and innovation could most help.

Our focus for these recommendations is Europe – but there are no borders for climate change, environmental degradation or inadequate and unhealthy dietary habits. Trade and digital media link us all, and what we in Europe do or do not eat has a ripple effect across the globe. Solidarity among peoples and nations is vital: Europe must not buy sustainability at the expense of other regions.[17] Still, action must start somewhere, and the EU has shown its willingness to lead the way – in the Paris Climate Accord, the Commission's Green Deal, and its plan to spend at least 35% of the Horizon Europe budget from 2021 to 2027 on climate-related issues.

When the COVID-19 crisis struck, we extended our work so that our recommendations could be as timely and useful as possible – fit for whatever crises may arrive in future. For if there is one thing we have learned in this *annus horribilis 2020*, it is that we must become more resilient to future shocks and changes. We must do better at preparing for crises and developing backup plans; do better at building more redundancy into our economic and social systems without sacrificing too much efficiency; do better at coordinating amongst governments and peoples; do better at rebuilding so that the world is a safer and fairer place; and do better at acquiring and using knowledge to guide all our actions. This year, we have reawakened to the role of science in society. Now, we must plan and deploy it wisely.

5 questions guiding the expert group's work
From the Commission's Terms of Reference

1. What are the key systemic transitions that meet the objectives of COP21 and the UN Sustainable Development Goals (SDGs) that are relevant for the sectors of biological primary productions and their use?

2. What are the enablers and lock-ins towards effective transitions? What are the tensions, contradictions, complexities and obstacles, and different types of unexpected events, taking into account the diversity of actors and regions involved?

3. What are the costs of transitions and of a continuation of "business as usual" for the actors and for society, exploring the windows of opportunities for all actors and for society in general? The full range of solutions may be considered but opportunities for "win-wins" should be highlighted.

4. How can R&I contribute to transitions, including co-design and co-delivery of robust solutions in different scenarios?

5. What are initiatives to break the silos and build bridges between disciplines, between sectors, between sectoral policies and between science and policy, taking into account the systems approach needed to address complexity?

CHAPTER II: WHERE ARE WE?

I often wished I had a farm,
A decent dwelling snug and warm,
A garden, and a spring as pure
As crystal running by my door,
Besides a little ancient grove,
Where at my leisure I might rove....
'T is well: I ask no greater blessing.
Horace, Satires II.6[18]

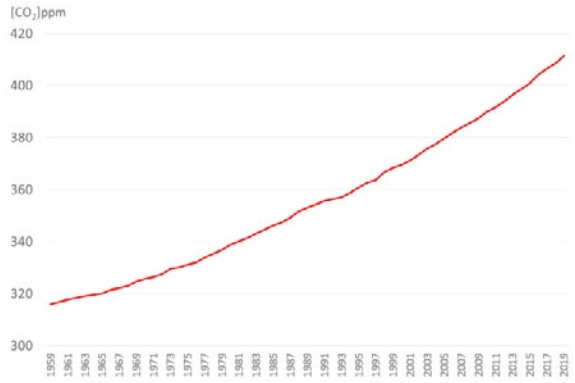
In any foresight exercise, one can dream a bit – an optimistic, if not quite utopian, vision that assumes we make the right choices. But the courage to make those choices must come from a hard-nosed assessment, based on science, of where we stand today and where we are headed. And when it comes to agriculture, food and the many planetary and human dimensions they touch, the picture is alarming. The scientific evidence suggests we have already, in many respects, gone too far – crossed over some fundamental boundaries of what is safe and sustainable.

One problem is climate. The Earth's atmosphere is choking with too much carbon dioxide and other gases that act like the glass on a greenhouse: things get warmer inside. Last year, 2019, was the hottest year on record; this year may beat that. The CO_2 concentration is now higher than what it was before the Industrial Revolution: to be precise, in 2017, 146% of pre-1750 levels.[19] Methane and nitrous oxide concentrations are also up. The cause is, by scientific consensus, primarily human: As our technology advanced and populations grew, so our energy, farming, transport and other activities pumped more harmful gases into the atmosphere. Clearing forests and wetlands for farms and cities added to the problem. Average temperatures are already rising – currently about 1.1 degree Celsius above pre-industrial levels. In some regions, it is worse: in the Arctic, the temperature rise is two or three times the global average. In our daily lives, we are seeing what some[20] call "global weirdness" in the intensity of hurricanes, typhoons, heat waves and cold snaps. With the Paris Climate Accord of 2015, most governments agreed to do something about it – though the commitments, experts say, are far short of the mark. EU nations, home of the Industrial Revolution that started it all, are clearly trying to improve, and are on track to meet a 2020 target of cutting net CO_2 emissions by 20% from 1990 levels. But, on current trends, the EU will miss its 2030 target and is far from its longer term goals.[21] In early 2020, we were all struck by satellite images of a planet under lockdown: blue skies, clean water. But temporary, emergency measures do not help much. At best, they remind us what happens when we do nothing to prevent an entirely foreseeable calamity, in health or environment. At worst, they can be quite brutal, economically and socially, in their own right.

THE PLANETARY DASHBOARD

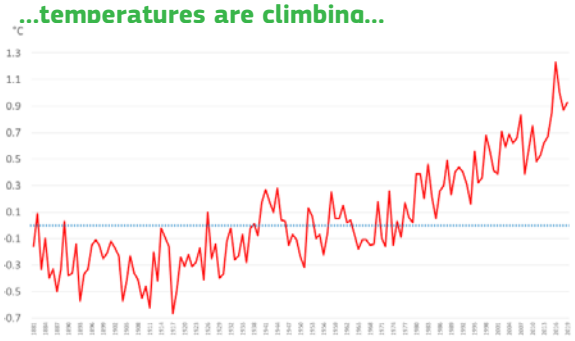
A quick look at vital indicators of how we are managing our planet, and ourselves

CO_2 concentration is rising...



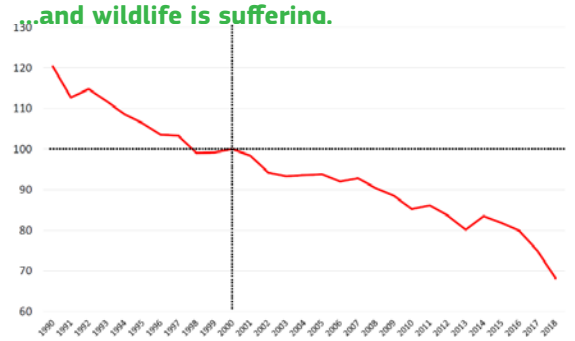
Average Carbon dioxide concentration in the atmosphere 1959-2019 (ppm) at Mauna Loa Observatory, Hawaii. Source: National Oceanic & Atmospheric Administration.[22]

...temperatures are climbing...



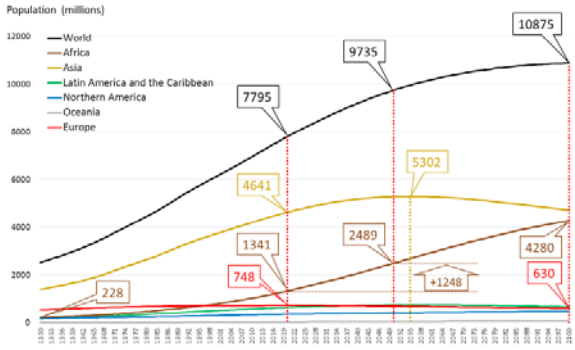
Global Land-Ocean Temperature Index (deviations from the 1951-1980 average). Source of data: NASA 2019.[23]

...and wildlife is suffering.



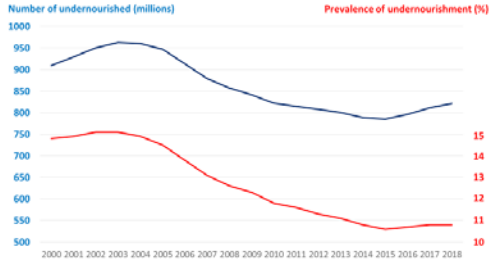
Farmland bird index (Year 2000 = 100), measures number of birds on farmland habitats in EU. Source: Eurostat.[24]

Meanwhile, population is growing...



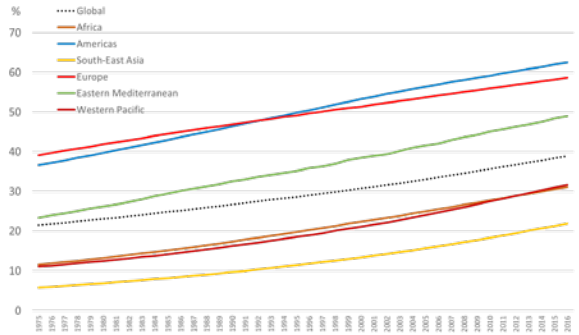
World population 1950-2100 by regions. Figures for the years 1950 to 2020 are estimates; for the period 2021-2100 the graph is based on the median projections. Source: UN.[25]

... after years of progress, hunger is worsening again...



Number and Prevalence of undernourished in the world, 2000-2018, according to FAO estimates (values for 2018 are projections). Source: FAOSTAT.[26]

...even as more people than ever before are overweight.



Prevalence of overweight (BMI≥25) among adults (18+) by region (1975-2016). The problem is worst in the Americas and Europe, least in Southeast Asia, Africa and the Western Pacific region. Source: WHO.[27]

There are other problems, too. We have degraded about a quarter of the planet's land area not covered by ice, the International Panel on Climate Change reported in 2019.[28] Of the wetlands we know existed in 1700, more than 85% had been lost by 2000.[29] Man-made fertilisers now release more nitrogen into the environment than all natural processes combined. Our world-wide pesticide use has been climbing at about 6% a year, and in China is three times the global average. In most parts of the world, the abundance of native species has fallen by at least 20% over the past century – and 40% of amphibians, a third of marine mammals and about 10% of insect species are threatened, according to another UN-convened scientific panel, on biodiversity.[30] The impact is shocking: One study reports a 75% drop since 1990 in the total mass of flying insects in protected areas of Germany.[31]

And then there is mankind. Two centuries ago, there were one billion humans on the planet. Today, we are 7.7 billion, and likely to add another two billion by 2050.[32] And that population is unevenly distributed. By 2050, 79% of humanity will be in Asia and Africa – the latter, with the fastest growth of all. Europeans already comprise less than 10% of the world population; and that number will decline over the next century.[33] One reason: age distribution. In Asia and particularly in Africa, the population is young and birth rates are generally high. In Europe, a few generations of comfortable prosperity have gone hand in hand with lower birth rates.

At the same time, we are moving out of the country and into the cities. Urbanisation is a world trend, driven by technology, globalisation and other factors. In 1970, there were just two cities in the world with populations greater than 10 million: Tokyo and New York. By 2014, there were 28; in another decade, perhaps 41[34]. By now, more than half the world's population lives in urban areas, and that proportion is growing.[35] Of course, it may be that we humans can live with the social strains, economic inequalities and general headaches of city life. But the ecological footprint of cities is huge. What happens in cities ripples into the countryside, linked by the food chain and social need. And their global impact is stunning: at present, they represent a mere 2% to 3% of the world's land area, yet account for 78% of carbon emissions and 60% of residential water use.[36] As former UN Secretary General Ban Ki Moon put it: "Our struggle for sustainability will be won or lost in the cities."[37]

And what is happening to all these people, whether old, young, urban or rural? They encounter mounting social, economic and political stresses. Around the world, societies now suffer extreme inequalities of income and wealth. In the US and Canada, the richest 10% of the population in 2016 had 47% of the income; Europe, while more egalitarian at 37%, has still seen inequality rise over the past 40 years, according to researchers at the Paris School of Economics[38]. Global conflicts are on the rise. Mass migration has been a growing worry – exacerbating xenophobia, and threatening the integrity of the EU. How much longer can we continue to just let things happen?

THE ROLE OF NATURAL RESOURCES AND FOOD

When thinking about all these problems, one theme recurs: how we feed ourselves. So reform of our food and agriculture system is a good starting point for anyone trying to fix the world. A few facts:

- At global level, agriculture, forestry and other land usage accounts for 23%[39] of all greenhouse gas emissions. Add in other emissions from the food chain, from farm to consumer, and the estimate rises towards 30%[40]. But the impact goes farther.

- In Europe, the agricultural sector accounts for 10.3% of GHG emissions[41]. This figure, however, does not consider the emissions related to land use and land use change generated by imports of commodities such as soy and beef[42].

- Agriculture is also responsible for 70% of all freshwater withdrawals today[43] (in Europe this figure amounts to 44%[44]) and water usage is growing twice as fast as the population. The toll on other species is great: farmland bird population in some parts of the EU has collapsed.

- There is no international agreement – not even in the Paris Climate Accord, beyond a general objective for all economic sectors – to set explicit targets for reducing agricultural emissions of greenhouse gases. Because it affects farm incomes and food supply, it is too divisive a topic to find agreement. In the EU, direct action would hit farm incomes in the countryside and food prices in the cities, and strain political relations among the member states. It would put even greater stress on North-South relations.

- Climate change – partly created by agriculture – is already affecting us. As it renders farmland barren, it could cut per capita supply of food by 3.2% by 2050, chiefly by making vegetable and fruit production harder.[45] Cereal prices could climb by an average 7.6%.[46] The impact is obvious: We could see twice as many deaths from poor diet as from starvation.[47]

So the status today is not good, and the trends are worrisome. A closer look, by sub-sector:

DIET AND HEALTH

For the past generation, world leaders have been congratulating themselves about progress on a global problem: hunger. As the Green Revolution spread and incomes began rising in many developing countries, starvation fell. But it is still dire in places: in east Africa, nearly one in three people are undernourished. In the EU, Bulgaria and Slovakia are the biggest continuing sources of concern, with 3.0% and 6.1%[48] of the population undernourished. But a bigger problem than quantity is quality. Our food industry serves up too many packaged foods high in empty calories

from sugar and fat, high in salt, and low in nutrition and price. The variety of what we eat shrinks: of the thousands of edible plant species, only six dominate agriculture today: maize, rice, wheat, sugar cane, soybeans and oil palm. Vegetable consumption is down (but in the wealthier EU nations, fruit is up.) To make matters worse, most of us do not exercise enough. The result of all this can be seen on the street every day: an epidemic of obesity. Today, some 2 billion people in the world are overweight or obese – 2.5 times as many as are undernourished.[49] In the EU-28 the proportion of adults (aged 18 years and over) who were considered to be overweight varied in 2014 between 36.1 % in Italy and 55.2 % in Malta for women and between 53.6 % in the Netherlands and 67.5% in Croatia for men[50]. In adults, obesity (body mass index greater than 30) grew by 1% every three years in the first 15 years of this century, with no sign of slowing. This causes diabetes, heart disease, some cancers and a host of other problems that add to the costs of our already overburdened healthcare systems. In much of the wealthy West, we are eating ourselves to death.

RURAL AREAS

It may seem obvious, but it needs restating: if we want a good food supply, we must also care about the welfare of food-producing regions. Close rural-urban links matter, for instance. According to the OECD[51], those rural areas that are less than an hour travel time to a large urban region are more likely to be prospering. This may explain why in countries like the Netherlands, Belgium, Germany, and Denmark, rural areas have incomes comparable to or even higher than urban areas[52]. By contrast, remote rural regions face "shrinkage"[53]: a declining population that results in a mismatch between supply and demand for services. That leads to some of those services becoming unviable, to local living conditions and quality of life deteriorating, to unemployment rising and skilled labour becoming scarce. This worsens the demographic decline, through falling fertility rates and an aging of the remaining population. A new vision for rural areas would invest in the most important assets of the countryside: its social, natural and cultural capital. If cared for, these assets promote well-being, and attract new residents and tourists. How to invest? Social innovation can provide alternative models for service provision. Digitalisation may favour distance-working and lighten the burden of commuting. In this new paradigm, agriculture could also change. Instead of greater scale, specialisation and integration into global value chains, farming can grow with new business models centered on local markets, ecosystem services, high-quality products, and better social solidarity within and between rural and urban communities. Difficult, yes. But a goal worth pursuing.

FARMING

If we want a sustainable food system, fair pay for farmers is a clear target. But what, today, is farming in Europe? How far is it from the model of the self-employed family farm, on which our Common Agricultural Policy was set up with the 1957 Treaty of Rome? Consider some numbers. Today, 97% of EU farms can be classified as family farms, while 2.8% are owned

by legal entities that manage more than 27% of the land[54]. Looked at another way: of the 11 million EU farms in 2013, 66% were smaller than five hectares yet occupied just 6.2% of agricultural land. More than 43% of land is owned under a tenancy arrangement. Some 56% of farmers are older than 55, while only 6% are younger than 35. Women manage 28% of farms, and 40% are older than 65 years. The farm workforce in 2013 was about 22 million. Many work part-time: one out of five farmers with fewer than five hectares of agricultural land spends less than a quarter of their working time on the farm. Since 2005 the number of family workers has decreased by 31%[55]. Utilisation of economies of scale and specialisation have helped many farmers keep their income levels.[56] COVID-19 highlighted how specialisation, seasonality and farm size have created a labour market with a seasonal demand that relies on migrant workers. Specialisation is particularly evident. Ireland has the highest level, with 87% of holdings specialised in grazing livestock. Finland has 60% specialisation in field cropping. In Mediterranean regions, specialisation in permanent crops passes 60%. In many cases, vertical integration has increased the income of farmers.[57] However, today's system, based on chain leadership by supermarkets or big processors, generates an unfair distribution of value. Farmer-owned cooperatives could support small and medium sized farmers to improve their position in the value chain. Fairer contracts could also help, together with business models aimed at keeping more added-value on the farm – for instance, through new environmental and tourist services, high quality products, on-farm processing, or short supply chains.

LIVESTOCK

This sector gets the most attention, because it uses the most land and produces the most greenhouse gases - more than half of all agriculture emissions. Within that, cattle are the biggest problem. But the picture is complicated. World demand for meat is rising twice as fast as the population; as incomes rise in the global South, people eat more meat. Already in advanced economies, about half of agricultural land goes to feed animals; in the EU, the proportion rises even higher, to 72%.[58] In addition, the EU both imports and exports meat in a global trading network of trains, trucks, planes and ships which in turn consume resources and emit greenhouse gases. We buy beef and poultry from (chiefly) Brazil and sheep from New Zealand. We export pigs to China, as well as poultry and veal around the world. To feed our animals, we buy soybeans from abroad; growing them occupies an extra 35 million hectares of land outside the EU, meaning we are in a sense exporting greenhouse gas emissions.[59] Raising animals is expensive – especially here where the EU's Common Agricultural Policy supports farmers, and where relatively high food quality and safety standards protect consumers. None of this is to say we should ban meat. There is ample evidence of its nutritional and economic value; and for some types of land – sandy, wet or steep – pasturage is the only realistic use[60]. But reducing consumer demand, while raising livestock efficiency, would help – if we can manage the trade-offs. On one hand, modern, intensive husbandry on feedlots produces fewer greenhouse gas emissions per unit product than pasture, because processed feed is easier to digest than live grass. But on the other hand, shrinking pasturage reduces biodiversity. And administering

antibiotics – a declining but still-extant practice in parts of the EU, according to the European Medicines Agency[61] – worsens the risk of drug-resistant bacteria spreading to humans. In short, the livestock industry is a complex, global system: if you change it in one place, unintended consequences appear somewhere else.

FISHERIES

The EU is surrounded on three sides by water – and yet, it is a major net importer of fish, relying on massive foreign fleets and fish-farms for about 60% of its fish consumption. How is that possible? Over-fishing, in part: in the Mediterranean and Black Sea, about three-fifths of stocks are depleting. Over the past half-century, the world's taste for fish has been growing even faster (3.1% a year) than for meat.[62] Much of that extra fish has come from the booming aquaculture industry in lagoons, ponds and other waterways; salmon farms, pools for turbot or cultivated mollusc beds are now part of the landscape in parts of Scotland, Spain, France, Italy and Greece. But climate change is a big threat. As CO_2 levels rise in the air, the water absorbs some of it. That makes the water more acidic – threatening coral colonies and shell molluscs, among other species. Moreover, as sea temperature rises, fish move to the cooler poles or deeper waters – making it more expensive to catch and transport them to the major population centres. And then, there is the growing problem of ocean pollution. One Norwegian study traced the cycle of perflourinated compounds (PFC) – a common chemical used in non-stick pans – from our factories, into the ocean, into the fish, and back onto human dinner plates.[63] Yet if we are to feed more than 9 billion humans, we will need more fish. There are wide margins for improvement in both productivity and sustainability[64].

FORESTS

Wildfires in California, Portugal and Australia, man-made fires in the Amazon: we are all aware now of the importance, and vulnerability, of forests. They cover 30.6% of the land mass (excluding Antarctica and Greenland), and like the seas are a major carbon sink: their conservation and restoration would offset about 30% of all our carbon emissions.[65] But forest area has been shrinking as we clear the way for more crops, livestock and housing; Brazil, Indonesia, Myanmar and Nigeria lead the world in forest loss.[66] But the story isn't all bad. We have also been planting new forest, especially in China. On the European continent, Russia's forests are vast; and in the EU, Sweden and Finland count most. But as with food, so with wood, modern lifestyles take a toll. Trade is down in paper and wood for furniture; technology brings us alternatives. But it is up in sawn wood and panels for building, and cardboard for packaging and online shopping. This worsens our problems with biodiversity. And as the climate changes, we will see more fires, more pests. We will face difficult trade-offs in managing forest lands. We have high expectations for them: a vast wealth of resources, a carbon sink, and a sanctuary for biodiversity all in one. Can we manage them sustainably[67]?

FOOD WASTE

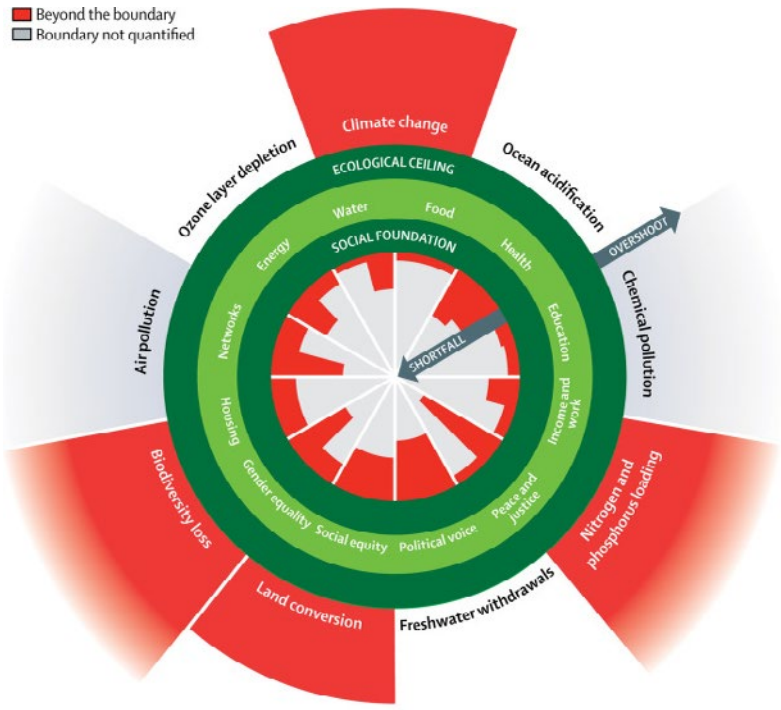
If it were a country, the Republic of Food Loss and Waste would be the third biggest greenhouse gas emitter in the world, after China and the US. Today's globe-spanning supply chains leave food behind at every stage – on fields and farms, in transport, in processing and packaging, in serving, and in disposal. In all, at least a third of potential food production, or 1.3 billion tonnes a year, is lost.[68] This, if saved, would be more than enough to feed all the undernourished people in the world – about 10.8% of the population. It would also slash greenhouse gas emissions, as we would not grow so much food in the first place. Recognition of this fact is behind the growing interest in zero-waste "circular economy" policies, such as those championed over the past decade by the EU. But progress is depressingly slow. How to make the benefits outweigh the costs? How to get to a tipping point?

WHERE DO WE NEED TO GO?

Clearly, we are not in a good place right now – but how bad can it get before we have broken the planet? It is laudable that the Commission has, COVID-19 crisis or no, continued to push member states to support its proposed Green Deal; but real risk remains that this climate agenda drops further down the list of political priorities, as governments worry about the continuing effects of COVID-19. In 2009, a group of prominent earth science specialists, led by Swedish environmental scientist Johan Rockström, suggested[69] that we think about the planet as having boundaries – guard rails, if you will, within which we should stay if we want to avoid catastrophe. They identified nine boundaries for "planetary life support systems" such as climate and water quality that make the world habitable. Oxford economist Kate Raworth[70] and others[71] have suggested that we also take account of basic human needs, such as food, health and safety. Combined, these biophysical and social boundaries form a "safe and just operating space" – a range of conditions within which both planet and society are sustainable. Many of these conditions also correspond to the 17 Sustainable Development Goals set by the United Nations in 2015.[72]

How close are we today towards attaining those goals, or at least not passing the boundaries? The Rockström group estimated we had already crossed the line for three of them: climate change, biodiversity loss and nutrient over-use (or, more specifically, nitrogen and phosphorous loading.) Further research[73] has developed a full list of indicators, and various attempts to show how close we are to the limits of maintaining a "good life."

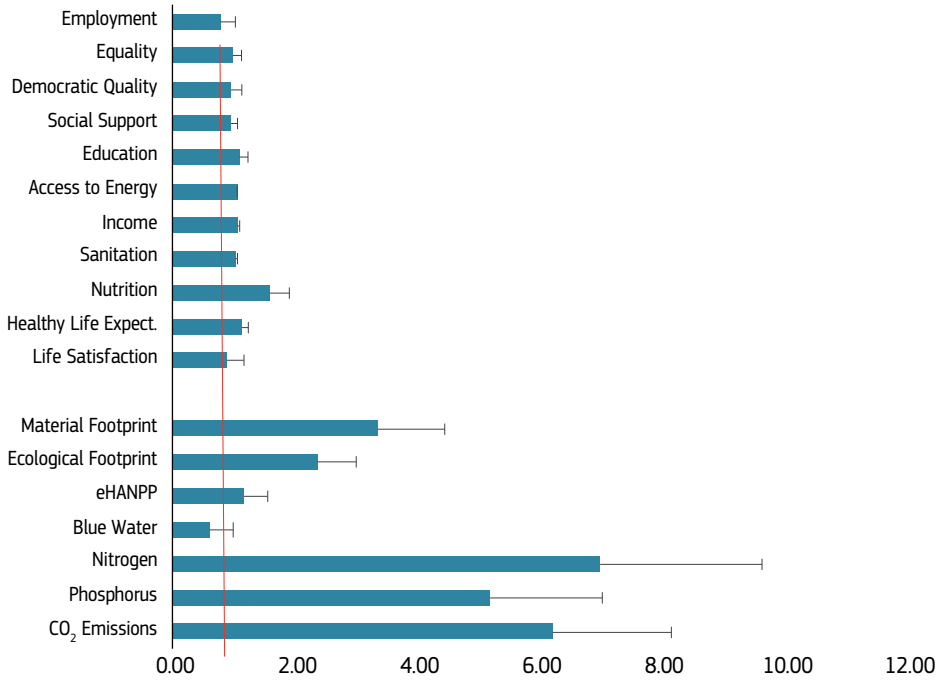
The limits of growth



What are our limits? In this diagramme, researchers have imagined an outer circle of nine physical boundaries beyond which we should not pass, such as changing the climate, using freshwater, or converting forest to farm. These form an "ecological ceiling." In the centre circle are 12 basic human needs, such as water and food, that form our "social foundation." The bright green space is where we want to be, in a "safe and just operating space." But the red stripes above and below us flash warnings of how precarious our situation has become. Source: Raworth (2017)[74]

How does this picture look if we focus on the subject of this report, food and agriculture? Answer: we have broken through the guard rails for most environmental factors needed for a sustainable food supply. And socially, we are skirting at or just past the limits for a safe and just society. The logical conclusion: we must act now.

Crossing the line in food and agriculture



This chart shows, for a series of social and environmental indicators within the EU, how close to or past the limit we have gone if we want a sustainable world. The red line, set at the index value 1.00, represents the safe limit experts think we should observe for such social dimensions as employment and environmental dimensions as our use of materials. The blue bars measure our current state of affairs, averaged for all countries; the thin black lines indicate the margin of error. Source: Báldi, András, calculated from supplementary data in O'Neill 2018.[75]

So far, this has made for depressing reading. But in any crisis, it helps to think strategically. Where do we need to be a generation from now? What must we avoid, through wise decisions taken now? For the key parameters affecting our food and agriculture systems, what targets could we set as matters of policy within the EU? For this, based on research to date, we have proposed a focus on six main physical boundaries, and five social boundaries – 11 targets in all. These are indicators of progress, or decline, in the food and agriculture system. Some are obviously physical, such as biodiversity and CO_2 concentration. Some are physical manifestations of human behaviour, such as land or pesticide use. And others are purely human dimensions, such as nutrition and gender equality. They are, collectively, boundaries to be obeyed and enforced – if the political will is strong enough.

11 TARGETS FOR A SAFER, FAIRER PLANET BY 2050

Following a review of existing data, we propose six physical targets and five social targets related directly or indirectly to the food and agriculture system. If met, these targets would suggest that the planet can sustain human and other life indefinitely, and people can thrive in society. Hitting these targets will require action on many fronts, as outlined in succeeding chapters. References for this table are in the endnotes. [76]

TARGET FOR EU+	BOUNDARY	EXPLANATION
Zero CO_2-equivalent net emissions by 2050	Climate change	In 2017 net emissions of agriculture were 80.9 million tonnes.[1] The European Green Deal pledges net-zero greenhouse gas emissions by 2050.[2]
Restore the level of biodiversity extant in 2000	Biosphere integrity	Biodiversity is defined as the remaining mean number of original species, relative to their number in pristine or primary ecosystems, which are assumed to be not disturbed by human activities for a prolonged period. The index for Europe was 0.45 for 2000 (base year), and is predicted to decline to 0.33 in 2050.
2/3 of Europe's land needs ecosystem restoration	Land-system change	Land-system change is accelerating due to human interventions, mainly intensive farming, and expansion of urban and built-up areas. Such changes deteriorate the natural capital and ecosystem services.
Keep freshwater use at recent level	Freshwater use	The original planetary boundary for freshwater use was specified as a maximum global withdrawal of 4 trillion m^3/year of blue water from rivers, lakes, reservoirs, and renewable groundwater stores. The estimate of this study from the planetary boundaries framework is that humanity is currently consuming 65% of the global freshwater boundary. Water extraction for agriculture in Europe is 97.2 billion m^3/year, with large variations across countries.

TARGET FOR EU+	BOUNDARY	EXPLANATION
Reduce phosphorous by 81% in 2050, and nitrogen by 86%.	Biogeochemical flows	The planetary boundaries framework provides two sub-boundaries for bio-geochemical flow: one for the phosphorus cycle and the other for the nitrogen cycle. Current data: • Phosphate in rivers (mg/litere) 2016: 0.007[3] • Gross phosphate balance 2013-15: 1.2 kg/ha[4] • Gross nitrogen balance 2013-15; 49 kg/ha[5] The Farm to Fork strategy pledges to reduce nutrient losses by 50% by 2030.
Reduce pesticides by 75% in 2050	Novel entities: pesticides, antibiotics, plastic	Conventional farming relies heavily on pesticides to defend crops from a host of invertebrate and fungal pests and diseases, and to control weeds.[6] Pesticide exposure is linked to various diseases including cancer, hormone disruption, asthma, allergies, and hypersensitivity.[7] Soil contamination by pesticide residues has become an issue of increasing concern in Europe. The EU Farm to Fork strategy plans a 50% cut by 2030[8].
Health	Normal weight (BMI-Body Mass Index: 18.5-25)	Across the globe, more than 2 billion people are overweight or obese. Within the EU-27, the numbers are: • Overweight (BMI>25) 2017: 51.8%[9] • Obese (BMI>30) 2017: 14.9%[10]
No gender discrimination	Social equity	Current gender pay gap in the EU-27: 15.0[11]
All animals treated according to stringent welfare standards	Good stewardship	No systematic data are available on this indicator of our social attitudes towards environmental stewardship. Available statistics at a national/ regional level on compliance controls are based on samples of variable proportions of farms.

TARGET FOR EU+	BOUNDARY	EXPLANATION
Fair income for farmers	Social equality	Income in the farming sector is generally low and below what can be achieved in other sectors in the economy (on average only 40% of average wages in the EU-28 economy). The contribution of off-farm work to farmers' income is relevant. Contribution of public support to farmers' incomes vary from country to country, and the average subsidy on farmers' income is 20%[12,13]
Access to Internet for all in rural areas	Technology access	As technology advances, being shut out of the Internet is a form of social and economic isolation. Some data: • Percentage of the EU-28 rural population accessing the Internet: 62%[14] • Percentage of the EU-28 urban population accessing the Internet: 75%[15]

HOW DO WE GET THERE?

Hitting these targets, and reaching the "safe and just operating space", will be difficult. It requires radical change – in how we produce our food, distribute it, prepare it, consume it and dispose of it. It requires change in the way farms and fisheries operate, in how food companies formulate, process and market their products, and in the way consumers select and prepare their food. It requires change in our laws – at every level of government, from small town to EU administration. And it requires change in the way we organise our society and our lives. For instance, since the start of the Industrial Revolution, the major Western states have operated on the assumption that more production and more trade are good for all, creating wealth that benefits everybody. But that is how we crossed the planetary boundaries. Now, we need a new way of thinking, uncoupling the idea of well-being from the idea of gross national product.

How? There are many tools we can deploy. Technologies could help, of course. Digital technologies are promising, and could for instance increase efficiency and reduce waste in the food chain; this year, it seems, the whole world has moved online. Broadening the genetic base of crops and animals through breeding could improve nutrition, sustainability and resilience in some cases. Knowledge of ecology, applied to breeding and farming methods, can reduce the environmental impact of agriculture – and make it a net source of environmental goods. Food manufacturers, in collaboration with producers and public health organisations, could use sustainable technologies to increase the diversity and healthfulness of what we can choose to eat. But it is more and more evident that, without a profound social transformation, technology will not help. We need to understand how this transformation may happen.

Social, behavioural and economic research could offer new ideas for organising ourselves more effectively, and understanding how we can best shape our own behaviour. Education and awareness raising is key – and not just for the young; the first step towards change is understanding the need for it. New policies are essential, and one positive trend over the past few years has been the rising level of political dialogue over climate and sustainability; the Green Deal, proposed by the Commission, is a recent and especially salutary example, decoupling economic growth from resource consumption. But no one of these tools for change can work in isolation. Making our food and agriculture systems sustainable is what some have called a "wicked" problem, of such complexity that a solution requires a systems-wide approach, and may never be fully resolved.

And lest we forget: change is about people, not abstract ideas or fancy tools. Any societal transition from one state to another requires the work of many: individuals, corporations, cooperatives, research institutes, non-governmental organisations, city councils, national leaders, media organisations, schools and more. All of them can get locked into comfortable, or convenient, patterns – by the technology they employ, the employment they depend on, the laws they live with. Every transition finds some resistance; people fear loss of money, power, comfort or all three. Do we compel change upon them? Offer incentives for change? And what about the trade-offs that can result? A small example: To stop plastic waste clogging our oceans and endangering wildlife, we could simply ban all plastic packaging of food. But will that lead

to more food spoilage, disease and cost? Another example: To help the climate, we could reduce international food trade and transport. But that could lead to higher food prices. Managing trade-offs like these is complex, requiring a mix of new research and technologies, new business models and supply chains, new ideas and habits. And it requires a wider, louder public debate on the ethics of such trade-offs, involving scientists, politicians, business people and citizens at large.

KEY RESEARCH TOPICS

- How can we improve monitoring and measurement of the entire food chain, from producer to consumer?
- What are the limits of growth? How bad, in the 11 planetary and social boundaries we list, can we get?
- How can we better track our progress, or lack thereof, in staying within the boundaries?
- How can research better connect to policy and society, so that evidence can guide us towards a 'safe and just' world?

In the chapters that follow, we examine in detail three key transitions required to make our food and agriculture systems sustainable – to bring us to the "safe and just operating space" at least in this area of human endeavour. But the key message is simple. We must change our lifestyles. At present, we can try to keep our economies growing today, but future generations will pay the bill. That must stop.

CHAPTER III: BUILDING RESILIENCE – THE COVID-19 LESSON

We call for disaster risk reduction and the building of resilience to disasters to be addressed with a renewed sense of urgency.
'The Future We Want', UN Conference on Sustainable Development, 2012[77]

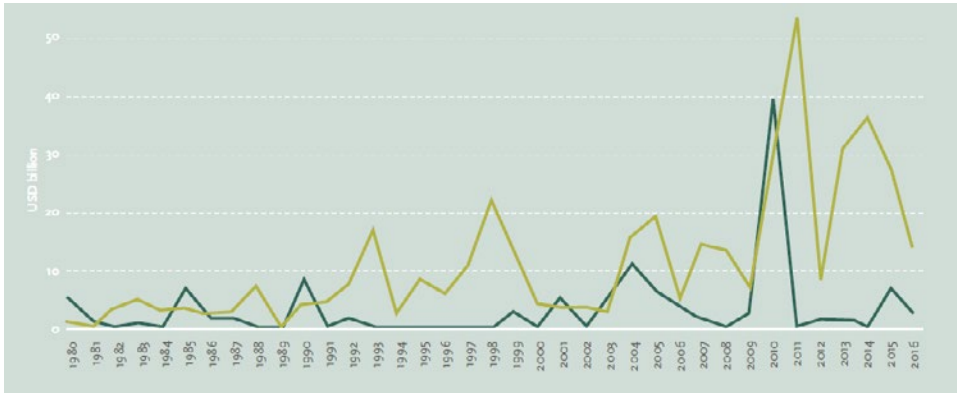
Forewarned is not, we now know, forearmed.

Long before the COVID-19 crisis began, there had been many warnings, from epidemiologists, virologists, microbiologists – even historians. The misnamed "Spanish flu" of 1918-19 infected about a third of the world's population, and killed more than 50 million.[78] In this century, a series of frightening but contained epidemics passed through news headlines: SARS, MERS, Ebola and others. Yet, as a society, we did relatively little to prepare. And now, a round of "I told you so" commentary has ensued – as it does after nearly every disaster, natural or man-made, from Fukushima 2011 to Wall Street 2008. A Cassandra, it appears, has no more credibility today than 3000 years ago at Troy.

So what are we to learn from this catastrophe of 2019-20 (and beyond)? In a word, resilience.

Resilient systems have built-in redundancy, embedded diversity: they offer options, so when one part of the system breaks another can compensate or mitigate. Even before COVID-19, from 2005 to 2016, developing countries were experiencing an average 260 natural disasters a year killing 54,000, affecting 97 million and costing $27 billion annually.[79] The Food and Agriculture Organisation estimates, 23% of the economic loss and damage is to the agricultural sector – taking a huge toll on the ability of disaster victims to rebuild and recover. Repeatedly, in these and other disasters, we have seen – for lack of resilience – catastrophes trigger systemic crises that disrupt social services, the economy, the environment, even the state of peace or war among nations. Clearly, we would all like to "build back better" from this particular crisis; and that includes building in more resilience for future crises. But doing so requires deeper understanding of how our complex, interconnected world operates, and developing better tools to manage it. Those are the fruits of research.

Economic loss from disasters in developing countries, 1980-2016



Loss from geophysical disasters (dark green) and climate/weather disasters (light green.) Source: FAO.[80]

THE COVID EXPERIMENT

To grasp what this entails, consider a few of the general lessons from the COVID-19 crisis:

Us v. them. People in stress have two competing reflexes: solidarity and selfishness. In the first few months of the crisis, a clear victim was the machinery for international cooperation: it appeared, at times, as if it was every country or region for itself. This strained relations between north and south, east and west, neighbours and competitors, within the EU. It damaged, perhaps permanently, how the world views both China and the US; a low point was the US administration's failed attempt to monopolise supply from a German vaccine company.[81] Only as the crisis evolved did the countervailing human instinct for solidarity re-emerge, in EU budget negotiations and coordinated international health research.

Fragility. Many systems we had long trusted proved not, after all, to be as reliable as thought. The most prominent example was the health system in many countries: Who, aside from medical experts, knew there could be a capacity limit for intensive care units or ventilators? But transport, finance and commerce proved at least as vulnerable. And in food and agriculture, as restaurants shuttered and school lunch programmes suspended, disruption in demand for food caused unpredictable ripple effects: food supply chains broke in places, local labour shortages hit some farms, food waste and loss rose. Nutrition suffered for thousands of children no longer receiving free school meals. Of course, from the narrow viewpoint of physical food production, the EU did better than most: High food stocks, strong government support, and a diverse and well-financed agricultural sector all cushioned the potential blow to primary supply. But for

many citizens, 2020 has been the first time they ever thought about the security of their food supply.

Inequality. How you experienced the opening months of the COVID-19 crisis depended a lot on where you lived, how rich or poor you were, and what kind of job you had. In the lockdown period, most white-collar workers continued functioning from home; in February and March, Internet traffic nearly doubled in Britain, and more than doubled in Italy.[82] But many blue-collar workers in factories or manual jobs were tossed into unemployment, while a whole army of "essential" workers in supermarkets, delivery systems and healthcare were obliged, at sometimes great personal risk, to keep going. Indeed, one oft-commented positive effect of the crisis was a widespread recognition that these chronically underpaid people are actually quite important to society.

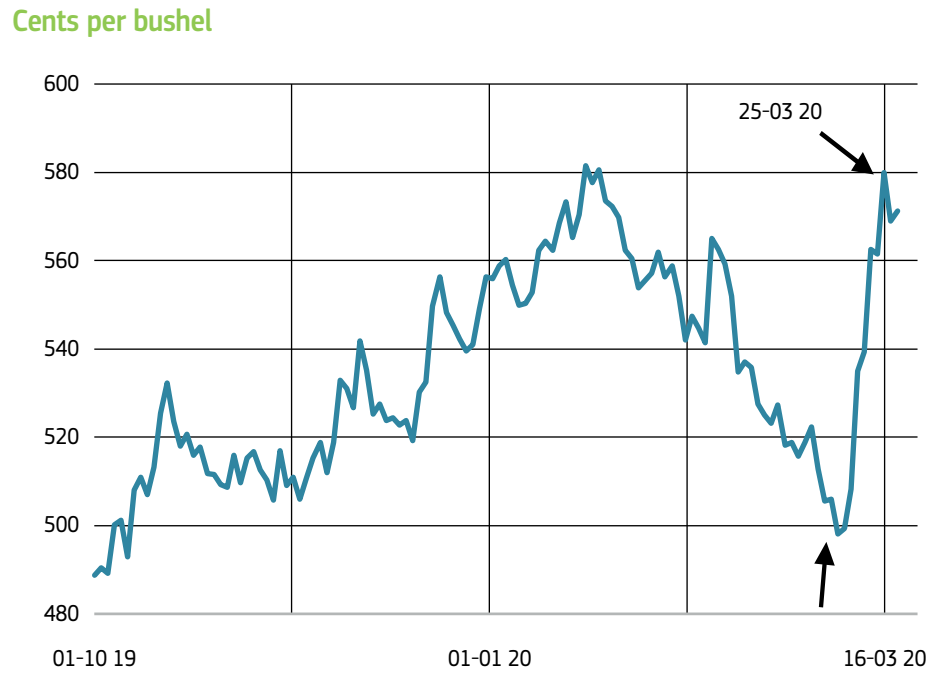
Expertise. Around the world, medical doctors and researchers suddenly became prominent public figures, appearing regularly on TV news alongside prime ministers. In the first lockdown phase, that was all to the good: their credibility was uncharacteristically high, and helped persuade most people to take the virus seriously. But in time, the "shocking" fact emerged that scientists do not always agree; and as attention shifted to *deconfinement***,** their arguments were weaponised for partisan politics. The long-term consequences are not yet clear: will it raise or diminish the credibility of science? The whole affair highlighted the deep and broad canyon between science and society. They were, it seemed at times, like two strangers on a first date - and finding they were not in the flesh as attractive as they first seemed on-screen.

A 'GOOD' CRISIS FOR AGRIFOOD SYSTEMS?

In the food and agriculture sector, the impact was also great. In the first weeks, the social media images of empty supermarket shelves, dark restaurants and milk going down the drain were shocking. But it could have been a lot worse[83]. At least in the EU, what we were seeing were temporary, localised disruptions in the food supply system, rather than outright shortages across the continent. Production, demand and international trade of agriculture and food products are relatively unaffected, compared to many other manufacturing and service industry.[84] As the OECD put it in April, "enough food is available globally, but COVID-19 is disrupting supply and demand in complex ways."[85]

One such way was visible in international trade. Wheat prices initially soared, despite high global stocks. Some governments overreacted: Kazakhstan banned wheat exports; Vietnam temporarily suspended rice export contracts. But more common were difficulties with food getting to where it normally goes, by its normal routes. With many airlines shut, air freight costs rose by about 30% between China and North America, and by over 60% on some trans-Atlantic routes;[86] that spiked transport costs for perishable food, as well as everything else that normally moves by air. At the same time, even within the EU, rail and road delivery times rose in many

places as border closures or checks multiplied and social distancing slowed border inspections. Shipping was also affected, as container traffic dropped in badly affected port areas of China or elsewhere. For the most part, however, these problems were temporary.



Price of wheat on the Chicago Board of Trade. Source: Hansen 2020, based on Nasdaq data.

Of greater concern were vulnerabilities in demand and supply systems – even within the relatively wealthy EU. As restaurants, schools and businesses temporarily shut, the usual market signals to producers went haywire. What was a farmer or fisher to do, who had built a business on supplying local restaurants or urban markets – often a higher profit outlet, especially for organic produce? What about the vast quantities of food routinely produced and delivered under contract to school systems across Europe? At the same time, border restrictions started to cause local labour shortage on many farms, and media reports multiplied of crops left rotting on the field; at one point, the Belgian government resorted to urging citizens to eat more *frites*, to avoid wasting potatoes. And problems rippled down the food chain: distributors repeatedly found themselves with the wrong food in the wrong warehouses; some soft drink manufacturers reported difficulty getting enough CO_2, a by-product of fertiliser production.

RESEARCH AND THE FUTURE

The actual extent of these problems is still being measured; many specialists believe the short-term impact on food and agriculture was more dramatic than deep. But what started as a local crisis in one country and spread across the globe has been – it sounds almost callous to say – a frightening global experiment in crisis management, health and nutrition, sociology and political science. We must, now, understand what happened. And we must apply that knowledge to the social, technological and political tools to make the post-COVID world safer, fairer and greener. Every aspect of the crisis bears extensive study.

For instance, food shopping changed. Online shopping for all retail categories jumped 4.4% in the first quarter of 2020, Eurostat reported.[87] And food retailers overall posted a 3.6% sales rise – this, in an indicator that normally moves in fractions of a percent. In short, normal patterns of buying got scrambled. If sustained, this migration to online channels could reduce food distribution costs and waste – but it could also increase concentration among mass online retailers and produce new waste related to packaging. To compensate, some cities promptly began marketing regional online retailers and delivery services - a model for the future? To really understand what happened, and how it can be applied to shifting our behaviour permanently, is a major topic for the social sciences. And from what we learn, we can devise better tools, and better policies, to connect farmers and consumers, producers and buyers, in a more efficient, low-waste system of food supply and demand.

Diet also changed. Many consumers grew more conscious of healthy diets, and most bought more pasta, rice and other long-lasting staples. But many also bought easily stored snack or ready-to-eat foods; sales of wine and beer for home consumption jumped. And of course, millions of people suddenly had to cook more at home than ever before. Mealtime became more important to many, a structure for the day and an antidote to social isolation. The food industry responded, as some brands tried to tailor their advertising to this “cocooning” behaviour. At the same time, however, the gaping holes in social safety nets in many countries were cruelly exposed. That will affect health, nutrition and hunger for months to come. Due to the pandemic, the World Food Programme forecast 130 million extra people on the brink of starvation by the end of 2020.[88] Research, again, is needed to understand how the crisis affected diet and nutrition around the globe – and how to apply those lessons.

The environmental impact of the crisis was also visible, in images of blue skies over Beijing, or better air quality in Brussels and Paris. But that quickly reversed, and climate change did not slow. Waste rose, and recycling fell. And, though the Commission is trying to push forward with its Green Deal, the economic pressures of recovery will, for many citizens, take precedence. Can we ever rid ourselves of fixation on economic growth? Can we shift our policies to value well-being more highly than wealth? Again, these are questions for which knowledge is needed.

But knowledge does not matter if it is not used. This is, for policy makers, among the most important challenges of COVID-19. Science can and does warn us of trouble ahead. It warned of a pandemic. It warns of more disasters if we do not observe the planetary boundaries outlined earlier in this report. But why is it a human trait to ignore "inconvenient truths"?[89] Can we develop the tools – in education, social media, political structure – to change? How can we better connect our scientific knowledge to the society that pays for it? For EU programmes, these questions are already on the agenda – but they need special application in health, nutrition, food and environment: all are factors that directly affect our well-being. Real crisis preparedness requires that we translate our knowledge into action. The following chapters suggest what that action could be, if guided by science.

Key research topics

- How did the crisis change patterns of food buying, diet, nutrition – and can we use this experience to improve digital tools, nutritional education, social solidarity?
- How did the crisis affect food production and distribution – and what effects will persist, or can be used to force lasting change?
- How did the crisis affect the environment – climate, rural areas, water and air? Can we use this knowledge to reshape our environmental and climate policies?
- How can we make our systems of food supply and demand more resilient, to avoid future disasters – with diversity, circularity and better production and consumption habits built in?
- How can we better translate knowledge into action? How to connect science and society?

The world can change. Following the Great Depression and World War II, a panoply of new international institutions appeared to try to manage global trade, economics and geopolitics. Many of our current health, income and social support systems were created. Those institutions have been tattered over time, as the virus of nationalism resurged or the haves ceased caring about the have-nots. But this new crisis has already had some positive consequences, on which we can build. We are more aware of the fragility of our systems, whether social, economic, health or food. We have seen how quickly we can, as a species, adapt to the unimaginable. And we have remembered the value of expertise, of validated science, of making decisions on the basis of evidence rather than prejudice or self-interest.

The values we share are expressed in the UN's Sustainable Development Goals, a set of 17 environmental and social targets. Their achievement has been set back by COVID-19, but their importance has been reaffirmed. This crisis could end up catalysing vast changes – a root and branch reform of the way we use the planet and live with one another. If so, it will be guided by knowledge, research and evidence. In the following chapters, we examine in more detail the transitions that will be required – in nutrition, circularity and diversity – to get from here to there. We are now rebuilding, Hopefully we will build back better than before.

How has the crisis affected the Sustainable Development Goals?

In 2015, the United Nations adopted "a shared blueprint for peace and prosperity for people and the planet", in the form of 17 environmental and social goals.

The COVID-19 crisis has set back our progress to most of them. Poverty and hunger are worsened by the economic fall-out, gaps in income and opportunity widened, health visibly damaged. But at the same time, the crisis has reinforced the importance of these UN goals. For the first time in a few generations, we have all become far more aware of the importance of good healthcare and a secure food supply.

What could we accomplish if we actually planned, invested in, and voted for policies that made some of these positive changes permanent? Can researchers analyse which changes worked, and how to translate them into coherent government programmes supported by all?

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CHAPTER IV: HEALTHY, SUSTAINABLE DIETS FOR ALL

"Sustainable development…meets the needs of the present without compromising the ability of future generations to meet their own needs".
From 'Our Common Future,' Gro Harlem Bruntland et al.[90]

The way we talk and think about food today in Europe is enough to give anyone intellectual indigestion.

On one side, we seem to be living in a world of extravagant plenty and choice. Even in COVID-19 lockdown, we watched celebrity chefs and cooking competitions on television. In social media, we paged through endless images and videos of perfect paella, exquisite chocolate ganache, and nostalgic comfort foods. In normal times, we can go organic, vegan, zero-carb or flexitarian. We can sample sushi, curries or burgers from around the globe. In the city, we can shop online, at a chain store, or in urban markets; in the countryside, we can also buy direct from the farm. Surely, all is for the best in this best of all possible dietary worlds.

On the other side, however, the reality is a food system of catastrophic imbalances – in which more than 2 billion people around the world are overweight, while another 800 million are undernourished – in the same countries. It is a system of ever-bigger farms and food distributors driving out small landholders and local butchers and greengrocers – an insult to our common notions of fairness and equity. It is a system of appalling waste, environmental harm and frightening climate impact. It is, in short, a nutritional system that is quite, quite unsustainable. But it is not irremediable.

"**Sustainable diets** are those diets with low environmental impacts which contribute to food and nutrition security and to healthy life for present and future generations. Sustainable diets are protective and respectful of biodiversity and ecosystems, culturally acceptable, accessible, economically fair and affordable; nutritionally adequate, safe and healthy; while optimizing natural and human resources."
- Food and Agriculture Organisation, 2010, "Sustainable Diets and Biodiversity."

At base, sustainability is a simple idea: satisfy today's needs without sacrificing tomorrow's. In the area of food and nutrition, this should translate into equally simple goals. A sustainable diet means meeting everybody's minimum nutritional needs with food that is safe, culturally

acceptable, affordable and continuously available. At the same time, such a diet must preserve and protect our resources – so we do not, in producing and distributing our food, also deplete the soil, waste water, pollute the environment or worsen climate change.

These two issues, nutrition and sustainability, are intimately linked. If we are to make progress, both must be treated simultaneously. The balance between them can be shifted by government action in new regulations or tax policies. It can be shifted by new technologies and practices in the production and distribution of food. It can be shifted by the choices of billions of individual consumers, in their daily menus and habits. Does a consumer choose beef or beans? Buy local produce or imports? Avoid waste, or consume wantonly? These choices are influenced by deep social norms, habits and contexts; and that means we must address the cultural and ethical dimensions of choice. The good news: choice can be influenced, by information, education, labeling, regulation, technology and taxation. It can be influenced by the "retail environment"[91], the conditions, unique to each community, that a consumer encounters when buying food.

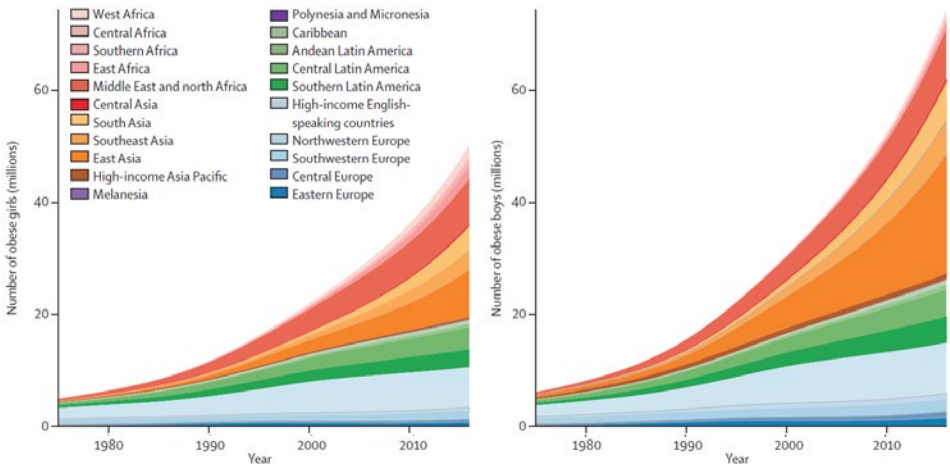
To be clear, however: "nudging"[92] consumer behaviour in a nutritious, sustainable direction is not enough. People must also have the means to choose correctly. They must have an adequate supply of nutritious and varied food, and the income to get it; healthy bio foods or new vegetable-based products do little good if too hard to find or too expensive to buy. There are many barriers to wider, fairer distribution of good food: the income gap between rich and poor, the social and financial strains on rural life, the market power of entrenched food retailers and processors. To make progress, we must tackle all such these problems at once: behavioural, economic, logistical, fiscal and more. If we aim for a "safe and just operating space", we are faced with a daunting task – but one that can be aided by research, technology and knowledge.

TRACKING THE TRENDS

One of humanity's greatest post-war achievements was reducing starvation – a feat permitted by the "green revolution" that introduced high-yield crops, fertilisers, pesticides, irrigation and integrated food supply chains in what were once the world's hungriest places. But this is changing. Since 2015, the trends have been reversing, as strife, economic turmoil and environmental damage leave more and more people undernourished – in 2018, about 10.8% of the global population. This selectively hits the young – our future: That same year, about 22% of children under five years old were too short for their age, and 7.3% too thin for their height.[93] Nor is wealthy Europe exempt: while on average under 2.5% of EU citizens are undernourished, the levels spike upwards in southeastern Europe – such as Bulgaria at 3.6%, Albania at 4.9%, and Moldova at 8.5%.[94] Even before the pandemic, the European Food Bank Federation said it was distributing the equivalent of 4.2 million meals a day to 9.5 million people across Europe.[95] After the crisis, food provision to the poor or homeless is an even greater problem.

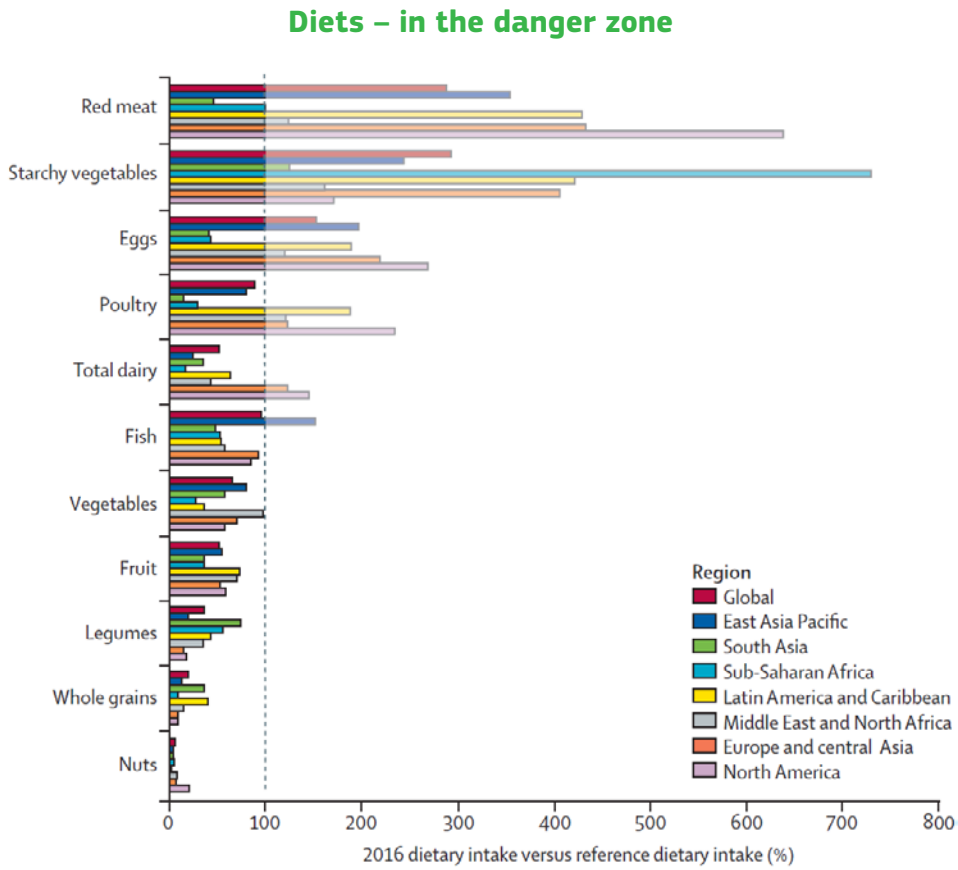
And yet, a great paradox of our age is that, alongside stark under-nourishment, we see an epidemic of obesity. Of the more than two billion people around the world believed to be overweight (body mass index greater than 25), a third are obese (BMI>30) – with obesity rates rising by 1% every three years.[96] Again, the young are vulnerable: From 1975 to 2016, the number of obese 5- to 19-year-olds rose more than tenfold. This presents a fearsome prospect for already-overtaxed health systems. It is a special problem in wealthy Europe, where more than half the adult population is overweight and about one-sixth is obese.[97] Compared to the 2,500 calories a day recommended for an adult, Europeans eat on average 3,700.[98] Other factors, such as insufficient exercise, also contribute. And it is not just a rich-country problem: the highest proportion of overweight children in the world is in southern and northern Africa.[99]

The obesity epidemic – girls and boys



Trends in the number of children and adolescents (5-19 y) with obesity by region (From NCD Risk Factor Collaboration (NCD-RisC), 2017. Lancet; 390: 2627–42)

In short, we have an epidemic of what you might call mis-nutrition: a dystopia of under-, over- and just plain badly nourished people. But it is what, rather than how much, we eat that poses the biggest problems to ourselves and to the planet. We eat 2.5 to 3 times as much meat as recommended by dietary experts, posing extra risk of cardiovascular, intestinal and other disease.[100] We eat too much potato and other starchy vegetables, and too many eggs, poultry and dairy products. By contrast, we eat not enough vegetables, fruits, legumes, nuts and seeds. This toxic mix of unbalanced diets, of over-consumption alongside under-nourishment – combined with its deleterious effect on the environment and climate – has been called[101] a global "syndemic" by a group of experts gathered by *The Lancet* medical journal. Another such group, the EAT-Lancet Commission, attributes 11 million premature deaths a year globally to dietary problems..[102]



Diet gap between dietary patterns in 2016 and reference diet intakes of food (EAT-Lancet Commission Report, 2019) 100%, indicated by the vertical dotted line, is the recommended level.[103]

WHY THIS IMBALANCE?

To begin with, economics and trade can affect how we eat. As globalisation proceeds, food supply chains stretch around the globe. This has helped sustain food supply in many parts of the world, and in richer countries it has permitted great luxuries – such as eating Honduran pineapple in Greece. But this system can also worsen inequalities; as it is, food prices are rising faster than inflation[104] and, due to the pandemic after-effects, may rise faster still. That is an extra burden on low-income families. Further, the economics of farming are hard on small producers, and can favour large-scale, homogeneous production: there are thousands of edible plant species, yet we focus on rice, maize, wheat and a few others. Then, too, we are working against a common phenomenon: As incomes rise, so too does an appetite for meat. In many

cultures, eating meat is a sign of wealth and status; in just two generations, per capita meat consumption in growing Asian economies has nearly tripled.[105] In Europe today, poor diet and its consequences have risen to be a major cause of disease and death. Our dietary choices, nudged by global economic trends, are killing us.

Another factor: we are social animals and heavily influenced by those around us. We heed what mega-food companies, retailers and advertisers tell us about food bargains, sugary drinks, new snacks and faddish foods. We listen to our friends and communities, and watch celebrity "influencers". We seize on fads or novelties. Consider: How and why in the past decade did so many up-market burger-and-fries restaurants proliferate across many European cities? They are neither inexpensive, nor nutritious, nor even – for most European citizens – part of a traditional diet. What we eat sends a powerful social signal – part of our cultural or political identity. Former US President George W. Bush banned broccoli from Air Force One as a bit of just-plain-folks symbolism; Michelle Obama reversed that by planting a socially conscious vegetable garden on the White House Lawn; and Donald Trump famously gorged on take-out burgers and fries. Food, like social media, declares whom we like and whom we don't. Changing what we eat amounts to changing who we think we are – a momentous task, if we want to push eating habits in more healthy and eco-friendly directions.

What is a model diet?

What, according to nutrition specialists, should be on our menus? Source: EAT-Lancet report.

Target 1 – **Healthy Diets**
2500 kcal/day

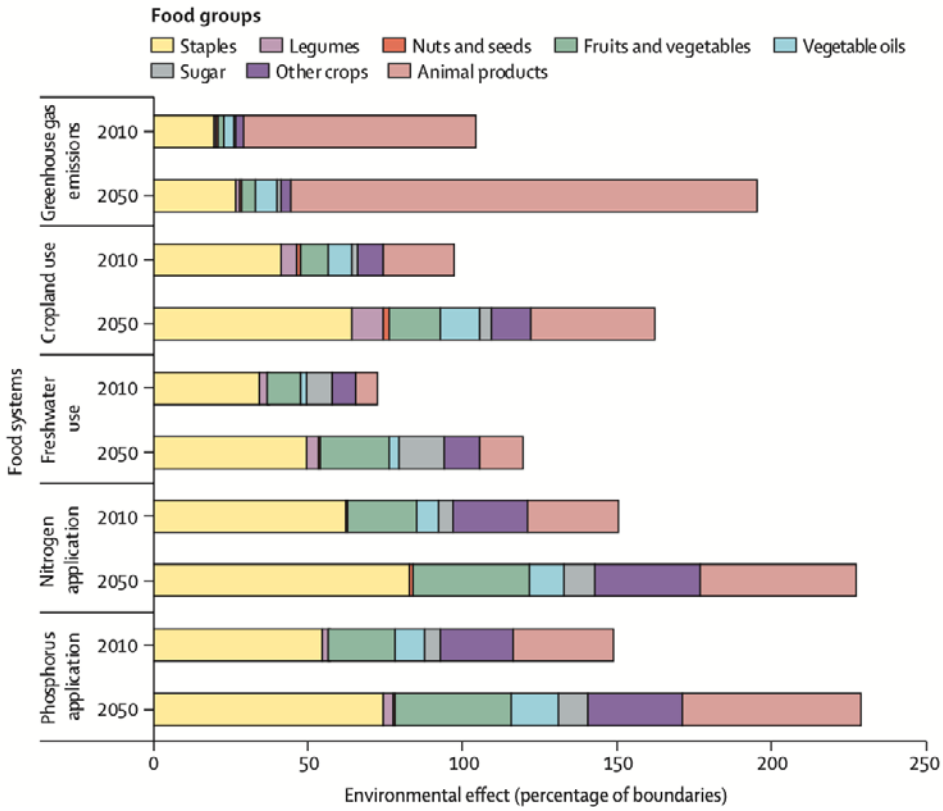
	Macronutrient intake grams per day (possible range)	Caloric intake kcal per day
Whole grains		
Rice, wheat, corn and other	232	811
Tubers or starchy vegetables		
Potatoes and cassava	50 (0–100)	39
Vegetables		
All vegetables	300 (200–600)	78
Fruits		
All fruits	200 (100–300)	126
Dairy foods		
Whole milk or equivalents	250 (0–500)	153
Protein sources		
Beef, lamb and pork	14 (0–28)	30
Chicken and other poultry	29 (0–58)	62
Eggs	13 (0–25)	19
Fish	28 (0–100)	40
Legumes	75 (0–100)	284
Nuts	50 (0–75)	291
Added fats		
Unsaturated oils	40 (20–80)	354
Saturated oils	11.8 (0–11.8)	96
Added sugars		
All sugars	31 (0–31)	120

Worse, several trends appear likely to skew our diets further from the desired norm. As a species, we are becoming more and more urban: by 2050, 67% of the world population is expected to be living in cities. That will widen the distance between production and consumption of food,

add extra steps in the food distribution chain, increase the impact of industrial food advertising, and further detach us culturally from farm life and diet. Further, Europeans are ageing: by 2050 there could be fewer people working than not working. That would further strain our pension and health systems, making it harder to feed a growing population of elders – who, furthermore, are themselves living longer and coping with the normal nutritional difficulties of extreme old age. These two trends combined, urbanism and ageing, could further widen the gap between the overweight and the under-fed.

But all these human problems – of diet, choice and demographics – have a direct impact on the earth around us. If we do not eat a balanced, nutritious diet, the cost is not measured solely in our health expenses; it is also visible in the carbon footprint, the chemical balances in soil and water, and the diminished diversity of land and life around us. In subsequent chapters, we discuss this issue in greater detail. For now, however, the main point is that our food choices are inextricably linked with our environmental impact – and we cannot consider solutions to one without the other.

The environmental impact of what we eat (source: Springmann et al. 2016)[106]



BARRIERS AND TRADE-OFFS

Change is easier said than done. There are always barriers, and every possible remedy may have a corresponding cost or trade-off.

For starters, any strategy for change must deal with the reality of the food industry today. The food and drink industry is the No. 1 manufacturing employer in half the EU member states.[107] It employs 4.72 million, and generates €1.2 trillion in annual turnover. Though most of its products are traded within the single market, its scale is such that the EU is the world's largest exporter of food and drink products – amounting to €110 billion and generating a trade surplus of €36 billion. Further, it is supported by a global processing and handling equipment sector of $137 billion in 2019. And it innovates – ever chasing after the latest consumer demand. According to the Food and Drink industry association, the soft drink companies are the most innovative in the sector, closely followed by frozen food and ready-made meal providers. This innovation has been great for the industry's growth, but as the foregoing discussion suggested, not all of these innovations are great for our health or environment.

Of course, the industry is both barrier and conduit for change. So too is international trade; imports affect what a local farmer can profitably produce, to good or bad effect. In so complex a system as food provision, every policy option has costs and benefits. Take food safety standards. To avoid food poisoning and contamination, the EU sets very high standards; it is, in fact, justifiably proud of its safety system, which has reduced the incidence of food-borne diseases and recovered quickly from such potential catastrophes as the BSE crisis of a generation ago. But the regulations must be constantly updated, to reflect changing technologies. And such is their complexity that they can benefit efficient, mass-market food producers and distributors, whose economies of scale make them better able to bear the regulatory expense than are small producers. That reinforces the trend towards larger, industrial-scale food producers and retailers, the economics of which require persuasive – even if unhealthful – food advertising campaigns to sell large stocks. The outcome: greater food safety, but less variety in type or source of food. Yet no one would advocate relaxing our food-safety regulations. Nor would anyone say that "big" is inherently bad in the food industry; the problem is more complicated. Several factors, from trade to economics to logistics, can entrench an established supplier and block an innovator.

Another example: organic and "bio"-labeled foods have been growing in popularity, but are usually more expensive, as their prices coincide with the 'true cost' of production, unlike the prices of conventional products. Moreover, they typically come from smaller producers, who may have lower yields than industrialised farms and more difficulty getting their produce to the big urban markets or distributors. And many consumers perceive these options as too expensive – not for them. The result: many consumers in disadvantaged areas simply cannot or do not go organic at present. That means citizens have unequal access to these foods.[108] If we try to change that by regulation or subsidy, the extra cost will have to be borne somewhere, in government taxes or in food-price inflation. Neither is attractive.

HOW TO MAKE THE TRANSITION?

This report is about solutions, not problems – or more specifically, about research to find these solutions.

The answers can start with technology, of course. Already a wide range of novel foods is now appearing – though much research remains to be done on their relative costs, benefits and health effects. Vegetable-based meat substitutes are most prominent; already, US-based Beyond Meat and its competitor, Impossible Foods, have at times been valued at more than $6 billion as their popularity soars (the fact that neither is European is a further cause for EU policy concern.) Next step: animal proteins grown like lab cell cultures in bio-reactors – without animals. There are also unconventional protein sources, such as mycoproteins, cyanobacterium Spirulina or insects; a Finnish start-up, Solar Foods, says it has developed a technology to grow food a flour-like substance fermented from CO_2 and nutrients.[109] Then there is the possible future of aquaculture and other new fish or marine food sources. All are potentially useful, but questions abound. Are the veggie-burgers really less harmful than meat, when all factors are taken into consideration? Are the energy and production costs of cultured animal proteins too great? Can an insect-based food, however sensible environmentally and nutritionally, ever appeal to more than a tiny number of culinary activists? Are ancient crops nutritionally better? We simply do not know the answers; we need more diversity of food sources and production technologies. And we need more research to create tasty, sustainable and nutritionally balanced foods.

What can drive change?

Moving from one economic or social state to another is always difficult. And getting healthier, nutritious diets and habits for all is no exception. Here are some key measures that could speed that transition along.

1. **Information** on making diets more sustainable exists, but it needs to be made more accessible to consumers. Beyond information, it is the whole **food environment** that needs to be structured.

2. **Social norms** cannot be decided upon by public policies, but policy levers include awareness-raising and education, as well as regulation of advertising.

3. **Public policies**, such as fiscal and procurement measures, have a crucial role to play to influence our food habits. Cities and local authorities can play a fundamental role.

CONTINUED ON NEXT PAGE

4. **Technological change** – from novel foods, digital innovation and artificial intelligence, bio- and genetic technology, consumer technologies - will transform our food habits and diets. It will be necessary to organise **multi-stakeholder dialogues to steer technological innovation** towards equitable access to healthy, nutritious and sustainable food

5. Ensuring **fair competition** between companies is critical, so that incumbents do not prevent innovative entrants from shifting the market towards new, better food habits.

6. Developing further the **social welfare system** to ensure that **access for all** to nutritious and sustainable food is equitable and just, even if prices are not continuing on a downward trend.

Digital technologies, generally, have vast potential to change how and what we eat. Some suggest 3D printing could create a new food-on-demand cuisine, perhaps providing more nutritious substitutes for our fast-food cravings.[110] Artificial intelligence, blockchain, Big Data, cloud and other tools could give consumers a great deal of information about the products they buy, enhancing their power of choice. They can also permit better stock management, reducing waste. ICT tools could help cut food costs, by reconfiguring supply chains more efficiently than is possible today. They could better inform and educate people about what they eat, and its impact on the environment. There are, of course, risks. As with all AI code, errors or biases – not easily visible to a user – could nudge us into wrong decisions about what we eat, or worsen inequality. For instance, if as a society we start relying even more heavily on these tools, will those without good Internet or computing access in the country or poorest districts suffer even more than today? Will all these extra computing resources, with their growing energy demands, worsen the climate balance of how we eat? And then there is the problem of freedom and privacy. Do we want some multinational food retailer – or, for that matter, our doctors, employers or insurers – able to track what we are eating and how healthful our lifestyle is at any particular moment?

New gene and phenotyping technologies are even more promising. Precision nutrition is, for many in the food industry, the Next Big Thing: fine-tuning diet to the genetic profile and gut microbiome of specific clusters of people. It could at the least help those with special needs, such as the elderly, pregnant or disabled; and advocates say it could eventually benefit everybody. New gene-editing or synthetic biology tools could, in theory, improve the nutritiousness of many common foods, lower the cost of production, or even create entire new categories of food. With all of these technologies, whether digital or genetic, we have at the moment more questions than answers about their costs, benefits, unintended side-effects and social consequences. And for many of them, we do not yet know how to scale them up from interesting experiments to profitable, mass-market businesses.

However, we should acknowledge that technology alone is not sufficient. Social and institutional innovation may be at least as important, also to shape technology in the right direction. Several

important socio-institutional trends could promote change. One is towards city-level action. With cities growing, "urban food strategies"[111] will become ever-more influential – or as former New York mayor Michael Bloomberg put it: "We're the level of government closest to the majority of the world's people. While nations talk, but too often drag their heels – cities act."[112] Some, such as Bristol in Britain and Lucca in Italy, had adopted integrated, regional food policies connecting farm and city. More than 200 cities have signed the Milan Urban Food Policy Pact (http://www.milanurbanfoodpolicypact.org/). Many are promoting farmers' markets, buying directly from local organic farmers, or encouraging urban farming on community allotments. This emphasis on local, urban action fits into a broader political trend towards "stakeholder engagement" – whether in community organisations or social media. And in the COVID-19 lockdowns, we saw far more political and consumer interest in locally sourced, readily available foods.

Another trend: online food shopping. We saw in 2020 a real-world experiment in this technology; and millions of people for the first time found their way onto local or mass-market food sites, arranging pick-ups or home deliveries. In theory, this could have lowered food costs by shortening supply lines; it could have spurred new, sustainable links between farm and city. In theory, online shopping can promote healthy or organic foods by offering better display and access. Or it could jump-start the acceptance of entirely new, eco-friendly food categories. But it can also add extra packaging, transport and waste. It could accelerate concentration in the food industry, providing an edge to online brand leaders. And in the face of these dominant retailers, the bargaining power of individual farmers could decline further – and with that, the diversity of the food supply to all. What was the outcome of this mass, international and involuntary experiment? We need research to know.

But certainly, it appears that even without an emergency, a range of emerging social trends can help change behaviour. It is encouraging to see how quickly awareness of climate change has spread around the globe in just the past few years; that is already affecting the eating and consumption habits of many. Food retailers have taken note. Some brands, such as Wholefoods (now owned by Amazon), deliberately target rising consumer interest in greener, healthier diets, and talk of "conscious capitalism."[113] As noted above, the food industry is expert at spotting, satisfying and somehow creating new demands; that suggests a powerful lever for change could be the influence that consumers have on retailers. Can the easy choice become the healthy choice?

In fact, an important insight emerges from the research to date: If people simply ate the way nutritionists recommend, they would automatically reduce human impact on the planet. For instance, the traditional Mediterranean diet is often cited as a model, and recognised by the Food and Agriculture Organisation as an exemplary sustainable menu. It is rich in vegetables, fruits, nuts and unrefined grain cereals, with some fish and limited amounts of red meat and saturated fats. Research[114] has shown it can reduce incidence of cardiovascular disease, some cancers and other health problems. Yet, compared with other Western diets, it also has low environmental impact. Of course, there are many other possible diets one could consider. But if

one ranks dietary recommendations against environmental impact, a striking picture emerges: A healthier diet is also a more sustainable diet.

That suggests at least some aspects of the imbalance between diet and sustainability can be fixed – if we could encourage people to make better food choices. An extensive social research literature documents how any new trend, to catch on, must appeal to individuals as a good idea; it must be supported by others they respect; it must be easy and attractive to do; and it must produce some kind of positive feedback.[115] Several tools could help. Governments could tax unhealthy foods; some cities are already doing that to sweet soft drinks. They could subsidise healthy foods or habits. With labeling, they can shape the way we view certain foods. "Traffic light" nutritional labelling – green, amber, red – is already being introduced in some European countries (not without critique of the simplified messages they convey). But attempts to communicate the environmental footprint of food choices are more sporadic, and focused on single components such as water, CO_2 or energy. New apps might help people think more about their choices. Better education – starting with school lunches – would certainly help, as would local initiatives tailored to individual communities. We could also regulate food advertising more effectively, or better target dietary guidelines; after all, the optimal message is not an abrupt ban on certain foods but a call for nutritionally balanced diets. And we could try to reform the way the economy works – so that companies respond not just to their shareholders but also to consumers, suppliers, the community, the environment. What if, in the food industry, promoting sustainable diets was a component of corporate social responsibility? What if R&D were organised around this concept? These options are discussed more fully in a later chapter.

Here's a thought experiment. Imagine a group of teenagers going into a fast-food restaurant. They skip the burgers, and order something veggie. What would tempt them? Perhaps a pop star, or a footballer, who promotes it to them as chic. Perhaps some trend-setters in their school groups. Perhaps a government tax policy that makes the veggie-burger cheaper. Perhaps an app that makes choosing the healthy option more fun and easy. Preparing and sharing food are supremely social activities, bringing people together. We can imagine any number of ways to tempt these teen-agers into the greener, healthier meal. We have to find them, efficiently combine them, and understand through research and experimentation how they could work best.

Key questions

- What can agriculture, fishery and forestry do to produce more nutritious, eco-friendly foods?
- How to improve food systems to foster sustainable consumption and improve city/countryside links?
- How can we use social and behavioural sciences to guide citizens to eat better, smarter, greener?
- Can we more accurately identify the drivers and the barriers to change, and potential winners and losers – and what would motivate them to embrace change?

But let's not over-simplify this. Nudging behaviour in the right direction is important. But the world's food problems will not be solved by good intentions alone. Government must step in. Technology can help change our eating preferences, but without government steering it will not necessarily make healthier food cheaper or more available. Better nutrition information will help; but that is only one aspect of the whole "environment" in which people choose food[116]. Public policies have a crucial role in shaping this environment – from farm, to factory, to retailer – through regulation, taxation and public awareness campaigns. Public policy also defines fair and unfair competition, and that affects which foods reach the market and which innovations see the light of day. And public policy sets the social welfare system to ensure that all citizens, rich or poor, urban or rural, have access to healthy food. Of course, governments can, and often do, make wrong decisions. And that is where research can enter, to increase the odds of wise policy.

EXPERIMENTS IN BETTER EATING

Change is hard, but not impossible. Around Europe, for several years, hundreds of interesting experiments have been underway to improve diets. Next task: scaling them up EU-wide.

FOOD CAMPAIGNS

In 2009, the Belgian city of Ghent began supporting a "Thursday Veggie Day" campaign by a local non-profit organisation, Ethic Vegetarian Alternative. It urged Ghent citizens to eat vegetarian at least one day a week, preferably on Thursday. It turned the initiative into a kind of civic festival, including pop-up vegetarian restaurants (one, in 2019, was offering gazpacho, vegan cutlets and – what else? – carrot cake.) The initiative, first in the world, was part of the local government's pledge to become a climate-neutral city by 2050. The group's next target is the Belgian capital, Brussels, where it aims to have one million *Bruxellois* eating green.

Ghent's campaign to make veggies cool (from city promotional materials)

SCHOOL LUNCHES

Good eating habits are formed in childhood – and that has made a range of school lunch programmes around the EU important promoters of healthy diets. Indeed, we saw vividly in early 2020 what happens when school lunches are suspended.

Even before the lockdown, however, the national Italian programme was praised. The rules require school lunches include a starchy dish alternating rice, pasta and soup; a main course based on meat, fish, eggs or cheese; two or more vegetable side dishes and plenty of fresh fruit.

Deep-fried foods, such as potato chips, frites or fried chicken, are forbidden. The programmes aim for all-local and organic sourcing. In Rome, for example, 70% of all food served at school cafeterias has been organic. Ingredients come from hundreds of organic farms, many in the nearby Lazio region. And teaching good meal habits is important: Tables are set with silverware, bread baskets, ceramic plates, cloth napkins and clear glasses. Water – the only beverage allowed – is poured from pitchers. The cost: in Rome, €3 a meal – though low-income families are subsidised.

URBAN FOOD STRATEGIES

Several cities around Europe have adopted local food plans – promoting both healthier and more eco-friendly diets.

In Ede, the Netherlands, the city has adopted an integrated food policy that employs a full-time staff of five and includes the country's first municipal food councillor. It subsidises a food enterprise incubator, "Foodfloor", to showcase innovations. And a third of primary schools in the city now have gardens for the children to learn hands-on where their meals come from.

In Ghent, again, city officials in 2013 launched a food strategy to reduce waste, promote sustainable food production and consumption, and shorten the food chain from farm to market. It claims to have distributed 1,000 tonnes of food waste to 57,000 people in two years, created 42 school gardens, and helped provide sustainable school meals to 4,500 students. The meals are not free, but 10% of the city's children are eligible to buy at a discounted cost of €1.

And elsewhere in Europe, Vienna procures organic food for its school and hospital canteens. Birmingham, UK, has moved to restrict unhealthy food and fast-food advertising in low-income neighbourhoods. Bristol set up a multi-actor Food Policy Council to develop a city-wide strategy, the Good Food Plan, to make the food system more resilient and sustainable. And in Berlin in 2016, a Food Policy Council got 175,000 locally produced organic meals delivered to 275 schools – a "mini stress test" of the feasibility of going all-organic, all-local throughout the school system.

CHAPTER V: TOWARDS A 'CIRCULAR' FOOD SUPPLY

"If it can't be reduced, reused, repaired
Rebuilt, refurbished, refinished, resold
Recycled or composted
Then it should be restricted, redesigned
Or removed from production."
-Folksinger Pete Seeger[117]

Rich or poor, rural or urban: if you look across European society with a critical eye, you see waste. Meals tossed away, only partly finished. Food lost or spoiled in transit, or left in the field to rot. We have come to accept this as normal – but a look at the numbers highlights just how extensive and, well, wasteful this has become:

- Across the globe, about a third of the food produced for human consumption each year gets lost or wasted, according to the Food and Agriculture Organisation. That is about 1.3 billion tonnes. It is worth nearly $1 trillion[118] - and just half of that waste would be enough to feed all the undernourished people in the world.

- The picture differs by region and country. The value of food wasted in the industrialised world is about twice that lost in developing countries, and the amount of food wasted by rich countries each year nearly equals the entire food production of sub-Saharan Africa. Within the EU, according to European Parliament data, the Dutch get the prize for most wasteful: about seven times greater than the least wasteful country, Slovenia.[119]

- By type of food waste: fruits, vegetables, roots and tubers are most frequently wasted – with losses of 40-50%. About 30% of cereals are wasted, 35% of fish, and 20% of oil seeds, meat and dairy. The differences reflect varying degrees of perishability and care in handling.[120]

- By source within the EU, households account for 53% of all food waste – more than processing, distribution, catering or retailing combined. In fact, food retailers and wholesalers are most careful, accounting for just 5% of food waste.[121]

- When confronted with these data, we can cluck self-righteously and move on: people are wasteful, and always will be. But, as with all food and farm issues, our behaviour affects the entire planet. To illustrate, another number: the food wasted each year in the EU is

also responsible for 170 million tonnes of unnecessary greenhouse gas emissions.[122] It is responsible for extra pesticides, fertilisers and pollution. It consumes more water and other resources than otherwise needed. It is wasteful on many levels at once.

IN SEARCH OF A CIRCULAR ECONOMY

The solution: a "circular economy." In this, we strive for zero waste. We change our behaviour to stop wasteful practices, at home and at work. We think before we toss or abandon food. More important, we design circularity into all our products from the start; by the Commission's estimate,[123] 80% of the environmental impact of products is set at the design phase – in the choice of materials, processing, application. Even more sweeping: we should also rethink the way our economy works, so that the output side-streams of one activity can be the input feedstock of another, and little gets lost in translation between the two. We can "upcycle" some waste. A homely example: we use only about 0.2%[124] of the available nutrients when making coffee, and so a Danish company, Beyond Coffee, is converting grounds into various higher-value products such as recyclable, edible coffee cups. Or we can "downcycle" waste: for instance, take unwanted food and make organic fertilisers or produce energy with it. In this way of thinking, an unwanted by-product of an industrial process is not something to toss out; it could be the input of another process. In a sense, with circularity, the aim is to create cascades and cycles of waste production and consumption – the way water runs down river, over rocks and into pools, before cycling back through the ocean and evaporation into rain.

This approach would go well beyond food. In fact, food waste, narrowly defined, is only a small portion of the entire economy of various types of biomass in the EU. Each year, we use about 1.2 billion tonnes of biomass – for energy, animal feed, materials (wood, for instance); only 9% is for human food. But we source each year only about 1 billion tonnes, mostly from crops.[125] The balance, about 200 million tonnes a year, comes from cascading uses of food, paper, paperboard and other waste – an indication of the scale of circularity already built into our bioeconomy. And this is only biomass; advocates of circular thinking envision it spreading throughout manufacturing, electronics, packaging, chemicals and virtually every other activity of the 21st century economy. The vision: to build a degree of parsimony into the global economy that humankind has not seen since before the Industrial Revolution – if then.

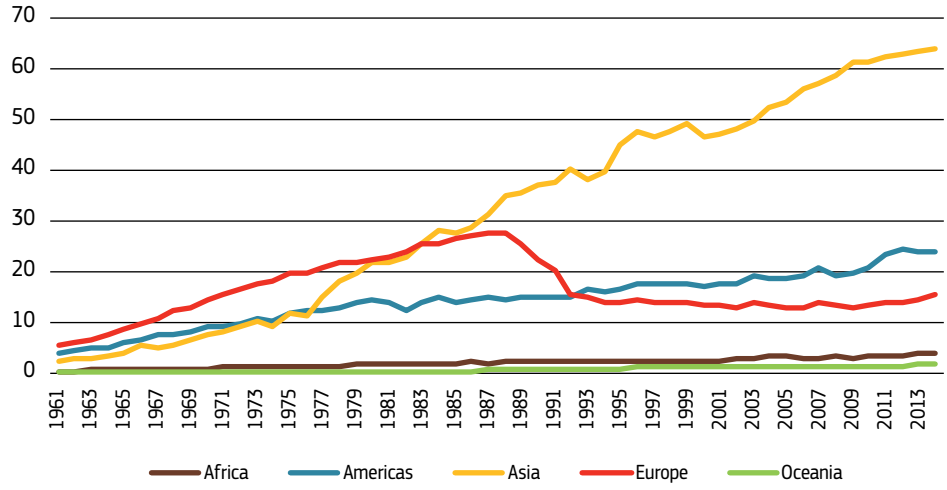
For the past decade, the Commission and many EU member states have recognised the gravity of the waste problem; but progress has been slow. In 2020, the Commission updated its Circular Economy Action Plan[126] to, among other things, end "the linear pattern of 'take-make-use-dispose.'" It said it plans legislation to require products be sustainable, and expand its earlier "Ecodesign" rules beyond energy-efficiency to include "the broadest possible range of products." It plans to establish a "right to repair", so spare parts and upgrade services are possible; no more built-in obsolescence in smartphones, for instance. The agenda is ambitious, and there is no way of telling yet whether it will be any more politically palatable than its prior efforts on

behalf of a circular economy. But it is encouraging that action is also spreading to the member states. In the Netherlands, the biggest per capita waste producer in the EU, the government aims to reduce natural resource consumption in its economy by 50% by 2030, and achieve a fully circular economy by 2050. Some companies are also trying. Retailer IKEA has said it aims to become a circular business by 2030.[127]

Obviously, retooling the global economy is a tall order, with many obstacles. And, though the Commission is developing new indicators, we still cannot consistently measure what we mean by circularity; so it is hard to say whether we are doing well or not. Circularity is more of a principle than a prescription. And then, achieving circularity in biomass does not necessarily mean we have achieved sustainability. Natural cycles are, by definition, sustainable. Our industrial food and agriculture system could be, but is not. We transport too much, too far, with too much energy. We leave too much waste behind. We must emulate nature in how we design, process and consume.

In nature, we rely on built-in cycles. Photosynthesis captures solar energy and transforms CO_2 into organic matter. Microorganisms in the soil turn dead organic matter into nutrients and make them available to plants. They also capture airborne nitrogen and fix it into plant roots. Plants feed animals. Animal waste becomes nutrients for plants, and part of the soil. And so the cycle turns. But industrial agriculture has disconnected us from these natural cycles. It takes from soil the biomass needed for the natural nutrients. It replaces missing nutrients with

Total nitrogenous fertilizer consumption, in tonnes per year (1961-2014)



Source: Food and Agriculture Organisation, "Our World in Data" https://ourworldindata.org/fertilizers

synthetic fertilisers. In 2017, farmers used 11.6 million tonnes of nitrogen fertiliser in the EU, up 8% since 2007. Use of phosphorous fertiliser – most of it based on minerals imported from Morocco – fell 9% in that same period, to 1.3 million tonnes. Yet, up or down, only a fraction of these chemicals actually stay in the soil for use by plants; much leaks into groundwater, polluting rivers and lakes. One measure: The average nitrate concentration in EU groundwater was 18.3 milligrammes per litre in 2015 – with peaks of 42.7 in Cyprus, 29.4 in Bulgaria and 28 in Belgium.[128]

Of course, it is not fair to blame individual farmers for this; they are also economic actors, following market demand to support an increasingly difficult rural lifestyle. To meet that demand, we use synthetic nutrients to pack higher-yielding crops and more animals into tight spaces – a kind of time-and-motion, mass manufacturing, 20th century approach to farming. Further, as consumers, we have come to expect a certain uniformity in our food: wheat flour from one package to another is supposed to look and be the same, and that necessity leads farmers to choose standardised fertilisers and methods with predictable results. These practices are part of the Green Revolution that so effectively tackled starvation in many parts of the world. But there are consequences. It reduces biodiversity, as the farm system moves to more efficient crop monocultures and intensive animal farming: less pasturage, more feedlots. It increases our imports of some resources, such as soybean from the US and South America to feed our animals; in 2016, the EU imported nearly 14 million tonnes of soybean oil. It stimulates demand for nearly 400,000 tonnes (in 2017) of pesticides, a multinational market. And it raises the risk of antimicrobial resistance, as many farmers use the drugs to prevent disease. Incredibly, about half of all the antibiotics deemed medically important for human health is actually used for livestock in most countries of the world; and in the US, the proportion rises to 70%.

AGROECOLOGY AND INNOVATION

A better approach, many experts now say, is "agroecology." There are many definitions[129] of this term, but it basically means wisely and deliberately taking advantage of nature's synergies. It means thinking about the complex interactions between humans and nature, about waste cycles, about conserving resources, about maintaining soil and animal health, about preserving biodiversity – and applying this knowledge to the way we farm. For instance, one application of this holistic thinking is "regenerative agriculture," which focuses on improving soil health naturally. With this method, there can be less tillage – hoeing and digging up the soil. With less disturbance of the soil, there can be less soil erosion and water runoff and more CO_2 captured naturally. Rather than using so much fertiliser, farmers pay more attention to rotating crops, organic fertilisers, crop cover and clever combinations of plants. For instance, lupines, a type of legume, can be planted between crop cycles to help the soil recover – and they, in turn, can be used to make plant-based yoghurt or other dairy substitutes. This is not without cost, of course. These practices are generally more labour-intensive, and require greater knowledge on the farm. For instance, using manure for fertiliser is not as simple as it might sound: for best use,

farmers need the right mix and concentrations of different kinds of animal waste. Could new, natural synergies between neighbouring farms help? What about new ways to time plantings of different species? What indicators can we devise, to measure progress? There is a vast untapped potential in agroecology; understanding and benefitting from it is the role of research.

> "**Agroecology** ... studies how different components of the agroecosystem interact. As a set of practices, it seeks sustainable farming systems that optimize and stabilize yields. As a social movement, it pursues multifunctional roles for agriculture, promotes social justice, nurtures identity and culture, and strengthens the economic viability of rural areas. Family farmers are the people who hold the tools for practising Agroecology. They are the real keepers of the knowledge and wisdom needed for this agenda. Therefore, family farmers around the world are the keys elements for producing food in an agroecological way."
>
> -Food and Agriculture Organisation, "Agroecology and Family Farming."

Better livestock management is also crucial. It matters for the climate, as the sector emits 7.1 billion tonnes of CO_2 equivalent a year, or 14.5% of all human-induced emissions.[130] Of that, beef cattle account for 41% of the emissions, and milk production 19%. And of the livestock emissions, nearly half comes from producing and processing animal feed, and nearly two-fifths come from the nature of ruminants' complex stomachs, as they digest the feed. Indeed, this kind of enteric fermentation is the largest single source of methane – a potent greenhouse gas – in the EU. There are plenty of solutions – the most obvious being a change in how and how much we engage in intensive livestock farming. Beyond that, research suggests that a key to circularity would be integrating the management of animals and crops on the land – mixing the right kind of crops with the right types of animal, rotating feed crops so imports can be reduced, or grazing livestock or poultry in orchards, vineyards or rice fields. Much progress is possible simply by studying, and thinking through, how we raise our animals.

Other solutions could come from new, under-used, yet more diverse food sources – but each of these has difficulties to overcome. Interest is growing for instance, in technologies to convert algae into food and feed. But, to be sustainable, it would have to be grown in areas that aren't ecologically sensitive; that could require more transport over long distances across Europe. Another much-discussed idea: Raising insects for food or feed. That requires just the right conditions: keeping them in farm buildings, heating the buildings, and providing proper care[131]. Plant-based meat, as mentioned earlier, is also increasingly popular; but many of the types available today are based on soybean, not a typical European crop. Some types also depend on an energy-intensive process – though research on which processes and products are 'greenest' is moving fast: one 2020 German study found certain soya-based meat substitutes produce as little as a tenth the greenhouse gases as beef production.[132] And some research is expanding to include citizens and consumers: again in Germany, the "1000 Gardens" project enlisted home

gardeners in developing and measuring new soy cultivars.[133] Meanwhile, in northern Denmark some are experimenting with mixing sea-based proteins – seaweed, mussels, starfish – into feed and food sources; it is technically difficult to make the machinery flexible enough to handle all the possible combinations. None of this is to say new food sources will not help. Rather, the point is that to contribute to sustainability and circularity, they will need much more research.

Information technology can help in many ways. It can boost efficiency, reduce waste and track the flow of feed and food more effectively. In-the-field and animal-borne sensors and decision-making aids can help farmers manage their crops and livestock. Blockchain and other tracking technologies can monitor food transport, avoiding waste and helping verify the origin of food. Data tools can help consumers choose foods more nutritiously, and with less waste. And 3D printing could be used to produce new foods from biomass where it is needed, when it is needed. All of this requires more data. Many of these ideas are already being experimented with across the EU. From this, we can imagine a time when how we eat depends on what we know, and what data tools we have access to. And that, of course, puts pressure on our governments to avoid new digital divides, privileging one group over another.

Biology and chemistry also matter. Like oil refineries, biorefineries are already in operation around the EU; but more research could find a way to make it economical for them to process more food and agricultural waste. New processes can filter proteins from the wastewater of breweries, combine multiple waste streams, convert waste CO_2 to new uses. Within the next five years, we expect to see more technologies commercialised to make liquid food from bioenergy and CO_2, new plastics from CO_2, and decarbonised cement. But biorefineries have long suffered from an often-dicey economic position – trying to perfect new processes under fast-changing market conditions, and subject to the whims of market or regulatory demand. Meanwhile, food packaging is being improved by dropping plastic for new biodegradable or recyclable biopolymers. And, for food safety, new antimicrobials are being developed – for instance, using natural bacterial toxins to attack other, more harmful bacteria. And researchers are working on "active packaging", incorporating natural antimicrobials into the food packaging.

Wood from the forest is of special interest in a circular economy: you can cut it or shape it, but it still retains many of its structural properties through a long cascade of uses. The first use is often to build or furnish homes, and there it can be in service for decades. Then it can be reconstituted into panels, recovered to produce the interior core of industrial furniture, pallets or other short-life products. Finally it can be burnt for energy. This long cycle, if optimised through research, could extend carbon storage, helping mitigate climate change – or at least reducing the climate impact of cutting the trees in the first place.[134]

What can drive change?

Getting to a circular economy in food and agriculture will be difficult. Here are some key measures that could speed that transition along.

1. The principles of **circularity, cascading and carrying capacity** should be applied to the whole bioeconomy systems, from production to consumption.

2. Closing cycles and "zero-waste" are principles: to make them real necessitates **long-term vision and persistence**, by a whole system of actors.

3. To foster circularity, **agroecology and bioeconomy strategies need to be aligned**. Many policy areas are involved – economy, health, work and wages, digitalisation, fiscal - not only agricultural policy. This necessitates an emphasis on **policy coherence**.

4. The transition can be driven by **recent developments**. Because of the pandemic, all citizens – including producers, processors, retailers and consumers – became more aware that food and food chains are important and **vulnerable**. Behavioural changes are already ongoing.

5. **Recent EU policies and strategies** on Circular Economy, the Green Deal and the "Farm to Fork" Strategy are supporting circularity but need time to be realised.

6. Making the bioeconomy circular necessitates that **different supply chains connect with one another**, particularly at **regional** scale. A critical policy lever is **support to networks** of enterprises and of a variety of stakeholders through physical and information infrastructures.

7. Retailers play a large role in a circular system and need to provide fair prices. **Fair prices in all parts of the chain** are necessary. **True cost accounting** (externalities due to waste, extended producer responsibility, environmental impact of transport, infrastructures and more) through new fiscal policies would also give a signal to entrepreneurs that they should engage in more circular models.

8. Making the bioeconomy more circular will be profitable in the longer run, but could be faced with the barrier of high **investment cost**. Specific public support to overcome investment costs can be designed, such as fiscal instruments and subsidies for access to credit.

9. **Information** and traceability are key levers for the circular economy to become real.

OVERCOMING THE BARRIERS

So possibilities abound, if we want to achieve a sustainable, circular economy. But there are good reasons why things are the way they are.

One barrier is, well, barriers: the brick and mortar of how and where we build our factories and food distribution systems. To make circularity work, it would be better to link infrastructure together, and organise supply chains in "industrial symbiosis" networks. For example, using waste heat for district heating systems works best when the plant is close to the customers, minimising heat loss and the cost of pipes and insulation. The same principle applies to biomass processing. In general, local and regional strategies will work better than global policies. It is easier for a county or municipal government to see and manage opportunities for circular production, first-hand; national or EU policies can only set the general direction of travel, not dictate the roads and speeds taken.

Transport pricing is another problem. At present, our food moves across the EU and the world based largely on the lowest-cost route, with intense price competition. This comes with heavy environmental and social costs, not factored into the sticker prices of transport; they are "externalities". This problem of unaccounted-for externalities runs right through the entire food chain, starting with farmers. Small and medium-sized growers are the weakest in the power game for revenue. Mega-farms, big distributors and multinational retailers have a firmer grasp on pricing in the market – and today's globalised food markets do not reward such goals as ensuring a liveable wage for small farmers, a sustainable use of land and resources, or affordable food for the poorest in society. Correcting these flawed pricing signals and power imbalances is necessary.

There are several possible ways to overcome these and other barriers – and as indicated above, in Europe and beyond many positive steps have been taken already. In a review[135] of 11 major countries, the Organisation for Economic Cooperation and Development found bans or taxes on landfill increasingly common, as a way to promote recycling and recovery. All 11 have made producers at least partly responsible for what happens to certain packaging or other waste – though the agency notes there are gaps in enforcement and other problems with implementation. Many promote "green" public procurement. In Germany, agriculture policies go beyond farm size in calculating subsidies; they also favour farms that provide environmental services and protection. And the Commission's Green Deal, if fully pursued, is likely to put pressure on all member states to up their game in these and other areas.

But real action will require change by all. A farmer of the circular, sustainable future will need new skills from the digital world, as well as broader knowledge of marketing, consumer behaviour, and resource management. Already, a common saying in modern agriculture is that money today is earned in the office, not in the field. But there will be real costs of making feed and food supply chains more circular, and farmers large and small will need assistance. In the

longer term, a truly circular economy should operate more efficiently, at lower cost; but in the short term, there will be high investment costs for which some form of public assistance may be needed. Work will also be needed on burnishing the image of farmers with an increasingly urban population, so they are seen not as obstacles but as leaders for green conversion. This is not a task for individuals: collaboration will be needed – in cooperatives, associations, social media and other networks. A new societal alliance between city and country, large and small, is needed.

Start-up culture in the circular economy

Across the Europe, a vibrant world of start-up companies has appeared to find new business models that hope to promote circular practices and make money.

Beyond Coffee – Here is a fun fact to consider over your morning coffee: you are really using only the barest of aromas from all those beans. Just 0.2% of the grounds goes into the brew; the rest goes into the bin. A Danish start-up, Beyond Coffee, wants to change that. From unwanted grounds, it grows white oyster mushrooms for sale in its Copenhagen shop. And online it sells small Gro-Kits, at DKK 175 apiece, so you can do it at home. And to drink the greener coffee, it re-sells online a cup made from old coffee grounds by another start-up, Berlin-based Kaffeefarm. It smells of coffee before you have even made it.

Karma – Next time you leave a restaurant, think a moment about all the food still unserved in the kitchen and likely to be tossed at the end of the day. A Swedish start-up, Karma, launched an app in 2016 to do something about that. With it, you can find still-good but surplus food from participating restaurants and grocery stores, and pick it up as take-away at half price. It says its app has 500,000 users in Sweden, with 2,000 merchants. It recently started operating in London and Paris, and claims to have rescued 295 tonnes of food to date. Nor is Karma the only such no-waste app: Too Good to Go, based in Copenhagen, claims 22.4 million downloads of its app, saving 39.4 million meals in 15 countries.

Kipster – A Dutch firm, Kipster, is practising what it calls "closed-loop" chicken farming: Feed the birds on recycled foodstuffs from bakeries and elsewhere. It says its feed is 97% leftover materials, supplemented with minerals and vitamins. It sells its eggs to local branches of Lidl, a major low-price food retailer, in boxes made from potato starch and other waste. Through that and other green practices, it claims to be the first carbon-neutral chicken farm in the world.

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BIGH – Alongside the old canal in Brussels, a start-up recently opened a big greenhouse on the roof of an old abbatoir. The company, BIGH – short for Building Integrated GreenHouses – wants to develop and operate urban farms "integrated to buildings using sustainable materials and resources in the spirit of circular economy." It uses solar energy, and heat from the pumps of refrigerators in the city food markets in the building below. It collects rainwater (of which there is plenty in Brussels). It aims to produce 15 tonnes of tomatoes a year, 2,700 potted herbs and 35 tonnes of fish, plus greens, for sale to retailers, restaurants and others. And its ambition is to develop a network of similar urban farms across Europe.

Industry must also change. Food processors, for instance, can optimise their factories to minimise energy and water use. One small example: cleaning up. Washing and disinfecting the machinery, floors and other parts of a food factory is an important daily and weekly cycle; doing it smarter can save money and reduce environmental impact. Packing for what they produce can be made more often of biodegradable or recyclable materials (expanding government restrictions on plastics are already forcing the industry in this direction.) And then there is how they handle "side-streams" of production. Their processes often include purifying and fractioning sugars, proteins and starches - but that leaves lots of unwanted waste. How to make better use of those? Another industry segment, producing flavours and specialised food ingredients, can also help. It already has some of the technology to make greater use of leftover fruits, wood, grass and other materials from the process industry. These technologies need support and collaborative action to become business models in a circular economy.

But the most important link in the chain of action is citizens. A growing number of consumers are willing to reduce food waste, but are trapped in their lifestyles – their habits of work, play, and food preparation, whether in city or country. The COVID-19 crisis provided the most dramatic behavioural test of behaviour in generations. Suddenly, all the old patterns of business or private life were upended. People became more aware of what and how they ate. More families cooked together, using what was left in the cupboard. Frugality became, ever so briefly, a virtue. From the narrow view of waste management, the results were confusing: as supply-chain disruptions spread, some extra foods were left in the field, warehouse or shuttered restaurant, while others appeared to be in short supply in the supermarkets. At the same time, the plunge in economic activity altered patterns of consumption and production across the EU. It also disrupted some food trade patterns – opening the question of whether, in a post-COVID world in which self-sustainability seems more important, better recycling could help reduce import dependence. Of course, an enforced, emergency change in behaviour like COVID-19 is not the same thing as one planned and nudged along by enlightened policy. But analysing just what happened to food waste during the crisis will be an important research topic, as we try to devise more effective policies for circularity.

Key questions

- How can a sustainable, circular bioeconomy produce more nutritious food while reducing its impact on nature?
- How can we re-organise the process cycles in the food and agriculture systems to move from linear to circular economy?
- How to apply agroecological thinking and practices in the food system – involving farmers, distributors, consumers and all others?
- What business models would give farmers a fair remuneration of their work in a sustainable bioeconomy?
- What spatial and organizational patterns should be established between farms and industrial enterprises to foster circularity?
- Can we find new ways of processing organic output, and make better use of forest, ocean and other resources?
- How to improve the efficiency and flexibility of biorefineries, and integrate them better into local economies?
- How can new digital tools improve supply-chain management and increase circularity?
- How to improve the calculation of externalised costs such as transport or social harm and their incorporation into business practices?
- How to encourage – and, more important, scale up – innovative companies willing to try new business models?

To consistently guide consumer choice, information will be important. As mentioned earlier, better systems for gathering and presenting data about the origins and handling of food would help steer people towards more sustainable, low-waste options. For instance, an Italian start-up, Mercato Circolare, has developed a free smartphone app that helps people search for circular economy products, services and events.[136] More-extensive labelling, on retail shelves, will also help – as will a growing number of public-information campaigns. Some food discounters, for instance, already see potential profit in promoting "ugly apples" to their customers: good for the environment, good for the pocketbook. And as our cities grow, the importance of getting more

people to recycle will also grow. Just a few per cent of our organic waste streams today are actually used – and are often polluted by plastic and other materials that cannot be recycled. This is partly a technological problem: How to separate these types of waste more efficiently? But it is also a social and political problem: how to get people to be more aware, not just of what they eat, but of what happens to their food before and after they have it?

None of this is about patronising consumers, farmers or anybody else in the food chain. Change is a complex process, requiring, in the EU alone, about half a billion individual decisions. These decisions, if we want a circular economy for food, must lead to a system that is sustainable and flexible. They must promote diversity on farms, in companies and in social organisation. They must win the support of consumers, reward companies that are first-movers and innovators, favour experimentation, and combine knowledge from all parties. And somehow – through regulation, education, taxation, subsidy or other means – our current market system's fixation on low cost and high quantity must change. We must make room for higher quality, and a fairer distribution of costs. Finding this magic policy mix will no doubt take years of experimentation. So research must accelerate.

CHAPTER VI: TOWARDS GREATER DIVERSITY

"By felling the trees which cover the tops and sides of mountains, men in all climates seem to bring upon future generations two calamities at once; want of fuel and a scarcity of water."
Alexander von Humboldt[137]

In 1799, a young German naturalist landed in Venezuela to begin a series of scientific expeditions that would start changing the way people viewed the world. Rather than a collection of individual species and specimens, the picture that Alexander von Humboldt had in his mind was of everything in nature interconnected and interdependent – a *Naturgemälde* that also included humanity and its often-destructive effect on the world around.[138]

This view, espoused by researchers from Humboldt and Darwin onward, now predominates: the world is an interconnected system of people and nature, environment and society. We have seen it in the past few generations in the rise of environmentalism, in Earth Day 1970, in the 1987 Montreal Protocol on ozone depletion, in the 2015 Paris Climate Accord and in more recent Extinction Rebellion protests. We have seen it most dramatically in 2020, with the advent of a crushing pandemic that arose from an unlucky and deadly interaction among virus, animals and humans. We have started to think through how our urban v. rural, human v. natural, consumption v. conservation systems have harmed the planet and worsened social injustice. Together, some scholars refer to this holistic man-nature view as "socio-ecological systems".[139] They emphasise humans as part of nature, view any line between man and nature as purely artificial, and study the way the two interact, feed back to each other, display both resilience and complexity. In this view, with our industry, commerce and cities, we are damaging the planet and ourselves. But also in this view, the world is a dynamic and hopeful system. We can change it, and ourselves, for the better.

Key to such change, however, is that we recognise the importance of a particular aspect of this system: diversity – not just in nature, but also in society. Diversity helps make a system resilient. A loss of one resource may be at least partially compensated by another. A shortage here can be mitigated by a surplus there. People or organisations can be complementary with one another, not just in competition. There can be a diversity of experience and skills. A toolbox of hammers is of little use; a toolbox with a diversity of tools gets the job done.

Diversity provides options – or as the influential Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) put it in 2019: "The diversity of nature maintains humanity's ability to choose alternatives in the face of an uncertain future."[140] Indeed, if we ever

needed a proof of diversity's value it has been the COVID-19 crisis. We saw diversity in the way different peoples, age groups and communities reacted to the disease; had we all gotten sick in the same – bad – way, the impact would have been even worse. Now, there is a call for local greater self-sufficiency and diversity, less globalization and uniformity. One writer, in *Foreign Policy* journal, forecast "a dramatic new stage in global capitalism, in which supply chains are brought closer to home and filled with redundancies to protect against future disruption."[141]

Diversity could have other benefits. In society it promotes creativity, helping us find solutions to difficult problems. Social diversity is a vital safety-valve when faced with mounting economic, societal or natural pressures. A society that is mostly poor or urban, or one dominated by white men or wealthy *rentiers*, is not stable. An economy that is heavily cyclical, with synchronous rises and falls in production by a few major industries, is not sustainable. One well-known study of American cities in the 1930s found economic diversity essential: "As a rule, since no two businesses have exactly the same seasonal and cyclical swings, the more types of production and trade are represented the more stable will be that community's business."[142] It is a fact so obvious we forget it: diversity counts.

Diversity also matters in food and agriculture. A varied and balanced diet, a wide range of crops and foodstuffs, a diverse system of production and distribution – all these together make a more resilient, stable and healthier food system. According to a large and growing body of research, a diverse farm system – household plots, mixed multi-crop farms, variety in farm type and size – does indeed enhance the availability and consumption of diverse foods needed for a healthy diet.[143] For farmers, while the most visible post-war trend in Europe is consolidation and specialisation, diversification is also needed to weather storms, economic or natural; it is a form of self-insurance. And diversity in food culture matters: those communities that retain their traditional knowledge of what and how to grow are better at preserving their local crop and livestock varieties, research shows – and, in fact, when people reintroduce traditional crop varieties the old knowledge comes back into practice.[144]

Of course, diversity has costs as well as benefits. Standardisation, economies of scale, international trade, "massification" – all have appeal if the aim is lower cost and economic growth. We have, for most of the past few generations, seen unparalleled gains in prosperity, education and health – even if it has been distributed with gross unfairness. But we have lost much: social solidarity, a clean environment, a world safe for diversity, to name a few. How to have our cake and eat it – to be prosperous, safe, healthy, fair and ecologically sound – is the challenge of the 21st century.

THE STATE OF AFFAIRS

So far this century, however, we have turned diversity – in both food systems and the planet generally – into an endangered species. In 2019, the IPBES report drew world-wide attention to

the fact that biodiversity "is declining faster than at any time in human history."[145] It reported that since the 16th century 680 vertebrate species had become extinct, and that by 2016 about 9% of all domesticated breeds of mammal used for food or agriculture had vanished. In all, around 1 million species of plant and animal face extinction, with devasting consequences. Meanwhile, our exploitation of the endangered biosphere has soared: since 1970, the value of crop production has risen three-fold to $2.6 trillion in 2016; and we have altered 75% of the land surface for our own uses. The IPBES chair, Sir Robert Watson, said: "The health of ecosystems on which we and all other species depend is deteriorating more rapidly than ever. We are eroding the very foundations of our economies, livelihoods, food security, health and quality of life worldwide."[146]

A torrent of new expert reports in just the past year or two have reinforced the message. The UN's Food and Agriculture Organisation reported that "nearly a third of fish stocks are overfished and a third of freshwater fish species assessed are considered threatened."[147] The biomass of insects has fallen by 75% over the past 30 years[148], while that of farmland birds has fallen 30% in 15 years.[149] The diversity of what we eat is poor: there are more than 14,000 edible plant species available to us, yet we generally use only 150 to 200 of them; and three – rice, maize and wheat – supply 60% of our calories.[150]

These trends are mirrored by growing concentration and shrinking diversity in our food and agriculture supply chain. Also in 2019, the International Panel of Experts on Sustainable Food Systems (IPES FOOD)[151] reported "major power imbalances." It said 70% of the world agrochemical industry is controlled by just three companies. Nearly 90% of the grain trade is run by four companies. And in 2011, it said, the five biggest retailers controlled more than 60% of the food market in 13 EU member states. Those alarming figures, the group argued, have restrained increases in food prices – good in some respects, of course – at the cost of reduced diversity in supply and ever-harder conditions for farmers. From 1995 to 2018, it said, the share of food value going to growers dropped from 31% to 21%; the power of processors, distributors and retailers has risen. The bottom line: in just one decade, from 2003 to 2013, "more than one in four farms disappeared from the European landscape."

Why is this happening? If the problem is so obvious, what blocks us from fixing it?

The agri-food system is complex – a global chain of supply and demand, distorted by politics and people, and embedded in the environment. Retailing and distribution gets concentrated in part because it is more efficient, and profitable, that way. Consumers often want food they consider tasty, which for many means starchy and processed – so industry provides it. Consumers want cheaper food, and that often goes with high volume and big companies. These market pressures go right up the food chain: big farms merge, buy out smaller farms, and specialise on whatever they judge to be high-volume, high-demand and high-profit plants and animals. Pastoral romance aside, farms are businesses. They follow the market. At the same time, the supply of arable land is tightening as farms (and cities) expand. And the booming international trade in

food and farm products adds an unprecedented new dimension to this economic story: a farmer in Hungary or Denmark is now competing not just with farmers at home or even in neighbouring countries, but also with farmers in the US, Argentina, Australia and elsewhere. And the growing demand of consumers in China, India and elsewhere further shuffles the trade dynamics.

Economics explain part of the problem, but there are other barriers at work. Governments in most parts of the world subsidise the farm sector, further skewing market dynamics towards bigger, specialised producers. At the same time, the agricultural industry is very slow to change. Farms lag most other industries in uptake of digital technologies, in part because broadband and wireless access is limited in many rural areas. And to change farming methods or crop choices is a slow affair – affecting land use, fertilisation and pest control, harvest and storage, transport and sale. In general, one should count on seven years to transform an entire supply chain. And change is expensive. Environmental innovation on the farm entails big, up-front investment. That requires finance, and banks are not cheap; the performance measures the banks require may actually discourage the very innovations a green, organic farmer might want. Innovation also requires time-consuming collaboration – with experts, government support, suppliers and other farmers. So even if we had all the answers for a more sustainable, diverse food supply, we would not be able to apply them as quickly as we might like.

Research result: On the farm, crop yield and biodiversity can work together

One way to manage farms is through ecological approaches. What means is letting a small part of each field go wild, attracting native plants, insects and birds. And, research shows, it works – for both farm and nature.

In the UK, researchers tried three approaches. One was business as usual – no change to the field, devoted entirely to crops. Another, ELS for Entry Level Scheme, removed 3% of the cropland from production; this approach is often subsidised by governments. A third approach, Entry Level Scheme Extra or ELSX, set aside 8% of the land. The results were dramatic. As the charts show, leaving more land wild helped bees and suppressed other pests – and at the same time boosted yields on the cultivated land. This is just one study, but it demonstrates that ecological approaches, when both nature and people win, can work in real situations.

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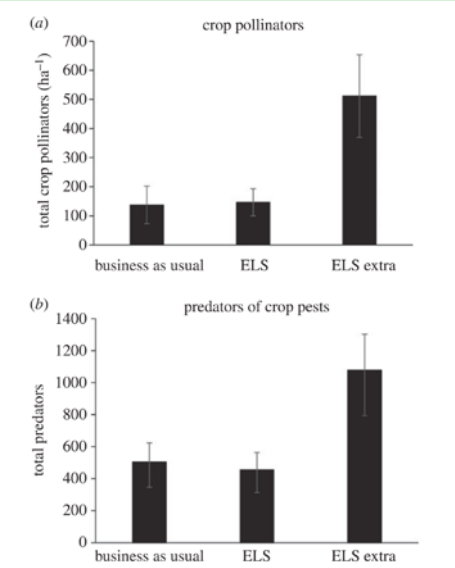

Figure 6. Mean (± s.e.) abundance of (*a*) oilseed rape and field bean pollinators (*Apis mellifera* and *Bombus* sp.) per hectare in each treatment between 2007 and 2010 and (*b*) predatory Carabid beetles recorded in each treatment in 2008.

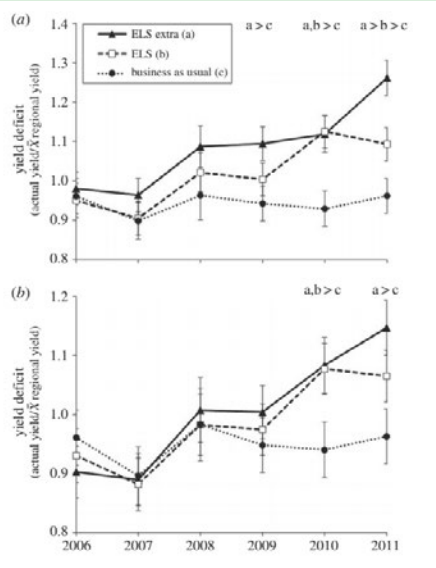

Figure 5. Trends in crop yield (mean ± s.e.) as a ratio of regional and national yields averaged for all crops (wheat, oilseed rape and field beans) for (*a*) cropped area and (*b*) whole field net of land removed for wildlife habitat creation. Treatments with a different letter are significantly different ($p < 0.05$).

Source: Pywell RF, Heard MS, Woodcock BA, Hinsley S, Ridding L, Nowakowski M, Bullock JM. 2015. Wildlife friendly farming increases crop yield: evidence for ecological intensification. Proc. R. Soc. B 282: 20151740. http://dx.doi.org/10.1098/rspb.2015.1740

CHANGING THE GAME

So how to make change happen? The first step is breaking down the silos between different disciplines and sectors in the food chain, starting from agricultural production. If, like Humboldt and his successors, we believe that nature and mankind are one interlinked picture, then we must research, implement and promote a socio-ecological view of the world and our place in it. A single measure, such as introducing subsidies for organic or traditional farming to encourage greater crop diversity, would not work on its own; it could affect food supply, prices and safety in ways we do not intend. A more holistic approach has been advocated, and tried out, in several domains.[152] For instance, to support diversity on the land, the emerging idea of agroforestry encourages farmers to integrate trees or shrubs into their fields or pastures. To support small farms and diverse crops, we can encourage tourism to the countryside; country rambles and pick-your-own require a variegated landscape. And to improve diets and sustainability at once, research on

nutrition-sensitive agriculture is ongoing, linking choices about what is grown back to the varied diets that people need. [153] There is no shortage of ideas for change on the farm. But to make them work, there must also be change further down the supply chain – through distributors, processors, retailers and consumers who find value in the resulting foods, region by region.

As in other aspects of food and agriculture, so in diversity, digital technologies are transformative. They can monitor: new sensors, data, analytics and networking can guide us towards which strategies are working and which are not, how quickly the problem is growing or receding, and whether the biodiversity indicators we use today are fit for the long run.[154] They can steer, and stimulate, private investment towards the most effective solutions. They can make people more aware of the diversity problem, through citizen-science platforms. For instance, today with the Global Biodiversity Information Facility,[155] a database of more than 1.5 billion observations of species, a scientist or amateur can check where to find dullgreen spleenwort (in the Vila Velha State Park, near Ponta Grossa, Brazil) or Australian stick-nest rats (on the Rawlinna Nullarbor Plain, in Western Australia.) A popular smartphone app, Pl@ntnet,[156] lets nature-lovers take a picture of a plant or tree, upload it to a pattern-matching database, and get a rapid identification of the species, with background information. Apps like this can turn thousands of people into amateur naturalists – and build a scientific database of biodiversity. And, of course, on the farm digital technologies to promote diversity will be essential; and it can boost yield by improving pest control, pollination, water retention and erosion control. "Smart farming" gathers data about a field or herd to support decisions about planting, pesticides, fertilisers and harvesting – at the micro-level needed to make diversity financially sustainable.

What can drive change?

Restoring biodiversity to safer, healthier levels will be difficult. Here are some key measures that could speed that transition along.

1. Protecting biodiversity through **biodiversity conservation policies** or **voluntary business commitments** can help ensure biodiversity in agricultural landscapes.

2. **Knowledge-intensive innovation** (including in digital and genomic technologies) is critical for diversification and will necessitate better understanding of the ecological functioning of agricultural systems.

3. **Promoting the production of ecosystem services** and stressing their role as sources of well-being can give value to more diversity in farms and agricultural landscapes.

4. In order to enable farmers to **invest in on-farm diversification** of products and services, it is necessary to build **more diverse supply chains and markets**.

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5. Strategies based on massification, specialisation and economies of scale should be progressively replaced by **business strategies based on diversity and economies of scope. Environmental policies (regulations and norms, fiscal incentives)** are necessary to ensure that larger food processing companies can consider this **a credible option**.

6. There is an **upfront cost of investing in redundancies** necessary for more resilience. Public support will play a key role for such **investments that reduce vulnerability and risk**, and they could be developed as **an insurance scheme**.

7. The possibility for **companies to become "mission led"**, which means to add to their economic profitability goal a social and environmental goal at the same level of priority, can be critical for these companies to engage in a diversification pathway.

8. Citizens as consumer are key to this transition. Education, information and enabling food environments should be coordinated to raise awareness about the link between sustainability and food diversity.

The impact of biotechnology could be greatest of all. Gene editing can produce new plant strains more resistant to drought or pests – and indeed, is already doing so. Some have already used it to bulk up the nutritional value of oilseeds, by adding the ability for the plants to make omega-3 fatty acids. Others have been studying and reproducing plant microbiomes – the community of microbes associated with a particular plant. For instance, Indigo Agriculture,[157] a Boston-based company, is selling cotton seeds coated with the microbiome of cotton varieties that are naturally drought-resistant – and thereby claims to boost yields by 11% to 15%. Still others suggest developing new feed for animals: replacing just 2% of normal feed with an engineered microbial protein could save on greenhouse gases by 5%.[158] And there are applications of gene editing that border on science fiction – but are quite possible. We can sequence the DNA of plants or animals from museums or archeological sites. And we have the tools to restore vanished species, reversing today's decline in biodiversity – or, as one researcher put it: "De-extinction has become a serious prospect."[159]

But, for good reason, these new biotechnology applications are controversial. Lots can go wrong. Gene-edited plants, introduced into the wild, could have unpredictable effects on other species – and, for the companies that develop them, increase their market power in undesirable ways. The engineered oilseeds, some research suggests, can harm butterfly larvae.[160] The microbiome engineering could affect other plants nearby. Making microbial proteins for feed could consume much energy. And of course, when it comes to recreating lost species, *Jurassic Park* fears are embedded in our popular culture. So far, EU policy treats these technologies with extreme caution, banning release in the wild. In Europe, the public has long been suspicious of any gene technologies in food or environment.[161] The advent of new, more-precise CRISPR gene-editing technologies is encouraging a re-examination[162]. However, breeding is much more than just genetic modification. The real issue us to develop breeding approaches for diversity and resilience, linking genotypes

to ecosystems. Promoting diverse systems with intercropping, crop mixtures or agroforestry or a better use of underutilised crops requires a different mindset in breeding.

From small seeds, biodiversity grows

Across Europe, hundreds of small experiments are underway – often by individuals or small groups. Here are a few notable initiatives.

'Bio-cultural' farming – In the Carpathian mountains of Romania, an interesting mix of local habitat and culture is adding diversity. There, some of the farmers are using traditional methods to cultivate a wide range of crops in what was formerly spruce forest. They manage small-scale hay meadows, cattle pastures, potato fields and other plots – in all, supporting 210 wild folk plant taxa, and more than 140 folk habitats. They use few chemicals and limited machinery. Their methods are locally developed – for instance, enriching the hay meadows by gathering hayseed in their barns, and then scattering it on the fields.

'Evolutionary participatory' farming – in Sicily, farmer Giuseppe Li Rosi is deliberately mixing wheat varieties to improve yields. He started with a mixture of 2,000 varieties and 750 crossings of soft wheat from Syria – 90 kilogrammes of seed in all. Now, he has some 60 hectares under cultivation. The result, supported by a Horizon 2020 project called Diversifood, is extraordinary resilience. Rosi likens the field to "a hard disk. It can keep the memory of every single event, transferring it from generation to generation. Thanks to its diversity, this wheat is able to fight pests."

Diversity lunches – In a small town in the Galician countryside, a school has put diverse and local food on the curriculum. Whereas many schools outsource lunches, the Xacinto Amigo Lera school develops its own menus of free-range meat, local fish, native fruits and vegetables. The deliverymen bring the produce right into the classrooms, and the children visit the local farms. They also get a monthly cooking class – usually making a seasonal fruit dessert. The aim: to be sure the next generation knows where and how their food arises, and the importance of a healthy, varied diet.

Another force for change is individual and corporate behavior, as in all aspects of food and agriculture sustainability. Apps, media, education, rural tourism, the influence of peer groups – all are important to get people to care more about diversity in nature and in their diets. And already, reflecting consumer support for biodiversity, there is a fast-growing movement among multinational companies. In 2013, a study identified five multinationals in Europe, including retailer IKEA and airline KLM, imposing biodiversity codes of conduct on their suppliers.[163] By 2018, 65 French companies had signed onto the Act4Nature initiative[164] to factor biodiversity into their business activities. In the pharma industry – for which unusual or remote organisms have long been a source of new medicines - Sanofi has started advising its site managers on preserving biodiversity locally.[165] And UK retailer Marks & Spencer has been trying to improve the sustainability of its supply chains in fish, wood and cotton, in particular. In 2015, it issued an internal biodiversity guide suggesting how its shops could, for instance, add "green walls" of varied climbing plants – which it costed from suppliers at £5 per plant and £30 a square metre for a wooden trellis to support them.[166] A trivial step? Perhaps. But its significance is in the recognition that growing numbers of its customers care about the issue enough that it could subliminally affect their shopping habits.

Key questions

- How to better understand the costs and benefits of diversity – in both nature and human society?
- How do our market system, and agrifood industrial structure, affect diversity in our food supply?
- How can diversity become a structuring principle of food systems?
- How to encourage social innovations, and on-the-farm experimentation, in new farming methods that can improve both biodiversity and productivity?
- How diversity can be mobilized to achieve more resilience?

Governments, too, have started pushing for biodiversity. The EU's new Green Deal is one of the most ambitious efforts to tackle sustainability issues, including biodiversity. In May 2020, the Commission took the next step with its "EU Biodiversity Strategy for 2030"[167] that promises, among other things, to expand the land and sea area legally protected for natural habitats – for instance, raising from 26% to 30% the land area with basic protection against development, and from 3% to 10% the land area with strict limits that leave "natural processes essentially undisturbed." At the same time, the strategy would take steps to restore some land and sea area already degraded, and through private and public means try to mobilise at least €20 billion

a year to spend on nature. As with all such Commission pronouncements, the programme sounds good – but its ability to deliver will depend on the willingness of member states to go along.

And on that score, there is some hope. In 2018, the French government adopted a Law for the Recovery of Biodiversity, Nature and Landscapes to incentivise landowners to create environmental protection zones on their properties.[168] Another example: The "4/1000" plan, another French initiative, to get farmers around the world to focus on land management habits that would increase the amount of carbon sequestered in soil. The name comes from the notion that if we can boost carbon stocks in the soil – part of the normal cycle of plant growth and death – by just 0.4% per year, we could make a major contribution to recapturing greenhouse gases and slowing climate change.

In the end, the right formula will be a mix of measures. We will need public and private action – government conservation policies, and voluntary business commitments. We will need innovations that arise through better understanding of farming and fishing as part of a human and natural ecosystem. We will need to create incentives, through tax or other means, to foster the development of new services that promote biodiversity. We need greater diversity built into food supply chains, so those farmers who invest in agroecology or other means have a ready channel to market. We need to invent a way to pay the up-front cost of new methods – for instance, with some form of insurance that is cheaper for diversified farms. And we will need to nudge big companies, through regulation or taxation, to favour diversity and economies of scope. It should not only be about scale, cost and standardization.

Of course, these kinds of initiatives are necessary – by national governments, municipalities, corporations, farmers and consumers. But progress is slow. In 2010, signatories to the international Convention on Biological Diversity set a series of ambitious targets – for instance, that by 2020 the rate of loss of all natural habitats is cut by at least half. Needless to say, it did not happen. And, it must be said, there would be something paradoxical in thinking we should achieve diversity by instituting unilateral, top-down orders from any supra-national, or even national, body. We will have to find some way to promote diversity through individual action – indeed, perhaps through market action guided by government. We are at a stage in our thinking – about climate, diversity, circularity, health – in which we must search for answers. That is the role of research.

CHAPTER VII: RESEARCH FOR REVOLUTION

> "And let it be noted that there is no more delicate matter to take in hand, nor more dangerous to conduct, nor more doubtful in its success, than to set up as a leader in the introduction of changes. For he who innovates will have for his enemies all those who are well off under the existing order of things, and only the lukewarm supporters in those who might be better off under the new. This lukewarm temper arises partly from the fear of adversaries who have the laws on their side and partly from the incredulity of mankind, who will never admit the merit of anything new, until they have seen it proved by the event".
>
> *Niccolò Machiavelli (1513) "Il Principe", VI, 5*[169]

The power, and peril, of mixing science and politics has been on full display during this year of COVID-19.

Across the globe, as the crisis worsened, learned doctors and epidemiologists suddenly found themselves in the spotlight, praised or pilloried online. Their models of viral spread were debated intensely. Their advice on whether to wear a mask or not was minutely parsed. And their rush to find vaccines and treatments was accorded the kind of breathless horse-race news coverage normally devoted to national elections or the World Cup. This faith in science may prove temporary; experts make easy scapegoats for decision-makers deflecting blame. Still, the change in attitude is striking: One UK survey in early May 2020, as the crisis worsened there, found 64 per cent of British voters said they were more likely than before to trust scientists.[170]

The episode also highlights the role of science in policy generally. Whether the issue is global warming, pollution measurement, cancer screening, or food safety, governments are accustomed to commissioning research in the hope it will make their decisions better or easier. In Washington, there has been a presidential science advisor in one form or another since World War II – a format now replicated from Auckland to Ottawa. In London, major ministries each have their own chief scientists. In many EU capitals, relations between researchers and policy makers have also been crucial for policy development, with specific mechanisms such as scientific advisory boards in government and policy units in research institutions; "evidence-based policy" is often the key phrase used to describe the outcome. In environmental and farm policy, agricultural research institutes have long played a key role in the design, evaluation and reform of public policies. In Brussels, the Joint Research Centre is the longest-standing source of scientific advice to the European Commission – but each policy branch of the Commission also contracts some of its policy research from academics and others outside the organisation; and

in 2015 a special Scientific Advice Mechanism was created to coordinate between the national academies and the Commission.

All this means there is no lack of scientific advice. But it is important not to forget that interactions among science, policy and society have long gone beyond a simple linear model of scientists providing "advice" to others; interaction with citizens, industry or others is also important. But to go forward now, what we need is a way to build common understanding on evidence and its policy implications, both within the scientific community and with society at large. We have seen some notable examples of this already. The UN's International Panel on Climate Change has had profound impact across the globe, influencing many inter-governmental agreements, and inspiring similarly constituted international expert panels in biodiversity, artificial intelligence and other fields. In food and agriculture, the link between science and policy dates back at least two centuries as researchers studied and helped implement better farming and food safety practices around the world. Science in a crisis is also important: one would wonder whether a stronger relation between policy and science would have avoided or mitigated the effects of the bovine spongiform encephalopathy scare that struck the beef industry[171], or Xylella bacterium killing olive and other plants in southern Europe.

But, as discussed earlier, more change is now needed in food and agriculture – no less than a revolution in the way we farm, fish and eat. Can research spark that revolution?

KNOWLEDGE IS POWER

Not surprisingly, scientists – political scientists – have an answer. It helps to think of the policy universe has having a "cognitive dimension", where knowledge feeds into the different steps of the policy process such as formulating the problem or devising policy options. Three domains of enquiry are particularly important here: framing, coherence, and evaluation.

Framing refers to the mental filters we use to make sense of the world. There is, in policy as in many fields, a tendency to be driven by the past – for political positions to get entrenched. New ideas come along, but often go nowhere. A common way to end the deadlock is to devise a new framework for thinking about the problem. For instance, consider the evolution of what we now call the bioeconomy.[172] It began in the last century in a technology to convert crops and other biomass into fuels, and quickly drew huge subsidies. It ran into trouble in the 2007-8 financial crisis, as food prices jumped and policy makers saw biofuels as worsening the problem. Then evidence mounted that biofuel production was not ecologically sustainable. A new framing of the idea, however, has worked – to think about it more broadly, going beyond farm and fuel and into many sectors, as a way to avoid waste, increase efficiency and promote a circular economy. Across the EU, new laws have facilitated this bioeconomy approach that would otherwise have stalled. Another reframing happened in climate change policy: the idea of "co-benefits" makes

costly climate-mitigation more palatable, suggesting mitigation can also have economic benefits such as improving energy efficiency or seeding job-creating cleantech companies.[173]

Frames and related narratives influence the choices we make. Social movements and policy makers are very aware of the importance of framing. Changing how something is framed, or questioning the implicit assumptions that underlie policies for example, is an important precursor for significant policy change. Framing is a way to mix new and old ideas into a new policy narrative. Changing the frame also allows for the inclusion of multiple perspectives which can offer alternatives to business-as-usual through asserting a greater diversity of (positioned) knowledge.

Coherence is about understanding how one set of policies affects another – and is an especially difficult issue in food and agriculture. The EU spends about €59 billion a year on its Common Agricultural Policy, supporting farmers and others. But, despite repeated efforts at reform, CAP continues to be criticised for undervaluing the environment.[174] Likewise EU trade policy sometimes conflicts with sustainability policy – for instance, securing major imports of soybean from the Americas and thereby encouraging those countries to worsen their own deforestation and greenhouse gas emissions.[175] And competition policy can conflict with the others, by focusing on consumer prices as a measure of market dominance; in fact, the most powerful agricultural groups and food distributors often have the lowest prices, and so their market power is seldom policed. For these kinds of cross-sectoral policy problems[176], research is essential to understand the problem, map the players and steps, and suggest ways to integrate the policies. A fresh look, with solid data, is helpful.

Evaluation also matters – that is, to gather data before, during and after a policy decision so one can judge its effectiveness. Is water quality improving? Is biodiversity coming back? Are farmers getting paid fair wages and are consumers eating healthier diets, with measurable consequences for public health budgets? Here research can help, for instance by further developing remote sensing technologies, data harmonisation, synthesis or dashboards that facilitate policy making. Moving from very slow, sporadic monitoring to day to day integrative monitoring on land use, farm wages and more can help. Governments often fail to do monitoring well. Political attention spans are often no longer than a term of office.

An idea is one thing. But getting action from it is another; for that, barriers must come down. Any policy – particularly a subsidy policy like CAP – develops a set of beneficiaries who block change; the system creates "lock-ins." After all, why would Hungarian wheat growers or Dutch dairy farmers advocate cuts in their own incomes?

There are several possible ways to break lock-ins – but as the French experience with pesticide regulation suggests, it is not simple. There, an agreement was reached in 2008 to cut pesticide use by half in 10 years. The public intervention programme was efficient in supporting local innovations: many farmers have, indeed, phased out or drastically reduced pesticide use. But it was not a success on a larger scale, to get the majority of farmers to think of deep pesticide

cuts as a credible option. By 2018, national pesticide use had actually risen by 12%[177]. The goal, cutting pesticide use by half, has been postponed to 2025.

A successful long-term approach, in this or other domains, requires that all affected recognise and discuss openly the trade-offs that will result – for instance, environmental benefit from less pesticide vs. higher costs or lower yields for farmers. The resulting laws must offer some benefits for all, around which a consensus can be built. A successful long-term strategy must also prepare for crises that could knock it off track, and consider how to handle them. Research is required at every step of the way. The Commission's new Green Deal is a good attempt at this kind of long-termism: Declaring clear targets to 2050, and a series of proposed laws and budgets that can provide many kinds of benefits, with consistent monitoring and periodic stock-taking along the way.

Another force for change can be "strategic niche management"[178]. That means creating policies that nurture little innovations – niches of hope, such as a cluster of farmers and processors trying out an innovative technology or method that could if successful be scaled up. Often, without benign policies or support, these innovations get crushed by the bigger economic or market forces already in play. There are already good examples of this. In organic farming, for instance, EU regulation supports a system of registering organic farmers, inspecting, and certifying their produce as organic. The aim: to give consumers confidence that whatever they buy labelled "organic" really is organic – and it has been a key step in helping this niche grow rapidly.[179] Another example: the EU's Protected Denominations of Origin[180] programme, under which specific foods and agricultural products – say, Kalamata olive oil from a region of Greece – is labelled and its branding protected, often by EU treaty with other nations. As this example suggests, regional action is especially important when protecting and nurturing strategic niches. Local or regional governments often have latitude to try new things that, later, become national or EU policy.

Experiments in policy

Research and innovation are already, in countless small experiments and initiatives across Europe, already pointing the way to new solutions for old policy problems.

Last Minute Market. At the University of Bologna, a research group in 1998 began studying food waste, focusing on otherwise good food near its expiry date or with packaging defects that would normally end up in the landfill. It organised local supermarkets, charities and others to get the food to those in need – but ran afoul of Italian food safety law. The happy ending: It lobbied to get an exception for such charitable activities, the "law of the Good Samaritan." The company now runs similar projects in other Italian regions.

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Community Seed Banks. Over the past 40 years, more than 100 mostly-local initiatives have sprung up to save, share and get informed about seeds. These Community Seed Banks come in all sizes and types: seed archives, libraries, networks, cooperatives – some founded and run by farmers, some academic or public sector. But collectively, they have been a powerful force in Europe to counteract the loss of locally adapted crop types, and to spread information about resources and techniques. networks of seed-saving farmers have created informal seed systems across Europe based on collective management. Activities of these networks are now funded through the Rural Development Policy and studied under Horizon 2020's DIVERSIFOOD project.

Latvian wheat farmers. One recurring problem for winter wheat farmers is avoiding fungal diseases that cut yields. In Latvia, a group of researchers and farmers is setting up an online decision support system to help decide when and how to apply fungicides. The pilot group involves two farmers and nine agronomists and others who can help. The aim: to scale it up to other farmers. It is happening under an EU initiative called a European Innovation Partnership for Agriculture, or EIP-AGRI. The result could lead to more efficient, ecologically sounder ways of managing fungicides than by regulation alone.

THE EU'S 'FARM TO FORK' AND 'BIODIVERSITY' STRATEGIES

In May 2020, the EU released two important strategy documents – one on the agri-food chain, "Farm to Fork," and the other on biodiversity. They both raise important policy points which research can help elucidate, and support. The first identifies three main objectives: a) ensuring that the food chain has a neutral or positive environmental impact; b) ensuring food security, nutrition and public health; c) preserving the affordability of food while generating fairer economic returns in the supply chain. The strategy also set some quantitative targets by 2030: reductions of 50% in chemical pesticide use, 50% in nutrient losses, and 20% in fertilisers. It also aims to have 25% of agricultural land organically farmed by 2030. According to the strategy, the food system should also reverse biodiversity loss and contribute to a 55% reduction in greenhouse gas emissions. The 'Biodiversity strategy' has several connections to agriculture and food: precision agriculture, organic farming, agro-ecology, agro-forestry, low-intensive permanent grassland, and stricter animal welfare standards are all considered instrumental to the goal of restoring biodiversity.

Sustainable corporate governance is another policy area addressed by both strategies, signaling a change of frame for public-private relationships. In the 1980s and 1990s, a neoliberal orthodoxy championed by Ronald Reagan, Margaret Thatcher and others restricted the role of government to policing market excesses. But in the past decade, a new narrative envisions a more active government. In this view, government should steer innovation towards its social

goals – investing and shaping the world as what University College London economist Mariana Mazzucato labelled "the entrepreneurial state."[181] At the same time, the private sector starts to recognise more obligations to society as well as to shareholders – protecting the environment, promoting health, advancing the UN's Sustainable Development Goals.

Knowledge is the engine that can drive the necessary changes; it can refresh, reframe or broaden a policy debate – stimulating a new way of organising how we manage the economy. In the field of food and agriculture, this report's earlier chapters on nutrition, circularity and biodiversity highlight three major policy areas critical for change to happen. They are three key areas in which public and private sector interact, and which need reform if we are to reach our desired target of a "safe and just operating space" for all.

1. **Agriculture and food**. Agriculture was part of the original bargain[182] by which what is now the EU was created in 1957: France, with a big rural constituency and memories of war-time privation still fresh, demanded it be included in the founding Treaty of Rome. Since the first formal programme began in 1962, the Common Agricultural Policy has been repeatedly "reformed" – to cut costs, get greener, support the countryside, manage food prices. It should, many now argue[183], become a food and agriculture policy rather than a farm policy alone. The latest proposed CAP reform, on which EU member states could not agree, is being kicked down the road to 2022. By now, many[184] consider the CAP as impossible to reform: its beneficiaries are too dependent, too entrenched, too powerful, and its tools are largely ineffective, as the European Court of Auditors states.[185]

Given all this, is the idea of CAP "reform" as proposed by the EU Commission already outdated? An agricultural policy, of whatever sort, cannot address all food-related issues. CAP should, some now argue[186], become a food and agriculture policy rather than a farm policy alone. Others say that, also in light of Farm to Fork, a brand-new policy framework should be designed. This will require the involvement of a much wider set of stakeholders and administrative bodies – connecting policy on food, health, climate, the environment, circular economy and, of course, farming. Here, new science-policy-society interfaces, of the kind discussed earlier, could help, addressing linkages, trade-offs and implications largely unknown today.

2. **Competition**. Market regulation also dates to the EU's origins: if there is to be a functioning Single Market, there must be rules and police to prevent companies from abusing a dominant market position – of particular concern to the smaller countries (the first competition case, in 1964, was against Germany's Grundig). Today, competition enforcement is widely viewed as the biggest gun in the Commission's arsenal – and, has won it headlines for its actions against Big Tech. But it has had several odd effects in agriculture. Its focus on policing only dominant players means that others in the market can get away with unfair practices, such as selling food below cost. And, as IPES Food[187] reported:

"The current focus of EU competition law on consumer welfare draws attention away from the impacts of concentration on production and processing activities, as well as environmental or public health impacts. Whether a farmer has been paid fairly is currently deemed to have little impact on the (economic) welfare of consumers. In this context, not a single agrifood merger has been blocked despite unprecedented consolidation across the sector over recent years, with major consequences for farmers' autonomy and livelihoods."

3. **Trade**. Until recently, with the resurgence of nationalism, the raison d'être of trade negotiations around the world has been to boost trade, the economy and jobs. But that could undercut other goals, such as preventing climate change, protecting human rights, preserving health, or spreading wealth more fairly. A recent study in *Nature Food*[188] argues:

"With international agreements to liberalise trade and investment being binding, and recommendations to address malnutrition and climate change being non-binding, there is potential for trade to hinder efforts against malnutrition and climate change." Reflecting such concerns, alarm bells have been sounding over an EU trade deal negotiated with the Mercosur countries of Latin America, on grounds that it will pay those countries to despoil their own environment and worsen climate emissions for the sake of more EU sales. One Latin American study forecast that the region's climate emissions will rise 6% in the poultry sector and 4% in ethanol if the deal is approved.

"However, protectionism may not be the solution, as trade can be a driver for sustainable development. A model of 'fair and sustainable trade', coherent with SDGs, is needed, but working it out will require a tremendous intellectual effort."

To address all of these issues, research – including research directed towards achieving our desired policy goals - can have a key role. At present, too much of the debate has been emotive, fed by lobbyists, exploited by populists. The food-chain disruptions of COVID-19 have intensified that; though there have not been any real shortages, the anxieties sparked by images of empty shelves have been powerful.

Emotions and facts need to be considered together. Deliberation, not diktats, are required. An open debate, informed by real-world evidence, would be best. For all of that, research is the tool.

CHAPTER VIII: THE KNOWLEDGE AGENDA

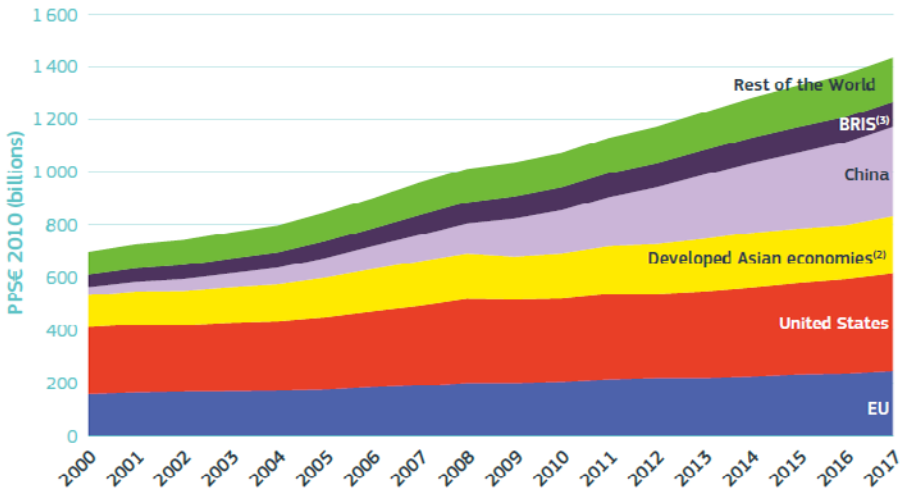
> Until philosophers are kings, or the kings and princes of this world have the spirit and power of philosophy, and political greatness and wisdom meet in one ... cities will never have rest from their evils – no, nor the human race.
> *Plato, Republic, Ch. V*

The world is full of problems: pollution, climate change, racism, inequality, recession, malnutrition, obesity, waste, mass extinctions, pandemics. For most of these problems, we either do not know the solutions, do not agree about them, or do not act on them. Yet act we must, even if knowledge is uncertain, values disputed, and interests in conflict. But how?

We can start with knowledge – and our age has seen a dramatic rise in the importance of science and technology. Since 2000, world spending on R&D has more than doubled, the research labour force has nearly tripled, scientific publications and patents have proliferated.[189] The EU, of course, has contributed to that rise, with R&D expenditures rising to 2.12% of gross domestic product in 2018 from 1.77% at the Millennium[190] – though still well short of the 3% target it set for itself about that time. Agriculture has long been a particularly research-intensive field, as the "green revolution" boosted yields across the globe; public agricultural research budgets across major economies climbed over a half-century to $18.6 billion by 2009, but then dipped in North America and the Mediterranean region after the 2009-9 crash, according to the US Department of Agriculture.[191] Regardless, the broad numbers, over time and across sciences, suggest that as a species we have decided that knowledge matters. And we lack no examples of the dangers of ignorance.

But science is not enough. As we saw in the early days of COVID-19, politicians will listen only so much to experts before they reject or ignore them. People will heed evidence-based warnings only so often before they get confused, lose interest or rebel. How many deaths will we tolerate to keep the economy alive? Will we sacrifice individual privacy to track and trace the virus' spread? Which patients, old or young, frail or hardy, get scarce ventilators or drugs? These are the kind of complex, ethical and emotional questions that experts neither could nor should decide. They are questions for science, policy and society to answer together. But why do they so often fail to do so?

Public R&D budgets across all disciplines are on the rise



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat, OECD, UNESCO

Notes: (1)GERD in PPS€ at 2010 prices and exchange rates. (2)Japan+South Korea+Singapore+Chinese Taipei. (3)Brazil+Russian Federation+India+South Africa.

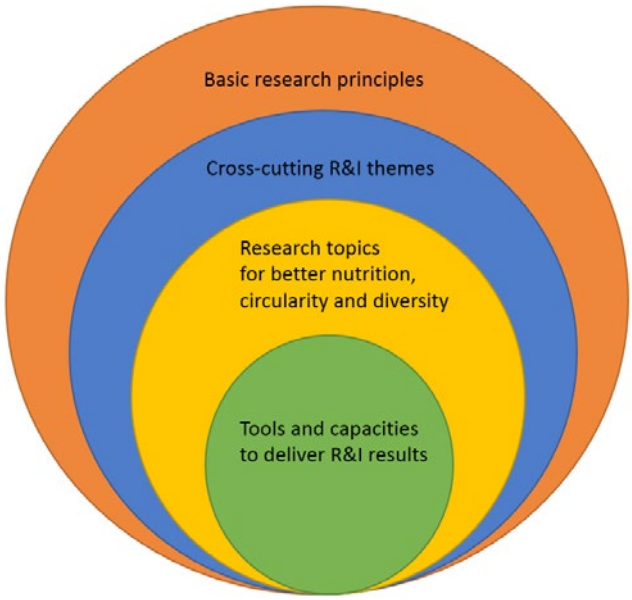
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/part1/chapter51/figure-51-1.xlsx

If there is one thing the pandemic highlighted it is the need to get science, policy and society working better together. Science has warned of catastrophic risk for years – the risk of global warming, of environmental collapse, even of pandemics. There has been some success: The International Panel on Climate Change is a rare case of science mobilising to force policymakers to pay attention to a problem, if not yet fix it. Other panels, such as the Intergovernmental Science-Policy Platform for Biodiversity and Ecosystem Services (IPBES), have also been effective. COP-21, and the European Commission's Green Deal, are consequences of this kind of work, years in the making. But climate change is (so far) a slow-moving catastrophe; COVID-19 is a sharp shock, with repercussions for years to come. How to handle such shocks without losing sight of slower-moving disasters? Better yet, can a crisis be turned to advantage, breaking monopolies, vested interests, bad habits? This is, of course, the question that the Commission is attempting in its COVID-19 recovery programmes: how to rebound faster – and better? Its plan placed research and innovation in a central role.

But how to get the fruits of that research pressed into action? In the final analysis, knowledge is a trigger for action, a necessary condition if we want to move society from one unhappy state to another more sustainable, more fair, more safe. And by knowledge, we do not mean just the product of labs and start-ups; we mean it as an active force, circulating among researchers, entrepreneurs, innovators, customers, citizens. But here is the crucial question: How can one

design a research programme that achieves that? How do we get research and innovation that produces new ideas, discoveries, products and services – and that also changes the direction of society? Some logical thinking is needed. Here, in this chapter, we start with some broad principles for research policy, then look at how they would be translated into specific themes that cut right across all areas of food and agriculture research. From there, we can narrow down to specific types of research topics that would deliver the three transitions towards better nutrition, circularity and diversity. And lastly, we look at the specific programmes and capacities for research needed to achieve our final goal: the safe and just operating space.

The 4 components of transformative research



PART 1: PRINCIPLES FOR TRANSFORMATIVE RESEARCH

To catalyse change, improve lives or mitigate harm, research must be "transformative." What does that mean? In our foresight work, we started from the belief that change happens when our goals are clear, our ideas about how to achieve them are good, our capacity to act – in technologies or policies, for instance – is adequate, and our people and institutions in fact do act. A transformative research policy helps define those goals, especially long-term ones, encourage new ideas, build new capacities, and help people change behaviour.

For that to happen, research and innovation – or at least a large part of them – must have a **direction**[192,193]. The need for this is clear: our ultimate goal is the "safe and just operating space" and applied research is a way to get there. The UN's Sustainable Development Goals help set a broad direction; and the Commission, in its Horizon Europe plan, has imported those goals as a framework for the thousands of research and innovation projects it will fund from 2021 through 2027. By law, 35 per cent of the money will be spent on climate-related research and innovation, 10 per cent on a cluster of issues around food, agriculture and the bioeconomy. Beyond those gross budget allocations, a significant portion of the work will be organised into "missions" and various types of collaborative partnerships with very specific goals. Further, the Commission's budget, though less than 10 per cent of total government R&D spending in the EU, echoes through most of the member state research programmes, providing some continent-wide coordination. Of course, this direction-setting is not monolithic: Innovation and applied research ultimately depend for many ideas on "bottom-up," investigator-driven projects such as those funded by the European Research Council. But for many other parts of Horizon, we view overall policy goals as essential. In addition, we must look beyond the seven-year Framework Programme planning cycle, and start thinking now about how research and innovation priorities may need to change in the 2030s and beyond. For that, foresight studies will help. But so too will continuous monitoring of the success and efficiency of the programmes – preferably by completely independent, outside parties able to critique Commission strategy with impunity. And, as described below, there must be a step-change rise in how EU governments involve its citizens in setting research priorities – and, crucially, in implementing them.

To be transformative, research must also be **responsible**. It must link the research to its consequences, intended or not. Innovation can permanently change lives and business – whether the topic is diet, food processing or environmental impact. Applying genetic technologies to agriculture is an important research area, but must be undertaken responsibly if it is to avoid harm or opprobrium. Responsible researchers or innovators are accountable for repercussions, and that requires that they anticipate problems and involve others. It is good news that the Commission has been expanding its Responsible Research and Innovation initiatives, to promote good behaviour. At the same time, it is noteworthy that since 2014 the Commission has obliged grantees to spell out the potential **impact** of their work – put simply: to say what they will achieve and why. But responsibility and impact are closely linked; and much more should be done, in both Brussels and the capitals of the member states, to improve the way these are defined and assessed. So far, the Commission's efforts to "mainstream" responsible research policies throughout Horizon have had limited impact.[194] It must connect its responsibility policies better with researchers themselves, and with other, non-research programmes in agriculture, cohesion and recovery. At the same time, impact should be about much more than how an invention or discovery would affect one single part of society or the economy. To take one example: Developing plant-based meat substitutes has potential impact far beyond the food-processing industry for which it is intended. Depending on how successful it is, it could affect energy consumption, rural incomes, urban diets and more. Of course, many of these changes

could be positive – and if so, transformative research must focus on them as a goal. At the same time, however, it must responsibly consider other possible consequences, and mitigate them.

Transformative research must also be **open**. Most societal challenges are multidimensional. To meet them, no one research discipline is sufficient; many different disciplines, ideas and perspectives must come together. At the same time, real transformation comes only if everybody involved – researchers, producers, companies, consumers, citizens – shares knowledge and acts together on it. All of this requires openness and interactivity – and that is, for many researchers, hard work. It forces them to change the way they do their jobs. They have to spend more time talking to people. They need to speak more simply, to reach more citizens. They need to go beyond their own expertise to understand the impact of their work. And openness can come with a cost – literally, in library budgets or extra paperwork. Openness is, perhaps, the hardest change of all for the research community. At present, our universities still conduct most research in specialised departments. They hire and promote based on publication or recognition in specialised journals and conferences. This fossilised system must change – and EU and member state programmes, at present, tend to reinforce rather than overturn these boundaries. Indeed, the way the Commission has historically organised itself in subject-specific departments mirrors the problem, as it already recognises. As we have said repeatedly in this report, the problems of diet, waste and biodiversity cut across all domains. We must invent a new way to fund and do research and innovation: open, interactive and dynamic. And we must invent a new way to evaluate research.

This will require new **collaborative** methods, promoting multi-disciplinarity. Of course, collaboration has been the hallmark of EU Framework Programmes since the start, in 1984 – originally as a way to bridge geographical boundaries. By now, a growing number of EU research projects also bridge disciplines; but relatively few also, as a matter of intent, involve all parties that could be affected by the research. One promising model is the Multi-actor approach, applied in an increasing number of Horizon 2020 projects[195], which encourages the establishment of "living labs" that structure the research agenda to include users, suppliers, citizens and policy makers. For instance, the DESIRA project brings together 25 partners, in 250 consultations, to assess the impact of digitisation on rural life. Likewise. Ljubljana authorities, as part of the ROBUST project, organise meetings and workshops bringing together city and country dwellers to discuss sustainable agriculture and biodiversity. These are a good start – but we need other, newer ways of doing research, with and for the community. Digital technologies, for instance, have barely begun to demonstrate their full potential for interactive community research. Now, more than ever, when the very notion of the EU and its Single Market have been challenged, research and innovation can be a unique tool to foster among citizens a better understanding of, and democratic participation in, EU issues. And where better to start than in so concrete, necessary and emotional a topic as food and agriculture?

PART 2: CROSS-CUTTING RESEARCH THEMES

To be transformative, then, a research strategy must tick many boxes: goal, impact, responsibility, openness and collaboration. The EU's programmes, and those of some member states, make a good start at this – though much more is needed if research and innovation in the EU are to go beyond "interesting" and make real change happen in society. To get there in food and agriculture, we have identified several cross-cutting research issues that, if amplified in government programmes, could help systemic change happen.

Food, well-being and society. In the developed world, we encourage too much consumption; it breaks through the planetary boundaries of climate, pollution, biodiversity and other factors discussed earlier. To remedy this, we must change our idea of the kind of life we want, and the products and services that provide it. Food is an important part of that equation: what we eat, how we get it, and its impact on the environment around us all help shape our sense of well-being. Do we feel healthy? Safe? Living in a just society? These are complicated questions of psychology, sociology, history, law, economics, biology, nutrition, ecology and more. Answering them requires research: into how food and environment shape our sense of well-being, how our identities and social ties affect what we buy and eat, and how that affects our social status and self-esteem. A community is what it eats – both literally, and psychologically. We must research how to move people from "having" to "being", from products to services, from "me" to "we".

Cross-cutting themes for a new agri-food sector

If, in the food we grow and eat, we want a safer, fairer world, a few broad themes for research cut just about every problem – and, if solutions could be found, would benefit all.

Food, well-being and society. How what we eat and how we grow it shapes our identities and well-being – and can speed or block change

Social innovation. New businesses, partnerships and services to help change happen.

Agro-ecology. How farming methods interact with the environment, and how to get a better, greener outcome.

Digital transformation of the bioeconomy. New tools, services and policies in digital technologies that can speed change.

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Foresight. New study methods to track and understand how major trends and technologies could shape our future – and how to prepare for them.

Coping with disaster. Understanding how shocks hit some people and regions worse than others, and how best to prepare for them.

Finance for transition. How financial markets, debt, subsidies and investment shape the way we produce and consume food, and how to bend those factors to support rather than block change.

Social innovation. Understanding how society must become more sustainable is one thing; making it happen, another. For that, a key tool is "social innovation"[196] – concrete experiments in new foods, new services, new partnerships that mobilise social capital to create public goods. This can involve social enterprises: companies and organisations that offer a for-profit service or product but have a social goal, such as better nutrition in the city or better life-styles in the countryside. It can involve farmers, food banks, cooperatives and others in the countryside. It must involve businesses, large and small; after all, they are the most common vector by which new ideas spread through the economy. It can involve new kinds of alliances among companies, local communities and public-sector organisations. It can be based on new technologies – or not. Either way, EU programmes have been funding a growing number of these socially motivated experiments in a public goal. It is time, in the area of food and agriculture, to encourage more and to scale up the successful ones.

Agroecology. As described earlier, agroecology is a more holistic way of designing and doing agriculture, so that it strengthens the environment and society around it. It includes improving soil health naturally, managing waste cycles efficiently, taking advantage of biodiversity and the ecosystem services it naturally provides. It is a science, a set of practices.[197] It has social, as well as environmental, benefits. We believe this approach to farming, already under trial around the EU, needs greater study – yet it has faced resistance in parts of academia and industry, and needs support to break disciplinary barriers.[198] Research now can help develop the theory, the practice and the ways to scale it up from individual field, to landscape, to a continent and the globe. We note the Commission has already started to move in this direction, with plans underway for a large, collaborative partnership and infrastructure on agroecology.

Digital transformation of the bioeconomy. The pandemic has sped up the process of digitalisation in many walks of life. It has shown how Internet, wireless services, Big Data and other digital applications are far more than a new product or service and, like other technological revolutions from steam to electricity, fundamentally reorganise the way we work, live and run society.[199] It can transform some activities, such as shopping or attending meetings. It skews who wins, and who loses, in markets and politics. And it overturns the way scientific research is done.[200] Of course, digital technologies are already front-and-centre in the geopolitical or

competitiveness strategies in Brussels and other EU capitals; but their potential to transform food and agriculture is breathtaking. We need research on how, as we alter the way food is produced and consumed, digital technologies will change our social and economic lives. We need research on how these technologies could get us closer to the healthier diets, circular economy and greater biodiversity we seek. We need research and innovation to provide the specific digital services and products needed from farm to market in a greener, more sustainable food system. We need research on how digital technologies could, for instance, help reduce our use of pesticides and synthetic fertilisers. And we need research, specific to the food and agriculture sector, on the ethics, data access rights and openness, and capacity to use these technologies; after all, it does no good to design a digitised, satellite-monitored farming system that promises greater precision and environmental gains if farmers cannot afford to use it or if the energy balance is negative.

Foresight. In recent years, we have learned to acknowledge the trends – in climate, trade, health or industry - that are disrupting our habitats and routines, and now threaten our future. Many people now challenge the old ideas about how society evolves through orderly stages of development, guided by the invisible hand of the market, or motivated by Pangloss-like optimism that, as technology advances, all will be for the best in this best of all possible worlds. Reality appears to be a lot more complicated. Coping with this fact requires a much greater effort at identifying, analysing and forecasting trends. It is good news that, in the current Commission, foresight has been elevated to be the direct responsibility of a specific Commissioner. But foresight in the food and agriculture area needs broad expertise, and the methods and effectiveness of foresight in this field must be improved. Foresight is no arm-chair exercise: workshops, community meetings, social media, surveys and other tools of participatory foresight are, themselves, part of the way we change public attitudes and behaviour. And if, as we assert, a transformative research agenda must include clear direction, foresight studies make the compass that point the way.

Coping with disasters. COVID-19 has made us all more aware that our society is increasingly vulnerable to shocks – but shocks have many causes, and their impact is distributed unevenly. Research is needed on what makes some groups, individuals or regions more vulnerable than others, and what policies can best mitigate harm. In other disasters, we have seen investment in preparation has paid off: for instance, cyclone preparedness in Bangladesh, or heat waves in France.[201] The Sendai Framework, a 2015 UN approach to managing the risk of disaster, is a good start.[202] At the same time, shocks should not be an excuse for postponing long-term goals – such as, in the pandemic, our focus on climate change. Intervention should be aimed at transformative reconstruction or, as the Commission said in on 27 May, to "repair and prepare for the next generation."[203]

Finance for transition. In any transformation, money talks – and it can block change entirely. If we are trying to move towards a greener, healthier food and agriculture system, policy makers can propose anything they like; but it will not happen if, for instance, too many farmers have too

much debt, and so cannot invest in new methods or technologies. So we must, with research, study the financial flows: identify when and how money is an obstacle to change, devise new financial tools to overcome the obstacles. We must study global, national and local trends in the agricultural finance market, and in the agri-food sector as a whole[204]. We must study capital markets for land, and how they constrain the abilities of farmers to change.[205] This kind of research can suggest new tools, services of policies to spur change. It can also, as discussed in the prior chapter, suggest more effective ways of designing and managing the Common Agriculture Policy – so that, while helping sustain precarious farm incomes, it also contributes more effectively towards broader nutrition, social and environmental goals.

PART 3: RESEARCH TOPICS FOR TRANSITIONS

Those are the broad, cross-cutting research themes required to transform our food and agriculture systems. But, as described in earlier chapters, there is a host of more-focused, subject-specific research topics that would help move Europe towards a greener, healthier, more just food system. The details, we have discussed in previous chapters. What follows are the key themes that emerge, in each of these three desired transitions.

Sustainable and healthy diets for all. Nutritious food should be a right guaranteed in law, not just another consumer good solely dependent on market dynamics. But providing nutritious food affects soil, plant and animal life, the climate and more; and this impact must be considered when deciding how to grow, process and distribute nutritious food. In short, what you might call *responsible consumption* should become a social norm. To get there, research can help. It can study how we teach, communicate and think about food and agriculture, and devise better ways to do so. It can analyse the impact, or environmental footprint, of food. It can develop new, sustainable foods and processing methods, and devise farm and fishery models that help get more nutritious food to more people. It can help design a better system, or environment, for supplying and buying food that helps people make healthier, responsible food choices. For these goals, as for all the transitions we have examined, digital technologies are crucial.

A circular bioeconomy. As a society, we must adopt a new economic paradigm, moving from a linear to a circular economy – cutting waste, boosting efficiency, planning good environmental stewardship into the way we make and consume the products of our farms, forests and waterways. To get there, research and innovation can help devise new business models that work in a circular economy and motivate citizens to embrace them. It can invent new logistic and digital infrastructures that support these business models, and new technologies for carbon-neutral biorefineries. It can develop more efficient, circular ways for different industrial groups to interact with one another – "industrial symbiosis" –and for local and regional communities to collaborate. And it can devise better ways to govern the economy, managing the inevitable trade-offs that the transition to circularity will require.

At the same time, to achieve circularity, the way we farm, forest and fish needs special attention. This is the "organic loop" of the circular economy. Many organic processes are by definition circular; they form the cycle of life. Our task is to amplify those processes. Researchers can study economically viable and resilient models of farming, fishing and forestry. They can develop regenerative farming practices that sharply cut the use of antibiotics and synthetic pesticides. They can, in projects and networks linking country and city, producer and consumer, produce a "strong sustainability" for farming – sustaining healthy diets, a clean environment, and a prosperous farm, forestry and fishing sector. Digital technologies, again, can help; they are a tool not available, in the same power and scope, to prior generations. But all other disciplines – economics, sociology, biology, ecology and more – will have their role to play in creating this new, circular bioeconomy.

Research for the 3 transitions

Getting to healthy diets, a circular bioeconomy and a diversified food system will take new ideas, new technologies, new strategies to get producers and consumers, policy makers and citizens, public and private sector, working better together.

Here is a quick summary of the main themes of research and innovation inquiry that needs pursuit. ***Digital technologies*** *support all of them.*

Sustainable and healthy diets for all – a social imperative

- Developing agriculture, fishery and forestry methods that result in more diverse and nutritious diets
- Developing new, sustainable foods, food production and processing models, and food quality criteria
- Improving and disseminating knowledge about the environmental and health impact of what we eat
- Co-designing food systems to foster sustainable consumption and improve city / countryside relations
- Education, communication, 'nudging' consumers to eat sustainably and healthily

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A circular bioeconomy – a road to sustainability
'Strong sustainability' in farming

- Developing methods and networks to 'close the loop' in agriculture, forestry and aquaculture, so waste is reduced and circularity achieved
- 'Regenerative' agriculture, harnessing natural methods to improve soil health, sustainability, diversity and productivity
- Strategies for radical reduction of antibiotics, synthetic pesticides and fertilizers in farming
- Ways to make farming, fishing and forestry more viable economically – and adaptive to weather and climate change
- New services for rural and agricultural communities that enhance their well-being

Shaping a bio-based circular economy

- New logistic and digital infrastructures for circularity
- New ways to get industries or regions working together for circularity
- Carbon-neutral technologies for biorefineries
- New materials, bioplastics, waste conversion techniques and other basic tools
- New ways to govern a circular economy, and the trade-offs required
- Devising new business models to get people to use and support circular food practices

Diversifying agriculture and food systems – a key to resilience

- Monitoring, measuring and disseminating knowledge about ecosystem services. This would include digital tools that encourage citizen science.
- Diverse farming and food production systems, sustainable food processing models
- Diversifying food retail channels, for a greener, resilient system
- Supporting the role of small farms and fishers in a diversified food system
- Interdisciplinary research to boost resilience and long-term stability in agriculture and food systems, and to reduce vulnerability to shocks.
- Identifying and managing competing values and visions among stakeholders

Diversifying food systems. If we were unconvinced before, the COVID-19 experience now has demonstrated the importance of diversity of supply – of medicines, equipment, food and even coping strategies. Diversity helps make a system resilient, able to withstand shocks. We have also seen that maintaining diversity depends heavily on economic and social factors: the cost of food, the money available, the way a country is organised politically and socially. Research can help build a more diverse food system by studying this link between social, economic and biological systems. It can help us monitor, and understand, our mounting problem of declining biodiversity. It can study the complementarity between farms of different sizes and types in a diversified food system. It can find ways to organise more sustainable food processing systems, and weigh the costs and benefits of diversification on wholesale and retail food channels – with the aim of providing a wider range of nutritious, affordable foods for all. And again, considering how online food purchasing soared during the early weeks of the pandemic, we can see that new digital technologies will be essential.

PART 4: BUILDING CAPACITY FOR CHANGE

For research to be transformative, we need special ways of translating it into policy and society. This often means creating groups, partnerships or networks that bring science, policy and society together – to agree on a strategy, and then to act on it. Such a strategy, once developed, must be translated into more specific objectives, ways of acting on them, and follow-through. It must involve everybody: producers, consumers, policy makers, researchers at every level from local to EU. We are fortunate in already having a number of organisations that perform parts of this task, but new groups and functions will be needed to accomplish the changes required.

Science-Policy-Society interfaces. As we have seen in the pandemic, the link between science and society is weak and fraught with misunderstanding. Expert groups, if properly constituted and supported, can help by gathering the scientific evidence for whatever needs to be done, and communicating it to the policy makers and citizens who could act on it. Successful examples include the UN's International Panel on Climate Change, which has made stellar progress in forcing world leaders to pay attention to the frightening evidence of global warming. In the area of food, the UN's High Level Panel of Experts on Food Security and Nutrition was created in the aftermath of the 2007-2008 financial market crash. Science-policy-society interfaces are especially important when the need for policy integration is highest, as in the case of food. If Europe wants to endow itself with a comprehensive food policy, it will need such groups to remove barriers to change and break down silos, from European to regional level. But for every success in such advisory groups, we can count many more failures – so the very nature of this interface between science and society is, in itself, a rightful topic for research.

Partnerships. One of the oldest tools in the EU's R&D kit is the partnership – and for good reason. It brings, into one group with one budget, some of the key organisations across the EU that can make happen whatever change is on their agenda. In the next EU R&I programme,

Horizon Europe, the Commission is planning at least 49 such partnerships, many involving a mix of private companies and public bodies across multiple EU member states. Of these, 11 partnerships are especially relevant to our work in transforming the food and agriculture sector. Many will have a central secretariat, devising their agendas and managing the EU funding. The list itself is promising. The Food System Partnership, in particular, has the potential to mobilise funders on a strategic research and innovation agenda for food system transformation. But the peculiarity of rural areas, where the link between environment, food, and development is strongest, is not sufficiently addressed. Most environmental services depend on the activity of rural areas, but to be produced they need a robust economic base and a vibrant social fabric, which cannot be provided by the agricultural sector alone.

Key Horizon Europe partnerships

The Commission is planning to institute a wide range of formal public-private partnerships that touch upon food and agriculture systems – and their environmental and social impact. These are all good steps forward. But it is not always clear how they will achieve the desired impact or directly engage rural and agricultural communities whose participation is essential for success. Here is a list of planned Horizon Europe partnerships to watch. In addition, Horizon Europe will include a "mission"- achieving an ambitious target through many research efforts – for soil health and food.

- European Partnership for Animal health
- Agriculture of data
- Environmental observations for a sustainable EU agriculture
- European Partnership for rescuing biodiversity to safeguard life on Earth
- European Partnership for a climate neutral, sustainable and productive Blue Economy
- European Partnership for Safe and Sustainable Food Systems
- European Partnership for a Circular bio-based Europe
- European Partnership Water Security for the Planet (Water4All)
- European Partnership for One Health/AMR Antimicrobial Resistance (AMR)
- EIT Climate-KIC
- EIT InnoEnergy-KIC
- EIT Food-KIC

Another form of alliance is the European Innovation Partnership, first introduced in 2011 (initially in the field of healthcare) as a way to get member-states working together on major innovation problems. Their success has been mixed – very much dependent on the sector and level of member state support. But the EIP-AGRI has been particularly important in its sphere, funding groups that get farmers, researchers and others working together on specific tasks. For instance, in Ireland, a pilot[206] has recently begun to see how small-scale, on-farm biogas facilities could reduce the climate impact of agriculture. For farmers, the attraction is the possibility of reducing their energy bills – and 260 farmers have expressed interest in joining. The EIP has highlighted the value of networking, especially at grassroots level. But networking is costly, and often farmers cannot afford it. Time and effort spent in this kind of networking activity, between farmers, experts and the wider community, should be recognised as a worthy investment for research programmes – the "living lab" approach. To support them, strategies to boost digital collaboration should be prioritised.

Long-term R&I networks. One problem with existing EU R&I programmes is their inherently transitory nature. Researchers come together to answer a published call for grant applications; and if they succeed (a very small chance for most, given Horizon 2020's average success rate under 12%) they generally get a few years of funding. And then they disband. That system has the virtue of focusing minds on getting specific tasks done, as determined by the Commission's research policy goals. But it is not always fit for the chronic problems we face in food and agriculture: mitigating climate change, improving nutrition, boosting diversity, turning to agroecology – these are all goals that will live with us for years to come. They require more long-term networks and infrastructures, that live beyond the usual EU budgetary cycles. Long-term networks keep relations alive among the participants. They encourage more attention to communications, implementation and impact. For poorer or newer member states, they provide sustained funding. Alas, the two- to seven-year timeframe of most EU research networking activities is an artificial constraint, imposed by a need to operate within its usual seven-year planning cycle. The world's problems and aspirations, as codified in the UN Sustainable Development Goals, do not fit in that straitjacket. Of course, this is not to say that short-term projects, with tightly focused goals, are not also important. But If the Commission is serious about the SDGs, it should devise more ways to allow appropriate research networks a longer perspective.

How to build capacity for research to change society

Research and innovation, to be transformative, need a new set of organisational, rather than purely technical, tools. These are some ways in which this could happen.

Science-Policy-Society interfaces. Put plainly, these are groups of experts and stakeholders that gather and communicate scientific evidence to policymakers – so that action becomes possible. With as complex a field as food and agriculture, we need more and better interfaces.

Partnerships. The EU's Framework Programmes have long supported research and innovation partnerships of various stripes. We urge creating more, and broader, partnerships to unite science, farming and communities.

Long-term R&I networks. The term of most EU research networks is too short for the long-term nature of the UN Sustainable Development Goals. Find a way to make them match.

International collaboration. Global R&D cooperation is vital for food and agriculture research, but will be difficult post-pandemic. The EU must find new, flexible tools to promote it.

New types of collaborative projects. For research to be transformative, it must involve all stakeholders in society and be quite inter-disciplinary. Horizon should invite more experiments in engagement, and other EU programmes should amplify the successful models.

Manage the siloes. Duplicative or contradictory policies are a common feature of food and agriculture work as rival ministries, agencies or regions fail to coordinate their work. Again, greater coherence and stronger coordination among policy areas is needed, and potential cross-sector trade-offs should be evaluated before taking decisions.

International collaboration. Research and innovation are, increasingly, international undertakings. According to UNESCO, in just seven years from 2008 to 2014, the number of internationally co-authored scientific publications rose 47%, beyond 316,000 a year.[207] And Europeans have long been central players; indeed, the Commission often boasts (with only a bit of exaggeration) that Horizon is the world's most open research programme. But the COVID-19 crisis will have unpredictable effect on the scale and scope for cooperation – and perhaps no more so than in food and agriculture, the ultimate field of research rooted in specific places and times; you cannot study biodiversity from behind a Zoom screen. So now more than ever,

the Commission will have to live up to its rhetoric of openness and find new ways to encourage international collaboration in food and agriculture research and innovation. This will require new flexibility in formal Horizon association agreements between the EU and non-EU governments, as well as in the thousands of ad hoc, unfunded "participations" by third-country researchers currently hampered by EU red tape. For instance, not all the standard contractual terms – for instance, for intellectual property or legal jurisdiction – of a Horizon grant agreement need be applied to non-EU partners whose participation in an important international food or agriculture research project is badly needed. And, while there is an obvious temptation to tie these collaborations to EU foreign policy – to make research a tool of diplomacy – we urge that the first priority in any possible deal be achieving the EU's research goals, rather than geopolitics. In agricultural research there are already promising initiatives such as the establishment of an International Research Consortium (IRC). This is a flexible way to coordinate R&I in areas which are considered key[208].

New types of collaborative projects. As suggested earlier, if research policy is to be transformative it must build in the operating links to all the people who would implement it: farmers, consumers, local politicians, researchers, businesses and more. For 35 years the EU's Framework Programmes have progressively invented new ways to collaborate, and they already fund many broad, "citizen science" or innovation partnership-type projects. But we need to invent new models – that involve all stakeholders in devising and implementing research-based strategies for healthier diets and sustainable agriculture. To this end, Horizon Europe funding could include more calls for experiments in engagement, while CAP and Cohesion programmes could be used to expand use of the successful models. At the same time, the unique nature of the food and agriculture sector suggest that the Commission, in designing its research partnerships and reviewing grant applications, should be more flexible. Under Horizon Europe plans, public-private partnerships are to get bigger and fewer; while efficiency is a laudable goal, there is a risk that small, niche ideas and groups could get shut out of the support. When it comes to collaborative research, bigger is good as long as the type of problems require a given scale, but it is not always better.

Manage the silos. In all governments, it is an old and familiar refrain: break down the silos between ministries, agencies, policy areas that encourage short-term, duplicative or contradictory decisions. The Commission is to be praised for at least attempting this in its Strategic Planning for Horizon Europe, with DG Research and Innovation working more collaboratively with other DGs. But we are a long way from results – in part because most member state governments persist in their own silos, and also because in some cases silos are necessary to guarantee effectiveness. Within the states, regions are actually encouraged by EU cohesion policy to operate semi-autonomously, devising "Smart Specialisation" strategies intended for them to focus investment on their own unique skills or assets; at the same time, resilience and diversity require some specialisation. In the case of food, while a coherent food policy is an emerging issue, it is not clear whether embedding the new policy into a new all-encompassing silo would be the right choice. Moreover, the variety of interests and values and the uncertainty

of knowledge make it necessary to involve multiple points of view by, for instance, funding research in "swarms", i.e. mobilising the knowledge of a large variety of scientists on a specific subject, perhaps through cascading funds. In short, this whole issue of silos has both good and bad features that need study, analysis and management.

THE ROLE OF SCAR

Our work takes place under the aegis of the Standing Committee on Agricultural Research, which since 1974 has advised the Commission and member states on how to spend their agricultural research money. As explained at the outset of this report, it performs foresight studies (like this report), develops a common research agenda, maps EU capacities, and communicates its conclusions. In the past, its work has led to Joint Programming Initiatives in food and agriculture, in which the member states voluntarily agree to coordinate their research programmes around a specific goal. It was also instrumental in creating EIP-AGRI, mentioned above.

We believe that, as the challenges of food and agriculture get more entangled with other problems such as climate and health, SCAR will become a key link among science, policy and civil society. Crucially, it will also be important in linking member state efforts with one another, and with the Commission. Of necessity, national programmes have localised priorities and some shorter-term goals. So it is important that there be an organisation to pool foresight thinking on food and agriculture, and to develop an EU-wide consensus on major, long-term challenges. SCAR should strengthen its structuring and coordinating role[209] on foresight, and give greater attention to monitoring and evaluation of programmes. These functions could become a key plank in EU efforts in coming years to strengthen the European Research Area.

CHAPTER IX: A FINAL WORD

> We are too narrow-minded a species to consider the possibility of events straying from our mental projections, but furthermore, we are too focused on matters internal to the project to take into account external uncertainty, the "unknown unknown," so to speak, the contents of the unread books.
> Nassim Nicholas Taleb, *The Black Swan*[210]

Foresight is an evolving discipline. Its methods and goals have changed over a long history, and its public profile has risen greatly. But that does not make it an easy task; despite our best efforts, as a society we are often blind-sided by the unexpected, the unknown or the unknowable. COVID-19 certainly proved that point. Despite varied warnings, we did not have the medicines, vaccines or protective equipment we all took for granted. We did not have fast or effective ways to share information and collaborate. We had no immediate response for the toxic turn of "me first" policies that erupted around the globe. And repairing the economic damage, totally unanticipated, will take years of pain.

But we had a food chain that, though it wobbled, basically held together. There was an initial panic about supply chains and food safety; and for the first time in generations the citizens of rich countries thought for a moment about the security of their food supply. But worries about basic supply have since faded, supplanted by more systemic concerns about the effect of economic distress on consumer diet and farm income. The crisis threw a spotlight on a lot of complex, and unstable, relations: between food trade and security, farm income and food supply, agricultural methods and environmental impact, diet and diversity, waste and efficiency. These are relations that, now, require much deeper research – to find solutions, develop new tools, and ensure that the post-COVID world works better than that before the crisis.

For this project, our foresight studies had the unexpected luxury of happening both before and during the crisis, forcing us to reassess our earlier assumptions just as society must do generally. We detailed our observations in prior chapters, but a few conclusions need underlining.

Our system of growing, producing, distributing and consuming food is dangerous and unfair – a danger to the environment and health, and unfair to large numbers of producers and consumers alike. It is an amazing system, in that it has in the EU pushed starvation or undernourishment into a fringe issue affecting a small minority. It has made food safety a given for most Europeans. It has kept millions of farmers, fishers and forestry workers in reliable employ. And it has, through research and innovation, spurred a bewildering array of new foods, new diets, new trends and new possibilities for many citizens. But it has also contributed heavily to global warming, waste, pollution, obesity, chronic disease and social inequality. Research and

innovation must now focus on how, post-pandemic, we can correct the food system's faults without losing its benefits.

To move society, both inside and outside the EU, to a "safe and just operating space" we must apply research and innovation towards effecting at least three key transitions. One is to provide healthy diets for all. This involves consumers making smarter food choices, growers adopting practices that make healthier foods more accessible, distributors and retailers providing – often with digital tools – the means for producers and consumers to do better. A second transition is towards a circular bioeconomy. This involves rethinking the way producers, processors, distributors and retailers interact with one another, to cut waste and boost efficiency, diversity and abundance; and it involves consumers paying more attention to the environmental consequences of their food choices. The third transition is towards a more diverse world – both ecologically and socially. This involves rethinking farming practices, so that we take advantage of nature's natural diversity rather than destroy it. It also involves re-engineering relations between the beginning and end of the food chain, so that in the ever-growing cities – where the greatest burden of ill-health will arise, if we do not act – it becomes easy for people to maintain a varied, healthy and affordable diet.

For all of this, research and innovation can be transformative forces. Research applied to policy can force political change that was previously unthinkable; just consider how climate science has galvanised most world leaders into at least the first stages of action. Research on the trade-offs and lock-ins, the barriers and opportunities, involved in changing agri-food policy can have a similar effect in this domain. It is time for an EU-wide food policy, backed by evidence.

Likewise, research and innovation can directly offer new ideas, technologies and strategies to achieve each of the three needed transitions. Digital technologies, biotech, social and behavioural studies, new financing and technical innovations: these are the normal, expected outcomes of major public research and innovation programmes, whether in Brussels, Berlin or Budapest – and the Commission's well-advanced plans for Horizon Europe will go a long way towards achieving them. In the additional materials to this report, listed in the Appendix and accessible online, we present a long list of specific research topics that emerged through the foresight workshops. But we wish to highlight the need to raise our collective heads above subject specialisation, and coordinate research efforts better across the EU on cross-cutting themes – such as disaster preparedness, social innovation, digital transformation and agro-ecology. At the same time, we need more tools to convert our research into action: new public-private partnerships, networks, international alliances and other ways of connecting citizens, experts, policy makers and businesses across borders.

In the end, this entire report boils down to one word: resilience. Diversity, circularity, health, social justice – all, if properly managed, lead to a safer and fairer world that is less vulnerable to catastrophe. Research and innovation can point the way.

APPENDICES

A. LIST OF EXPERT GROUP MEMBERS AND AFFILIATIONS

Gianluca Brunori (chair), University of Pisa, Italy

Richard L. Hudson (rapporteur), Science|Business, Belgium

Lilia Ahrné, University of Copenhagen, Denmark

Jessica Aschemann-Witzel, Aarhus University, Denmark

András Báldi, Centre for Ecological Research, Hungary

Stefano Bisoffi, independent expert (formerly Council for Agricultural Research-CREA), Italy

Kerstin Cuhls, Fraunhofer Institute for Systems and Innovation Research (ISI), Germany

Fabrice De Clerck, Bioversity International and EAT Foundation

Jessica Duncan, Wageningen University, the Netherlands

Henning Otte Hansen, University of Copenhagen, Denmark

Johanna Kohl, Ministry of Agriculture and Forestry, Finland

Begoña Ruiz, AINIA, Spain

Grzegorz Siebielec, Institute of Soil Science and Plant Cultivation, Poland

Sébastien Treyer, Institute for Sustainable Development and International Relations (IDDRI), France

B. SUMMARY OF ONLINE ANNEXES

As part of their work, the expert members of the group prepared a series of specialist papers on topics related to this report. They were an important part of the process by which the group reached its conclusions, and reflect the expertise of the members who wrote them. They are available online here (https://scar-europe.org/index.php/foresight/documents) for readers who wish more information.

TITLE	AUTHORS
Methodology	Kerstin Cuhls, Fraunhofer Institute for Systems and Innovation Research (ISI), Germany; Johanna Kohl, Ministry of Agriculture and Forestry, Finland; and Stefano Bisoffi, independent expert (formerly CREA), Italy
Macrotrends	Stefano Bisoffi, independent expert (formerly CREA), Italy
Planetary boundaries: the numbers of targets	András Báldi, Centre for Ecological Research, Hungary
Socio-ecological systems of healthy and sustainable food systems	Fabrice De Clerck, Bioversity International and EAT Foundation
Food processing technologies	Lilia Ahrné, University of Copenhagen, Denmark
Digitalisation in agriculture and rural areas	Gianluca Brunori (chair), University of Pisa, Italy
Life sciences in the bioeconomy	Begoña Ruiz, AINIA, Spain
Chemicals in the bioeconomy	Grzegorz Siebielec, Institute of Soil Science and Plant Cultivation, Poland
Social practices related to food	Jessica Aschemann-Witzel, Aarhus University, Denmark
Finance and corporate strategies in agriculture	Henning Otte Hansen, University of Copenhagen, Denmark
Will Covid-19 mean a setback for international trade in agricultural and food?	Henning Otte Hansen, University of Copenhagen, Denmark

TITLE	AUTHORS
Safe and just food systems in an urbanising world: Trends and transitions	Jessica Duncan, Wageningen University, the Netherlands
Changing policies to enable transition: what are the research needs?	Sébastien Treyer, Institute for Sustainable Development and International Relations (IDDRI), France
Sustainable forestry: facts and figures	SCAR Strategic Working Group - FOREST
Sustainable animal production: facts and figures	SCAR Collaborative Working Group on Sustainable Animal Production
Sustainable food systems: facts and figures	SCAR Strategic Working Group – FOOD SYSTEMS
Sustainable fishery and aquaculture	SCAR Strategic Working Group - FISH

C. NOTE ON THE METHODOLOGY

For any policy study, it matters how you reach your conclusions – and so, in this summary note we outline our own methods. The purpose of our expert group, as described in the introduction to this report, was to suggest how society could reach a "safe and just operating space" in the realm of food and natural resources. For this, over more than 18 months, we applied well-recognised foresight methodologies in our research, in a series of workshops with other experts, and in our internal deliberations. A full discussion of this can be read online at https://ec.europa.eu/transparency/regexpert/index.cfm?do=groupDetail.groupDetail&groupID=3619&news=1.

FORESIGHT: A CONCEPTUAL FRAMEWORK

The concept of foresight has evolved rapidly over the past 20 years; some already call it a "discipline". We regard foresight as a systematic debate about different futures[211] - with a long-term view, involving heterogeneous actor groups, and incorporating views of the present and potential decisions of today. As an expert group, our terms of reference highlighted three concepts on which the report should focus:

1. *System approaches*. In foresight work, system approaches look at the interdependency between phenomena, rather than reducing them to their simplest terms and isolating them from their context. System approaches consider the possibility that any action may have

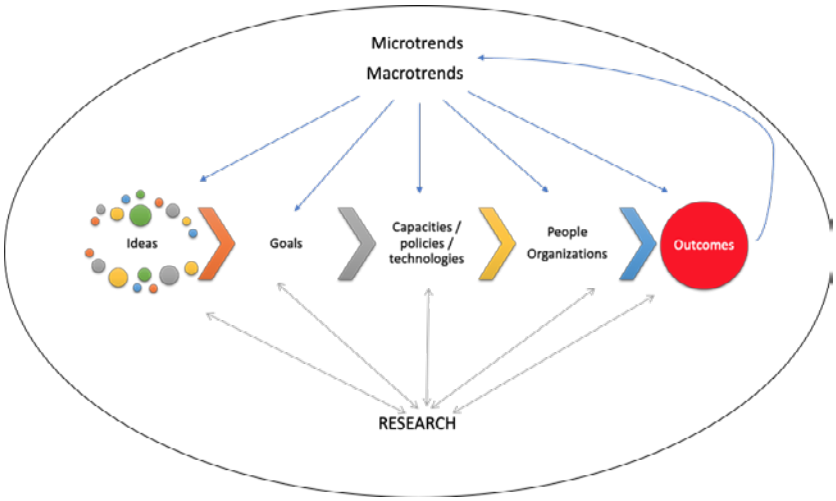
a multiplicity of outcomes. System approaches are particularly relevant when problems – the gaps between the expected and current state of affairs – involve interaction between different realms, such as the social and the biophysical.

2. *Transitions.* A focus of work is analysing and describing how, as a society, we will get from here to there, from our current imperiled world to the "safe and just operating space" we seek – in short, how to accomplish a transition. That requires that we look at the constraints to change. These constraints can be in the *landscape:* the set of drivers affecting the system but not controlled by the system, such as global warming. They can be in the *regime:* the core rules, actors and technologies that regulate the functioning and stability of the system, such as the structure of the agricultural industry. And they can be in the *niches:* subsystems that operate under rules alternative to the ones provided by the regime and that test new solutions to emerging challenges, such as the growth of the organic food sector[212,213]. These three constraints, of landscape, regime and niche, explain why technology alone cannot solve societal problems; the impact of technologies will depend on the social context in which they are embedded, and setting "missions" for R&D can have varied effects[214]. Furthermore, transitions are usually non-linear; and in complex systems, unpredictable major transitions may occur. For any desired transition, "lock-ins" – social or technical barriers to change, path dependencies – must be overcome. As a result, future innovation policies need to consider the whole system in which desired transitions would occur, and concentrate resources where constraints are stronger or opportunities are most promising. Foresight thus draws attention to the potential for change.

3. *Safe operating space.* The concept of a safe operating space was introduced by Swedish environmentalist Johan Rockström and colleagues[215] to help develop policies from the study of the impact of human activities on the Earth's biogeochemical cycles and ecosystems. It considers "alert indicators" and thresholds for these biophysical indicators (called "planetary boundaries"[216]); when trespassed, these boundaries destabilise and harm global ecosystems. In light of the UN Agenda 2030 goals, other scholars have adapted the concept and proposed a safe and just operating space[217] that includes minimum social standards, such as nutrition and health indicators. The recent EAT-Lancet Commission Report[218] provides a quantitative assessment of a number of primary sector-relevant planet boundaries, which may be taken into consideration as targets for the scenarios of the foresight exercise.

With all this in mind, we adopted a conceptual framework showing how ideas, trends, single developments, technologies and other factors interact to produce desired transitions.

How change happens: from ideas to outcomes



This diagramme shows transition to be a complex process. Different *ideas* – ethical principles, visions of the world, scientific paradigms, methodological approaches – lead to different *goals* or interpretations of those goals, such as the UN's Sustainable Development Goals. The different ideas may lead to different solutions in term of *capacities, policies and technologies*. What happens with these ideas and capacities depends on real-world *people and organisations*: lifestyles, business models, organisational patterns. In order to figure out how a goal can be achieved, or the desired *outcomes* reached, it is necessary to imagine how the broad goals (e.g. the SDGs) will be translated into the daily life of people, industry and farms. Some broad inputs also come into play. Our methods thus concentrated on the long-term future but always went back to the present ("backcasting", in the terminology of this discipline) to be able to describe full paths in the end.

Asking the right questions is one of the major tasks in foresight. Here are some of ours when we started.

1. What are the SDG indicators and the available data in Europe?

2. *How to turn SDGs into targets relevant to Europe?*

3. What are the key elements that might be missing in the SDGs?

4. What are the main tensions and trade-offs between competing targets?

5. How fast can change happen?

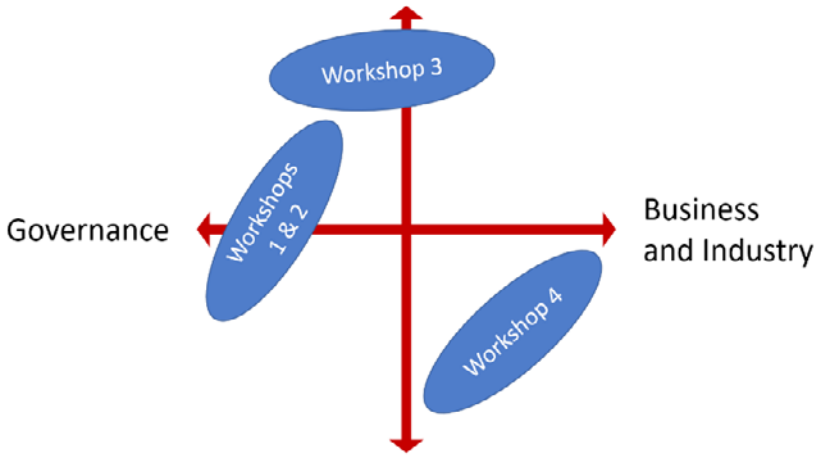
To answer these questions, we began with an analysis of megatrends, macrotrends, and single - sometimes disruptive or newly emerging - developments. Here we made a synthesis of existing foresight exercises[219] and of the drivers chosen, highlighting those that are relatively new compared to past SCAR foresight exercises and highlighting changing priorities. Meta-scenarios from the 2018 BOHEMIA foresight study conducted for the European Commission[220] were used, too. For each broad trend, we considered the main indicators and projections to 2050; the contribution of agriculture, forestry and other land use to the trend; and the impact of land use on the trend, itself. Members of the expert group summarised the findings in "Facts & Figures" papers or essays. (These are accessible online at https://scar-europe.org/index.php/foresight/documents.)

We then examined possible transitions and paid special attention to lock-ins and other obstacles to change, as well as enablers to accelerate change. We used a well-regarded methodology from transition research (the Geels/Schot 2007 model of Multilevel Perspectives) adapted to foresight, as templates in workshops to help identify the systemic nature of lock-in situations, and to discuss how levers of change may be addressed systemically. The multi-level perspective stresses that technological systems change through the interplay between the landscape, regime and niche-level processes described earlier. Regimes tend to generate incremental innovations, while "radically new", disruptive innovations are generated in niches protected from normal market selection. Radical innovations need protection or support because their cost efficiency, technical performance and usability often need improvement, or need to reach a minimum size to be viable.

One of the major barriers to change is the fear that it will be costly. For an individual economic agent, will her or his economic status or well-being after transition be more or less profitable than before? If less profitable, does the difference in well-being have to be compensated by subsidies? Could putting a price on externalities lead to the transition? If, by contrast, profits could be higher after transition, the problem could be in the upfront cost, the opportunity cost, the "valley of death" of an innovation, or the temporary lack of profitability in the first years of a transition (consider, for example, the slow pace of conversion to organic agriculture.) How can the necessary investment be covered by financial actors, insurance, or mutuality mechanisms? A regional development perspective must also be considered. For example, regions phasing out a coal economy have important social costs to consider; they could be lowered through anticipation and requalification of the workforce, on top of other types of social compensation policies. Lastly, the costs of transition should not be considered on average but in their distributional effects: who loses and who wins? It is also important to compare the socio-economic impact of the transition scenario with that of the "business as usual" scenario.

All these questions were brought to a series of four workshops we conducted with other experts.

Workshop participants, by sector



Variable groups of stakeholders attended the workshops. In the first two workshops, most participants were representatives of member state ministries (in general, of agriculture) and of European Commission directorates-general. The third workshop saw a range of experts from different disciplines present facts and figures related to the transitions and targets already identified, while the fourth workshop was opened up to representatives of industry, business, farmers, finance and non-governmental organisations.

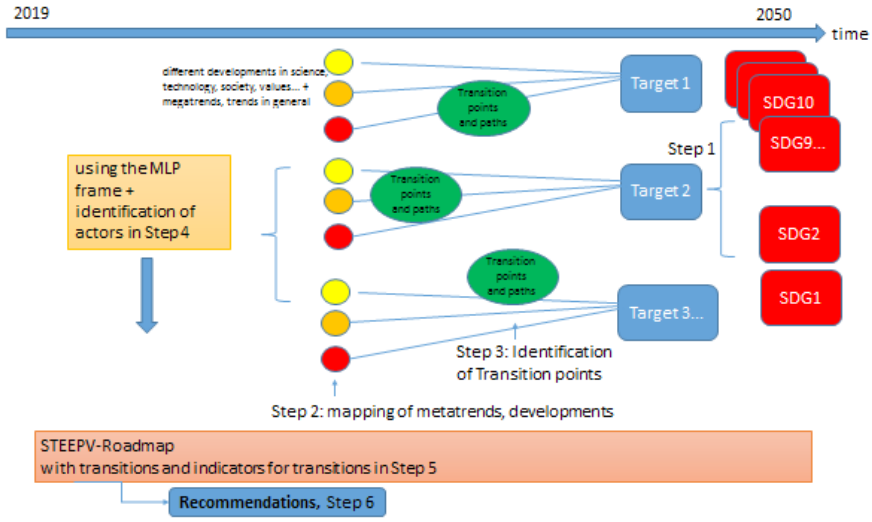
The first and second workshop in May 2019 were conducted together during two half-days and started with the question: *What are the targets derived from the SDGs and other challenges that Europe should set?* As background, information on the SDGs, European Union targets, strategic goals and targets in the literature were provided. In the first half-day, we defined "targets" for agriculture and food, derived from the SDGs. We also looked at driving forces affecting the targets, and the boundaries and limits to action.

We used the SDGs as a sort of puzzle in our first workshop, to understand systems thinking.[221] As the diagramme shows, the solutions can be found where the pieces meet. For instance, achieving "zero hunger" (SDG 2) may require an understanding of "industry, innovation and infrastructure" (SDG 9) coupled with "gender equality" (SDG 5) and also special research of future "life on land" (SDG 15) and "climate action" (SDG 13.) Thinking in terms of a puzzle made us more aware of the possible cumulative impacts, possible trade-offs, but also the possibility of a more nexus-driven future thinking across the sectors and disciplines. Achieving the SDGs require researching future crops, animals, migration, warming climate, forest policy, social policy and much more. Each policy area must be dealt with separately, but also with others in a big picture with a system-level and forward-looking approach.

Solving the SDG 'puzzle'

Workshop 2 examined "*developments to 2030 and 2050 - Scanning general developments, trends, possible game changers and the actors involved.*" The purpose of the workshop was encouraging out-of-the-box thinking, considering different options or alternative perspectives, collecting meta-trends and trends, identifying transformation points, paths and "seeds" for the pathways (first ideas for actors, bottlenecks, enablers).

Charting the foresight process



The foresight process. This diagramme shows the steps involved in the foresight methodology we used. The first step is identifying the specific targets we should aim for, if we wish to achieve the SDGs. Second step is to map the major issues and developments affecting those targets. Third step is identifying "transition points" at which change actually happens. Step 4 entails

identifying who must act to realise these transitions. Step 5 puts it all together into a kind of roadmap, and the final step is to develop recommendations for action.

Workshop 3 followed in July 2019. This workshop started with presentations from the European institutions, SCAR members and scientists to give an overview of recent and upcoming research in the field. From these presentations and from additional expert papers written independently, the groups got input to their discussion at this workshop. The third workshop also served to fill the templates of the previous meetings with more content. Different perspectives from different stakeholders were brought into the discussion when the expert group was expanded with this specialised knowledge. In the first part of the workshop, specialists of different disciplinary areas provided inputs to refine the targets and the sub-targets identified in the first and second workshop. In the second part, participants discussed the transition pathways (each of them identified by a broad target) in three areas: nutrition, circularity and diversity. This time, the focus of the discussion was on the transition points, carriers and barriers for the new paths, and on the role that existing trends or new developments may play.

During Workshop 4 in October 2019, we asked the question: *How to achieve the targets in 2030 and 2050?* The workshop was about matching targets and developments: a focus on business models and social organisation**.** Here we crossed the trends and developments with the targets and identified further transition points and measures. A distinction of our approach from other foresight activities is a focus on the transitions required to get from here to there – and for that, we needed to hear voices from the business world because they hold the key to any change. The discussion was starting with the pre-filled draft roadmaps. Participants had to fill the gaps and discussed the industry supply chain, the lock-ins and gatekeepers, and the new ideas that are (doubtless) being tried in various places. The output was an in-depth analysis of transitions, visions and narratives for business models, social organisation, consumer patterns; lock-ins and trade-offs, identification of consensus and dissent.

Subsequent, internal meetings of the expert group synthesised the varied input and began developing recommendations for a research and innovation programme that could help deliver the desired changed. As described earlier in this report, we believe research can both inform policy changes and catalyse them.

SCAR FORESIGHT GROUP

SCAR REFLECTION PAPER ON THE 5TH SCAR FORESIGHT EXERCISE

November 2020

EXECUTIVE SUMMARY

Since 2007, SCAR develops "reflection documents" on its foresight studies and coordinates the resulting recommendations with the SCAR member states and the EU Commission. Foresight studies are seen as a pillar of the strategic work of SCAR and serve SCAR in its role as an advisory body on research questions in the field of agriculture, food, fisheries, forestry and the wider bioeconomy.

The 5th Foresight Study entitled "Food Systems and natural resources" aims to identify opportunities for a safe and just life, while taking into account the UN SDGs and the fulfilment of the Paris Agreement COP21. It finds that it will be essential to strengthen diversity and circularity to make food systems more robust. In addition, greater attention must be paid to more sustainable and healthier diets as well as to resource management and waste avoidance.

Results and recommendations from the 5th SCAR Foresight shall be used to help implement the Green Deal and the corresponding EU Farm to Fork and Biodiversity strategies and shall provide inspiration for research and innovation in the new framework programme Horizon Europe.

Research is key to achieve safe and just living conditions respecting planetary boundaries. For this reason, appropriate research policy frameworks and conditions must be created and aligned at European and national levels.

The challenges highlighted in the 5th Foresight Study resulted in the following recommendations for an appropriate research policy framework:

1. A research policy capable of triggering an effective and inclusive transition towards a safe and just operating space is optimal. Reaching agreement among European partners for a common vision to build sustainable systems is needed to facilitate a commitment to reform policies.

2. Given the complexity of the challenge, systemic and multi-actor approaches in research have to be generalised and strengthened.

3. Research has to build on systemic game changers; it must be open, inter- and trans-disciplinary and impact-oriented, based on long-term evaluation, and capable of re-framing policy problems.

4. The territorial dimension is crucial for guiding research design while recognising that local and regional levels are appropriate for a manageable circular approach.

5. Social consequences of innovation adoption must be one of the core subjects of research.

6. Directionality should always be applied to research policies, meaning that the European Commission and National Governments should steer research and innovation towards radical transition for the benefit of the public good. These challenges should be addressed across borders.

7. As the COVID-19 pandemic has shown, enhancing food system robustness and resilience should be one of the priorities for future research and, in turn, for the policies supporting it.

8. Diversity of varieties and species, farming systems, food processing methods and supply chains, is what makes Europe special and acts as a source of social, economic and ecological resilience. This diversity should be respected and strengthened, while promoting alignment and harmonisation of research policies.

9. Numerous other policies influence our societies. Correct coordination of their design and implementation would strengthen their effectiveness in promoting the transition towards a safe and just operating space.

10. SCAR, in its position as a link between European countries and the Commission, and as a strategic advisor to both on agri-food research matters, has a key role to play going forward to support the transition and alignment of these policies at European level and beyond.

The new generation of European policies gives us an opportunity to effect these transformations. In particular, Horizon Europe's instruments and approaches such as research and innovation projects (R&I), networks, partnerships, missions and coordination and support actions are available and should be utilised and supported. SCAR will take up the Foresight recommendations in order to continue its role as strategic advisor for SCAR members and the Commission.

1. REFLECTIONS OF SCAR

1.1. SCAR and the 5th Foresight exercise

Foresights are a key pillar of SCAR's activity in the accomplishment of its advisory role for Member States and the European Commission on research themes (priorities, organisation) in the fields of the agri-food and in the context of wider bioeconomy, broadly defined to include agriculture and soils, fisheries and aquaculture, food processing, forestry and biorefineries. Foresight studies are not predictive exercises, but a means to explore possible futures in order to enhance preparedness for expected changes due to current trends, emerging risks and opportunities and unexpected events. The 5th SCAR Foresight focuses on the transition pathways for the primary production sector and the wider bioeconomy. The main goal is to give advice on how to fulfil the UN Sustainable Development Goals (SDGs) and the Paris climate agreement for reaching a "safe and just operating space" for all. The recommendations of the 5th SCAR Foresight exercise will support SCAR in its advisory role at regional, national, European and global level.

1.2. The 5th Foresight – reasons for a reflection paper

The exercise was promoted by SCAR in a period of global commitments aimed at devising a better world for the coming decades and recognising the dangers posed by old and new threats on the very survival of civilisation, if not of humankind.

The Paris Agreement of 2015 put the risk of climate change and the need to take actions for its mitigation on the top of the agenda for almost all countries in the world. The UN Agenda 2030 with its SDGs broadened the scope of international efforts to also include a range of indicators of well-being that represent a minimum floor for a decent living that is a fundamental right for all.

A series of reports by International organisations (UNFCCC, CBD, IUCN, IPBES, EEA, etc.) portray an environmental system that is deteriorating fast, even faster than predicted in the past, from many points of view: Biodiversity is declining at a speed that is of two or three degrees of magnitude than would be normal; the temperature of the earth is already 1°C above preindustrial levels and rising, with net CO_2 emissions (and other GHG) still surpassing captures; land degradation and land use change are widespread and increasing in some key parts of the world, pushed mainly by the expansion of agriculture; pollution and eutrophication are degrading the quality of air, soils and waters.

At the same time, hunger rates are rising again, after more than a decade of decline. In contrast, nutritional requirements for a healthy life are not correct, as billions of people are overweight in both developed and developing countries. Inequalities are rising within countries and, if some

developing countries are catching up with the rich ones, some, especially in Africa, are drifting towards increasing poverty.

The theme chosen by SCAR for the 5th Foresight makes explicit reference to two seminal works that have shaped, and are shaping, the public discourse: it combines the "safe space" concept advocated by Rockström (and the Stockholm Resilience Centre) that is a development within "planetary boundaries", with Raworth's "just space", a world in which basic quality-of-life indicators are secured for all.

A "safe and just" operating space is thus constrained by the need to satisfy basic needs of a just society and the need to do so without trespassing the natural boundaries and real "points of no return" for our world.

During the development of the Foresight exercise, the outbreak of COVID-19, had dramatic consequences, not only on public health but also on economies and social norms. Despite the fact that the food sector was less severely affected than others, remarkable shocks occurred, such as food services closures, labour shortage and trade disruptions (in particular for perishable foods, wine, cheese, etc.). The experts were, therefore, asked to also consider COVID-19, not so much in anticipation of a new pandemic (which scientists say is quite possible) but as an example of the need to be prepared for unexpected disasters of global scale and enhanced resilience of global systems, including food systems. COVID-19, was not the only significant novelty that occurred during the development of the exercise. The European Green Deal (EGD), which sets ambitious but necessary goals for the European Union with a view to reducing its impact on climate change and on the use of natural resources, was launched. The EGD, with its companion "Farm to Fork" and "Biodiversity" strategies, indicates a direction that largely agrees with the findings, and recommendations of the Foresight exercise. This is a very encouraging sign for their implementation in supporting Partnerships and Missions in Cluster 6 of Horizon Europe. SCAR is taking up the scientific recommendations of the 5th SCAR Foresight exercise and translating them into strategic goals and political advice for SCAR members, the Commission and for global dissemination. In addition, a declaration "The Berlin declaration" should be prepared and discussed at the EU Agri-Fish Council.

1.3. Contents overview

Section 2 introduces the transition pathways identified by the experts in the context of unexpected events like the Covid-19 pandemic, the new EU policy landscape and global interconnectedness.

Section 3 explores the implication of the transition for research, with attention to the priorities and to the most important research fields, but also to barriers and opportunities that have been identified at national and European level for the valorisation of research and research results.

Section 4 reflects on the characteristics of a research policy required to trigger and support that research, and to valorise its outcomes, with focus on the potential and opportunities provided by the Horizon Europe framework, while also paying attention to the wider policy landscape.

Section 5 gives some advice, recalling the role of SCAR in this complex and challenging process towards a research policy capable of triggering a transition towards a safe and just operating space.

2. MOVING TOWARDS A SAFE AND JUST OPERATING SPACE

2.1. The complexity of a multidimensional transition

The Foresight exercise process started, with the involvement of external experts and stakeholders, among which were the SCAR members and the SCAR Strategic and Collaborative Working groups, which were consulted at physical and virtual events and through written consultations. The process was also expected to investigate key elements related to the transition, like enablers and lock-ins, costs, the search for win-win solutions and the role of R&I with specific reference to the EU policy context. As already mentioned, unexpected game changers modified the context in which the Foresight was being developed. It was later agreed to address potential crises such as the Covid-19 pandemic and the Green Deal (e.g. Farm to Fork strategy, Biodiversity strategies). This strengthened the need to concentrate efforts on the transition towards more sustainable configurations and ensure the aims and rationale of the Foresight were consistent with them. In particular, the integration of the social justice dimension in the analysis of the transition is one of the elements characterising the European Green Deal.

2.2. The Covid-19 outbreak and its impact on the goals of the transitions

The COVID 19 outbreak has a dramatic impact on all aspects of social, economic and political life in Europe and the whole world, beyond its huge direct impact on the public health and on health services.

The pandemic started after a lot of the Foresight exercise had been carried out. In particular, the three main transitions supporting the transition towards a safe and just operative space had been already identified. Experts and SCAR representatives agreed that the three transition pathways, discussed in the next paragraph, were still valid and even reinforced their relevance and urgency. However, the new situation gave rise to several new thoughts and suggestions; hence the need to include a discussion on COVID-19 in the final version of the report.

Each of the SCAR Groups were given the opportunity to contribute to these reflections with the submission of a set of open questions addressing the most relevant aspects of the COVID-19

crisis in relation to the transition to the safe and operating space. Although the impact of the pandemic has been deep and dramatic everywhere, some sectors, some functions, some regions have been more affected than others and their ability to recover varies, which means each opinion has to be carefully considered.

2.3. The three identified transitions

The overall transition towards a safe and just operating space requires specific transformation pathways. The Foresight exercise, has identified three key pathways:

- moving towards healthy and sustainable diets for all, ensuring availability and accessibility of sufficient, affordable and nutritionally adequate food, in respect of social and environmental requirements

- moving towards circular zero-waste food systems, which implies full circularity in the use of resources through the adoption of a cascading approach and the framing of food production in the wider sustainable bioeconomy vision;

- moving towards greater diversity, seen as a key component of stable systems with enhanced robustness and resilience, reflections on crises as like the recent COVID-19 crises is essential.

The process, which led to their identification, ensures that they not only represent a point of agreement among different scientific observations, but also elements of a shared vision among sectors and countries.

Despite, not being the only possible pathways, the combination of these ensures a wide range of changes that together can substantially drive society towards the necessary transformation and contribute to the identification of specific barriers, enablers, needs and practices and thus the definition of adequate policy recommendations.

The consideration of the three transitions individually and together, prompts systemic thinking, for the identification of barriers, game changers, solutions, synergies but also possible trade-offs, both among them and with other policies and developments. This leads to the need to break the silos in which disciplines, approaches and policies are designed and developed, or at least to build bridges between them.

2.4. The global dimension of the transition

The EU as a political entity, and Europe as a geographical micro-region, are part of a much wider world, which is the level at which any sustainability goal and any related transition must be assessed and benchmarked.

This concern has been widely taken into account in the Foresight process, and is now reflected in the report outcomes, which links reflections and suggestion for transition to the global picture by underlying the need to minimise the export of negative impacts while pursuing sustainability within its borders.

On the ecology side, the replacement of locally produced products with high environmental impacts, by the importation of substitute goods and resultant land use change in third countries may have the effect of worsening the problem without solving it. EU regulation already considers these issues for some sectors (e.g. norms on import of wood deriving from illegal cuttings leading to deforestation) setting standards that have to be met for imported products. However, in other sectors deforestation or greenhouse gas emissions through import flows are still possible. On the social side, the combination of trade and competition policies and practices in a global market (and the need to remain competitive during the transition) may indirectly encourage unfair working conditions, especially in the primary sector.

Both these levels of interrelation require a global response, and a careful management of the interplay among different policies legitimately pursuing different goals (research and innovation, trade, competition, food and rural development just to name some). These ideas will be developed in this paper.

We can anticipate the crucial relevance of the inter-continental and cross-policy level of any transition pathways and related policies, and the awareness that costs and benefits of any decision regarding future re-alignment of the policies will not be equally shared among EU regions and countries. The “just transition mechanism” highlighted in the new Green Deal, reflects these concerns, in the view that no one should be left behind in the transition process.

3. WHAT RESEARCH IS NEEDED FOR THE TRANSITION

3.1. Transition-specific research themes (the three transitions and the Covid-19 lessons)

Considering the limits of growth and taking into account basic human needs for the transition towards a safe and just operating space – the 5th Foresight experts focussed on six physical and five social targets. The physical targets include net zero greenhouse gas emissions and significant reductions of phosphorous, nitrogen and pesticide use by 2050, restoration of biodiversity and ecosystems, and keeping the present level of freshwater use. The social targets

focus on improvement of human health, gender equality, farmers' income, internet access and animal welfare. To fulfil these targets and reach the safe and just operating space the exercise points to the three main pathways: healthy and sustainable diets, circularity including the wider bioeconomy systems and diversity in ecosystems, production chains, and society. To reach these goals, research for transition is needed. It entails research on models, insight into transitions processes, and a deeper knowledge about adaptation to changes.

Nutritious, healthy and sustainable food for all

On the one hand, foods must be sufficient, nutritious, safe, culturally acceptable and affordable, while at the same time they must be produced, processed and otherwise handled sustainably in the food chain. Fish catches must receive similar attention. Research should be directed at a transition towards growing, processing and distributing nutritious food in a sustainable manner. This will involve innovations all along the food chain. New technologies must be applied to support the improvement of existing productions as well as the development of novel foods in order to achieve more diverse, nutritious and sustainable foods.

On the other hand, excessive and unbalanced production and consumption of food may hamper sustainability because they involve the over exploitation of natural resources. This fact should be brought to the attention of consumers and society in general. Better communication strategies must be developed to ensure information regarding sustainable diets is accessible, applicable and utilised by the consumer. R&I strategies should build on place-based innovation towards new ways of constructing food environments and supporting behavioral changes.

Full circularity of food and agricultural, fisheries and forestry systems

The need for a change from a linear to a circular bioeconomy is a key message from the 5th Foresight Exercise. Circularity has to be integrated into all stages of farming, aquaculture, fishing and forestry and their associated industries aiming for a sustainable and cascading use of all resources and zero-waste. Agricultural production is currently characterised by a diversity of systems. Thus, a process is needed which includes research for different transition approaches, depending on the system. The development of diverse and *ad hoc* AKISs at the EU level should accelerate the uptake of transitions. The overall goal is a carbon neutral sector and healthier soils. For forestry, wood should be for long term use, thereby contributing to carbon storage and thus aiding climate mitigation. Large scale, low impact aquaculture and fisheries should be made possible for multiple species of fish, shellfish and algae. To address this, research needs to include a transition to a circular bioeconomy. The biorefinery sector should be expanded and further developed for handling and upgrading of different products and waste from agriculture, forestry and fisheries. Research is also required for new associated organisational models and business models for both the farmers, fishers and foresters and innovative companies while taking into account externalisation costs.

Diversity in food, farm and social systems

An alarming decline in biodiversity is observed at land and in the sea and the uniformity in food production systems and forestry, processors and retailers points to the need for more diverse systems, regarding both nature and society. Biodiversity, in addition to being important in its own right is fundamental to agricultural production and responsible fishing is necessary to maintain sustainable and diverse fish stocks. Different production systems, healthy soils, a wide range of crops and foods, a number of distribution channels and varied and balanced diets will be a basis for resilient, stable and healthier food systems, while also integrating local food production. Research should be conducted to ensure the transition to diversity at all stages of the production chains, including diversity within and between production systems and ecosystem services.

The COVID-19 lessons

The COVID-19 pandemic has been a challenge in several areas, including in the agri-food sector, with unstable food supply chains, increased food waste and the loss of necessary seasonal workers. Overall, it became clear that food security could not be taken for granted. Habits were changed, online shopping increased. In some cases, this lead to more cooking at home and healthy diets, in other cases, people ate more ultra-processed long shelf life foods with little concerns to their health characteristics. Research should be performed based on the experiences from the crisis, to examine the basis for future secure and sustainable solutions for food systems, nutritious diets, the environment, and climate and how to support a permanent change in consumer behaviour. Focus should be on the uptake of scientific results into society and a translation of knowledge into action. Contingency planning of the food systems for future disasters is essential.

While having almost no known direct effect on health of plants, animals for food or aquatic species, the COVID-19 pandemic impact on food systems was significant. Harvests were hampered everywhere as they depended on human labour; transportation became problematic, especially when crossing country borders and for perishable goods and processing plants (especially slaughterhouses and the meat processing industries) became sources of infections due to close working conditions.

The clear message of the Foresight exercise is that both the robustness (ability to withstand shocks) and the resilience (ability to return rapidly to full functionality) of the system should be the priority for future policies and, in turn, of science aimed at supporting them.

Diversification is one element: avoiding putting all the eggs in one basket. Stronger local production is another and the two combine in the need for a better integration of territories, stronger links between urban centres and their rural and coastal surroundings with mutual

benefits. This does not mean ignoring the fundamental role of trade, especially of grains and other bulk products, but to provide alternative sources.

Social research, aimed at the diversification of business models, the reinforcement or establishment of territorial networks (such as the Milan Urban Food Policy Pact) should become a priority both at the European and national level. Important items like food production, marketing opportunities, food safety and security, sustainability, traceability, healthy diets and lifestyles, waste reduction and recycling should be integrated. Working conditions in the farming and fishing sectors and at animal processing plants should also be a priority both for policies and for social research. The COVID-19 pandemic has shown how essential farm workers and fishers are for the welfare of society, but their working conditions (physical, economical, legal) are among the worst in the labour force.

A conundrum has also to be addressed by research: the effects of increased mechanisation, now aided by digitisation, on labour requirements. On one hand mechanisation and digitisation reduces the toil of workers in the fields and improves productivity and efficiency; on the other hand, it may lead to the further expulsion of workers from agriculture. It may also lead to a further disappearance of small farms and fishing boats as these are often unable to invest in expensive modern equipment. Therefore, the social consequences of increased mechanisation and digitisation in farming on the livelihood of rural and coastal economies should be the subject of research.

3.2. The multiple dimensions of research for transition and the cross-cutting research themes

Solutions to the complex challenges for each of the three pathways requires interdisciplinary research and system approaches with multi-stakeholder participation. The same applies to overall combined solutions for the three pathways, taking into account the eleven targets. Importantly, synergies as well as contradictions between research results should be taken into account both within and between the three pathways. The great complexity requires a long timeframe, even beyond the Horizon Europe programme. Basic and more disciplinary research is still an important basis and a prerequisite for solving the more complex problems. Research must be transformative and be based on goals, impacts, responsibility, openness and collaboration and lead to real change. It must provide new products and services but also affect society.

Based on the inter-related problems, the Foresight experts have identified seven cross-cutting research themes. Food, well-being and society focuses on a transition from “having” to “being” and points at research to change the attitude to food and the environment and on how buying and eating habits shape our identities. Social innovation is about creating a sustainable society that is still based on profits, on services and products, but which also incorporates social goals. Agroecology, based on circularity and increased awareness of soil quality and biodiversity, requires further research into both theoretical and practical aspects and ways to scale up

this form of production. Digital transformation of the bioeconomy is rightly expected, just as digital technology has transformed activities during the COVID-19 pandemic. There is a need for research into the optimal use of digital technologies throughout the food chain adapted to different forms of production, including agricultural, aquaculture and fishing practices and taking into account data ownership. Foresights are essential tools to identify, analyse and forecast trends. A foresight exercise is a complicated task in the food sector with need for improvement based on research but still outlines directions of research leading to transformations. Coping with disasters and the need to be prepared when they come in any form became clear at the outbreak of the COVID-19 pandemic. Research is needed to mitigate damage to primary production and society, but it must be borne in mind that focusing on disasters should not prevent planning for solutions to longer term challenges like climate change and biodiversity loss. Finance for transition is a prerequisite, but can be a challenge where the farmer or business owner cannot generate sufficient financing to introduce new technology. Research should focus on developing new economic models to tackle such challenges.

3.3. Challenges and opportunities for implementation of research results at national level

Knowledge exchange is vital in all SCAR members to put innovation into practice. Many efforts have been made, but it is still difficult to reach and involve all the stakeholders. A systems approach, emphasising connections among silos, combined with open discussions with all the stakeholders, should lead to deepening knowledge sharing and cooperation between scientists, industry, and society and policy makers.

Such an involvement requires changes to be made to the current, often fragmented, research funding and evaluation strategies. The SCAR members envisaged two main areas for improvement:

Research programmes should include an obligation for communication, dissemination, and participation targets as part of the funded projects. The translation of scientific results into an understandable language for a broad audience and into adoptable practices for end users, as well as the 'early' engagement of all stakeholders including citizens, have resulted in an increased uptake of the research results. End-users, networks with strong involvement of pioneer adopters, multi stakeholder participatory initiatives, digital support tools and demonstration labs are some examples where this success was achieved. There are still critical issues, such as time availability of interested stakeholders; therefore, tools that make the scientific results more user friendly are necessary to engage as many stakeholders as possible.

Better alignment of the research funding with the innovation policy should overcome current funding gaps for long term, cross sector, or high risk research initiatives and investments and will also lead to more involvement of companies and SME's and more public-private cooperation.

4. THE ROLE OF EU RESEARCH POLICY

4.1. Rationale and principles for transition

For the successful achievement of the three transitions, a wide-ranging research landscape aimed at overcoming barriers and building on game changers is needed. This should be based on a long-term EU wide policy that is updated as necessary.

The report identifies the following key research principles necessary for transition: directionality, collaboration, responsibility, impact-orientation and openness. This requires a research policy capable of promoting these principles, while considering barriers and lock-ins occurring at the national and global level and with special attention to the development of science-policy-society interfaces.

From the SCAR point of view, some of these principles require specific attention and are discussed below.

Directionality means that the European Commission and National Governments should steer research and innovation towards radical transition for the benefit of the public good while taking into account all types of interests in a balanced manner.

Directions for future research can be better identified with the development of forward-looking methodologies and approaches like foresight exercises. An agri-food and wider bioeconomy research foresight culture is already well established at the Commission level, but is lacking in most SCAR members. This needs to be improved as no planning exercise will be effective if horizon scanning is ignored. Foresight is neither trend analysis nor prediction; it is about horizon scanning and indicating how to prepare for future scenarios. Policies (and research policies in particular) that would prepare society in case these scenarios became a reality should be the result.

Preparedness in case of disasters, a lesson learned the hard way with COVID-19, is best built by foresight work. This is now more necessary than ever, given that the next emergency could be totally different, possibly environmental, economic or political, or a combination thereof, and the contingency plans required should therefore be in place.

In terms of collaboration, the inclusion of citizens and interested community groups in policy development must increase considerably at European and National level. Participation in the development phases, of both policies and research priorities, increases the social acceptance of innovations, be they social or technological and helps avoid the failure of scientific results producing a positive impact on society.

Citizen engagement has the added benefit that a broad spectrum of opinions will delve into relationships and connections that might otherwise be missed, either due to a sort of "lateral blindness" or from outright conflict of interests.

Openness of information in research, whereby research findings are made freely available to everyone, is another fundamental principle that should be mandatory for all research funded with public resources, even if carried out by the private sector. It must be acknowledged that the Commission has strongly embraced this idea and that a "sharing" mentality is spreading among researchers with the publication of extensive data sets in addition to scientific papers. This trend should be reinforced by National and Regional funding agencies and research organisations. Research silos also have to be broken if true inter- and trans- disciplinary approaches are to become the norm in research; the main obstacle to it continues to be the boundaries between academic sectors and disciplines, whereby careers are rewarded for remaining loyal to a specialised research area rather than by a courageous blending of competences outside the researcher's main area.

The introduction of the multi-actor approach has been an important change to Agri-Food research projects leading to more open collaborations. For instance, the EIP-Agri with its Operational Groups, although having some difficulties in achieving a balanced mix of partners constitutes a huge step forward in the multi-actor approach. These efforts should continue, and the prospective "Living labs" and "Lighthouses" and research infrastructures, are to be encouraged, supported and expanded to the European level.

Alignment of national research programmes between countries in the frame of Horizon Europe is also advocated in the report. The principle is straightforward: when more than one country faces similar challenges, the most effective and efficient way to address them is by pooling resources, competences and knowledge which results in mutual benefits for all. However, different programming timelines, internal funding rules and national priorities have limited the potential of ERA-NETs, which were started in FP6. The new Partnerships approach in Horizon Europe, building on the experience of Joint Programming Initiatives (JPIs) and other initiatives, should be viewed with interest by SCAR members. The effectiveness of partnership approach will largely depend on its geographical coverage and on strategic investments in resources and competences by partnered countries and research performing organisation as well as the role of the private sector. These can work if there is a sincere commitment to the common goals. However, it is also recognised that this may impact negatively some businesses, but we should not let this minimise our ambitions for transitions. Although, this will require more political and financial efforts to accompany these actors into the transitions ensuring nobody is left behind.

Research policies, shall have to consider the territorial dimension as a main concern. A geographical region is the appropriate dimension for a circular approach to economic development, by integrating waste streams without having undesirable long-range transportation that would undermine the potential benefits. The regional dimension is also appropriate for the development

of innovative rural-urban relationships that increase the resilience of food systems. It also keeps added value locally and avoids exporting environmental damages elsewhere. It has to take into account the preservation of healthy living places.

4.2. Partnering, alignment and collaborations for a common vision of transitions

During the Horizon 2020 framework programme the European research and innovation policy was challenge-driven but with Horizon Europe it will become an impact-driven policy. Being one of the major research and innovation programmes in the world, Horizon Europe, is considered a pioneer programme by the process by which it sets its priorities. By changing focus in 2014 to solve global challenges, Horizon 2020 had the knock-on effect of fundamentally changing the agri-food, fisheries, forestry and wider bioeconomy policy discussions which in turn led to the European Green Deal. The challenge-based approach and the impact driven objectives had an influence on national research and innovation programmes. However, Europe still faces scattered and varied approaches when it comes to agri-food research priority setting at national levels. Moreover, the inter-disciplinarily, cross-sectoral and systemic approach for policymaking is still not to the fore.

The report highlights that it is very difficult to reach agreement among European countries on how to build sustainable agri-food systems and it is more difficult to attempt it at a global level. However, this global agreement is required to encourage individual countries to change their own policies, otherwise economic factors will continue to dominate over environment, climate and social concerns.

The European research agenda should support such a global agreement while taking account of diversity at all levels.

Diversity of national production, processing and research systems is very much driven by national policy decisions. Moreover, the diversity of climatic zones, landscape and cultural heritage adds another layer of complexity to the approaches required to tackle sustainability. Thus, diversity of systems may result in differing approaches within Europe on how to become sustainable. Therefore, an open dialog at a research-policy-societal level should aim to achieve a common understanding on reaching a safe and just operating space.

Diversity can yield positive effects, if the alignment is done properly. Aligning research programs along the common acceptance of scientific results is very important. Due to the lack of agreement on major transition pathways, the European Research Area is, despite its best efforts, not yet fully aligned. The three transition pathways proposed by the report should be placed at the core of a European level agreement and SCAR members priorities. The core element for networking should be built along these three pathways: healthy diets, circular food systems and diverse systems.

SCAR is emphasising the need to build sound multi-actor approaches in sectoral policy development, research and innovation-based partnerships and long-term network building, while influencing national research agendas. Based on its strong reputation, the EU should also attempt to influence other countries world-wide to join its research policy vision for transition.

4.3. Bringing the scientific results closer to policy making and citizens

The Foresight exercise clearly endorsed the challenged based approach and investigated the potential pathways deriving from results at our disposal. It advocates for radical transition stating "change is now needed in food and agriculture – no less than a revolution in the way we farm, fish and eat".

This revolution is needed if we want to prevent major breakdowns in our society and to avoid the exhaustion of ecosystems services which would be deleterious to humankind. The responsibility of avoiding this lies in the hands of policy makers, but also in those of the wider society. The response to the question "Can research spark that revolution?" should be considered in the realisation that neither researchers nor farmers alone will be able to address these global challenges.

Influencing private sector needs and public sector demands should be driven by a deep systemic change and long-term rethinking of how we wish to govern our society. This reframing should be based on research findings, and politicians should not delay incorporating these findings into the core of decision making. These research and systemic outcomes should support the development and alignment of policies for the three pillars of sustainability.

For a more impactful agri-food and bioeconomy research policy, it is necessary to bring the research funders actions closer to the sectoral interests and political priorities, through a method of co-creation at national and European level.

Transition requires strong understanding, awareness and engagement of the citizens. Thus, the impact of scientific breakthroughs should be communicated to them better. New instruments might be required to translate and explain the research results. At the same time, the trade-offs and tensions generated by the transition should not create a negative impact, particularly on the most vulnerable groups. As the report clearly shows that this is a Europe wide possibility, research policy should highlight potentially harmful impacts of the transition.

Research policies of the future should go hand in hand with other policies.

4.4. Beyond research policy: a policy landscape for the transition

The EU policy landscape goes far beyond research and innovation. All EU policies are inevitably interconnected in their influence on the real world. A fragmented approach to their design and implementation would make them less effective and less efficient, potentially resulting in a waste of time and resources.

The report identifies some key EU policies that, alongside the agri-food research policy, are particularly relevant for the achievement of transition-oriented research goals, they are the CAP, and the environmental, food, trade and competition policies. These and other policies and regulations (like the CFP and Health policy for example) respond to perfectly legitimate and worthy ends, but not necessarily always in line with the perspective of a transition towards a safe and just operating space. They can be levers of change, but can also act as lock-in factors, or pushing in different directions, strengthening or limiting the transformative potential of research and innovation.

It follows that their design and implementation must be considered in relation to all research policies and strategies, so as to minimize trade-offs and avoid the risk of having different policies following different ideals and potentially conflicting with each other. Existing tools and opportunities for enhancing, coordinating must be strengthened.

Moreover, a reflection on future research policy must consider the extent to which these policies can be reformed in the light of the needed transitions, and the role that research can play in supporting this process. Separating general policies from research policies is neither advisable nor possible and would contradict the wish for coherence, launched by the Commission.

Undoubtedly the CAP has reached important goals to date, however some of its current policy directions may hinder rather than promote a transition towards a safe and just operating space. It is not an easy task to promote an agricultural landscape capable of providing sufficient, affordable and healthy food while also supporting a sustainable food system and bioeconomy. However, all these goals must be pursued together, and this is possible through a carefully managed coordination with research policy. This is an overarching concern which goes beyond the CAP and CFP. It should also incorporate synergies between Horizon Europe and all the European structural and investment funds.

The trade and competition policies are cornerstones of the EU economy, and of the EU economic relations with the rest of the world. The report indirectly suggests that, as these policies are expected to regulate existing socio-economic configurations, they tend to manage the current situation and to strengthen existing successful models, rather than looking at risks and opportunities related to possible futures. In other words, free trade and market competition, as currently shaped by EU and global policies, set the scene for a day-to-day competition which is not always optimal for the search of alternative solutions. A transition which is expected

to be safe and just requires integration of these policies with a research policy capable to promote and explore new approaches and practices. It constitutes an opportunity to increase the portfolio of options and the diversity in production methods, business models and market arrangements.

In the light of these elements, some questions arise on how all these inputs and needs for transition can crystallise and contribute to shaping clear research agendas, to define efficient instruments and applicable supporting policies.

5. RESPONSIBLE ADVICE AND DECISION

SCAR, in its position as a link between European countries and the Commission, and as an advisor to both on agri-food research matters, made it very clear that the status quo is not an option when it commissioned the 5th Foresight exercise. The current status is neither "safe" from an environmental point of view nor "just" from a social point of view and therefore the need for transitions to a "safe and just operating space" is non-negotiable.

The first step towards a "transformation" is to agree that it is necessity; once this consensus is achieved, the debate can focus on the most efficient, equitable and quick way to achieve it and dispense with debating if it is needed or not.

SCAR agrees with the Foresight exercise recommendations on the best pathways to take. The three transitions resonate well with the European Green Deal, the Farm to Fork and the Biodiversity strategies. A common approach to sustainability is required despite differences between national policies on how to tackle the related issues.

Historically policies were mainly driven by the economy. Nowadays, European and National policies are moving towards an increasing regard for planetary boundaries and climate change but with significant discrepancies between countries. Countries which do not consider yet climate change as an urgent matter should increase their efforts to align with the European policies.

The 5th Foresight exercise attempts to provide evidence-based targets and transition pathways. Consequently, this SCAR reflection paper draws attention to the need for a consensus on the most urgent policy steps to build up a sustainable European agri-food system. In addition, SCAR advises a consistent construction with a further development of an inclusive ERA based on the principle of "leaving no one behind".

A transformative research and innovation policy is a prerequisite to return to living within planetary boundaries. Research and innovation are key to improve modern society. The report identified that the challenge does not only rely in finding more results, but in the acceptance of

these findings and on agreeing where to go to by 2050. Alignment of policies should happen as soon as possible while allowing for diversity of systems and exploiting all sources of knowledge.

There is a need for European countries to continue with the work of SCAR and to dedicate energy to accompany the transition and alignment of policies at European level and beyond.

The Foresight exercise shows the importance of a European wide organisation for reaching an agreement on direction. SCAR will take up the Foresight recommendations in order to continue its role as strategic advisor for SCAR members and the Commission.

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Appendix B: Methodology

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There have been four such SCAR foresight reports since 2007 – looking at the challenges facing agriculture overall; resilience and crisis in agriculture and food systems; resource scarcities; and the bioeconomy. Each has led to new EU initiatives to address the issues raised. This fifth report takes a somewhat broader view, reflecting the mounting urgency of our food, agriculture, environmental and health problems. The focal point: How to get to "a safe and just operating space" for society, through better management of natural resources and food systems? The report focuses on ways and develops recommendations for a research and innovation programme how to achieve three main transitions: 1) sustainable and healthy diets for all; 2) a circular bioeconomy; 3) diversifying agriculture and food systems. More knowledge and better policies in these three transitions will lead to a more resilient EU and global food system.

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