Food Transitions 2030

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How to achieve the transitions to a sustainable, affordable, trustworthy and high-quality food system in the next decade or two that will fulfil the needs of a diverse and growing world population.

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Index

Introduction	5
Rationale	7
Nutrition for sustainable and healthy diets	13
Climate smart and evironmentally sustainable	31
Circularity and resource efficiency	41
Innovation and empowerment of communities	51
Intertwined implementation	59
Colofon	63

Introduction

Given the current and future needs of the human population and the finite resources our planet can provide, we will need to transition from the current unsustainable food system to a healthy, circular and resource-efficient paradigm. These transitions will be hugely complex, since the multiple aspects of food production and consumption are closely interconnected and changing one aspect can easily have major unintended consequences. Yet the transitions are urgent and must be driven by science as well as values. Therefore an integrated vision is proposed characterised by four objectives, which are to be pursued through eight scientific approaches combined within a matrix.

> Complex transition processses are urgently required to ensure a circular and resource efficient food system that provides the healthy food that billions of people need for their wellbeing.

The subjects of potential public-private partnerships in which transdisciplinary consortia are encouraged to collaborate can be found at the crossroads of various objectives and approaches. The extent and complexity of the tasks at hand demands a coordinated action that will include all stakeholders: the Food System Transitions. This should be a joint undertaking of industry and public partners committed to implementing a better system. In many ways, Europe is uniquely well placed to be at the forefront of these transitions and must take a lead in the years to come.

A key aspect of the vision is its multidisciplinary nature. This allows policy makers, funding agencies, researchers and programme managers to work on one dimension while remaining aware of how their work contributes to the whole, identifying any gaps and managing the balance. In keeping with this, the document can be read from front to back: however, its matrix approach means that readers who wish to do so can also focus on specific challenges or scientific approaches.

Rationale

Food and drink are essential to our survival, health and wellbeing, while also being important sources of enjoyment. They are a major part of every culture and are strongly associated with many social interactions. The provision of sufficient and high-quality food to every individual worldwide can be seen as a moral obligation—however, the production of food by definition interferes with the ecological cycles of the planet.[1] The combination of a rapidly growing global population with the accelerating pursuit of higher incomes has led to industrialised food production systems that deplete natural resources, pollute the environment and marginalise farmers and labourers. At the same time, many current food producers lack the tools, labour and entrepreneurial skills to produce a surplus, and population pressure has broken down traditional fallowing and grazing systems. Fewer and fewer people are left in rural areas to feed the growing cities. However, although some may be nostalgic for an idealised past, there is no turning back: we need a paradigm shift in order to produce and distribute enough affordable nutritious food in a sustainable way. There is no silver bullet: agriculture and food production are continuous local adaptations of general ecological and socio-economic rules.

> The need to provide enough high-quality food for the growing world population in a sustainable way is a challenge that will require multiple solutions.

When it comes to food-related topics, change can be difficult. While eating patterns have never really been stable due to migration, urban life style changes and diffusion of new foods, food remains intimately linked to identity. Moreover, once it is ingested, it can often not be easily expelled if something goes wrong. Evolution has taught us to be cautious about what we eat. The reluctance to accept new food, high-tech products or foodstuffs for which their safety cannot easily be gauged by consumers (even if scientifically proven) is therefore perhaps only natural.

> Solutions must be adopted and appreciated in societies, trusted by consumers and economically viable.

1 Fresco, L.O. Hamburgers in Paradise, the stories behind the food we eat. Princeton, Princeton University Press 2016

Trust in science, government and the private sector is eroding. The agricultural and food sectors can only regain this trust by giving absolute priority to nutritional quality, food safety and sustainability.

Any solutions need to be feasible on a relevant scale. Food products must be affordable for the majority of consumers. Given the small profit margins on food products, this is in itself a significant challenge. As long as the industry is focussed on maximising short term profits, innovations that require investments with long payback periods will not be readily implemented, even if societally desirable.

> In Europe the circumstances are right to guide the rest of the world towards a sustainable food system.

Europe and the European Union have an important role to play in the transitions towards a more sustainable food system and production of healthier food. European governments, producers and consumers are very aware of the need for change, both in Europe and elsewhere. The availability of state-of-the-art science and technology in the food, agriculture and health domains, the diversity in dietary traditions, climate conditions and production systems, and Europe's sophisticated system of governance in terms of public values like the environment, nature, biodiversity and health make the continent an excellent living lab for future food systems. This provides interesting opportunities for European industry to innovate and develop new markets.

Goal

The aim of this vision paper is to provide a structure for a large-scale systematic and integrated research and technology development effort to design new food systems so as to improve the health and wellbeing of the world's population, as well as new opportunities for the agriculture and food sectors and associated European industries to implement these solutions in Europe and worldwide.

Results

The results provide contributions in three dimensions: bringing the availability, quality and safety of food for everybody to the level required to ensure good health and wellbeing; improving the sustainability of the agricultural and food sectors (including environmental and societal impact, animal welfare, etc.) as quickly as possible; and building flexible food systems so as to adapt to changing ecological and socio-economic conditions.

Structure

The background document of the Food 2030 High-level Conference[2] defines four challenges that need to be solved to secure a sustainable, high-quality food production system:

1 **Nutrition** for sustainable and healthy diets
2 **Climate** smart and environmentally sustainable food systems
3 **Circularity** and resource efficiency of food systems
4 **Innovation** and empowerment of communities

Although they are often phrased slightly differently, there is worldwide agreement on these four aspects. They are prominently included in the Sustainable Development Goals of the United Nations[3] and many similar plans. Formulating objectives is the first step to resolving them; defining the methods to follow is the next step.

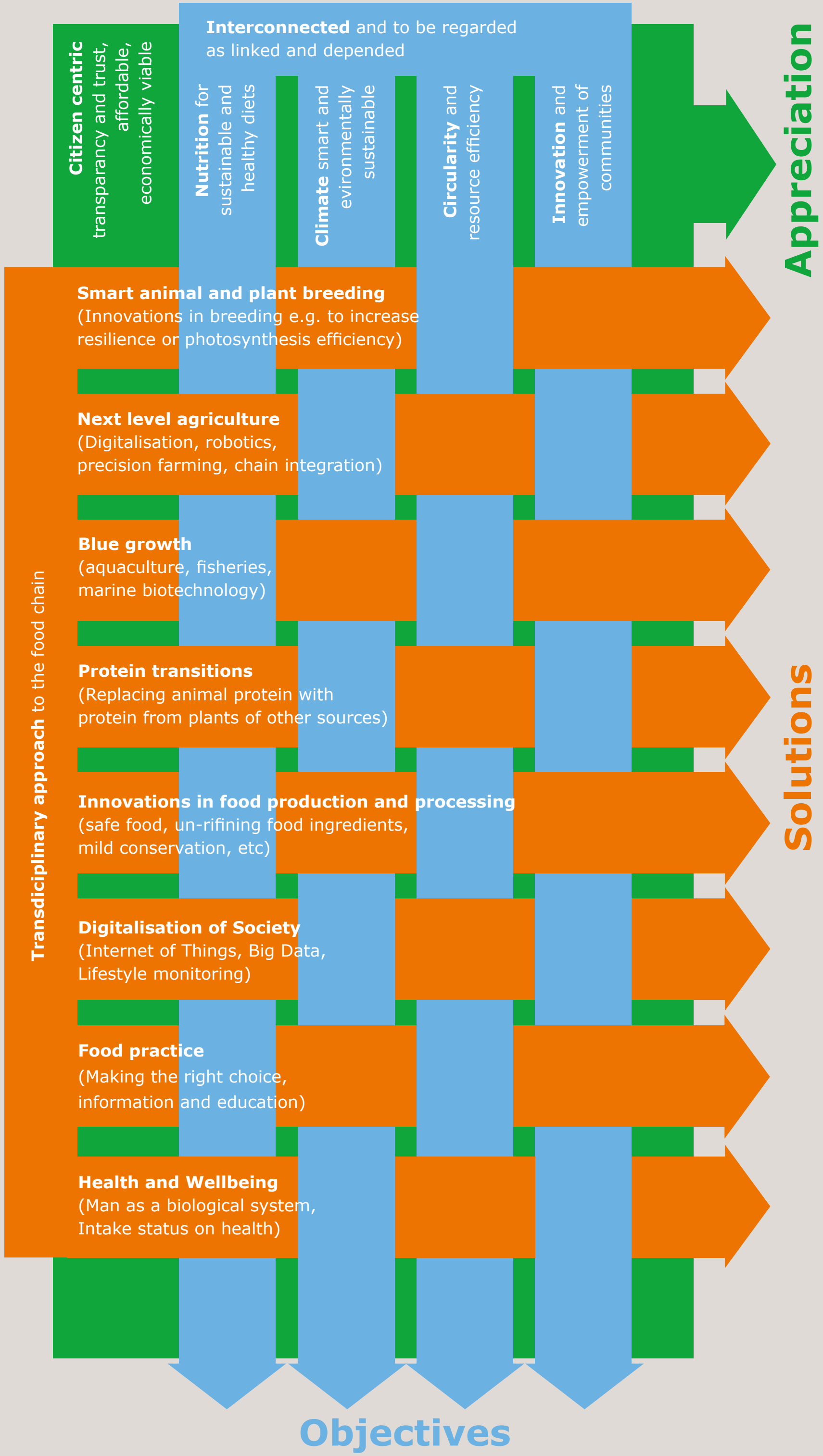
> Four objectives have been identified. They are pursued in eight directions to provide the necessary solutions.

There are eight developments in modern science that are particularly relevant to addressing the objectives:

- Smart animal and plant breeding (optimising genetic pools; innovations in breeding techniques; enhancing photosynthetic efficiency)
- Next-level agriculture (use of certain key enabling technologies in primary food production, respecting and making better use of biodiversity and natural resources (e.g. soil) for improved growth and resilience)
- Blue growth (making better use of freshwater and marine resources)
- Protein transitions (a more sustainable production of animal proteins or their replacement with proteins from plants and other sources)
- Innovations in post-harvest food production and processing (un-refining food ingredients, return to basic molecules, full utilisation of harvested biomass for feed and food)
- Digital societies (utilising the information available in the Internet-of-Things era)
- Food practice (consumer empowerment, dissemination of information, choices about, and interaction with, food, social innovation)
- Public and global one health and wellbeing (food safety and personalised nutrition and health, including attention for zoonotic diseases, food safety and mycotoxins)

2 ec.europa.eu/research/conferences/2016/food2030/pdf/food2030_conference_background.pdf

3 www.un.org/sustainabledevelopment/sustainable-development-goals/



The intertwined structure of the objectives and applicable science is shown in Figure 1.

> The subjects for interesting PPPs can be found at the intersections of objectives and solutions.

The four challenges cannot be resolved in isolation. They are interdependent, i.e. partial solutions should not be detrimental to others, as indicated by the vertical connector on the left. Likewise, the research fields are also connected through an interdisciplinary systems approach. At the intersections of the horizontal and vertical arrows, research activities emerge as opportunities for public-private partnerships to develop new product × market combinations or boost acceptability by society and involvement of consumers. A discussion of each of the four **challenges** follows below, with examples of issues that can be resolved by the eight **scientific approaches.**

Figure 1

The **challenges** in our food system are intertwined with **scientific approaches**. Topics for cooperation are identified at the intersections. The **appreciation** of results by society must be considered everywhere.

Nutrition for sustainable and healthy diets

This challenge aims to produce sustainable, sufficient, safe and nutritious food products. It includes four sub-challenges: 1) to produce enough food and make it available to everybody; 2) to make sure it has the correct nutritional value to sustain health and wellbeing; 3) to make sure it is safe when consumed for prolonged periods; and 4) to achieve all these goals sustainably.

In 2050—when the world population will have grown to about nine billion people—the increase in welfare and the demand for better food quality will mean that food production needs to increase by 60% compared to its 2007 level.[4] In many, if not all, areas, the available land area for food production is decreasing rapidly due to competition with urbanisation and other uses, nutrient depletion, soil degradation, water scarcity and climate change. In some places average day and night temperatures are rising. Rising sea levels may cause flooding or salinisation of coastal regions and (usually fertile) deltas. Higher temperatures combined with irregular rainfall represent a challenge for current arable cropping practices in the Middle East, North Africa and parts of sub-Saharan Africa. Climate change may, however, also allow an expansion of agricultural areas in the higher-latitude regions of Europe, North America and Asia, or at higher altitudes. In such a context, flexible resource use efficiency optimisation become the new focus.

> The first objective is to supply enough healthy and safe food for the growing and increasingly wealthy world population in a sustainable and resilient way.

The '**Breeding**' approach in Figure 1 basically addresses sub-challenges 1, 2 and 4. It builds upon current understanding of how the biochemistry of plants and animals functions and how they defend themselves against pathogens. New, sophisticated breeding methods in combination with novel genetic and gene editing technologies like the CRISPR-CAS system speed up the breeding process, enhance

4 Alexandratos, N. and Bruinsma, J., World Agriculture towards 2030/2050, the 2012 Revision, FAO, 2012

Breeding methods, both traditional and novel techniques, allow crops to develop that are resilient to pests or changing conditions.

product quality and allow the development of crops and animals that are more tolerant to drought, pathogen pressures, heat stress and soil salinity. In addition, better characterisation of biodiversity increases genetic options. More fundamental breakthroughs in primary production come from enhanced photosynthetic efficiency, well over the current 10% or less of its theoretical maximum.[5] Recent scientific breakthroughs have shown that improving photosynthesis is a very promising route to producing crop varieties with better yield in terms of food, feed and biomass.[6] Breeding is of little use if crops and animals are not incorporated in optimised management systems, but it can still contribute to greater resource use efficiency, such as increased water or nutrient uptake.

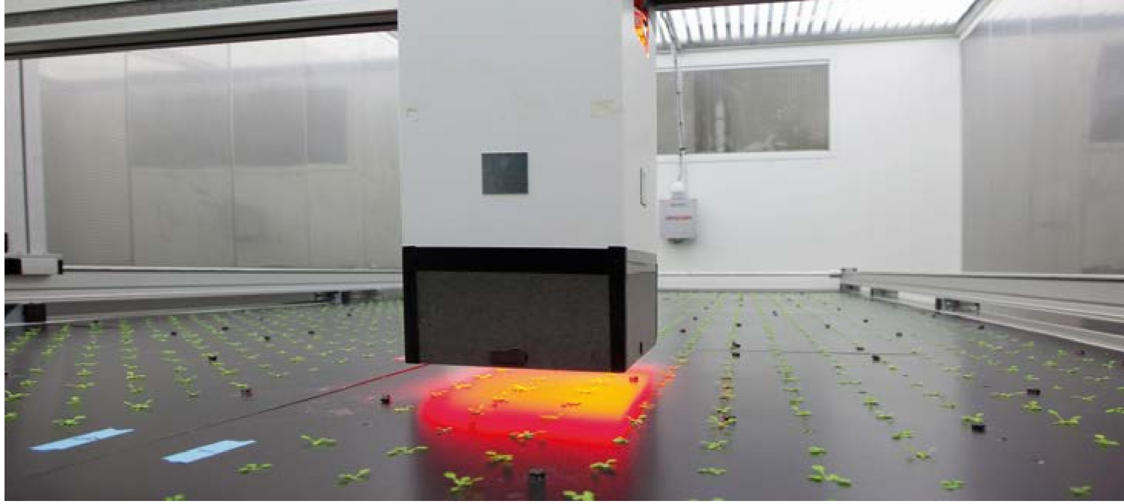
These techniques can also make crops healthier or reduce allergies.

Gaining insight into the interdependence between health and food provides opportunities to increase nutritional value and reduce the levels of undesirable components in food products for specific societal groups. Golden rice, which has increased levels of pro-vitamin A, is an early proof of concept for such an opportunity, as are apple varieties with reduced allergens through targeted elimination of specific genes. Similar approaches can be used to modify energy content through the reduction of fatty acids or increase in dietary fibre. Such advances rely heavily on improved knowledge of satiety inducers, resistant starch synthesis, etc.

The sustainability of primary food production increases when plants and animals are better adapted to ecological interactions and less susceptible to pests or diseases, reducing the need for pesticides and drugs while simultaneously reducing losses before and after harvest. The ongoing evolution of pathogens means that flexible strategies are needed. At the post-harvest stage, new genetic techniques can adjust genes that are responsible for the first steps in the spoiling process of food products, increasing shelf-life and reducing food waste. In animal production,

5 Ray, D.K., Mueller, N.D., West, P.C., and Foley, J.A. (2013). Yield Trends Are Insufficient to Double Global Crop Production by 2050. PLoS ONE 8, e66428

6 Improving photosynthesis and crop productivity by accelerating recovery from photoprotection J. Kromdijk et all, Science 18 Nov 2016: Vol. 354, Issue 6314, pp. 857-861



sophisticated breeding of plants used for feed may reduce the output of methane from animal husbandry. It is necessary to monitor unintended side effects, e.g. increasing the consumption of vegetables by reducing their bitterness may make them less healthy and also less resilient to pests (bitter substances are often natural pesticides).

The introduction of new production technologies requires new crop varieties and animal breeds. To select the best combinations as early as possible in the process, it is necessary to set up **safe-by-design strategies** which entail integrated risk assessment tactics so as to reduce the burden of today's pre-market assessments.

It is essential to address societal issues to make certain solutions acceptable.

In the past, advanced breeding using genetic modification has been a source of widespread misunderstandings and has encountered fierce opposition, especially in Europe.[7] There is urgent need for the regulation of novel methods like CRISPR-CAS, cloning and precision breeding. From a scientific perspective, and given the challenges of future food production and their use in competing economies outside Europe, it is not feasible to ignore these technologies altogether. However, a social dialogue between governments, science, the private sector and consumers must accompany their introduction to determine what products will be **acceptable** and under which conditions.

7 The GMO Stalemate in Europe, Editorial by Louise O. Fresco, Science magazine, 22 Feb 2013

Next Level Agriculture and food systems make use of advances made in other disciplines and applications. The Global Positioning System (GPS) (originally developed for military applications), combined with smart sensors on agricultural machines and drones, allows for high-resolution precision farming in which water, fertiliser and pesticide use is optimised for the needs of individual plants. The addition of autonomous farm machines may make more efficient and sustainable systems like intercropping economically feasible. The declining workforce in agriculture in industrialised and urban areas can thus be counteracted by automation wherever hazardous, dull, heavy or dirty work needs to be performed, freeing up the intelligence, flexibility and versatility of humans for more demanding and appealing tasks. Such key enabling technologies can make the sectors attractive once again to young entrepreneurs. This can result in new varieties of crops and animals with

> Providing optimal conditions for each individual plant or animal will make the primary production system even more efficient. These concepts are only economically viable if they make use of automation and robotisation.

favourable characteristics, synchronous development, ripening uniformity, etc. that are compatible with automation.

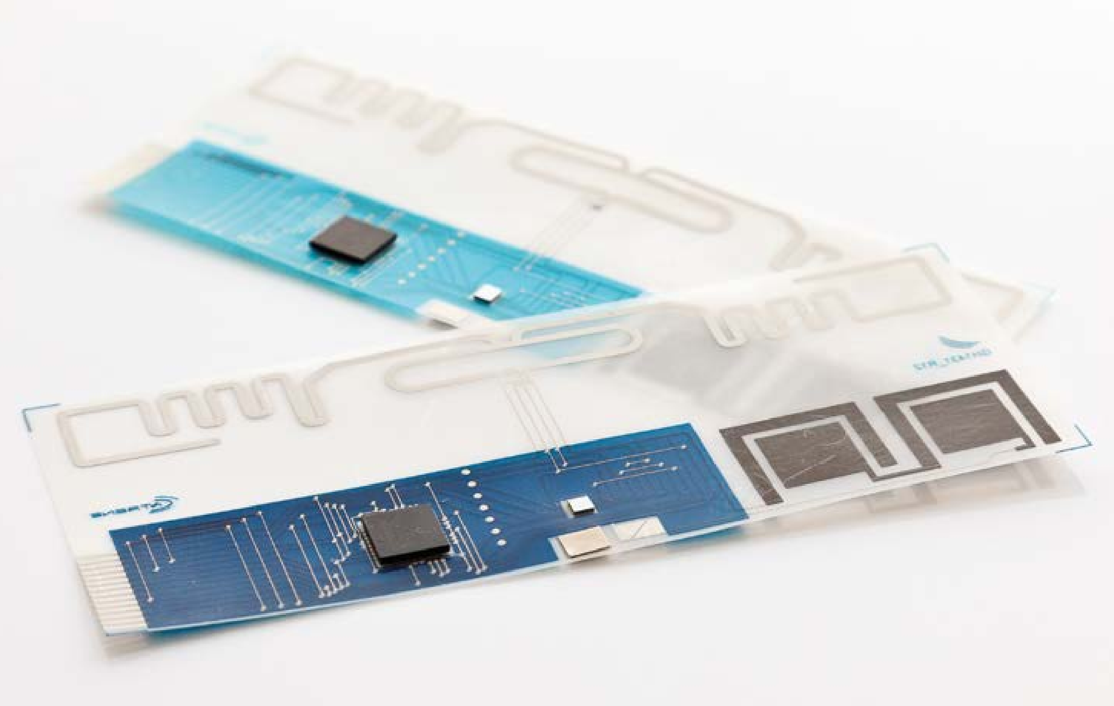
Most people will live in metropolises where opportunities for food production are limited and underexploited. It will be necessary to implement vertical farming with specially designed crop varieties in semi-artificial climates and light conditions. Vertical farming is possible within horticulture, aquaculture and aquaponics.[8] Conventional rooftop production systems will require further adaptation to better cope with urban microclimate stresses such as wind.
Next Level Agricultural systems can be made more effective since the need to adapt to the human scale or conditions compatible with human labour becomes obsolete. For instance machines can be made small and lightweight in order to prevent soil structure deterioration, and they can be designed to reach much higher and carry heavier loads than humans; a fully automated food packaging line can run in the dark, near or below 0 °C, or in a modified atmosphere. This would also eliminate the human factor with respect to hygiene, reducing contamination and increasing safety.

> The applications of key enabling technologies will not only make Next Level Agriculture more economically sound; it will also trigger paradigm shifts that will make production systems more efficient while providing solutions for the declining workforce in the relevant sectors and making them more attractive to young people.

In the dairy sector, milking robots have proven their added value for the welfare of farmers and their cows, and have allowed for increased production. Many other tasks can also be automated in Precision Animal Production systems. Sensors can monitor and communicate, in near-real time, the status of production systems in combination with models that accurately predict the effects of interventions on the quality and quantity of the end product.

Micro and nanotechnologies provide cheap, accurate and reliable methods to measure a wide range of parameters. The resulting Internet-of-Things applications—especially in agriculture and food processing—provide a higher level of control that will soon become available at low cost, just like mobile smartphones have near universal penetration. Sensors will, for instance, become capable of detecting emerging diseases or pests and triggering an immediate

8 aquaponics.eu



response. Data on storage conditions in combination with quality deterioration models will allow optimal consumption periods to be determined for fresh food products. Combined with smart packaging concepts—in which ultra-low-cost sensors are integrated in packaging materials—and smartphone-based food analysis,[9] food product quality will be monitored throughout the chain and waste minimised, provided the **socio-economic factors** are addressed.

The Internet of Food & Farm 2020 (IoF2020) project accelerates the uptake of Internet–of-Things (IoT) technologies within the European farming and food chains in view of strengthening their competitiveness and sustainability.

The core of the project is organised around five trials. These cover five sectors (arable, dairy, fruits, vegetables and meat), while involving end users (e.g. farmers) and IoT developers and demonstrating innovative IoT solutions and their application in the farming and food sectors. To showcase each of the trials, the project is organised around 19 cases.

9 www.foodsmartphone.eu

The digitalisation or *datafication* of the food chain will allow for much more elaborate and accurate management of product quality right to consumers' homes.

Advances in new high-tech materials range from greenhouse coverings with precise and even tuneable light transmission properties (linked to crop-specific/developmental stage-specific requirements) to anti-fouling surfaces in food production. The application of such materials not only makes food production more efficient and safe, but also contributes to sustainability by enabling more energy-efficient production or reducing the need for detergents.

One of the main challenges in the application of high-tech and other key enabling technologies in agriculture and food is **economic viability**. In Europe's poorer areas and non-industrialised countries, it is essential to focus research not only on sustainability, but also on **affordability**, even if cost prices decline.

To unlock the potential of the 71% of the planet which is covered with water, we need a strategy for so-called **Blue growth**. This involves increasing the understanding, investigating the possibilities and developing the opportunities for freshwater, brackish and marine systems to contribute to the production of high-quality and attractive food products as well as the production of feed, bio-chemicals, energy and other valuable products. The development and utilisation of coastal zones and deltas has increased, leading to further major socio-economic and environmental changes—a trend which is expected to continue in future.

Given the fact that the largest part of the world's population lives near shores, there is enormous potential for marine ecosystems to contribute to the production of food. These resources must, naturally, be developed responsibly.

Historically, the use of marine resources has predominantly been limited to fishing, which in essence is the hunting of free-ranging animals. Increasing production capacity by keeping the animals in confinement at locations where conditions are good and harvesting is easy is a logical next step. Aquaculture, developed in a variety of regions, is the fastest-growing subsector of the food and agriculture sector. New sources of protein and oil for fish feed are necessary to avoid the over-exploitation of forage fish. Future developments rely on microorganisms, still poorly understood. New technological solutions are called for to ensure sustainability and animal welfare and control pathogen pressure. Smart husbandry systems enable efficient breeding, feeds and feeding. The combination of aquaculture with horticulture in aquaponics results in a system which is efficient and in which water and nutrients can be controlled, especially in regions with limited precipitation.

Coastal regions contain other resources which have largely been overlooked so far: seaweed and algae. Marine plant production is most interesting because of spectacular growth rates: due to being suspended in water (no need to counteract gravity), they contain fewer poorly digestible fibres like lignin while retaining high nutritional content. Except in South-East and East Asia, seaweed is currently mainly harvested at locations where it grows naturally. Research into production on an industrial scale is needed, while post-harvest processing must be developed to improve animal and **consumer acceptance**. More work should also be devoted to food composition and possible toxicities.

Micro and macroalgae and other marine organisms are efficient, sustainable producers of pharmaceutical compounds, with the potential to partly replace the petrochemical industry. Linking to the ‘Breeding’ approach in Figure 1, marine biotechnology production can open new fields, especially in the context of food versus fuel where marine systems might provide viable alternatives to current land use.

The production of meat is a complex process. Not only is plant protein generally converted into meat protein at a poor rate, the method also requires larger amounts of reasonably clean water. Although animal manure is an important source of nitrogen and phosphorus for crop production and of organic matter that contributes to soil fertility, in many intensive production systems it is regarded as waste and associated with environmental pollution. Finally, beef and dairy production is associated with emissions of the greenhouse gas methane. At the same time, animals can also be a part of sustainable land use thanks to their capacity to recycle plant waste and potential to unlock nutrients from marginal areas that would otherwise be unusable. Grazing by animals is essential to maintaining ecosystems and landscapes. Although alternatives are being developed, it is crucial to modernise ineffective animal production systems.

Because of the poor sustainability of meat production, other production methods or alterna-tive protein sources must be included in the diets.

Protein transitions are new processes to make high-quality proteins more readily available to humans, either by producing animal feed solely from protein sources which are unavailable for humans, by turning plant proteins directly into a product that closely resembles real meat, or by partially substituting plant proteins for animal proteins. This is especially compatible with flexitarianism (selective and limited meat consumption), which thus becomes a sustainable alternative saving land and water resources.

New protein-rich products as alternatives for meat need to be assessed for their short and long-term effects on human health. Reduction, or even elimination, of animal protein from diets may have beneficial effects, but protein from non-animal sources do not always contain the entire range of amino-acids available in meat, or contain them in different ratios. Vitamin B12 and iron are essential elements which are abundant and highly bio-available in animal products, but far less so in plants. Protein of animal origin is generally

One of the alternatives are meat re-placement products based on plant proteins. Others are proteins from insects, seaweed or algae.

10 “Dietary protein quality evaluation in human nutrition”, Report of an FAO Expert Consultation, (2013), ISSN 0254-4725, FAO FOOD AND NUTRITION, paper 92

The health effects on specific social groups of diets based on protein sources other than meat must be assessed and understood.

characterised by a much higher nutritional quality than protein of plant origin.[10] Although vegetarians and vegans have demonstrated that a lifestyle without animal protein is feasible, questions remain as to whether this can hold true for all groups, populations or cultures, especially children, individuals suffering from illnesses, the elderly, and pregnant or lactating women. Vegetarianism is more common in certain ethnic groups and in warmer climate zones, whereas people living in arctic regions traditionally tend to prefer animal protein. The causality is partly ecological, but may have genetic, as well as cultural, roots.

There are other sources of protein than land plants and animals, however. Insects, seaweed, algae and other organisms can provide high quality proteins. Most consumers are currently reluctant to accept some of these (especially insects), although this appears to be culture-dependent. Feed from these protein sources (and from by-products in the food industry) can in essence convert them to meat, however. Research on toxicities and allergies is still in its infancy.

A major achievement of the modern food industry is that food products, at least in industrialised countries, are subject to safety checks on a scale never seen before. Large-scale and revolutionary **innovations in food production**, and the adoption of new technologies, are in the pipeline, but consumers and the industry often remain conservative. In most industrialised countries, the demand for 100% safety for new products limits opportunities for product development and suppresses industry's willingness to innovate. Incidents related to global trade and food fraud lead to further consumer concern. Climate or weather-related outbreaks of, for example, mycotoxins, are likely to increase.

Given the enormous challenges the industry faces, such as unacceptably high food waste (discussed in the **Circularity** challenge), high energy inputs (addressed in **Climate**) and the unhealthy or disputed nature of some ingredients, innovation policies and investment by public and private agencies must change. This requires a discussion of risk within current regulatory bodies to ensure sufficient room for innovations while maximising food and feed safety. In addition, understanding of the potential harmful effects of long-term use and chronic exposure to products gained through new technologies (e.g. nanotechnology) is still limited. Such research is expensive and generally cannot be covered by a single company.

MyToolBox is a project funded under the EU Horizon 2020 framework programme with 23 partners from 11 countries. It considers the entire soil-field-crop-food processing-waste management-alternative energy chain to ensure food & feed security and safety within a sustainable economic approach. The project will provide a variety of information to support decision-making in mycotoxin management by all actors in the food and feed chains. www.mytoolbox.eu

In the past, the optimisation of shareholder benefit has introduced concepts in the food industry that may not align with the optimisation of benefits to consumers or society. The increase in low-cost sugar and other refined carbohydrates in many food products has contributed to rising rates of obesity and diabetes. Consumer-centric innovations are required to counteract these trends. Reformulated and new products must fit a healthy and diverse diet that supports an active lifestyle and prevents food-related health problems. Instead of the classical 'isolation for purity' paradigm that the food industry has followed in the past decades, it is now possible to switch from pure ingredients to 'un-refined' ingredients, which are richer but not pure in terms of specific components (e.g. proteins) while still retaining a significant part of the structure of the natural raw material from which they are made. This results in much larger fractions of raw materials being used for high-quality food products, with more fibre and micronutrients in these fractions, giving them more stability. Unrefining combines much better use of raw materials, much lower use of energy and water and much less waste with healthier food products that may be perceived as more natural. Allowing the natural structure inside ingredients to remain intact may eliminate the need for E numbered additives. Simultaneously, isolating pure components, e.g. amino acids, to fortify existing food products, assists in designing foods with specific compositions.

Solutions from other areas like new protein sources or personalised nutrition will also require process innovations in food production.

If new sources of raw materials for food products (e.g. seaweed, insects) are to be exploited, the food industry must innovate to use these materials in new and existing products. This requires product innovation to create not only healthy, tasty and stable products, but also new processes. Food safety, shelf life and ease of use for consumers must all be addressed. To stimulate the adoption of these new products and to optimise the nutritional value of meals that contain such products, recipes must be developed and marketing strategies implemented.

Due to the advent of personalised nutrition, consumers need help to tune their personal ingredients to their individual needs. 3D food printing in the kitchen allows tailor-made products to be made from pre-manufactured ingredients. Combining this with unrefined ingredients makes personalised nutrition easier.

Regaining the trust of consumers in products from the food industry must be the highest priority.

New packaging improves quality and safety, especially of fresh products. Low- cost sensors and smartphone-based food analysis (see previous section) enable direct consumer assessment of critical quality parameters. Packages that can exchange gases with the outside atmosphere allow products to continue their natural processes, further extending shelf life. This can reduce food waste. Of course, for optimal results the packaging itself must be designed for reuse or biological degradation. Innovations in food production require consumer **trust** in the industry, requiring a strong role for social science research.

The advance of Internet-of-Things applications is an aspect of the **digitalisation of society**. In the future, many sensors and data collection systems will surround individual citizens. This will allow automatic data collection, but the public itself may also be involved in submitting data (citizen science) on a wide range of parameters. From smartphones and cars, data collection will expand to medical

The H2020-MSCA-ITN project 'FoodSmartphone', started in January 2017, proposes the development of smartphone-based bioanalytical sensing and diagnostic tools for the simplified on-site pre-screening of quality and safety parameters and wireless data transfer to the servers of relevant stakeholders.

The scientific training in novel smartphone-based sensing technologies offered by the project, plus the complementary skills training provided, will have a major impact on future EU monitoring practices and will pave the way for citizen science. www.foodsmartphone.eu

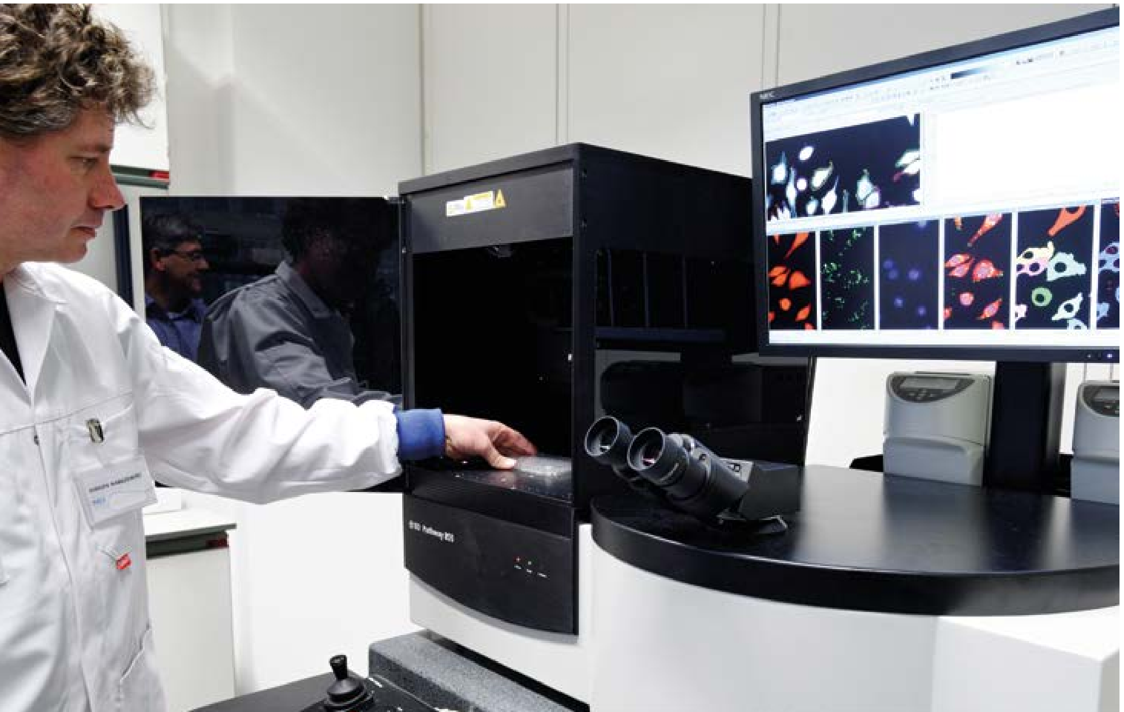
The digital revolution will make much more data available on individual consumers and on groups in society, enhancing the understanding of processes related to food and food consumption.

and household devices. Combining data from different sources will provide a complete picture of the status and lifestyle of each individual and target consumer group, and allow extensive demographic studies, creating opportunities for preventive healthcare interventions.

The digitalisation of society will also offer opportunities for less developed regions. For instance, relaying detailed satellite data to the mobile phones of smallholder farmers in isolated areas will allow optimal use of scarce resources like fertilisers and water.

The hidden treasures in the data can only be revealed and exploited if owners are willing to share their data. This will only happen if the manner in which the information will be used is transparent.

Data use and mining requires permission from data owners to share the data. The big data challenge is that data from different sources must be understandable, storable and usable. Ambiguity regarding ownership and privacy lead to scepticism because benefits to consumers are unclear while large companies seem to profit.



Transparency and communication about the benefits and the purpose of data sharing should build trust. Anonymisation can help if an independent organisation safeguards the interests of individuals.

Neither knowledge nor availability alone are sufficient to guarantee optimal dietary choices. **Food practice** is also influenced by other aspects of daily life and culture, such as social interactions. In combination with the fact that there is rarely immediate feedback on unhealthy choices, this causes eating patterns that can result in health problems later in life. Understanding these mechanisms requires further research into the dynamics of lifestyle and food choices. Knowing what good food is does not automatically lead to adopting the perfect diet. **Food choice** is also determined by time and place of consumption, convenience, group dynamics, economics and trust.

Influencing consumers to make the right choices requires cooperation across the food sector.

Taste, price, availability, acceptability and convenience may push consumers towards less desirable eating behaviour. The breakdown of traditional families and associated family meals also plays a role. It is often more difficult and expensive to eat healthier products. It is entirely possible for industry to develop products that contain lower levels of salt, saturated fats and sugar, but consumer tastes, partly caused by evolution, prefer sweet, fat and salty products. Changing the composition of food products requires the entire food manufacturing sector and the authorities to be in agreement. **Collaboration** in the precompetitive phase is needed to reduce or replace these ingredients with acceptable alternatives and implement them in a concerted, gradual way.

It is obvious that food affects the **health and wellbeing** of individual consumers. The development of genetic technologies has made it feasible to determine the genome of each individual. Internal (e.g. type of cell, health, reproductive status, etc.) and external (time of day, season, temperature, etc.) factors determine which genes are switched on, and therefore which proteins are produced in which cells, at a given time. This in turn determines the biochemistry of the body. Aligning food intake with biochemistry ensures that the different processes in the body can operate at their best.

Aligning individual nutrient requirements with the composition of food products is an important component of preventive healthcare.

More research is necessary to ensure health and wellbeing based on an adequate diet.

Issues related to food intolerance and food allergies can thus be diagnosed, monitored and avoided more effectively.

Unfortunately, this is all still largely theoretical. Science on the link between internal and external factors and gene switching (transcriptomics and epigenetics) is still in its infancy. The effects of culture and lifestyle are complex. Long-term imbalances may extend into subsequent generations. Interactions with systems that do not share our genome, like the gut microbiome, are still poorly understood but are expected to make a significant contribution to the design of personalised nutrition. This would make interventions far more precise than current correlations based on epidemiology.

Understanding the long-term effect of the presence or absence of certain components in relation to individual characteristics such as genetic make-up, age, lifestyle, culture, etc. is an enormous challenge and requires close collaboration between the medical & pharmaceutical sectors and food & nutrition scientists. It would also help to identify possible food-related causes for conditions for which the causes are not yet fully known (e.g. Crohn's disease) and many other food-related sensitivities and allergies.

Providing sufficient safe and high-quality food in a sustainable way requires a **transdisciplinary approach**. Different disciplines must be combined and partners from different fields must cooperate, overcoming their varying perspectives on economic viability and societal acceptance. A high-tech company which usually works for the semiconductor industry, for instance, is used to cleanroom conditions and large budgets. Their technology might be applicable for harvesting tomatoes in a greenhouse, but it first needs to be made compatible with high humidity, variable temperatures, dirt and a poorly defined world model. Moreover, to make the system effective in practice, it needs to be cheap and operable by personnel without technical skills.

The complexity of the issues and the interdependencies between solutions means that a systems approach is required.

Collaboration between researchers in different fields is a challenge in itself.

Food is vulnerable to degradation in terms of quantity, quality and safety. Identifying, controlling and mitigating these risks is a challenge for all actors operating in food supply. There is therefore a need for proactive early warning systems based on a systems approach that take into account the complexity of production systems and their environment.

Climate smart and environmentally sustainable

Food production is an intricate part of our environment. As such, it affects the environment and is also affected by it in a feedback loop. Intensive animal husbandry produces too much manure to be absorbed by plants in the direct vicinity, for instance, and dairy production emits large amounts of methane. The production of animal feed crops leads to a transfer of nutrients and may deplete soils elsewhere, whereas grazing can also lead to erosion and depletion. The use of chemicals in crop and animal systems may negatively affect surface water, while farming and many types of greenhouse horticulture require substantial energy inputs, contributing to CO_2 emissions. Finally, changing weather conditions due to climate change are likely to influence crop and animal farming and its vulnerability to natural but harmful bio-toxins, pathogens and abiotic stresses.

Food production contributes to both the problem of climate change and the solution.

The only future-proof way forward is to modify human activities, including food production, in such a way that they do not affect the environment in the long run, restore ecological damage, adapt to variability, and mitigate climate change where possible.

The development of flexible and resilient plant and animal systems depends on advanced **breeding** methods to reduce susceptibility to pests or diseases and any dependency on agrochemicals or drugs. New crop varieties and even species with increased resource use efficiency, e.g. of water, nitrogen and phosphorus, substantially lower the long-term environmental footprint of agriculture. Optimising abiotic stress resistance against extreme temperatures, drought and mineral deficiencies or

The only future-proof way forward is to reduce the ecological footprint of activities such as food production.

The planet will never return to the state in which most plants and animals originally developed. Species used for crops must be bred to be resilient to changing conditions.

excesses increases adaptability in areas of weather variability. Furthermore, improved photosynthetic efficiency of crop plants results in higher carbon uptake from the atmosphere, increasing root biomass and thus soil carbon. This will, in turn, contribute both to lowering global atmospheric CO_2 levels, and to soil fertility.

Externally applied inputs should completely be taken up by the production plants or animals and not be left behind after harvest. To ensure that this is indeed the case, **Next Level Agriculture** optimises the use of inputs. The Holy Grail of precision agriculture is to determine the spatial and temporal needs of individual plants and animals and to apply inputs accordingly.

Certain production systems are more vulnerable to perturbations than others and require more interventions to mitigate the effects of these disturbances. Monocultures, for instance, may be vulnerable to pest and disease build-up.

Versatile robotic systems will promote inter or multi-cropping, reducing the risks. Early detection of pests or diseases using smart sensors will allow adequate small-scale interventions to contain and eliminate the threat. Next Level Agriculture will therefore eliminate preventive spraying, just like the preventive use of antibiotics.

High-tech applications can improve the sustainability of certain agricultural systems or can make them economically viable.

Applicability is also dependent on societal acceptance.

The aim of protected cultivation is to create a controlled micro-climate that aligns with the optimal growing conditions for crops and animals. To achieve this, greenhouses are normally heated (in cold regions) or cooled (in warm regions), extra light is provided and the concentration of CO_2 is raised. Apart from the CO_2—which is a by-product of current heat and electricity generation—these inputs are energy-intensive and currently dependent on fossil fuels. Greenhouses, however, can also be designed to generate energy. Excess heat in the summer can be stored in the ground to be recovered in the winter; solar cells in the glass cover can generate electricity; nearby CO_2 waste streams can be fixed in the biomass produced. These high-tech systems require further adaptation for incorporation in urban farming.

The desire for natural foods and production methods - no chemicals, handmade—needs to be matched with the realities on the ground: guaranteeing quality and safety of food while reducing chemical additives. Or showing that robots in primary food production are not necessarily 'unnatural'. The **emotions** surrounding chemical additives and robots, including the supposed supplanting of labour, must be addressed transparently and rapidly.

Because 71% of the surface of the planet is covered with water and water is much more dynamic than dry land, oceans play a major role in the earth's atmosphere. It can therefore also be an important element in helping to mitigate the effects of past human interference in atmospheric processes. The **blue growth** strategy aims to produce, from marine resources, biological base materials for all sorts of applications.

It has become clear that oceans are not infinite waste dumps. However, they do produce valuable products while also contributing to the mitigation of environmental problems.

The oceans have long been regarded as infinite in their ability to absorb by-products and pollutants of human activity. In recent decades, however, it has become abundantly clear that this is not the case. Moreover, it is now better understood that oceans play an important role in the delicate equilibrium of atmospheric processes, as they absorb substantial amounts of CO_2. We need to better understand these dynamics before designing large-scale aquaculture so as to increase the mitigation capacity of marine systems.

Food product innovations sourced from marine production systems, especially species lower in the food pyramid, can clash with **consumer acceptance**, probably requiring a multi-actor approach.

Protein transitions provide acceptable alternatives for the production of animal protein, as well as substantial contributions to sustainability.

Eliminating part or—theoretically—all animal protein would reduce greenhouse gas emissions substantially (not to zero, since natural grasslands would be grazed by other emitting species) while decreasing excess plant proteins from feed and feed imports. In principle, water can be extracted from animal slurry, but that requires energy. The provision of balanced proteins from animal and plant sources remains key to future food security.

A transition to more efficiently produced proteins will contribute to the sustainability of the food system.

Redesigning industrialised food production through **innovations in food production and processing** such as sterilisation or drying with low-energy inputs increases sustainability. Pascalisation or Pulsed Electric Field pasteurisation are recent examples, and there are others still which need further development. Modern industrially produced food products are usually made up of discrete ingredients that have been obtained by fractionating base materials from primary production. Since the behaviour of the discrete ingredients is well understood and quality can be defined within small margins, the processes used to make the end product can be controlled more easily. But fractionating base materials requires energy inputs. This can be avoided by using non-fractionated, complex base materials while maintaining the quality of the end product.

Process innovations like the use of non-fractionated base materials can make post-harvest food production more sustainable.

The large investments needed to replace production facilities based on old process concepts, and market insecurity, understandably make companies reluctant. Another aspect that inhibits innovations in food processing are European and national **regulatory frameworks** that require demonstration of absolute product safety if new processes are used. When given the choice between low-risk evolutionary improvements to existing products and high-risk revolutionary product innovations that require large investments in facilities and proof of safety and health effects, most food companies choose the former. Tackling this requires concerted research and policy actions.

Regulatory frameworks need to be revised to make implementation of process innovations acceptable from a business point of view.

The **digitalisation of society** strongly affects agriculture and food production through better control and monitoring of production. The avoidance of suboptimal conditions enables the optimisation of the entire food system.

The establishment of more data hubs allows for improved data exchange while preserving the interests of data owners. Individual producers can better benchmark their own results with the (anonymised) results of similar enterprises. Digital communication and transparency between all links in production processes allows for further optimisation.

> Combining data will result in more information on the efficiency of processes, consequently improving them.

Block chain technology is expected to enable the safe exchange of information throughout food systems. This documents the complete history of a product, allowing informed choices to be made about products that are climate smart, more sustainable and produced under fair trade conditions.

All this hinges on **trusting partners** in information exchange to respect ownership and privacy. Governmental and intergovernmental involvement and industry standards must be established to ensure objective brokerage and data exchange.

Consumer choices impact the ecological footprint. Ultimately, new technologies must be accompanied by improvements in **food practice** to nudge consumers towards more sustainable choices.

The choice for convenience by the modern consumer often means precooked meals, theoretically leading to more packaging than would be produced by the individual ingredients separately—although it is hard to make a definitive judgment, since people often waste considerable amounts of food and water when preparing meals. The opening hours and prices of food retailers have placed an enormous variety of products at the disposal of consumers, especially in urban areas. The effect of such limitless availability raises questions of how consumer practice can be influenced while maintaining freedom of individual choice.

> The demands for convenience and availability often conflict with the need for sustainability. The choices citizens make regarding their food need to be nudged towards better alternatives.

Everywhere, urban middle classes are accustomed to imported products that need to be shipped from afar. 'Seasonal diets' require transportation, greenhouses and storage. Importation provides employment elsewhere and may meet important equity goals.

Changing the dietary patterns of large groups in society is not trivial, although changes, such as in those seen in the last generation, can go very fast. Education, communication and information on the effects of consumption do have some effects, especially where the true environmental cost of certain choices is hidden. However, informing consumers does not guarantee sustainable or healthy choices.

One of the benefits of the availability of out-of-season food products is that it allows for a varied diet. Vitamin or other nutrient deficiencies have thus become a thing of the past in industrialised countries. Although it is highly unlikely that we will return to diets from before the Nutrition Transition,[11] it is essential to assess carefully the effects on **health and wellbeing** of more sustainable diets. A fundamental understanding of the relationship between the individual components of such diets and health is therefore essential. As an added bonus, this might also reduce allergies and certain other chronic health issues, since it cannot be excluded that

11 Popkin, BM, "Nutritional Patterns and transitions", Population and Development review 19.1 (1993), 138-157

The year-round availability of food products generally contributes to the health and wellbeing of consumers.

However, the role exotic fruits and vegetables play in sensitivities and allergies need to be understood better.

these may be related to sensitivities to specific ingredients. There is an ongoing search for other essential components, such as anti-oxidants and special fibres.

If foods are produced from more complex base materials to avoid energy intensive fractionation, the health effects of all the different components must be understood. Moreover, since the composition of a complex ingredient is not always the same, the regulatory framework designed to ensure safety needs to be broadened.

Solutions in one field may negatively influence results in another. Lower pesticide requirements might be linked to more natural toxins, thus impacting food safety. Making large-scale marine production economically viable would require innovations in both primary production and post-harvest processing. Mild conservation impacts shelf life and therefore requires changes in food practice to prevent more waste. This is why there needs to be an emphasis on a **transdisciplinary approach** and **acceptability by citizens**.

In a complex system a solution for one problem can easily deteriorate the situation elsewhere. A transdisciplinary approach can prevent that.

Circularity and resource efficiency

Food is a part of local and global ecological cycles. Problems arise when imbalances occur and large amounts of certain components accumulate, so that the absorption and recovery potentials of ecological systems are exceeded. Large-scale production often results in lots of waste that cannot be recycled in the vicinity. Fossil resources created over millions of years cannot be replenished. Other resources are also often depleted and important reservoirs polluted.

The only solution to this is circularity and a more efficient use of resources. This demands a change in mindset and new technologies to turn hitherto unused process streams and waste into an opportunity to unlock new values. In such a system, manure is used as a valuable fertiliser, for instance, while excess heat from factories becomes an input for greenhouses. To move from food chains to circles means matter is returned and responsibility is shared.

Efficient use of resources and care that they can be used over and over again should be the basis of a sustainable food system. This requires a shift from chains to circles.

As discussed in previous sections, **breeding** is a powerful tool for ensuring desired characteristics for plants and animals. The most important biological process on the planet is the conversion of sunlight into energy-storing organic compounds and oxygen by plants. Studying the process at the molecular scale makes it possible to breed more efficient plants. Improving the efficiency of photosynthesis would increase yield and have direct effects on resource efficiency.

Photosynthesis is the basis of all life on earth. Improving its efficiency will substantially increase resource efficiency.

Breeding can also positively contribute to the reusability of by-products and side streams.

Breeding can also be used to boost circularity by optimising the by-products of food production processes. Looking at waste as a value proposition promotes designing the properties of the waste to make it optimal for the next process. In the past, waste has tended to be used 'as is', that is, without changing its composition. This resulted in a clear difference between co-products (by-products) and waste. Take manure, traditionally used for fertilisation or burnt for energy. Improving the composition of waste to make it better suited for these processes might reduce its primary value, but offer a better, more circular and more resource-efficient system overall.

The **business case** for extracting these components is often poor and cascading can help improve it. In cascading, waste streams are viewed as a complex mixture of more and less valuable components, while keeping in mind that different components can have different values at different stages. The cut-off depends on the type of waste, the economic feasibility of extracting certain components, the market for these components and cultural issues. This is a dynamic system that can change over time and by geographical region. However, it can be influenced if breeding is used to improve the co-products with cascading in mind. The processes used to unlock or extract certain components are often biological and can be optimised with state-of-the-art genomic techniques. Breeding plants specifically to enhance their waste value alongside the value of their current product is a field that is only just becoming established. As long as this is achieved in a manner which does not impact the primary product, a win-win situation with added value can be created.

The transition from a fossil to a bio-based economy or the rate at which by-products are used can often be determined by economic factors. Improving the business case through breeding will therefore improve resource efficiency.

Plant breeding will also help the transition of our current fossil economy to a bio-economy in which food production forms an intrinsic part. Replacement of parts of the fossil feedstocks used in the chemical industry by bio-based feedstock produced as part of an integrated agricultural system will dramatically improve the overall resource use efficiency of the system, eliminating the competition between food, feed and fuel (although the effects of withdrawing organic matter from soils must be monitored).

Examples include the production of bioplastics like PEF from biomass and the production of rubber from dandelion (*Taraxacum koksaghyz*). Modern breeding technology, in combination with a better use of available natural genetic diversity, is pivotal in realising the desired development of crop plants with improved water use efficiency, mineral usage and photosynthetic efficiency.

One of the important drivers of **Next Level Agriculture** is sustainability. By managing production capacity at the individual plant or animal level, input can be matched to need and very little is wasted. Fertiliser is dosed according to the condition of individual plants and pesticides are largely replaced by biological agents and only applied when and where necessary.

In animal husbandry the amount and composition of feed is optimised for the production status of each animal and the early detection of diseases makes cures simpler and requires less and less-strong drugs while the risk of spread is reduced.

Fine-tuning the inputs to the needs of the plants and animals in Next Level Agriculture optimises their use and protects the soil and the environment.

Soil is an important production factor, and excessive nutrients/chemicals and soil depletion threaten sustainability. Soil is generally considered a non-renewable resource with limitations on use. In organic agriculture, leguminous plants and animal manure are used to maintain the fertility of the soil, but this requires ample grazing areas and makes the fine-tuning of nutrients much more difficult. Removing affected plants before a pest has a chance to spread widely minimises the need for pesticides but is labour-intensive. Autonomous machines can replace such additional human labour in onerous tasks. Scientifically, it is most likely that future sustainable food systems will use the best techniques of conventional and organic systems, depending on **economic viability** and potential for upscaling.

In **blue growth strategies**, large scale production in marine systems must become sustainable and pollution eliminated.

While seawater contains all sorts of valuable compounds and minerals, their concentrations are usually too low to harvest directly from the water. Biological systems have the ability to accumulate them, however, and a cleverly designed harvest system would replace the need for deep-sea mining. An interesting option is the development of cascades of combinations of organisms that can convert organic debris or waste into valuable and possibly even edible products. Large amounts of nitrate and phosphate currently leak out of agricultural and industrial production systems and are eventually transported via the rivers to the oceans. Placing large scale seaweed cultivation areas in estuaries and along coastlines would enable the recovery of vast amounts of fertiliser for agriculture which would otherwise be lost.

Marine systems contain valuable compounds that can be exploited through biological systems.

The conversion rate of plant protein to meat protein in traditional meat production can be as poor as 10%. This means that a cow must eat ten kilograms of plant protein to produce one kilogram of meat. Given the growth in global demand for meat and fish, we need to develop integrated protein transition packages which include meat replacement on the basis of plants (such as seaweed) or insects. This is what **protein transitions** address.

Replacing animal products with plant-based products increases resource efficiency. But animal husbandry is also useful because of its ability to unlock certain resources for human consumption, especially when circles can be closed.

Although livestock can recycle biomass from resources not suited for human consumption, this is not common practice in intensive animal husbandry. Feed is not usually produced on nearby fields but is transported from other regions, often even other countries or continents. The animals only partly convert the feed into the desired product, while the rest locally becomes manure, methane and CO_2. Manure is an important source of nitrogen and phosphorus in crop production and provides organic matter that contributes to soil fertility. If it could be transported to the region where the feed was originally produced, the production cycle could be closed. Unfortunately, this is currently not economically viable. Other forms of use must be found, for instance the harvesting of nutrients from manure.

To improve circularity and resource efficiency, it is necessary to implement **innovations in food production and processing** that reduce by-products. If by-products are unavoidable, processes must be designed to enhance their value through the extraction of valuable components. Cascading can turn the waste of one process into raw material for another.

Food products are susceptible to spoilage. Efficient storage and logistical processes can, however, deliver them to consumers with as little quality degradation as

A dominant factor in the poor sustainability of the food sector is waste. Reducing waste and unlocking the value of waste is the key to resource efficiency.

possible. Preservation is used to slow down quality deterioration. The demand for fresh products in combination with the demand for convenience and longer shelf lives has triggered the development of mild preservation techniques. Such methods are only feasible for a limited number of products. Moreover, some of them are batch processes which are much more expensive than continuous processes. New processes, or improvements on existing ones, are required to improve their economic viability.

A new approach to shelf life extension makes use of stabilisers against microbiological or chemical degradation that naturally occur in the relevant foodstuffs. This is simply done by leaving intact a part of the structure that would normally be removed through processing. For example, whole oil bodies that still have their phospholipid/protein membrane remain completely stable for months. The use of benign fermentation and antimicrobial and antifungal components which occur naturally in plants, seeds and sprouts lead to products that combine sustainability with longer shelf life and better health through the retention of fibre, micronutrients and natural antioxidants.

The **digitalisation of society** offers better opportunities to align supply and demand, especially for perishable food products. New business concepts make use of the internet to combine information on the supply of fresh food products, like fish or fruits, with the demands of individual customers. Clever logistical systems ensure that these products are delivered only one or two days after production. Other e-commerce tools deliver the complete set of fresh ingredients required for a meal, including the recipes, to the home of the consumer, combining convenience, freshness and minimal waste.

Information exchange between supply and demand in combination with new production and logistics concepts can ensure better use of resources through just-in-time delivery of the right food products.

Fresh products are often given short sell-by dates: producers are conservative in setting these dates in order to ensure that their brand image does not suffer from spoiled products. Past their sell-by date, these products can, at best, be sold at reduced prices—mostly, they end up as waste. To counteract this tendency, sensors can be added to the packaging to directly monitor the quality of the product inside and adjust the sell-by date as appropriate. Moreover, such sensors can also be integrated within home automation systems to enable a warning from the refrigerator if it detects a product that is approaching the end of its useful life. This has the added value of reducing the domestic waste stream as well.

Climatic fluctuations in a given area are experienced by all producers, resulting in prices that oscillate depending on the period. These fluctuations also occur because farmers tend to switch en-masse to products that brought in a good price the previous year, resulting in overproduction in the following year. From a resource efficiency point of view, this is highly undesirable. Digitalisation of production systems and data exchange with retail organisations can prevent this, and accurately predict alternative markets.

A **citizen-centric approach** is required to build support for the benefits of digitalisation. Governments, science institutes and the private sector therefore need to invest in a food digitalisation dialogue.

In most industrialised countries, consumers demand convenience—in other words, ready-made meals. At the same time, consumers want products to be as fresh as possible. To accommodate these conflicting demands, the food industry has developed intricate packaging concepts that can substantially increase the shelf life of fresh products. **Food practice** with regard to fresh unpackaged foods may partly

change, although the demand for convenience remains strong. Recyclable packaging is still in its infancy. Changing logistics reduces the travel time of individual consumers to supermarkets. E-commerce and, ultimately, delivery by autonomous vehicles on a large scale are also well within reach.

Sophisticated packaging concepts respond to the demand for convenience, but they contribute to a waste of resources. Citizens must become aware of their role in this and be willing to change their practices.

Industrialised production leads consumers to expect product uniformity. The food industry therefore tries to control production processes so as to ensure that there are few products outside of certain size, colour and shape formats. Produce below certain quality limits is destroyed or sold at a lower price. This leads to entire waste streams of only marginally undesirable products. This can be solved by new product specifications and changing consumer behaviour. Shifting undesirable products to feed is feasible but demands regulatory adjustments.

Although food in Europe is very safe, vulnerable groups such as the elderly may occasionally experience food poisoning. Furthermore, there is an apparent increase in the prevalence of food-related sensitivities like allergies. At the same time, social media are instrumental in spreading hypes around supposed food allergies or pseudoscientific concepts like 'detoxification'. There may be reason to investigate if there is a widespread shortage of some micro-organisms in our food or environment that is contributing to this apparent increase in food-related sensitivities. It could very well be that our **health and wellbeing** are negatively affected by the practice of throwing away everything that is even suspected of being contaminated or spoiled.

Consumers with more resource-efficient diets may miss out on critical nutrients. Some vegetarians and vegans, for instance, require supplementary or alternative sources of B12, and sometimes iron, to stay healthy. When encouraging such diets in less developed countries, it is important to pay attention to vitamin and micro-element deficiencies.

Throwing away everything that is even suspected of quality deterioration is a way to make food products very safe. But can the absence of micro-organisms also account for the increase in food sensitivities?

Innovation and empowerment of communities

Food is a basic need, and it is a primary concern for all humans to make sure that their food supply is guaranteed. This is much easier to achieve collectively than individually. Social structures have grown over the years to ensure that surpluses in one period or region are used to cover shortages in another through storage or trade. The vested interest that individuals have in these structures helps bind them together. Communities are therefore in many ways the core units of human society. Food and activities related to eating —like buying food products at markets or preparing meals—are, in turn, important elements in the cohesion of communities.

Food and eating behaviour are part of the glue that holds communities together. The production of food is an important economic activity that provides work for many people.

Food production is also an important economic activity for rural regions. Many people earn a living in the food sector, from primary production and post-harvest processing to transportation and retail, but also in bars, restaurants and food stalls. A substantial part of any country's gross national product is associated with food. However, working conditions in the food processing and service subsectors are not always optimal nor hygienic. Any proposed technological changes must be assessed on their social effects as explained below.

Coastal communities are vulnerable to flooding, salinification and extreme weather. Climate change may make agriculture altogether impossible in already arid regions. These developments may result in large-scale migrations. The new **breeding** methods

Innovations through new breeding methods can help coastal communities to develop more climate smart and sustainable ways to produce their food.

discussed earlier are an important source of innovations that may help communities to increase production in a climate smart and more sustainable way within a circular economy. It is important to remember, however, that such methods may not be instantly accepted by everyone, and that farmers and consumers need to be involved in the decisions on breeding priorities.

To ensure worldwide level playing fields for these innovations, rules and regulations need to be harmonised between countries.

Another key aspect of the new breeding techniques is governance. This ranges from international rules that can minimise recourse to multiple national (e.g. American, Chinese and European) legal systems to the national (entry into force of international agreements), and even the local level, once new techniques have become so cheap that they lead to do-it-yourself biotech kits, with results that will be hard to oversee by governments.

A third, related topic that calls for attention is the business models used with these new techniques. The European system of plant breeders' rights is quite open, with relatively fast introduction of new cultivars and innovation available to breeders.

Genetic modification and new breeding techniques are increasingly covered by patent law, which is more closed, but has the advantage of being able to attract more financing.

With retailers (and, via big data, perhaps others) unlocking new insight into consumer preferences, new alliances could be formed with breeders (and even consumer NGOs, for instance those that represent consumers with a certain allergy) to create specialised varieties and market these jointly.

In many countries, it is becoming increasingly difficult to find the labour force necessary for many types of work in current agricultural or food industries. The work is often seen as having many negative aspects and does not appeal to young people. As a result, the average age of Japanese farmers is 67, with succession a major problem. Other industrialised countries are in a similar situation. Against this backdrop, **Next Level Agriculture** can be a real source of innovation that may replace hazardous, hard, dirty and dull labour. It can also make the agri-food sector attractive to technology-oriented youth and halt migration.

In many communities, it is difficult to recruit enough workers for food production. In addition to alleviating physical strain, the implementation of key enabling technologies can also make the sector more appealing to young people.

Like mechanisation in the 1950s, the increase in the use of ICT can lead to a large outflow of labour from the countryside. Value-added processes will move to areas with a high quality of life. This will improve the resilience of communities in remote areas. ICT can also support such communities.

Robotisation may lead to shorter working hours. As many rural areas in Europe are not too far from a city, this may create new chances in areas rich in natural beauty and biodiversity.

The information-driven innovations require solutions that acknowledge ownership rights of data.

Next Level Agriculture will require innovation processes that bring farmers, other food chain partners and the high-tech and ICT sectors together. There will be a need for innovation hubs, and the availability of venture-capital remains an issue. Systems

within which farmers and consumers can exercise their ownership rights on data platforms based around the consent that others can have access to their data for certain purposes represent an interesting option. The trend to big data will require oversight (perhaps via an ombudsman or algorithm authority) over the quality of the data science behind the big data machines.

The cohesion of communities that rely on fishing is under pressure from threats to traditional fishing practices. A next-level **blue growth** strategy can allow new contributions to the prosperity of coastal communities to be developed.

Blue growth strategies can provide alternatives for communities that relied on fishing in the past. But they also require balancing the interests of new stakeholders.

Aquaculture, industrial production of marine plants and other elements of blue growth strategies trigger innovations and provide alternative sources of income to coastal communities. In the future, blue growth strategies will also require the interests of different stakeholders to be balanced. Take the North Sea, for example: in the past, the open sea was reserved for shipping and fishing. Today, oil platforms (one day perhaps repurposed as seaweed farms), wind turbines, nature reserves, aquaculture and more are all also competing for space.

Humans have complex relationships with many animals. We have millions of pets, use animals as beasts of burden, keep them for their products such as honey, milk or wool, eat many of them, and benefit from their ecological roles (pollination, for instance). At the same time, many urban consumers do not want to be confronted with the realities of raising and killing animals for consumption (especially when it concerns mammals), suffer the environmental effects of large-scale livestock production, or risk health problems due to zoonoses, antimicrobial residues or resistance in livestock production. **Protein transitions** must therefore aim at providing meat-like, protein-rich products that will partially substitute protein from animal sources by plants or replace current practices by more sustainable and animal and consumer-friendly ones.
Good treatment of animals is also helped by sensor technology (monitoring of stress levels), and putting cameras in farms and slaughterhouses increases transparency and discourages abuse.

Alternative protein sources can help to resolve the problematic relationship of communities with eating meat.

The relationship between the occurrence, scale and intensity of diseases in animal systems is complex. This requires further study, for instance to establish whether less intensive systems lead to lower disease pressure or, on the contrary, that there is better control in highly intensive systems.

Furthermore, low disease pressure may make animals more resilient to mild disease challenges, thus reducing the need to administer drugs such as antibiotics.[12] This in turn may reduce the risks of creating antibiotic-resistant (AMR) strains that pose serious threats to humans.

Agricultural production, post-harvest processing and the food industry usually benefit from scale increases. Unfortunately the local community usually experiences few of the economic benefits and most of the environmental and societal burdens. **Innovations in food production** optimise the scale of production without negative

12 Van Dixhoorn ID, Reimert I, Middelkoop J, Bolhuis JE, Wisselink HJ, Koerkamp PWG, Kemp B and Stockhofe-Zurwieden N, 2016. Enriched Housing Reduces Disease Susceptibility to Co-Infection with PRRSV and A. pleuropneumoniae in Young Pigs. PLoS One, 11, e0161832.

consequences for economic viability. This will require manufacturing processes that are efficient, with much smaller units and batches, and with parallel processing if larger operations are needed. Franchising models could ensure that the fixed costs that need to be covered by large volumes (e.g. marketing, R&D) stay centralised.

Innovations will enable local production that makes communities more self-sustainable and reduces the need to transport food products.

Local production and processing may empower local communities and provide employment. However, further investigation is necessary to see whether more local production really results in shorter value chains, a fairer distribution of incomes and greater consumer engagement.

The prices of agricultural produce often fluctuate strongly, especially during and just after harvest, leaving producers exposed. Farmers need to stabilise their harvested materials in order to sell at appropriate times. Slowing down processes like dehydration, partial fermentation or partial processing will allow perishable crops to be stabilised. This will in turn reduce dependency on large trading houses. At an even smaller scale, new food production and preparation concepts also benefit individual households. It will soon become possible to produce foods in the home that could previously only be made in large factories. This will allow ingredients to be fine-tuned to the **individual preferences** of household members.

New business propositions, in which demand for fresh products within a **digitised community** is met by local producers, will give rise to new opportunities to connect supply and demand. These functions can initially be developed via websites and subscriptions, which will eventually be substituted by Internet–of-Things developments that will enable more household devices to communicate autonomously with external systems. Ultimately, these functionalities can become fully automatic, for instance signalling a supplier just before a given fresh product runs out in the fridge.

The exchange of information will enable supply and demand for food products to be balanced locally. These opportunities require trust among consumers and new business models.

As such large-scale and sometimes intimate information exchange will require **trust** between partners, the first implementation should take place within a pre-existing community. For many, it will be much more acceptable to share information with a local supplier with which they are acquainted than with a large and anonymous organisation.

Digitalisation can lead to new distribution models, as is already being demonstrated in cities with concepts of home delivery. This is revolutionising food retail.

At the moment the common **food practice** of the majority of consumers is to choose what they eat based on emotion, tradition, availability and financial considerations. Further investigation is required into the ways in which food practice is evolving and the effects of community, social media, education and government policy.

The evolution and impact of food practice need further investigation.

Intertwined implementation

The challenges for the agriculture and food sectors are obviously connected, and facing them will require a concerted effort based on cooperation between different stakeholders and a strong emphasis on innovation. It also requires clear and concerted policies on the European and national levels to enable innovation through suitable regulatory and fiscal frameworks. The transitions to a sustainable, affordable, trustworthy and high-quality food system can be achieved in the next decade or two if the following steps are taken.

The extent and complexity of the challenges the food system faces require collaboration between all actors. This can best be achieved if they are united in their efforts through a joint undertaking.

Pan-European collaboration in public-private partnerships

Open innovation—accepting any partner who can make a positive contribution—is a key prerequisite. Subject to the usual scientific scrutiny, knowledge institutes must work together with large food companies who are able to develop products and scale up processes. SMEs have a pivotal role to play as local and agile specialists. Cross-disciplinary work must be incentivised within universities, including in curriculum development, to boost collaboration with innovative companies, both large and small. Openness to disciplines, companies and partners from outside the food and agricultural sectors ensures maximum society-wide effectivity and the efficient adoption of concepts developed elsewhere.

The agriculture and food sectors need to learn from other sectors how to implement open innovation so to increase the effectivity of R&D efforts. The most effective way to complete the challenges as quickly as possible is by building consortia of partners that share a common long-term goal. Precompetitive public-private partnerships (PPPs) can overcome the fundamental hurdles much quicker than individual companies. The development of the compact disc (CD) in a partnership between two competitors (Philips and Sony) or competitors in the automotive

Transdisciplinary public-private partnerships, which include all partners necessary to ensure success, in combination with roadmapping to align individual strategies with common goals, are the ideal collaboration framework.

industry sharing the development costs of certain complex car components are both examples of the kind of open innovation that unfortunately remains rare in the agriculture and food sectors. The collaboration with partners from high-tech sectors to solve complex problems can demonstrate the effectiveness of open innovation to the more conservative agriculture and food companies.

Cross-overs with other fields

As many of the challenges are not exclusive to the agriculture and food sectors, other sectors also need to be involved. There are issues that no sector can resolve in isolation, and which require awareness of the developments in neighbouring sectors and the possible negative consequences of certain solutions in other sectors.

> The food system has close links to other sectors. Cross-overs between sectors allow solutions from one to potentially also be implemented in others, improving efficiency for all.

There are many interdependencies between agriculture & food and other sectors. Food is an important component of preventive healthcare, and this links it to curative healthcare in the medical and pharmaceutical sectors. In the future, agricultural production systems will also produce chemicals that are currently refined from fossil sources and provide inputs to the chemical sectors. Both the agriculture and food sectors are very much dependent on large amounts of clean water, which they consume and turn into polluted water. The valorisation of by-products and the waste streams of the agricultural or food industry produce materials that can be used in other sectors. Furthermore, the agriculture and food sectors are also strongly dependent on sectors such as transport and logistics, process engineering and control, materials sciences, ICT, retail, mechanisa¬tion and high-tech.

Cross-overs between the agricultural & food sectors and sectors like ICT, high-tech, water, chemistry and medicine stimulate the exchange of successful concepts. Interdisciplinary collaboration between different sectors enables the quick adoption of solutions and maximises the efficiency of research efforts: it should therefore be encouraged.

Roadmapping

To enable this type of collaboration between partners of different types, mechanisms need to be put in place to align individual ambitions, plans and activities. Roadmapping is a proven way to achieve this.

A roadmap is a combination of a long-term goal (or set of goals) and a series of steps or stages designed to achieve it. Partners—even competitors—who have identified similar long-term goals and recognise the importance of collaborating to achieving those goals can form a consortium. Collaboration can only succeed if all partners have a clear view of which part of the roadmap is precompetitive and where the competitive phase starts, and have a strategy to capitalise on the results along the way. Inclusion of competitors in future consortia may even be a good criterion for evaluating the maturity of partners in the consortium and for ensuring open innovation. Backcasting from the long-term goal can permit the definition of intermediate goals required to make progress towards the main goal (see Figure 2).

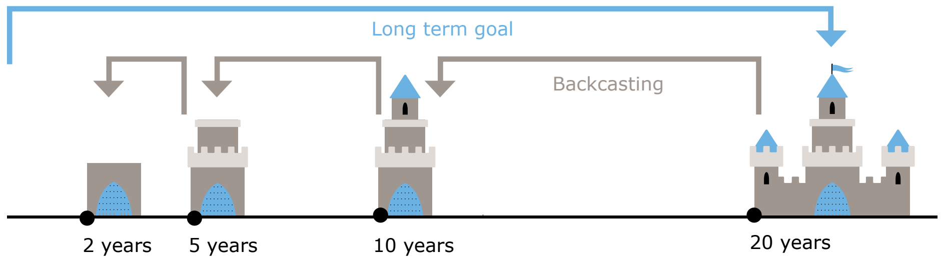


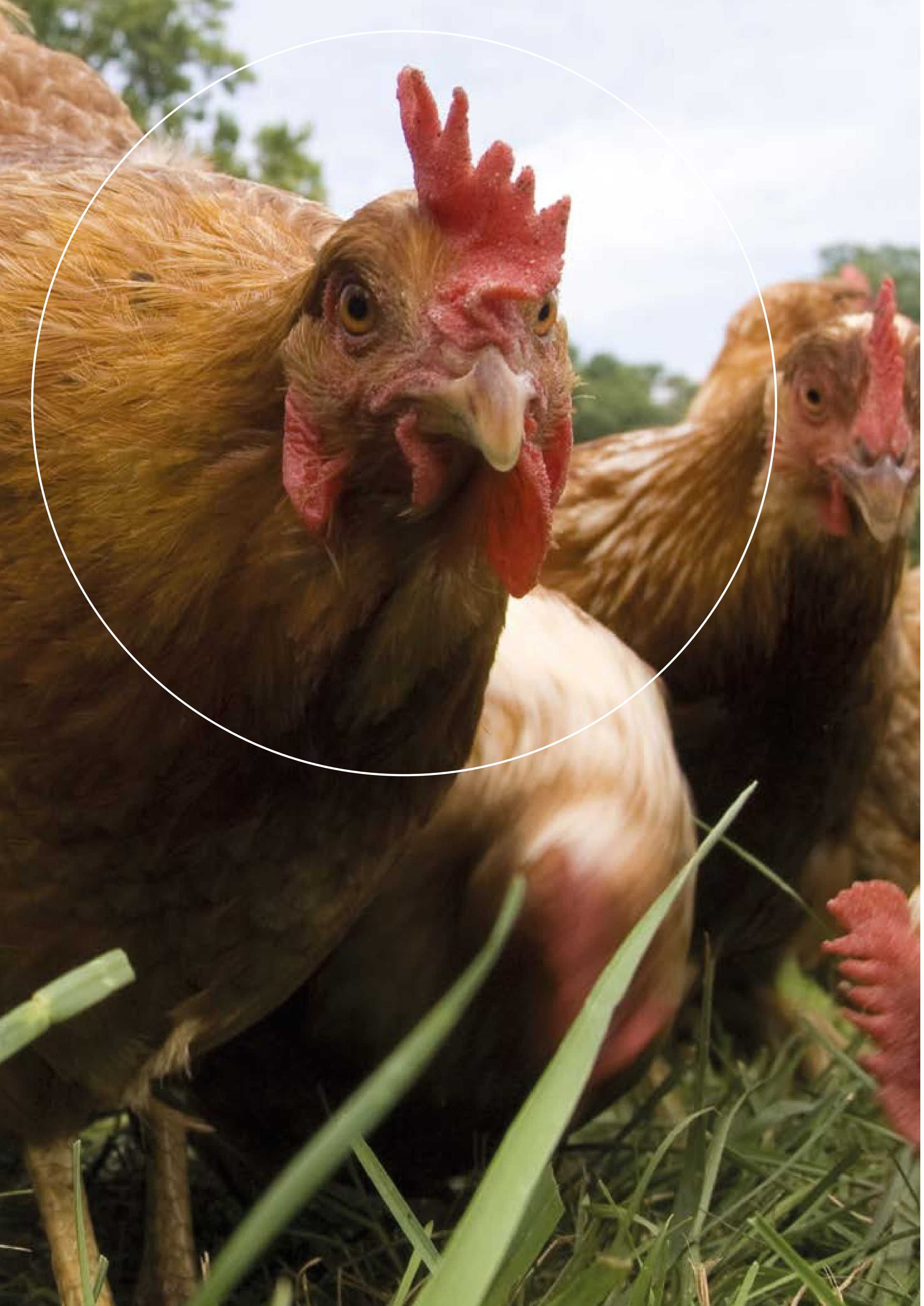
Figure 2

Roadmapping relies on a shared long-term goal that aligns the research and development activities of individual partners in a precompetitive phase.

The roadmap links short-term activities to a long-term perspective and involves partners such as SMEs, who usually focus on goals that can be achieved in one to two years.

Food system transitions—a joint undertaking

More than ever, agriculture and food cannot be perceived as isolated sectors that require separate policies. The time has come for a massive, pan-European joint undertaking to lead the transitions to a sustainable, affordable, reliable and high-quality food system in the next decade or two that will fulfil the needs of a diverse and growing population. Only a large-scale cooperation between private partners, knowledge partners, consumer organisations, NGOs, investors and governments can generate the momentum required to shift the paradigms, develop components of the system to new states and demonstrate that the required transitions can be made as long as all stakeholders are committed to making them happen. Despite the good intentions, however, the devil remains in the details of the many interconnected parts of such transitions.



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