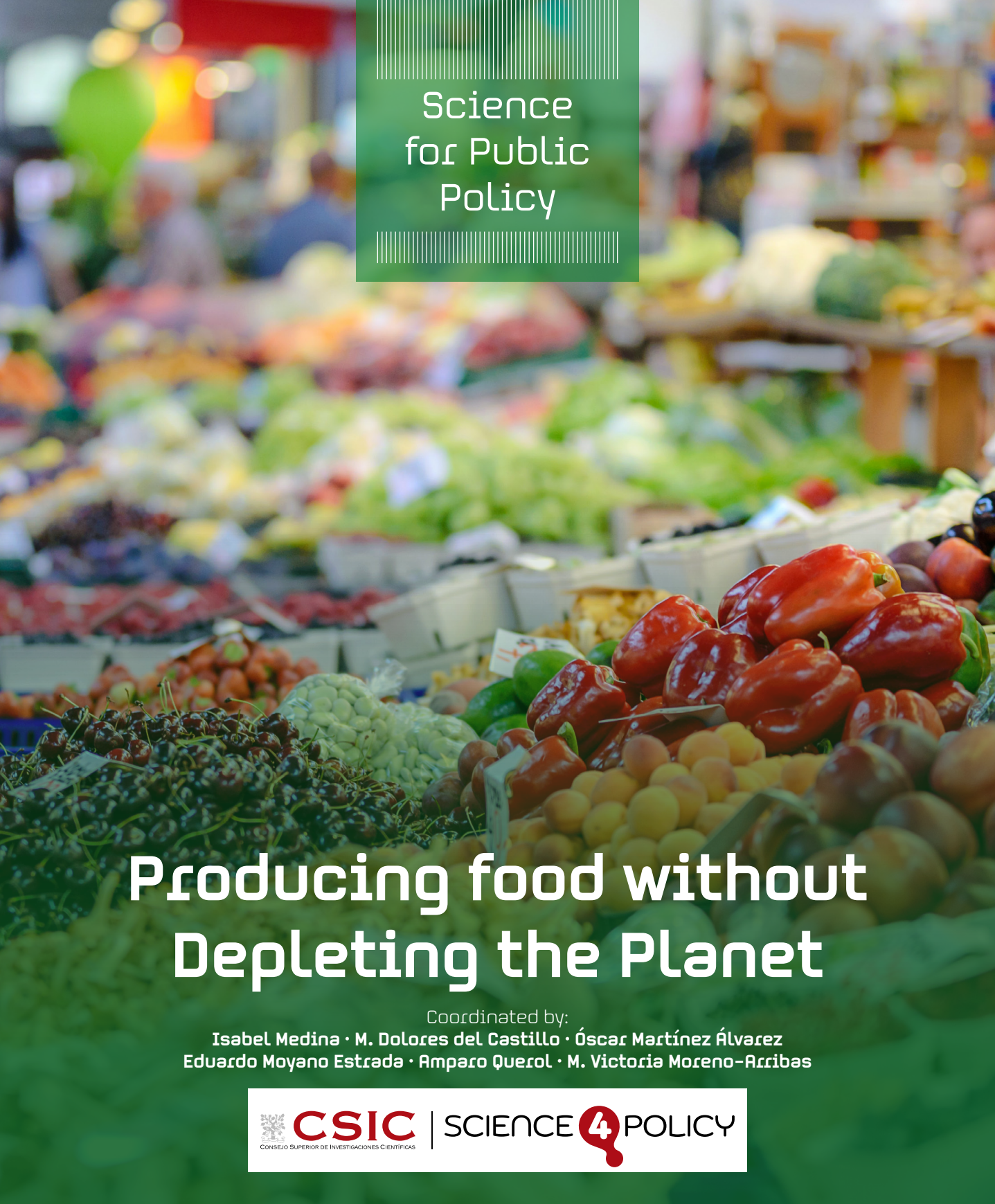


Science for Public Policy

Producing food without Depleting the Planet

Coordinated by:
Isabel Medina · M. Dolores del Castillo · Óscar Martínez Álvarez
Eduardo Moyano Estrada · Amparo Querol · M. Victoria Moreno-Arribas

CSIC Consejo Superior de Investigaciones Científicas | SCIENCE 4 POLICY

Science for Public Policy

Knowledge Transfer Report



GOBIERNO DE ESPAÑA

MINISTERIO DE CIENCIA E INNOVACIÓN

CSIC

Consejo Superior de Investigaciones Científicas

SCIENCE 4 POLICY

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The CSIC's functions include informing, assisting and advising public and private entities in the field of science and technology, as stated in article 5 of its Articles of Association. Undertaking this task, we present the report on *Producing food without depleting the planet*, from the Science for Public Policy series, as a document targeting public administrations and society in general. Herein, the current food crisis is discussed along with the factors that have caused it and its consequences. Authors present the impact of food production on our planet and vice versa: the influence of a changing planet on the food supply. Finally, the report outlines some of the organisation's most important lines of innovation that aim to tackle the challenges posed.

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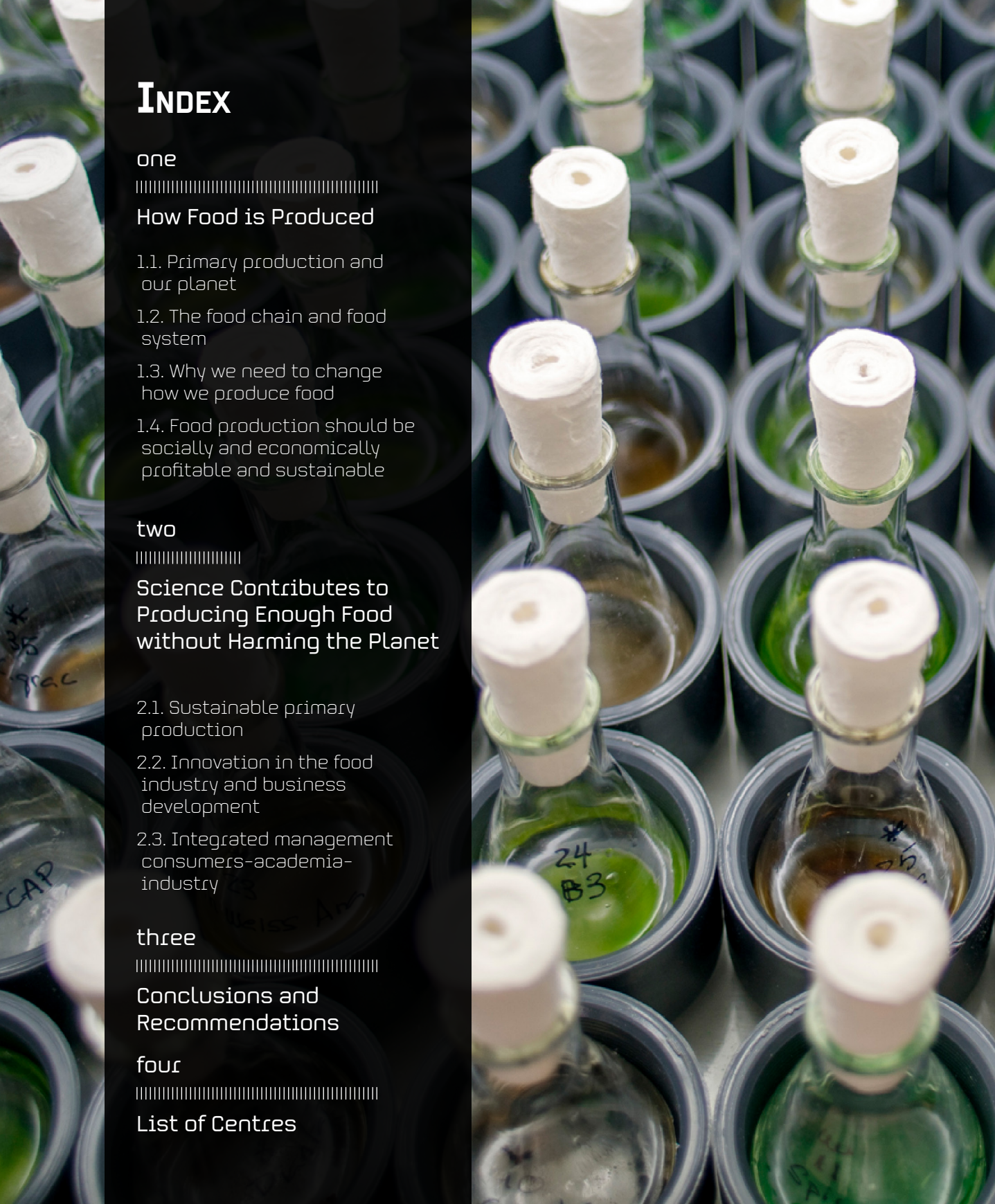
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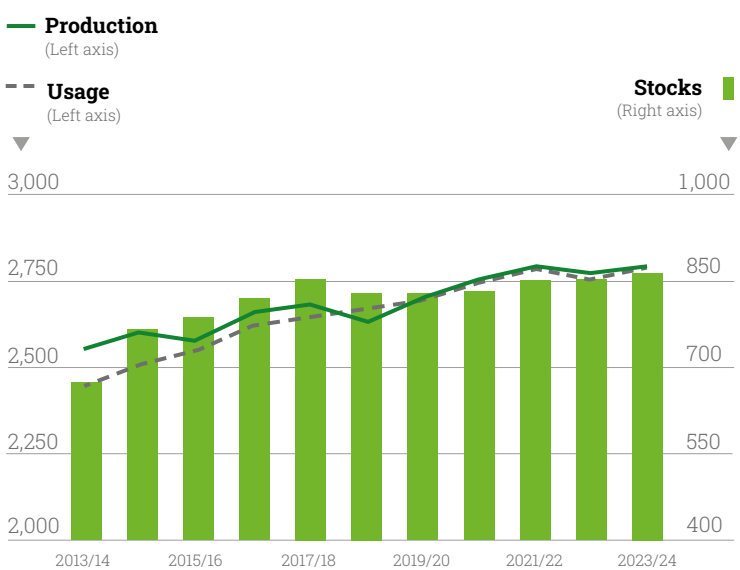
one

How Food is Produced

Since time immemorial, mankind has been concerned about having enough resources to feed a growing population. The British economist Thomas Malthus, in his famous Essay on *The Principle of Population* (1798), predicted that only **"wars and epidemics could correct hunger by reducing the population to a manageable size"**. Countries' food policies must ensure a sufficient quantity and variety of safe and good-quality food to nourish the population properly. To meet this demand, governments, especially in low-income countries with food-deficit, which are also the most populous countries, encourage increased food production. This involves strong development of agriculture, livestock, fisheries and aquaculture as basic productive activities. Clearly, decision-makers in these primary production sectors, as well as those in the other stages of the food chain, must be aware of the nutritional needs of the population and understand the food and nutrition security implications of their actions.

Figure 1.1 Cereal production, usage and stocks

FAO



1.1.

Primary production and our planet

Currently, most of the world's food comes from cereals. Just three crops, namely rice, maize and wheat, represent the main staple food for the global population, which stands at about 8 billion people. The second major food group comes from roots, bulbs and tuber crops, such as potatoes, onions and beets; and the third from pulses and legumes, such as lentils and beans. The world produces approximately 3,070 million tonnes of cereals, 876 million tonnes of root crops and 90 million tonnes of pulses per year, according to the United Nations Food and Agriculture Organisation (FAO). However, recent crises, the covid-19 epidemic and the war in Ukraine have highlighted the risk of ensuring access to food for the entire population due to this dependence on a daily energy requirement per person. Undernourished people, in chronically food insecure situations, are those who cannot access this minimum daily energy requirement. Requirements differ for populations with diverse lifestyles and levels of habitual physical activity. Sustainable food systems are needed to meet the nutritional needs of all people and contribute to economic growth and the conservation of valuable natural resources, which are necessary for future productivity.

In fact, throughout history, farmers and fishermen have continuously increased production at a faster rate than population and income growth. Agricultural, livestock and fishing activities have expanded and occupied larger areas of land and water. And from the mid-20th century to the present day, the world's population has doubled, accompanied by an even greater increase in food production. Indeed, since the end of the last century, we have also witnessed the intensification of crop and livestock production based on innovation, such as the use of synthetic fertilisers, improved crop varieties and chemicals for crop and live-

Figure 1.2 Sustainable food system



To achieve sustainable and efficient food production and stability, we must reach agreements that balance societal well-being with production-system sustainability. The commitment of different social and political actors together with education and research is essential / IRENE CUESTA (CSIC) AND RAWPIXEL.

stock health protection. Better practices have been adopted, such as crop rotation to preserve soils and localised irrigation to improve water use. In the case of fisheries, new technologies have been exploited and the expansion of aquaculture is increasing the production of marine and aquaculture species. These innovations have allowed an increase in production without increasing the use of soil and water, and the production of high-quality food, but often at the cost of excessive use of natural resources.

We are witnessing profound and unstoppable transformations of the planet. Scarcity and competition for limited natural resources such as water and increased demand for energy are putting at risk primary sector activities for food production, such as livestock and agriculture. And vice versa: food production impacts on the climate and the planet itself. Agriculture, a key driver of economic development and a basic element of social articulation, is responsible for more than 20% of global greenhouse gas emissions and 70% of total water consumption, according to the FAO. In addition, one third of all global agricultural production goes to waste and, despite this and the steady increase in farms, 700 million people are still suffering from hunger.

Environmental factors and globalisation are determining factors in food production and supply. Extreme temperature fluctuations and severe water shortages for irrigation and flooding increase the risk of erosion of arable land and reduce the area under agricultural production. These changes in climate encourage the emergence of new pests and diseases, which also have a major impact on production. Climate variations, especially rainfall, lack of rainfall and inclement weather, also lead to problems such as the need for special food storage. In some cases, higher prices may be linked to the cost of food storage and the lack of efficient organisation of official food stocks.

In this context, food policies in the European Union (EU), and in general in countries around the world, have shifted from focusing mainly on increasing productivity and efficiency to taking into account more social and environmental factors and concerns. **The big challenge for the next thirty years is to feed more people with less water and better land use in an environment of globalised and urbanised societies.**

Figure 1.3 Human activities emitting greenhouse gases

WORLD RESOURCES INSTITUTE

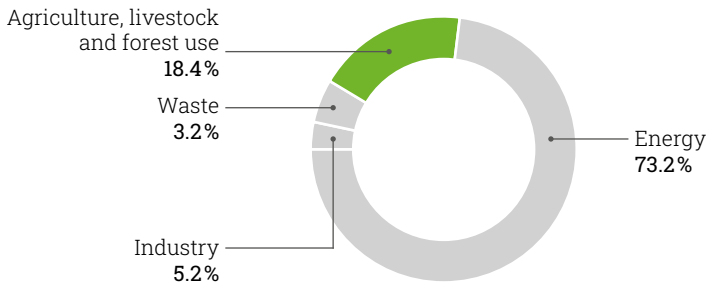


Figure 1.4 Safety elements in the food systems



ENERGY AND FOOD PRODUCTION (NELSÓN HERNÁNDEZ, 2017)

IRENE CUESTA (CSIC) AND RAWPIXEL

1.2.

The food chain and food systems

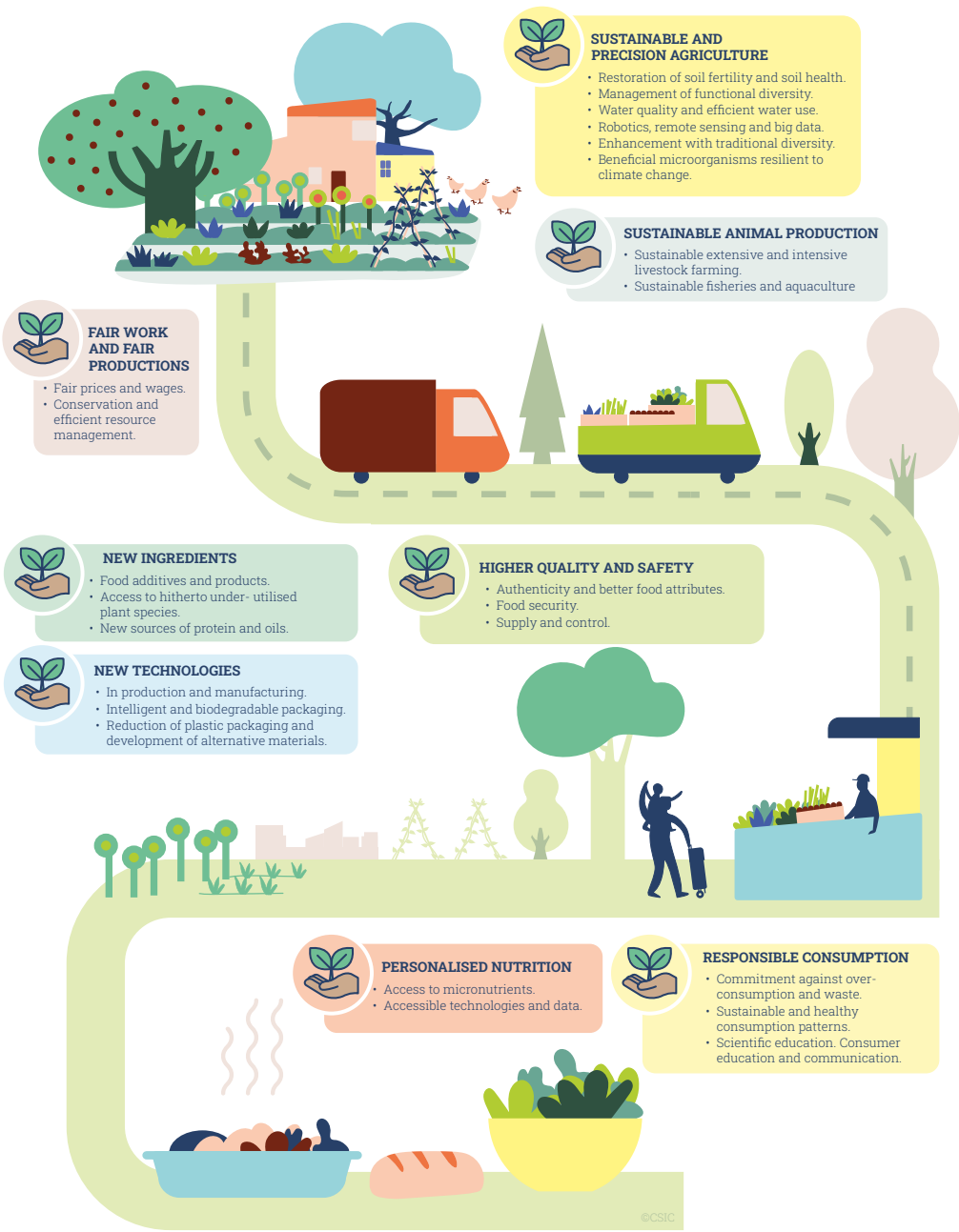
The food chain of a food product encompasses all stages of food production, i.e. all stages or events from production to consumption. Literally, from field to fork. The concept of *chain* refers to the added value achieved as processes are added together. It includes the care of the product, ensuring good quality and hygienic conditions for consumption. In the case of processed food products, it involves the different steps in the production chain, from primary production, the industrial or processing sector, to the distribution or marketing sectors.

The European Commission, aware of the serious problems facing global food production and the planet, has recently published its From Farm to Fork strategy, based on the food chain. In its commitment to the environment and the protection of the planet's health, this European strategy is part of the Green Deal. It sets as challenges for 2030 to reduce by 50% the use of pesticides, 20% the use of fertilisers, 50% the use of antimicrobials in farm animals and aquaculture, and to achieve 25% organic farming on arable land.

On a broader scale, European and international policies have recently emphasized research and innovation strategies focused on Food 2030, placing the food system at the forefront. **The food system refers to the set of interconnected activities, infrastructures and processes involved in feeding the population:** cultivation, production, processing, transport, consumption and food waste management. The food system is a larger structure that encompasses the different links in the food chain.

For FAO, sustainable food systems are "those that ensure food security and nutrition for all people in a way that does not jeopardise the economic, social and environmental foundations for future generations". Population growth and climate change will mean that **we need to produce more food more efficiently by optimising the use of natural resources, especially water, and by preserving soil quality and health.**

Figure 1.5 Farm to Fork Strategy and CSIC Approach



European strategies

Food 2030: The EU's research and innovation policy to transform food systems and ensure that everyone has enough nutritious and affordable food to lead a healthy life.

The European Green Deal: This pact, adopted in 2020, is a set of EU policy initiatives aimed at making the region climate neutral by 2050.

Farm to Fork Strategy: As part of the European Green Deal, in May 2020 the EU launched the Farm to Fork strategy, whose scope covers production to consumer, and aims to ensure a sustainable food value chain.

Bioeconomy Strategy: Targets the set of economic activities that produce products and services, generating economic value and using bio-based resources in an efficient and sustainable way, as key elements of the EU's strategy.

In addition to these challenges, **profitability** is one of the most important challenges. This is why the development of new production systems with lower energy costs must be encouraged. The European Commission insists that the world's food systems must be transformed to make **"healthier diets more accessible for all, while increasing the sustainability and resilience of these systems".** This idea is aligned with the 2030 Agenda for Sustainable Development Goals, an action plan that sets out 17 Sustainable Development Goals (SDGs) with 169 targets covering the economic, social and environmental spheres.



ADOBE STOCK

Attributes that characterise a sustainable food system:

- Productive and prosperous (availability of sufficient food)
- Equitable and inclusive (access to food and livelihoods for all people)
- Empowering and respectful (all people are able to make decisions and make their voice heard)
- Resilient (shock stability)
- Regenerative (sustainability in all its dimensions)
- Healthy and nutritious (nutrient absorption and utilisation)

1.3.

Why we need to change how we produce food

Our current food systems are unsustainable. Greenhouse gas emissions from global food production could contribute to an increase the planet's global temperature by 1.5°C in 2050 and almost 2°C by the end of the century, even if fossil fuel emissions were to be curbed immediately.

These data relate to emissions from both livestock and crop production and land-use changes, as well as from manufacturing, processing, storage, transport and waste disposal. Furthermore, agricultural land degradation not only negatively affects productivity, but also decreases the capacity of agricultural land to absorb carbon, exacerbating climate change. And, likewise, climate change increases soil degradation in a vicious circle that makes it necessary to adapt agriculture to new models of sustainability to provide plant-based food for the population.

On the other hand, the livestock sector, which is essential for securing food supplies, can have a negative impact on the environment. Intensive livestock production leads to deforestation through clear-cutting for new pastures, high water consumption, pollution from slurry and poor crop rotation for feed grain production. And as for fish production, although today only 2% of food for human consumption is produced in the oceans, the reality is that 30% of fish stocks are overexploited, many of them unsustainably. The growing demand for seafood resulting from population growth is leading to increased pressure on most commercial species, making it necessary to move towards sustainable fisheries with responsible economic, social and environmental measures. This is coupled with an extraordinary increase in aquaculture, with the consequent demand for proteins and oils for feed production.

The world's food systems have effects on and are affected by:

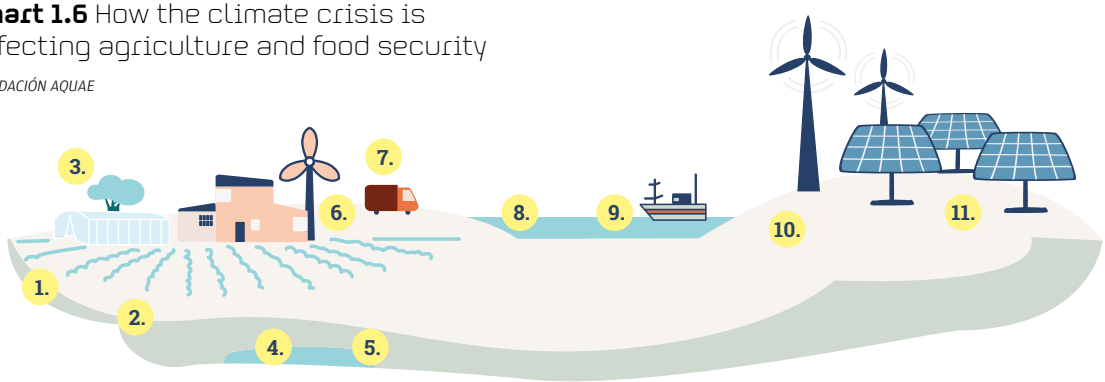
- Climate change
- The scarcity of resources
- Pollution and waste
- Environmental degradation
- Biodiversity loss
- Population growth
- Malnutrition and diet-related diseases



ADOBE STOCK

Chart 1.6 How the climate crisis is affecting agriculture and food security

FUNDACIÓN AQUAE



1. **HARVESTS are poorer, threatened** by extreme weather events and drought.
2. **PESTS AND DISEASES in crops** due to the loss of biodiversity and resilience in agro-ecosystems.
3. **FOREST LOSS and lower resistance** in plants, affecting the water cycle, biodiversity and temperatures
4. **AQUIFERS are depleted or altered**
5. **HIGHER SALINITY of soil and freshwater.**
6. **DETERIORATION of agricultural** soils affecting food security and producers.
7. **DISTRIBUTION made more expensive and local** by the energy crisis.
8. **RISING SEA LEVELS** threatening agriculture in coastal areas.
9. **REDUCTION of fish catches** and marine food resources.
10. **MODIFICATION** of the agro-ecological zones
11. **ABANDONMENT** of farmland and desertification

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Sustainable food systems:

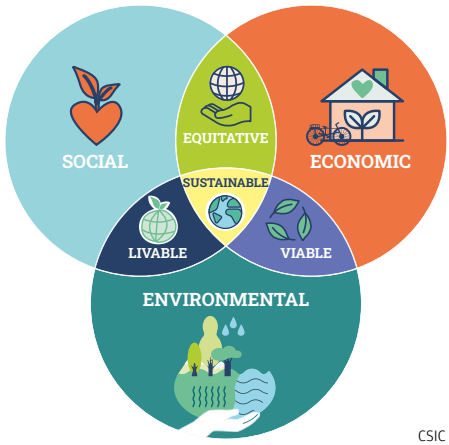
- It is cost-effective at all stages (economic sustainability)
- It provides extensive benefits to society (social sustainability)
- It has a positive or neutral impact on the natural environment (environmental sustainability)
- It should seek to ensure that the long-term health of consumers is maximised (nutritional sustainability)



ISTOCK

Objectives of the new framework of the European Food 2030 policy:

- Adequate nutrition for sustainable and healthy diets
- Food systems as the basis for a healthy planet
- Circular economy and efficient use of waste
- Community empowerment and innovation



CSIC

The above factors are exacerbated by fragmented food systems and incoherent food policies. The EU, through its **Food 2030 policies**, provides the frameworks to speed up the transition of how food is produced within safe and sustainable planetary boundaries. These policies are in line with and support the objectives of the **European Green Deal**, the **Farm to Fork** strategy and the **bioeconomy** strategy.

Food sustainability must be understood in its different aspects of **environmental, social, nutritional and economic sustainability.** Production processes must be economically sustained to achieve a high degree of autonomy, achieving economic and environmental sustainability. They must also contemplate and comply with criteria of social justice and the fight against precariousness, and thus contribute to greater social sustainability of the system. Intrinsically, **projects must preserve the planet, as far as possible, in order to contribute to the environmental sustainability of the whole.** And, finally, they must seek to ensure that the long- term health of people they provide with food is maximised, thus promoting sustainable nutrition.

Food loss and waste, a challenge in designing sustainable food systems

- **Food losses** are defined as "the decrease in the quantity or quality of food as a result of suppliers' decisions and actions throughout the food chain, excluding retailers, food service providers and consumers".
- **Food waste** relates to the decrease in quantity or quality of food as a result of decisions and actions of retailers, food service providers and consumers.

The latter aspect of nutritional sustainability will be discussed in more detail in the volume *Sustainable and Healthy Nutrition* in the Science for Public Policy series.

Food policies in all countries set a number of urgent goals with common connotations to achieve food sustainability. These goals are to produce food more efficiently, to help producers in low-income countries to increase their yields, to eat healthier food, to avoid overeating and to waste less food. In addition, factors such as levels of food in storage and post-harvest losses due to pests and diseases, spoilage, high temperatures, etc., can greatly affect the food supply. Reducing food loss and waste is also an integral part of the **Farm to Fork** action plan.



ISTOCK

14.

Food production should be socially and economically profitable and sustainable

One of the key requirements of sustainable food systems is that they should be economically sustainable. and meet social justice criteria, in order to contribute towards the socio-economic sustainability of the system. The principle of sustainability in food systems is defined generically as one that guides producers' decisions to ensure the profitability of their farms (economic dimension), the preservation of their material base (environmental dimension) and the improvement of the well-being of the rural population (social dimension).

There seems to be a broad international consensus on the need to take into account all three dimensions of sustainability. It is not possible to ensure the well-being of future generations if attention is paid only to the preservation of the environment. Development methods must guarantee sustained, territorially balanced and equitable economic growth for the people who inhabit our planet. If agricultural, livestock or aquaculture farms are not profitable and do not generate sufficient profits for their owners, environmentally friendly agriculture that is proactive in combating the effects of climate change will not be possible.

Likewise, it will not be possible to help solve the problem of depopulation in many rural areas if agriculture is not linked to the territory in those areas and serves as an impetus to local development. Another fundamental aspect is the fight against rural abandonment by investing in basic infrastructure and encouraging policies that promote the integration of different production systems, knowledge transfer and innovation. All this through collaboration with the private sector to advance in the commitment to sustainable production. Among the social aspects to be considered, the promotion of responsible consumption is also crucial.

These three dimensions of sustainability can be analysed-economic, environmental and social - from two points of view. On the one hand, individual interests, through the analysis of the strategies used by producers to optimise investments, rationalise the use of inputs and make their activity as profitable as possible. On the other, we consider general interests, through the study of public policies aimed at achieving the SDGs.

In practice, however, individual interests do not always coincide with general sustainability interests, as the corporate goal of sustainable food often diverges from the SDGs of the 2030 Agenda. This fact can lead to misunderstandings when addressing sustainability, which is reflected in the business strategies adopted by producers but also in the way public authorities define the goals of sustainable development, formulate the policies adopted to achieve them and set the pace and deadlines for their implementation.

In the EU, the programme of agri-eco-regimes to combat climate change and promote low-carbon agriculture, or the environmental and social conditions outlined in the new CAP (Common Agricultural Policy) are good examples of public actions aimed at the agricultural sustainability. In Spain, clear examples of public actions addressing the sustainability of the food chain are reflected in *Law 16/2021 to improve food chain functioning,* and the draft Law addressing the prevention of food waste losses and *Royal Decree 1051/2022 establishing standards of sustainable nutrition in agricultural soils*.

The 2030 Agenda for Sustainable Development includes the 17 Sustainable Development Goals (SDGs). The SDGs shape national development plans for the next fifteen years. Eradicating poverty and hunger, combating climate change and protecting our natural resources, food and agriculture are

In summary, all three dimensions of sustainability affect food production models, but not all in the same way. Individual and public actions are key elements in moving towards more sustainable models of food production and distribution. These include economic profitability as well as ecosystem balance and social and territorial equity.

two

How Science Contributes to Producing Enough Food without Harming the Planet

2.1.

Sustainable primary production

As discussed above, humankind faces the inescapable challenge of moving towards a new and more sustainable future. In a global context, food systems also face the major challenge of meeting the growing demand for quality food for the whole population, while at the same time creating economically and socially sustainable scenarios.

The CSIC aims to move towards innovation that is capable of integrating the environmental and social perspective by combining the most cutting-edge basic and applied research, providing solutions to the impacts of agriculture and animal production, both terrestrial and aquaculture. The following is an analysis of some of the advances in the institution's research within a broad framework of sustainability, conceived in its different aspects and taking into account the needs of future generations and the fact that any sustainable solution must be sustainable for the whole planet.

Agricultural production systems

The necessary evolution of agricultural models to produce sufficient and high quality food requires a transformation of the system to curb soil degradation and the impact of erosion, through the protection and promotion of plant and animal biodiversity. At the same time, it is necessary to better manage available resources, prioritising the use of local resources and the conservation of species and natural areas. This should be done without causing price rises that impede people's access to certain foodstuffs. The role of farmers and agricultural heritage should be highlighted, the latter being fundamental for socio-economic sectors such as tourism and culture and for social welfare.



Information and Communication Technology used in agriculture, livestock and fisheries improves conditions. /ISTOCK

Science has shown that it is possible to combine sustainable agricultural practices that preserve the optimal quality and functions of soils and vegetation on a small scale, without negative effects or even through increased productivity. CSIC is leading studies on large-scale agro-ecosystems aimed at developing **sustainable extensive and intensive agriculture.** Through the ecosystem services approach, the problem of the production of food, feed, fibre, fuel and raw materials for different industrial uses is addressed, as well as the regulation and support of natural systems, climate, water supply, pollination or the control of pests and plant pathogens.

The CSIC's cross-cutting know-how in the economic and social analysis of agricultural practices and cost-benefit ratios, via consideration of environmental issues related to agricultural activities, support regional and international policies and sustainable business development, based on effective science-policy and science-business communication..

- **Biodiversity conservation.** The institution's groups are working on the characterisation of biodiversity and the **health and functionality of the soil, ecosystem and agroforestry landscape** to identify the most innovative practices. This is coupled with research infrastructures for monitoring, prediction and early warning of natural hazards, with the integration of remote sensing and modelling. This area also includes infrastructures for a more efficient irrigation system, as well as the development of new methods of water purification.

- **Genetic improvement.** One of the most effective tools to increase crop resilience to climate change, optimise plant and animal resource use and diversify crop varieties is through genetic improvement programmes. The CSIC is working with the new approaches provided by **biotechnology and genetic improvement** with this aim in mind. This research also promotes the exploitation of local genetic variability that has not been explored so far in Spain and the search for new varieties and crops that are more resistant to drought and water stress, more productive and of high quality. The application of high-throughput *omics* technologies - genomics, transcriptomics, proteomics and metabolomics, among the main ones - supported by bioinformatics approaches of unprecedented capacity, and innovative tools - such as synthetic biology in agricultural species, model and cultivated plants - contribute to the development of crops to produce food, products and feed on demand, highly demanded by agriculture and industry.

- **Plant and animal health.** An essential area of work at the CSIC is **pest and pathogen control.** Despite efforts made in recent decades to prevent biological invasions, the spread of agricultural pests and pathogens continues at an unprecedented rate, endangering the world's food supply.

  Infectious plant diseases and emerging and re-emerging pests are one of the major threats to food security. Their incidence is increasing due to changes in epidemiology, often associated with the invasion of new species and populations of pests, weeds and pathogens. CSIC research groups approach the control of these harmful organisms from a sustainable perspective, including the rational use of plant protection products, plant breeding for pest and disease resistance, remote sensing techniques, for all types of fruit crops (stone, pip, olive, vine, custard apple, avocado, etc.), horticultural crops (tomato, melon, cucumber, cauliflower, etc.), extensive crops (cereals, legumes, sunflower, etc.), and forestry. This research also focuses on curbing some of the pests and diseases that the European Commission considers to be a priority for action, such as those caused by the pine wood nematode, *Bursaphelenchus xylophilus*, and the bacteria *Xylella fastidiosa*, currently affecting Mediterranean crops such as olives and vines, and for which there is no cure to date.

  As an alternative to synthetic plant protection products, CSIC proposes the use of biopesticides and biofungicides based on soil micro-organisms, plant extracts and biomolecules of natural origin. In addition, new genetic engineering approaches using genome editing tools are used against major fungal, bacterial and viral pests and diseases, seeking more durable resistance.



Biotechnology and genetic improvement are two key tools to improve crop resilience to climate change

CÉSAR HERNÁNDEZ

- **Agroecology.** Numerous CSIC research groups work with a transdisciplinary scientific approach that encompasses various areas of specialisation. These include soils, biodiversity, forestry systems, extensive livestock farming, and waste composting; as well as biogeography, archaeobiology, history, economics, anthropology and sociology. This approach involves the application of a set of practices to grow and produce food sustainably through the use of renewable resources and the maximum possible reuse of resources, such as the production of fertilisers from food waste and other alternative uses of by-products from agriculture, livestock breeding and the food industry.

- **Efficient use of water.** CSIC research staff participate in the expert panels and reports of the Intergovernmental Panel on Climate Change (IPCC). One of the key priorities of the ongoing research programmes is the adaptation of Spanish agro-ecosystems to future climate scenarios and the design of agricultural strategies that involve reduced and more efficient water-resource use to face the increasingly hotter and drier climate. The institution's groups identify and characterise crop varieties that are more tolerant to drought and salinity, they also model and optimise the precise application of irrigation, providing Spanish irrigation with cutting-edge management tools. Also deficit irrigation strategies are being developed in order to apply water to crops only when it is most needed, and agronomic practices are adopting strategies for water conservation and the reduction of greenhouse gas emissions and other pollutants.

  Our society must endeavour to prevent the disappearance of our great agricultural, livestock and forestry diversity. The CSIC has banks of seeds and varieties, which form part of the institution's heritage and are actively used in research to produce new, high-quality, diverse varieties and make them available to society.

- **Precision agriculture.** Precision agriculture uses sensors in arrabal fields, as well as drones and satellites for birds-eye monitoring in order to control and manage fields remotely. In a cross-cutting way, through collaborations with experts in artificial intelligence, the CSIC currently promotes different **precision agriculture** projects. These use deep learning models (or deep learning through computational architectures) which, with the help of remote sensing, enable the construction of a big data platform suitable for crop characterisation and management, as well as for the detection of crop diseases from aerial and satellite images. These projects also deal with the management of mobile and cognitive robots, which integrate **robotics** in agriculture.

Livestock, fisheries and aquaculture production systems

In line with sustainability in agricultural production, livestock and aquaculture systems should be oriented towards environmental sustainability and even towards the regeneration of eco-systems. Furthermore, these models contribute to improving the quality of life of rural communities, as they are often their main source of income, providing greater purchasing power.

Sustainable livestock farming implies the elimination of the use of hormones and chemical products - antipyretics, antibiotics, antiparasitic or anti-mastitic treatments - that are currently used. It also means concern for the level of emissions and rationalisation of natural-resource use. Sustainable fishing respects marine ecosystems in tune with the reproductive rhythm of organisms, maintains balance and ensures the survival of species, while rejecting the indiscriminate capture of juveniles and endangered or non-commercially valuable species. The production of low trophic level species (such as algae and molluscs), which feed on what the sea provides without requiring added feed, can reduce production costs, is more efficient and contributes to reducing the carbon footprint, as they act as carbon dioxide (CO_2) sinks. This helps to reduce greenhouse gas emissions and minimises their contribution to global warming.

CSIC research projects address different disciplines such as **animal nutrition,** applied to both monogastric animals and ruminants, and the production of farmed fish. Alternative livestock systems and land use are considered, as well as ecological production and the use and valuation of by-products. The projects focus on reducing environmental impact and improving the quality of animal products. For example, work is being carried out on the diversification of species and the search for new alternative sources of ingredients f o r animal feed, such as insect proteins, algae, waste from the agri-food industry and discards from the fish processing industry. Tools are also provided to the livestock sector to reduce gas emissions from ruminant livestock. In fact, CSIC researchers have participated in the development of the only feed additive so far approved by the European Food Safety Agency (EFSA) with the capacity to reduce methane emissions by 30% without affecting digestion or animal health.

Another of the CSIC's priorities is to progress in understanding the **epidemiology and pathogenesis of animal diseases**, as well as the mechanisms involved in the development of **antimicrobial and antiparasitic resistance in animal health.** Progress is also being made in the conservation and characterisation of genetic resources and the biological bases (genetic, epigenetic and molecular) that determine the efficiency and resilience of plant and animal species.

Projects are also underway for the implementation of **technologies (sensors, software, big data)** for continuous data collection to assess animal health and monitor their welfare. These technologies also make it possible to check the efficiency of the production system and the economic profitability of livestock, aquaculture and fishing companies.



Regenerative livestock farming targets soil conservation and regeneration. / PEXELS

All these projects are performed from the perspective of reducing water use and the carbon footprint, and assessing the nutritional resources required by animals. Finally, several CSIC research projects aim to improve the nutritional value and health properties of animal products, thus promoting socially and environmentally responsible consumption.

22.

Innovation in the food industry and business development

Nowadays, industrial food processing requires continuous improvement. These include and the safety and quality requirements imposed by EU legislation. Moreover, to these we should add Innovation in the food industry and business development consumer demands, ever growing food requirements, and the availability of new foods and products. These improvements must cover all stages of processing, distribution and sale, as well as upstream stages of primary production.

Modernisation in the food industry must be linked to optimal traceability of the system, enabling the transfer of information along the chain, as well as the control of product quality at all times. Furthermore, this modernisation of the systems must be environmentally friendly. The Spanish Ministry of Agriculture, Fisheries and Food (MAPA) has recently published a document on comprehensive sustainability of the food industry *(Decálogo de sostenibilidad integral de la industria alimentaria).* Adhering to this Decalogue is not compulsory, but companies that do so improve the sustainability of their production processes and in competitiveness compared to other companies in the sector. The MAPA also provides food industries with an online tool called *e-SIAB*, which allows them to self-assess the environmental sustainability of their processes.

Waste from the food industry

So-called green strategies for sustainable food processing are numerous and varied. They are necessary not only from an environmental perspective, but also to increase the competitiveness of agri-food processors - meat, fish and fruit and vegetable processors - at national and international level.

These "green" improvements include those that cost- effectively and sustainably lead to less waste being generated during processing, as well as using the waste generated. In other words, it means implementing a **circular economy**, making use of the waste that is generated, not wasting it and reducing emissions.

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PEXELS

Decalogue for integrated sustainability in the food industry

It is a voluntary commitment for companies that want to improve their processes and make them sustainable in a comprehensive way, with special reference to:

1. Supply chain
2. Local economy, stakeholders and consumers
3. Workers
4. Environmental impact management
5. Energy consumption management
6. Ethical conduct
7. Sustainable agriculture and livestock farming. Biodiversity
8. Eco-design of products and packaging
9. Waste management
10. Research, innovation and development

The processing industry produces thousands of tonnes of waste during handling, post-harvest and retail. Waste disposal is a serious environmental problem.

For this reason, the CSIC gives priority to the use of non- marketable foodstuffs that are in optimum condition and can be exploited when used in the manufacture of other products and the production of ingredients. Good examples of these nutrient-rich by-products are fish muscle trimmings derived from filleting, mechanically extracted meat for the production of restructured products, the use of pulp for the production of juices, and the use of fish flesh for to manufacture fruit juices or the production of gluten-free flours from various materials. In fact, many by-products of vegetable origin are a rich source of compounds of interest, providing natural additives as alternatives to synthetic ones (antioxidants, flavour enhancers, gelling agents, preservatives, etc.).

The circular economy is "a model of production and consumption that involves sharing, renting, reusing, repairing, renewing and recycling existing materials and products as often as possible to create added value. In this way, the life cycle of products is extended." (EU)

The CSIC is also working on obtaining compounds with healthy properties of interest for sectors such as the food, pharmaceutical or cosmetic industries, based on by-products from the food industry. One example is bioactive compounds that can modulate the gut microbiota, and thus strengthen the immune system, or to regulate blood sugar and blood pressure. Ultimately, if no properties of interest are found, the waste could be used to produce biogas, pesticides or fertilisers.

In addition to research into the use of food waste, various CSIC groups are turning their attention to the use of animal or plant species that are abundant in nature but underused. They are studying pseudocereals (e.g., quinoa, amaranth and buckwheat or black wheat), algae or different non-commercial marine species, which could be a source of value-added compounds for certain sectors, after appropriate processing.

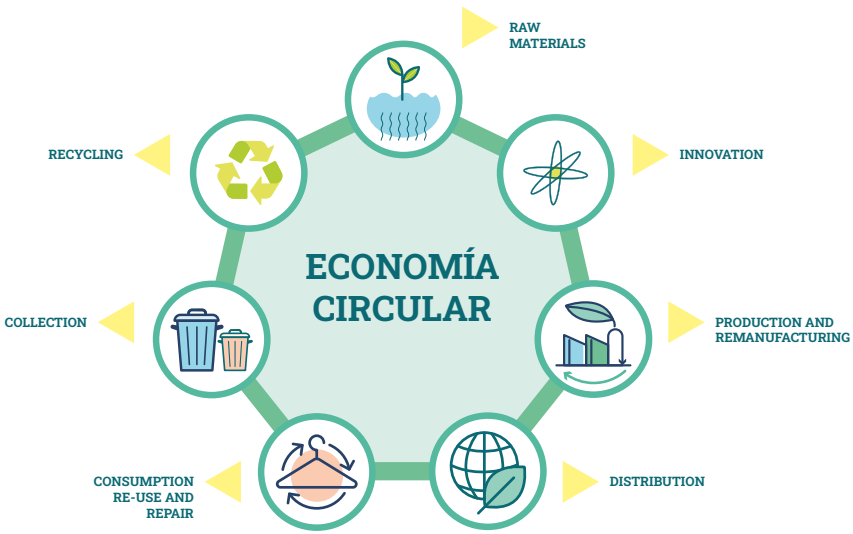
In addition to the waste generated by the food industry, 931 million tonnes of food are wasted worldwide every year, according to the 2021 food index published by the United Nations Environment Programme (UNEP). This represents 17% of the food available to consumers. Of this, 569 million (61%) comes from homes, while 244 million is attributed to restaurants and other catering services, and 118 million tonnes from retail trade.



ISTOCK

Figure 2.1 Circular economy

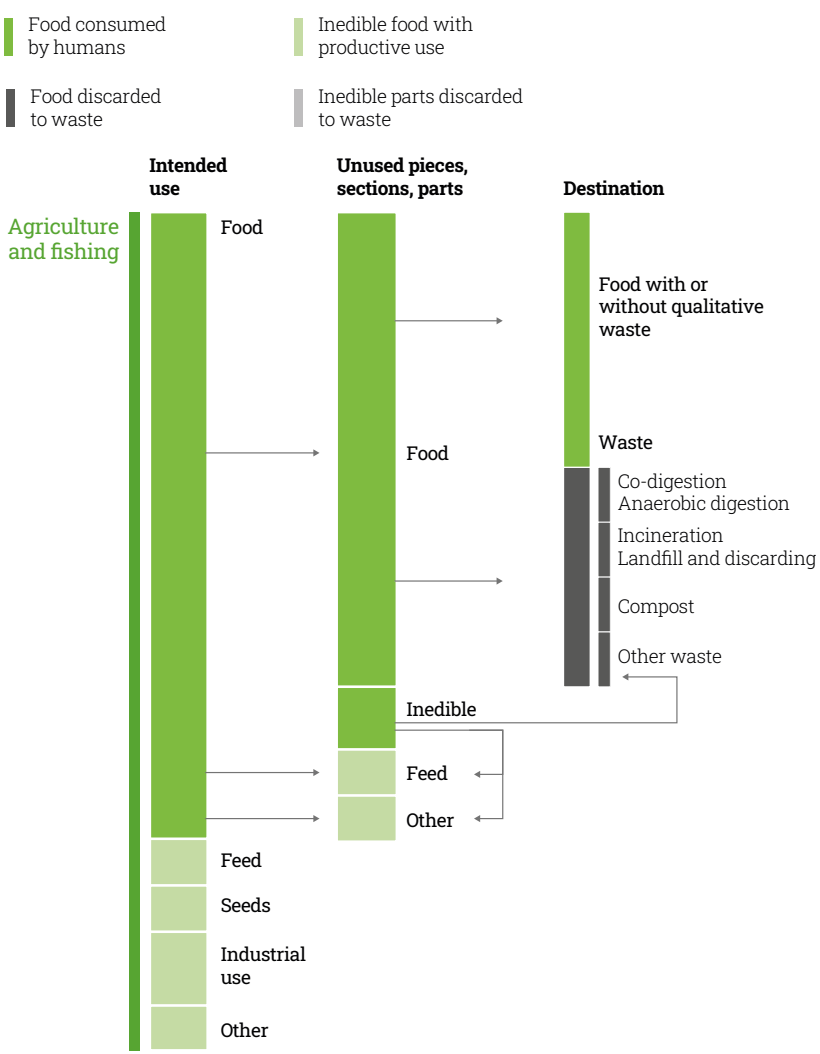
PARLAMENTO EUROPEO



CSIC

Figure 2.2 Where does waste go?

FAO



Improvements in the processing of foodstuffs

CSIC research staff are also working on implementing improvements in food processing. This involves, among other things, designing more efficient processes, as well as guaranteeing and extending the shelf life of food to reduce food waste. Priority improvements include research into reducing the consumption of inputs and natural resources such as water, more efficient use of energy and the use of renewable energies. This reduces production and sales costs, and ultimately carbon dioxide emissions.

To give some paradigmatic examples, the CSIC is developing the **industrial use of fermenting micro-organisms** with lower heat and cooling requirements. This implies less water consumption in temperature maintenance systems, as well as a more efficient use of energy. The reduction of processing times, the use of more efficient and cleaner technologies or the application of water and energy reuse systems, both on fishing vessels and in the processing industries, are other objectives sought by our research staff.

Another field of study in which several research groups are working is the development of sustainable processes for the production of molecules, biomolecules and products with high added value for the food sector. These include additives and nutraceuticals as well as nutritional supplements. In this context, their production through the use of microorganisms or enzymes, and the use of clean technologies will play a key role in future sustainability as they involve less polluting processes. The CSIC has a solid biotechnological track record. This places the institution in a privileged position to make fundamental contributions to research into the use of microorganisms as future cell factories, intelligent green biofactories for the bio-production of agro-chemicals, biofuels, nutraceuticals and pharmaceuticals for future generations.



The CSIC has collections of microorganisms that are used to obtain probiotics, new enzymes or even to improve industrial processes. To carry out these approaches, they are characterised using different scales of growth as shown above. /IATA/PIXABAY

In this section we should mention the collections available at the CSIC, where the biodiversity of plants and micro-organisms has been conserved, together with initiatives based on the microbiome of food systems. These collections will play an important role in obtaining ingredients, additives and nutraceuticals, through the use of innovative and sustainable technologies.

The CSIC aims to **avoid the use of polluting compounds in various processes**, for example, by studying their substitution with environmentally friendly compounds. Research is underway on the application of clean techniques to extract compounds of interest, such as supercritical fluids, the use of microorganisms, enzyme treatments and fermentation processes, among others. Studies also focus on the optimisation of processes for the extraction of ingredients of technological or bioactive interest from waste or unused animal or plant species.

The **implementation of management tools** in production processes is key to achieving the modernisation of the food sector with a view to sustainability. One of these is life cycle analysis (LCA, a tool that can assess the environmental impact of a process or product throughout its life cycle. Advanced traceability systems covering all links in the chain have also been implemented, a tool that has a long way to go; their implementation also meets the needs of consumers seeking information about food before they buy it.

The development of processes for the **protection of bioactive ingredients** against technological treatment or gastrointestinal digestion also plays an important role. For this purpose, microencapsulation and nanoencapsulation in different matrices are mainly used as a protective method. Also under study is the bioaccessibility of bioactive compounds, understood as the fraction released from food during digestion and available for absorption. Likewise, we study their bioavailability, which represents the speed and quantity with which the nutrient, or part of it, is absorbed and reaches the bloodstream. These studies are carried out both *in vitro* and *in vivo*.

New foods

Our current pace of life and population ageing lead to consumer demands for new foods and ingredients, which must be taken into account by companies in the sector. This includes the development of consumer-ready products (organic, vegan, allergenic, dysphagic, functional, etc.), as well as healthy ingredients. The CSIC contributes to developing foods demanded by today's society, for example, by substituting certain ingredients, like animal protein, with protein from other sources (e.g., vegetables).



People are demanding alternative sources of protein, such as algae. / PIXABAY

We should point out that we already have high quality protein on our market, such as legumes, which are sustainable, healthy and economical. However, industry is seeking to respond to society's demands to replace traditional animal food sources. One of the great future challenges is to have alternative protein sources, such as microorganisms, microalgae, insects, cell cultures and pseudocereals, among others. Several CSIC groups are working on obtaining proteins and functional ingredients from algae, as well as fermentative strategies to develop sausage analogues through mixed animal and vegetable protein sources, always observing nutritional value, safety and consumer profiles. In this context, it is important to note that the nutritional requirements of certain vulnerable population groups, such as the elderly, who need a higher protein intake, should be taken into account. Different CSIC research groups are involved in this field.

Innovative packaging



Biodegradable packaging created from almond shells and cheese whey. / CSIC

Modernisation in production involves the development of sustainable packaging materials to replace plastic packaging, which is often single-use. Packaging helps to reduce food waste, but the huge amount of plastics used globally and discarded after food consumption calls for the development of **sustainable alternative materials**. The aim is for these materials to come from natural sources, be biodegradable or biocompostable, cost-effective and, as far as possible, incorporate compounds that increase the shelf life of the product, which is necessary to reduce food loss.

The CSIC focuses its studies on the search for polymeric materials not only for the development of packaging, but also for coatings. Several CSIC groups are studying the improvement of their physical, mechanical and functional properties, and the production or extraction processes of the materials to make them environmentally friendly. The polymers that generate most interest are those produced by microorganisms (from by-products), those extracted from food industry waste and those from abundant and underused species, such as algae.

The improvement of packaging properties through the application of micro- and nanocomposites as fillers and with bioactive potential, the development of polymer blends and their modifications, and the controlled release of bioactive compounds is and will be the focus of CSIC research staff in the coming years.

In addition, it is a priority for these new packages to incorporate antimicrobial or antioxidant compounds to extend the shelf life of the product. Work is also being done to develop **intelligent packaging**, for example by integrating sensors in the packaging or in the coating to provide information on the food quality and safety. Different research groups are working on the development of nanomaterials for the production of nanosensors and nanoprobes, with higher sensitivity and accuracy than the sensors commonly used in the food industry.

Information and Communication Technologies (ICT)

Another of the great challenges facing the food sector is to attain intelligence, efficiency and sustainability at each stage and each of the actors in the agri-food chain through the use and development of cutting-edge ICT. The integration of automated processes and digitalisation must be supported by the implementation of fifth-generation networks (the so-called *internet of things*), the use of robotic tools and big data country-wide.

Artificial intelligence can be useful in the food industry to avoid, for example, production surpluses, to find substitutes for ingredients or to combine ingredients to achieve specific flavours and textures. It will also be instrumental in the development of personalised foods or to gather information on consumer preferences and needs. Its implementation will help to reduce food waste. ICT development for the sector is very new. An increasing number of CSIC projects include these technologies, thanks to specialisation in this area and the fact that they are considered strategic lines of funding. It is one of the lines that will be developed the most in the coming years.

The beverage and aquaculture sectors are currently applying modelling, prediction and digital twinning for decision-making. Some of the CSIC projects are pioneering in this area. The development of innovative, rapid and non-invasive techniques to determine food quality, traceability, safety and adulteration or fraud is of great interest to companies. The CSIC has leading experts in this field, both nationally and internationally. In this context, we can talk about fraud control in all sectors: plant, dairy, meat and seafood products. Its scope ranges from safer food preservation to reducing the use of additives and preservatives in foodstuffs, including fermented products, bringing added value to the processing industry in Spain and thus fostering its competitiveness internationally. Furthermore, the implementation of digitalisation improves marketing through innovative mechanisms based on predictive models and big data, and favours the development of platforms for data storage, management and processing.



Marine research uses satellites and drones to study the seas and the fisheries sector. The picture shows aquaculture farms in South Korea captured by Sentinel-2 satellites.
/ SENTINEL-2

In the field of technologies, CSIC research staff have and will continue to play a key role in the development of **computer applications** to improve production systems or to provide consumers with information on the quality and safety of a product before purchasing or consuming it. For example, the SafeFrying application has been developed to help reduce acrylamide formation in French fries. Also of great interest to the primary sector are applications that help improve production, such as SHuBest, which allows farmers to identify sustainable soil and water management practices best suited to their conditions.

2.3.

Integrated management: consumers -academia- industry

A fundamental objective of European food policy strategies is to achieve sustainable food production by 2030 that fosters a healthy innovation ecosystem, understood as a process of collective construction in producer communities. This means understanding that innovation is not solely about organisations, but also about the people, activities and resources involved. All actors must therefore be connected. In this way, people, organisations and activities will be linked both vertically and horizontally within the food chain, and actors operating in isolation will be avoided. It is believed that through closer partnerships with industry and society, markets can function responsibly, promote fair trade and pricing, inclusiveness and sustainability. This will help create new jobs in the EU and promote urban prosperity, rural and coastal economies and communities based on local production.

Due to its transversal nature and its vocation for innovation, the CSIC fosters progress based on substantiated evidence and the development of business and social innovation, proposing sustainable and healthy foods. The institution promotes knowledge transfer through initiatives that contribute to transforming our food system towards sustainability in all its facets. These initiatives include:

- The creation of technology-based companies and innovation ecosystems that generate new business models and new products in the agri-food and gastronomic sector, with the aim of developing solutions to challenges posed by the food industry.

- Outreach and education to promote sustainable and healthy food for all people, in towns, cities and regions, as well as collaboration in local, national and international initiatives.

- Increase consumer confidence by involving the public in food science and food safety and in local food policy.

The CSIC's assets

- Experimental farms
- Greenhouses
- Pilot plants and industrial scale-up
- Animal nutrition and production farms
- Marine research vessels
- Aquaculture facilities
- Artificial intelligence and omics platforms



CÉSAR HERNÁNDEZ

- Support an economy based on the *farm-to-fork* concept by contributing to social innovation, for example, through biorefinery projects aimed at the valorisation of by-products from the agri-food industries.

- Develop smart food- and nutrition-based data tools tools that respond to the needs of society, such as projects aimed at developing predictive models for suitable nutrition of different population segments.

In the field of business creation, it should be noted that CSIC groups have significant scientific assets in many areas of the food system, and know-how that they make available to farmers, producers and society as a whole. These assets encompass experimental farms, which provide resources and agricultural plots for experiments with heat and water stress conditions, greenhouse services or farms for animal nutrition and production, and animal health. Advanced omics platforms contribute

to the automatic recording of multiple data and parameters, which are useful for future research into animal production and the association between the environment of animals and their well-being. And finally, marine observation platforms, such as coastal research vessels and aquaculture facilities, which are essential for the study of marine ecosystems.

The CSIC has a wealth of unique collections. Indeed, a priceless asset is to be found in the banks of seeds, genetic resources, microorganisms, insects, micological cultures, pollinators, repositories of natural resources of biodiversity and geodiversity, from Spanish regions and the rest of the world, microbiomes of plants, bacteria and fungi and other microorganisms, tissues and DNA. Not to mention all the technical and human resources as well as the reference laboratories that support all these infra- structures.

The CSIC has unique collections, representing an extensive and complete record of the distribution of organisms worldwide and through time, and are the only direct documentation of the biological and physical diversity of our planet in space and time.

They include: seed banks, genetic resources, micro-organisms, insects, mycology cultures, pollinators, repositories of natural biodiversity resources (and geodiversity) of Spanish regions and the whole world, microbiomes of plants, bacteria and fungi.

Aligned with social agents and the productive sector, the CSIC launched a set of multidisciplinary cooperation initiatives in 2018, aimed at tackling numerous challenges currently facing society and the industrial sectors, including the food industry. The Interdisciplinary Thematic Platforms (PTI) represent one of the initiatives of particular relevance, created to provide practical and global responses to specific social challenges.

Within this framework of action, the CSIC provides society with interdisciplinary thematic platforms (referred to as PTI) whose objectives are directly related to agri-food. Thus, the platform PTI Clima+ seeks to provide a coordinated response to the effects of

climate change, while the PTI Agrofor aims to increase the productivity of agricultural and forestry activities. AgriamBio seeks to improve the socio-environmental effectiveness of the Common Agricultural Policy. PTI Horizonte Verde (Green Horizon) addresses the future sustainability of agricultural and forestry systems in the face of the impact of climate change. SosEcoCir offers innovative solutions for the recycling of waste materials through circular economy systems. And the PTI Food-Allergy focuses on numerous aspects aimed at understanding and managing allergies to certain foods.

Some of these platforms include actions currently connected to the Recovery Plan for Europe, and focus on areas in which the CSIC promotes high-impact collaborative projects. Work is also being carried out on projects that provide solutions to the problem of the sustainable management of plastics due to their enormous environmental impact and impact on the food chain (PTI SusPlast). Research is being carried out on the development of industrial-scale prototypes for energy storage and CO_2 capture technologies (PTI TransEner+). Directly involved with nutritional sustainability, healthy ageing linked to nutrition is addressed within a comprehensive clinical and scientific approach to the main neuro-degenerative processes together with biological, environmental and social factors (NeuroAging). The main zoonoses with food-related repercussions are also addressed as part of a global health approach (SaludGlobal). These measures allow the development of coordinated multidisciplinary projects promoted by research groups from the three core areas of the CSIC: *Society, Life and Materia.*

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Conclusions and Recommendations

Conclusions

The science developed at the CSIC, in collaboration with other national and international research centres and universities, seeks solutions to the current and future challenges of food production in a changing planet.

In the future, population growth and climate change will mean that we will need to produce more food more efficiently by optimising the use of natural resources, especially water, and by preserving the quality and health of soils.

The way we produce the food we eat influences the planet and the challenge of ensuring healthy diets for all people.

The food system is the set of interconnected people, activities, infrastructures and processes involved in food cultivation, transport, processing and manufacturing, distribution, retail and, finally, also in food consumption and waste management.

Current food systems encourage unhealthy consumption and diets, generate large amounts of food loss and waste, produce inequalities and have major negative impacts on the environment (loss of biodiversity, depletion of natural resources and significant contribution to climate change).

Sustainable food systems must be economically sustainable and meet social justice criteria by contributing to the socio-economic sustainability of the system. They must preserve their material base (environmental dimension) and improve the well-being of the rural population (social dimension).

There is no doubt that our current food systems are unsustainable. Countries agree on the need to transform them in order to ensure food security without depleting our planet. Science has an essential role to play in addressing this challenge.

CSIC researchers are working on this transformation by providing the basis for improving the future sustainability of agricultural, plant and marine ecosystems in order to promote safe, responsible and healthy food production for the whole population.

Recommendations

Access to healthy, high quality food must be a reality for the entire world's population. The Earth's resources are adequate to meet current food demand, but an increase of more than 70% in current production will be required to feed a world population, which is expected to grow by more than half by 2020, will be approximately 9,7 billion by 2050, according to the United Nations.

The food production needed to supply a population in a given year will be requires a significant research effort and constant development. This effort must be aimed at developing sustainable and achievable strategies for agriculture, livestock, fisheries and aquaculture.

Crop and livestock production depends to a large extent on environmental conditions. Their maintenance is based on the availability of varieties, breeds and production methods adapted to the different agro-ecosystems. This requires robust research and a local development component.

Food loss and waste must be reduced and, where possible, prevented. Research and innovation in processes and technologies that enable the valorisation of by-products and avoid the generation of new waste should be encouraged.

Sustainability reaches all links in the food chain. Sustainability in the food industry is a necessary and possible reality. This requires an effort on the part of the food sector in collaboration with the research sector, which will improve its competitiveness.

Companies in the sector that are sustainable will have added value that will put them at an advantage over their competitors. This will improve their corporate reputation and create a connection with consumers who are increasingly aware of and demand healthy, safe and sustainable food.

In the transition to sustainable Food Systems, the calculation of the "real cost" of production may be effective, as well as a potential realignment of tax incentives to favour environmentally friendly production systems.

Fiscal policies and actions can help the transition to sustainable food systems, which protect the supply of healthy and sustainably produced food.

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List of Centres

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Centro de Investigaciones Biológicas Margarita Salas (CIB)	www.cib.csic.es	direccion.cib@csic.es
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Instituto de Agricultura Sostenible (IAS)	www.ias.csic.es	direccion.ias@csic.es
Instituto de Agrobiotecnología (IDAB)	www.idab.csic.es	direccion.idab@csic.es
Instituto de Agroquímica y Tecnología de Alimentos (IATA)	www.iata.csic.es	direccion.iata@csic.es
Instituto de Biología Molecular y Celular de Plantas Primo Yufera (IBMCP)	www.ibmcp.csic.es	direccion.ibmcp@csic.es
Instituto de Bioquímica Vegetal y Fotosíntesis (IBVF)	www.ibvf.us-csic.es	direccion@ibvf.csic.es
Instituto de Ciencias Agrarias (ICA)	www.ica.csic.es	direccion.ica@csic.es
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Further Information

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Knowledge Transfer Report



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