3.5

ECS Key Application Areas

AGRIFOOD AND NATURAL RESOURCES

3.5 Agrifood and Natural Resources

3.5.1 Scope

In recent years , the conditions of the planet have changed abruptly as predicted by the Intergovernmental Panel on Climate Change (IPCC). According to the latest report from IPCC[1], global warming is causing major changes in precipitation patterns, oceans and winds, in all regions of the world and, in some cases, irreversibly so. The intensification of natural phenomena is putting the viability of life on Earth at risk, and from now on will have serious repercussions on food security, health, and sustainable development. Extreme hot temperatures in normally cold countries; melting of the poles at an accelerated rate, and consequently, rising sea levels threatening coastal areas; prolonged droughts in previously fertile and productive places on different continents; scarcity of fresh and affordable water for human consumption in large cities are just some of the issues we are now regularly facing. Moreover, forest fires have doubled worldwide in the last 20 years destroying around 3 million hectares each year particularly in boreal forests, leaving the largest climate change related carbon deposits on the planet so far according to a study conducted jointly by three institutions: Global Forest Watch (GFW), World Resources Institute (WRI) and the University of Maryland (UMD). The study concludes that we will lose or degrade these important lungs in the medium term despite these forests being one of our best defences against climate change and agriculture with agroforestry practice.

There is a strict relationship between climate change and agriculture. The two-way relationship of climate change and agriculture is of great significance because we need to adopt effective practices to mitigate risks to human health and crop production. Because of these reasons, the term Climate-Smart Agriculture[2]has recently been adopted to describe the innovative use of technologies in agriculture as highlighting the fact that it is important to have smart/precise agriculture, but it has to be respectful of climate. The actual climate-agriculture interaction can be considered a lose-lose exchange, being climate problematic for agriculture and because agriculture is one of the main reasons for greenhouse gas emissions. New smart technologies and increased agroforestry practices can change this relationship to positively impact both sides.

Moreover, two other emergent processes are becoming relevant: desertification and tropicalization[3]. The last one is related to multiple climate-induced range shifts, including the expansion of tropical species towards the poles and concomitant loss of temperate species from warming areas. This alters the species interactions and may lead to changes in marine biogeographic structure, with a lot of consequences for general ecosystem functioning and fisheries system.

On one hand, as explained above, the impact of climate change on agriculture is mainly related to extreme heat events,reduction in precipitation and/or intensive flooding and water availability, that result in

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[1] IPCC Report: Climate Change 2023 https://www.ipcc.ch/report/ar6/syr/

[2] https://www.fao.org/climate-smart-agriculture/en/

[3] The ecological and evolutionary consequences of tropicalisation, Trends in Ecology & Evolution, March 2024, Vol. 39, No. 3

decreased crop productivity. On the other hand, the impact of agricultural activities to climate change is related to two specific factors:

- Farming in particular releases significant amounts of greenhouse-gas emissions, in particular methane and nitrous oxide. The agriculture sector alone represents almost a quarter of global emissions.
- Agrochemicals released to fight against pests contaminate soils and waters as a direct consequence of the use of these substances.

However, climate change is only one of the many problems that agriculture must face[4]. In fact, growing global demand and competition for resources, food production and consumption need to be redesigned in a proper way, linking agriculture, energy, and food security.

Consequently, contemporary economic and ecological challenges mean our food production must support a new balance between production in quantity and production of quality. Achievement of this new balance in food production exposes us to risks in various forms (war, market fluctuations, large scale public health and animal health) . These risks must be addressed to obtain a transition towards a more sustainable and inclusive food system from farm to fork. This will require significant actions such as reducing food loss and waste, adopting dietary changes, and adapting how we use arable land. These actions will help industry meet global food needs while safeguarding farmers' livelihoods as well as contributing to decarbonisation and climate change stabilization.

As a primary sector, digitalization of agriculture is not trivial because of the great variability (e.g. climate or other natural phenomena, farm typology) of events on crops and land. In particular, the diversity of farming systems and farmers is essential for targeting agricultural interventions in any mixed crop-livestock farming system. . Moreover, farmers will need to change their behaviour. Service support and maintenance with adequate education on new technologies must be introduced, as well as a robust and reliable precision farming infrastructure.

The G20 Ministers of Agriculture, assembled on 16-17 June 2023 in Hyderabad, India[5], emphasized their commitment to food security and nutrition for all, through the development of inclusive, resilient, and sustainable agriculture and food systems, with the need to work together to promote food security and nutrition. The G20 meeting recognized that the current crises (lastly the war in Ukraine) are multi-dimensional and therefore, require a multi-layered approach, combining coherent and effective short-, medium-, and long-term responses in the spirit of "One Earth, One Family, One Future", tackling all crises with the same urgency. It is expected that this message will be repeated in the G20 meeting in November 2024 which is after the publication date of this document.

Among the high-level principles established by G20, Principle 6 is related to the need of Acceleration of Innovation and the Use of Digital Technology in Agriculture. This is relevant because it is a further emphasis to promotion of development and safe application of digital tools tailored to the various needs

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[4] Agriculture and Climate change, European Environment Agency, 30 June 2015 https://www.eea.europa.eu/signals/signals-2015/articles/agriculture-and-climate-change

[5] https://g7g20-documents.org/database/document/2023-g20-india-sherpa-track-agricultural-ministers-ministers-language-g20-agriculture-ministers-meeting-outcome-document-and-chairs-summary

of the agriculture sector. The importance of strengthening digital solutions to empower all farming communities, including smallholders, was recognized.

All of this creates many opportunities for the ECS community to contribute to the disruptive move of the agrifood sector towards a sustainable future. Innovations for, and digitalization of agriculture should be available as soon as possible to bring a new level of agri-food system resilience, capable of having a more productive, decarbonised, and sustainable agriculture globally.

Smart Internet of Things (IoT) systems have become very important for sustainable production and consumption of safe and healthy food, as well as for sustainable practices in agriculture, livestock, aquaculture, fisheries and forestry. They can foster access to clean water, fertile soil and healthy air for all, in addition to helping fighting against pests while preserving biodiversity and restoring the planet's ecosystems. In short, the use of these connected objects (IoT) helps the stakeholder to increase productivity while ensuring sustainability. Finally, IoT systems should provide innovative GHG emissions tracing solutions to facilitate decarbonization. The rise of AI will also allow for novel digital support systems, like such as expert advice systems built on Large Language Models like ChatGPT which not only refer to knowledge bases but also to live data provided by afore mentioned IoT systems.

Digital farming support should also considered novel development like the digital product pass which supports circular economy in other domains but may also be an important tool to support related topics like the variable due date.

In this Chapter, five Major Challenges have been identified. The first two Major Challenges relate to livestock and crop health, connected to farming systems and food supply chain assurance and management. For instance, IoT system technologies can be used in pest management or towards minimising the use of pesticides and antibiotics. Farming systems and food supply chain management benefit from smart IoT systems, including the use of traceability frameworks with trustworthy and security features[6], as well as from robots and drones, to revolutionise modern agriculture and food production. The third Major Challenge addresses issues such as soil health, air quality and the environment, all in terms of smart integrated monitoring technologies, and the use of smart waste management systems and remediation methodologies. The objective is to protect the environment to reduce the destruction of ecosystems caused by a myriad of anthropogenic activities and to reduce GHG emissions. A large decrease in the use of chemical fertilizers is a major aspect. These fertilizers are made artificially from soil-essential macronutrients like nitrogen, phosphorous, and potassium and they may contain ammonium sulfate, urea, potash and ammonia, among other substances, depending on their structure and the crops and soils for which they are intended.

Great advantages of these fertilizers are undeniable related to high production per hectare, they can be a boost to the health and expectations of plants in advanced stages of cultivation. Nevertheless, main drawbacks are linked to soil degradation, groundwater contamination and salt burns. Therefore, it's relevant to take into account among the challenges the way to support the reduction of these chemicals.

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[6] K. Demestichas, N. Peppes and T. Alexakis. "Survey on security threats in agricultural IoT and smart farming." Sensors 20.22 (2020): 6458

The reduction of fertiliser dependency is also encouraged by the EU Member States' Common Agricultural Policy (CAP) Strategic Plans. The fourth Major Challenge refers to the key role that IoT systems can play in water quality monitoring and management and access to clean water. An important aspect here is the overall management of water usage, as well as smart treatments to foster the circular use of wastewater, rainwater and storms/floods.

The fifth Major Challenge relates to biodiversity restoration for ecosystem resilience, how electronic components and systems (ECS) can contribute to the restoration/preservation of a greater variety of crops, and greater fauna and flora species diversity, to ensure the natural sustainability of healthy ecosystems (agriculture, aquaculture, fisheries and forestry) by enabling them to better withstand and recover from misuse, abuse or disasters.

All five Major Challenges in this Chapter align with key Horizon Europe missions, as well as the European Green Deal and Digital Europe. To efficiently address these challenges, significant advances are crucial in the fields of new materials, manufacturing technologies, innovative sensing solutions, information and communications technology (ICT), Artificial Intelligence (AI), robotics, energy management, harvesting and transfer, electronics and photonics, and other technologies, as well as in circular industries. These challenges also address most of the technologies required to support the decarbonization actions in the farm proposed by McKinsey[7] to achieve the IPCC 1.5° C pathway[8]. Together with the best management of agricultural resources and the good practises for a sustainable agriculture, all the challenges form a great occasion for farmers to change direction to minimize damage to the environment, while taking into account the economic needs of the farmers themselves.

Figure 3.5.1 illustrates the main challenges that our society is faced with a) the demand shift from resource-intensive consumption to resource-efficient consumption and b) markets shift from low-connectivity to high-connectivity solutions. Both are required to reach an open-source sustainability.

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[7] The agricultural transition: Building a sustainable future, McKinsey & Company, June 2023

[8] IPCC Sepcail report "Global Warming of 1.5 °C pathway, Korea 1-5, October 2018

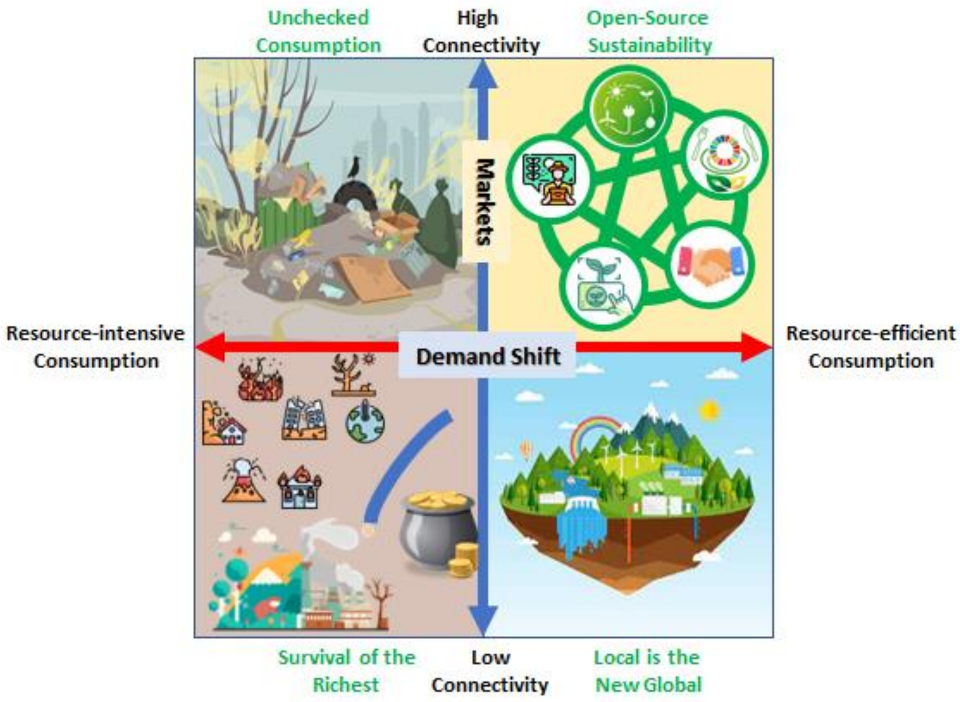

Figure 3.5.1 - The Scenarios: Four Potential Future Worlds[9]

3.5.2 Application trends and societal benefits

External requirements

According to the UN[10], if the global population reaches an expected 9.8 billion by 2050, the equivalent of almost three Earth planets could be required to provide the natural resources needed to sustain current lifestyles. Increasing food production is driven not only by population growth, but also by more demanding and sophisticated diets, with zero net emissions, as populations become wealthier. On the other hand, productivity is being hit hard by climate change in regions where food scarcity and inefficient resource management is most prevalent. The necessary acceleration in productivity growth is being hampered by the degradation of natural resources (including soil), a reduction in biodiversity, and the spread of transboundary pests and diseases of plants and animals, some of which are already becoming resistant to antimicrobials[11]. Investments in changing agricultural practices and incorporating technological innovation has boosted productivity, but the yield growth is far from sufficient. A more holistic and innovative approach is needed to reduce the strain on natural resources and enhance their quality, while also increasing food productivity. At the same time, food losses and waste claim a significant proportion

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[9] Shaping the Future of Global Food Systems: A Scenarios Analysis, World Economic Forum White Paper
[10] Microsoft Word - Key Findings WPP 2017_Final EMBARGOED (un.org)
[11] 2017 FAO. 2017. The future of food and agriculture – Trends and challenges. Rome

of agricultural output, whereas poor bio-waste management and packaging increases environmental pollution.

Figure 3.5.2 - Main Agrifood and Natural Resources goals and associated challenges

Addressing key issues on food security and sustainable production would lessen the need for production increases while improving the natural resource base. For instance, reducing GHG emissions is a priority because they significantly contribute to climate change. Three major sources (land-use change, enteric fermentation and energy use) combined account for almost 74% of the total GHG emissions. Other examples are, mitigating the effect of natural and human pressures on water bodies, namely by reducing general pollution and plastics, eutrophication, acidification and warming-up as much as possible. Less than 2.5% of the world's water is fresh[12], and water pollution in rivers and lakes is occurring faster than nature can recycle and purify. Currently, more than 2 billion people live with the risk of reduced access to freshwater resources[13], and by 2050 at least one in four people is likely to live in a country affected by chronic or recurring shortages of freshwater. Now, 2.6 billion people are economically dependent on agriculture[14] despite 52% of arable land being moderately or severely affected by soil degradation. Air quality has also been deteriorating in both rural and urban areas because of the spread of particulate matter in addition to the release of greenhouse gases (GHGs) all of which have detrimental effects on the population[15] and on the climate.

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[12] All about water, https://www.iaea.org/sites/default/files/publications/magazines/bulletin/bull53-1/53105911720.pdf

[13] UN 2019 The Sustainable Development Goals Report 2019: Goal 6: Clean water and sanitation / https://unstats.un.org/sdgs/report/2019/The-Sustainable-Development-Goals-Report-2019.pdf

[14] ibid: Goal 15

[15] https://www.eea.europa.eu/themes/air/health-impacts-of-air-pollution

Today, farmers still spread much more fertiliser than is required on their fields. Consequently, excess nutrients such as nitrates and phosphates accumulate in the soil and filter into groundwater with a dramatic impact on the environment and public health. Therefore, there is increasing pressure on the agricultural sector to find decarbonized and sustainable solutions for reducing environmental pollution caused by fertilisation, pesticides, livestock and energy production emissions. Smart production processes and intelligent logistic systems across the whole supply chain are some of the solutions that can yield optimisations to reduce emissions with increased productivity, while ensuring safe food production. This is particularly important given that currently, every year, almost one in 10 people fall ill due to food-borne diseases.

The pandemic crisis has shown the vulnerability of the overall agri-food supply chain when compromised by employee illness or travel restrictions enforced by the lockdown constraints. These circumstances appear unprecedented, but they are relevant for every type of pandemic that could occur worldwide, crossing international borders and affecting large populations.

New epidemiological methods that utilize dynamic network analysis[16] to analyse the key drivers of emerging pathogen movement are needed. In the agrifood sector, this is compulsory, because the overall agrifood elements are strictly interconnected (from seeds and plants to livestock management and crop production, as well as postharvest transportation are single point of risks of pathogen and mycotoxin movement in stored food).

Effective surveillance strategies are essential to support agrifood health programs, crisis prevention, improvement in biosecurity and agriculture decarbonization. Here also, ECS solutions are the efficient way to contribute to all these topics.

Societal Benefits

In response to an ever-increasing set of challenges faced by the world, the UN defined 17 Sustainable Development Goals (SDG) to act as a blueprint for achieving a better and more sustainable future for all. The SDG implementation plans (SDG 2, 6, 12 and 15 are particularly relevant) to address the global challenges we face in protecting biodiversity, our natural resources and acting on climate change. Furthermore, it includes actions relating to socioeconomic drivers aimed at eliminating poverty, hunger, inequality, and achieving responsible consumption and production, sustainable prosperity, peace and justice. In Europe, national and EU policies such as the **"From Farm to Fork"**[17] and **"Biodiversity Strategy 2030"**[18]**,** reflect and amplify the underlying SDG objectives with a set of measures – from regulatory frameworks to incentives and investments for development, and the deployment of holistic innovative approaches in a circular economy, agroecology, agroforestry, climate- smart and sustainable agriculture, bioeconomy, and the Blue Economy.

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[16] The persistent threat of emerging plant disease pandemics to global food security at https://doi.org/10.1073/pnas.2022239118

[17] https://ec.europa.eu/food/sites/food/files/safety/docs/f2f_action-plan_2020_strategy-info_en.pdf

[18] https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52020DC0380&from=EN

3.5.3 Major Challenges

This section discusses the five Major Challenges that need to be addressed in the domain of agriculture (food security, food safety, environmental protection and sustainable production), natural resources and biodiversity, and how smart IoT systems and associated key enabling technologies can help achieve them.

- **Major Challenge 1**: Food Security.
- **Major Challenge 2**: Food Safety.
- **Major Challenge 3**: Environmental protection and sustainable production.
- **Major Challenge 4**: Water resource management.
- **Major Challenge 5**: Biodiversity restoration for ecosystems resilience, conservation, and preservation.

3.5.3.1 Major Challenge 1: Food Security

Food security[19] and food safety[20] are two complementary/interdependent concepts that are characterized in different ways: one indicates the economic and social security of availability of food supplies; the other indicates their health and hygiene safety. Together, these terms refer to the same processes linked to agricultural production, and it is relevant to manage them simultaneously.

Figure 3.5.3 presents the interrelation between food security and foot safety concepts, as well as their main constituent elements. This section and the next will address the challenges related to food security and food safety from an ECS perspective.

Figure 3.5.3 - Food security and food safety

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[19] Food security has been defined by the FAO as “Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life”

[20] Food safety is an umbrella term that encompasses many facets of handling, preparation, and storage of food to prevent illness and injury. Included under the umbrella are chemical, microphysical, and microbiological aspects of food safety

3.5.3.1.1 Status, vision and selected outcome

Consolidated advances in Industrial Internet of Things (IIoT) have already started to shape smart manufacturing in the food and beverage[21] industry. Access to relevant and role-based information, in real-time or near real-time, is key to ensuring the efficient storage and processing of data, and their appropriate use for optimised decision-making at every level of next-generation automation systems and robotics, e.g. cyber-physical systems (CPS). Therefore, sustainable production, safety and quality do not only depend on the product itself, but they also depend on respective processes and their control as offered by key data gathering and monitoring, smart autonomous sensing, data analysis,diagnostics and predictive maintenance, and control systems. Ultimately, intelligent food production frameworks can consider consumer needs in specific markets, and such systems can provide intelligent recommendations for adjusting the amount and quality of food, accordingly, assuring food security (i.e. enough food for each market, avoiding food loss) and food safety (i.e., healthy food), while also considering environmental concerns and societal impact, paying attention to the food traceability process as well, because it is a real core of any quality assurance for agrifood sector.

In particular, smart sensing had a recent important benefit thanks to the appearance of low-cost, low-power, self-powered solutions, giving the possibility of not only remotely monitoring the crops (satellites, multi-spectral cameras), but to install the sensors inside the crops and plants, for receiving directly from the site the data needed to understand the health status of plants and soil. A LinkedIn post from World Economic Forum indicated the technology of Plant Wearable Sensors as one of the 5 technologies about to change the world[22], and as one of the key solutions to increase food production by 70% by 2050 to be able to feed the world population.

Following the trend in manufacturing industries, digital twins[23] are the next step for the food industry and farming systems. In short, digital twins allow digital/virtual representations (models) of physical objects and processes, coupled with behaviour models that enable simulation and prediction upon changes to variables associated with the objects or the surrounding conditions. Digital twins are remotely and real-time connected to the objects in the physical world to reflect the dynamics of real systems. Thus, digital twins are expected to take the farming and food industry to the next level in terms of productivity and sustainability. As a use case example in precision farming, a digital twin can be used in the event of a plague infection for simulating the effect of applying multiple alternatives, taking into account the current condition of the crops, the available biological models, the expected evolution of weather conditions, etc. to figure out what is the optimal treatment (and timely application) against the plague in order to minimize both the impact in productivity and the environment footprint of the treatment. Essentially, digital twins will become ultimate decision-making optimisation tools by integrating production process variables and market and consumers variables thereby avoiding food loss. In any case, development of digital twins in farming is far behind its counterpart in the manufacturing industry for several reasons

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[21] Beverage will be considered as food in the rest of the document.

[22] https://www.linkedin.com/posts/world-economic-forum_wef24-ugcPost-7149142642344296448-lxGR/?utm_source=share&utm_medium=member_ios

[23] https://www.sciencedirect.com/science/article/pii/S0308521X20309070

because physical objects in farming are “living” objects (crops, trees, animals…), and because variables of interest in farming are highly heterogeneous and are complex to model and measure.

3.5.3.1.2 Intelligent and adaptive food production

To develop intelligent food production systems, solutions are required in (but not limited to) the following fields:

- In-line inspection, networked packaging systems and robot technology in the warehouse to allow for a smart workflow to manage, monitor, optimise and automate all processes accordingly.
- Intelligent control room systems to enable correlations between machine malfunctions and load parameters to be detected immediately, thereby enabling maintenance work to be carried out early and on schedule, with a reduction in costly downtimes.
- Food industry imposes specific requirements (e.g. in food processing) that may take advantage of smart bio-sensing high-quality monitoring to reduce the amount of water and chemicals used in such processes, and to prevent contamination.
- AI/machine learning (ML) and big data models must be devised and used to offer further intelligent decision-making and, whenever possible, should be employed directly at-the-edge for greater energy efficiency.
- IIoT systems, based on AI and digital twin technology, can provide the flexibility to tailor-make new products to help cope with ever demanding diets.
- Integration or combination of IIoT systems with Large Language Models to generate a new generation of smart expert advice systems

3.5.3.1.3 Re-designing Farming Systems

Precision Farming Systems

Advanced farming machines and robotic collaborative systems are needed for cost-effective land and livestock management, as well as for large-scale arable and fruit crops management. Tasks can be performed in parallel, enabling economies of scale. Advanced machines include the following:

- *Robotic systems (for harvesting, weeding, pest control, pruning)*: autonomous robots or swarms of light(er) robots (causing less soil compaction) can replace intensive and strenuous labour practices as the worldwide population transitions from rural to urban areas and manual labour declines as farmers get older. These low cost, adaptive, edge-AI based, multifunctional robots provide high levels of labour input to deliver productive, biodiverse, heterogenous landscapes of diverse cropping systems. Agricultural robots need to be equipped with improved capabilities for sensing and perception. This aspect should be accelerated to tackle this problem and increase efficiency. Special attention must be paid to safety and trustworthiness aspects for those robots expected to work collaboratively with humans or close to livestock.
- *Drones:* remotely piloted or autonomous unmanned aerial vehicles (UAVs), either flying alone or in swarms, can mainly improve efficiency in two application areas: (i) monitoring large areas with intelligent computer vision devices to provide a higher level of detail and on-demand

images, especially as drones can overcome limitations of satellite imagery (e.g. images below forest cover); and (ii) in the use of phytosanitary (plant health) products to increase efficiency and reduce environmental impact by avoiding indiscriminate chemical dispersion and following predetermined prescription maps.

- *Satellites:* these allow for improved information regarding fields, although a combination of data from further sensors with increased update frequency, improved performance and spatial resolution would also be needed. Moreover, small satellites (micro, nano) could provide larger IoT connectivity services when internet coverage may not be available at any location where a WSN network is to be deployed. Hence, low power and low-cost solutions are needed where either links can be established or where data can be collected for later processing in powerful backends.
- *Wireless sensor networks (WSNs)* and smart actuators deployed across fields will form the backbone of heterogeneous - multi-agent - collaborative approaches. Local parameters (e.g. ambient temperature, soil pH, soil salinity, relative humidity, etc.) measured from multiple sensors planted in the soil or attached to the plants could be retrieved remotely by e.g. drones and/or robotic systems to deepen the field analysis provided by image-based techniques. Coupled to the proper AI and decision systems, WSNs will also further help in automatically triggering the appropriate actions (e.g. drones could locally release agrochemicals after interrogating/analysing sensors, water irrigation systems could be activated only in some land areas, etc.).
- *Decarbonization:* To achieve zero net emissions in the different agriculture areas carbon verification and monitoring tools are required to measure carbon emissions and sequestration. Decarbonization is also requiring robust and trustable measurement methodologies, allowing producers, but also policymakers, on one side to control the quantity of carbon emitted and on the other side of carbon sequestrated, allowing trustable information about decarbonization control. As stated in the FAO document "Carbon sequestration in dryland soils ", "... continuous monitoring of carbon losses and gains in the farming system must be an integral part of a project for which a designated local institution could be responsible".
- *Digital farming Support as a Service (FAAS):* Most of the farms in Europe are small scale, below 10 hectares, whilst only about 1% of all farms are above 500 hectares[24]. An important challenge remains that all sizes of farms, including small and medium sized, should have access to digital solutions, namely cost-effective ones, and to facilities to easily exploit them. Whilst large scale farms have the means to setup and maintain large infrastructures and even robotic appliances, smart scale farms should benefit from the provision of digital support solutions, for instance, farm-monitoring via sensors, local maintenance, virtual cooperation, precision agriculture applications, etc. - as a service. This kind of services should be created and provided through local cooperatives or new service providers specialised in the HW infrastructure and SW applications involving several types of expertise in agronomy, communication, data analytics, computer science, etc. Having digital farming as a service, business models may help to finance CAPEX while technology transition to provide better cost model scenarios and facilitate the deployment of this

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[24] Destatis Statistisches Bundesamt, Betriebsgrößenstruktur landwirtschaftlicher Betriebe nach Bundesländern, retrieved October, 6, 2022 from https://www.destatis.de/DE/Themen/Branchen-Unternehmen/Landwirtschaft-Forstwirtschaft-Fischerei/Landwirtschaftliche-Betriebe/Tabellen/betriebsgroessenstruktur-landwirtschaftliche-betriebe.html

technology in the European farms. As with most non-ECS domain experts, famers would benefit by digitalization expertise being provided by ECS tools and services supporting e.g. experience sharing, education and remote assistance. This can include digital ecosystems, remote support via XR technology, or simple interactive support systems using technologies like LLM, e.g. ChatGPT, to facilitate existing knowledge which can be effectively queried

Couplings[25] between the technologies cited above and the data sources are possible and make it possible to enrich knowledge and respond to other field issues. Take the example of the drones above. Georeferenced imagery data by drones can be completed:

- on wider perimeters but with lower frequencies by satellite imagery.
- by images acquired by proximity sensors onboard self-propelled vehicles (tractors or robots) and their associated equipment during interventions in the plots as well as during pedestrian observation phases by farmers.
- by data collected via networks of communicating sensors covered by the Connectivity Chapter.

All the proposed solutions should meet important requirements such as cost-efficiency, compactness, reliability, lifetime, low power, security, interoperability with existing machinery and between systems implementing appropriate security schemes and taking human factors into account. Furthermore, training systems based on virtual, augmented, and mixed reality and simulators are needed for training people (e.g. operators), independent of seasonality or safety issues.

Horticulture/greenhouses, urban and vertical indoor agriculture, and agrovoltaics

Urban agriculture is being promoted as a promising option for sustainable food, a better quality of life, and community engagement. The goal of this modern version of agriculture is to grow and deliver high-quality food with a minimal waste of resources.

Many crops in vertical indoor farms are often cultivated using hydroponics, a technique where there is no need for soil and fertiliser as the growing plants are supplied with irrigation water. In fact, recent environmental challenges have promoted the intensification of “soil-less agriculture” in an urban context to decrease the negative impact on nature. Even if hydroponics produces quality crops with high efficiency, there is an area of opportunity here to better monitor and control the fertiliser components in the irrigation water, such as through the development of:

- novel and low-cost online sensors for optimised control, such as nutrient sensors to enable smaller discharge of fertiliser into natural waters.
- robots with a high precision level to perform automatic harvesting to reduce the overall production costs, which are currently high, to be competitive with traditional agriculture.

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[25] See in French https://blog.irt-systemx.fr/ameliorer-la-production-du-secteur-agricole-avec-les-nouvelles-solutions-technologiques/

- autonomous indoor farming systems in which cultivation is controlled remotely via AI, based on measurements of crop properties with the help of intelligent sensors and (edge) AI-based digital twin models of such plants.

Climate change is causing high temperatures, torrential rains and hail, causing significant damage in large crops. The introduction of **Agrovoltaics** has the potential to sustainably increase agricultural yields, reduce water use, create additional revenue, and promote equity for small-scale farmers[26]. Additionally, solar panels can provide energy directly to farms, reducing their dependency on fossil fuels and encouraging energy independence for small-scale farmers in developing communities; excess energy can be sold to the grid. The shade provided by the panels and the possibility to add environment sensors and ad hoc irrigation systems can make farms more water-efficient and provide valuable shade for livestock, leading to greater productivity for both crop and animal yields.

3.5.3.2 Major Challenge 2: Food Safety

3.5.3.2.1 Status, vision and expected outcome

Application of high-tech sensors and AI to monitor, quantify and understand individual plants and animals, as well as their variability, to ensure food safety is key for next generation novel ecology-based agricultural systems. Smart sensors and monitoring technology that can adapt to the unpredictability and variation of living systems are required. This Major Challenge will require integrated digital technology solutions such as ecology-based robotic systems that can control the bio-physical processes (including growing conditions) and understand the biological environment (for plants and animals). However, innovative ecology-based robotic systems' manipulation of operations is a huge challenge in environments that are only modestly defined and structured. Furthermore, detection in the supply chain and "at the fork" should be also considered. This implies low-cost and power-autonomous compact sensors, connected to information processing systems used in the food supply chain and by consumers, that allow, for instance, freshness and food safety detection for meat and vegetables (which could be integrated into smartphones).

3.5.3.2.2 Crop Quality & Health

Integrated pest management (IMP)

Novel IPM strategies are needed to detect diseases and prevent their spread on crop production for European organic and conventional agricultures, to increase organic farming and allow the development

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[26] "Our global food system is the primary driver of biodiversity loss," United Nations Environment Programme (UNEP), February 3, 2021

of horticultural systems that will use less/no pesticides. Improved IPM will require developments in the following fields:

- Smart systems based on portable real-time pest disease detection, diagnostics and monitoring platforms to provide rapid local and regional disease incidence alerts (georeferenced) e.g. weather/climate information for predictive models providing risk assessments and decision support for IPM.
- IoT devices specialized in pests and disease measurements, such as insect traps and other systems based on image recognition or AI models.
- Wearable Plant Sensors for directly monitoring the plant and being able to quickly detect pest appearance.

Agro ecology based: Move from conventional to organic, regenerative agriculture

To support the EU "*From Farm to Fork"* implementation, smart ECS can help farmers to drastically decrease the use of pesticides and their impact on human health and the environment. This will require:

- Development of cost-effective and intelligent intra-row, herbicide-free weeding techniques using advanced robots and robot fleets for individual plant recognition with high precision, based on advanced (vision) sensor technologies and edge AI working under in-field conditions.
- Development of smart and power efficient sensors to monitor the quality of spraying, as this is essential for biocontrol products and contact pesticides. Moreover, new sensors to monitor soil and plant health are needed such as pH, NO3 & EC, soil moisture, CO2, leaf wetness, surface temperature, airborne pathogens. They should be precise, low cost, highly miniaturized and biodegradable electronic and sensor components (printed antennas, organic batteries, biodegradable substrates, elimination of sensor/chip packaging) to avoid a negative Impact of electronic products on soil.
- Integration, into the same framework, of decision-support tools and precision agriculture tools to simplify farm management, improve crop quality and reduce costs.
- Advanced tools may yield on just farming 80% of the most productive soil leaving 20% for natural recovery reducing costs of fertilizers, energy to harvest and human time to collect, by this precision agriculture some complementary activities or species may be used to fix soil and reduce erosion and desertification.
- Dedicated services such as technical support (infrastructure deployment and maintenance), precision agriculture as a service, education, etc.

Plant precision breeding and plant phenotyping

The development of smart technologies can support precision plant breeding and phenotyping. This could be nanotechnology solutions or smart sensor solutions to support the following:

- Genomics and transcriptomics: DNA informed breeding, gene editing, genome prediction, breeding optimisation, phenotyping and seed sowing optimization.

- Large scale and high precision measurements of plant growth, architecture and composition: these measurements are required to optimize plant breeding by increasing our understanding of the genetic control and response of plants to their environment. Sensor systems should allow the study of plants in relation to biotic and abiotic factors, including plant-microbiome interactions, plant-plant competition, plant diseases and exposure to a multitude of variable abiotic environmental conditions such as light quality, irradiance levels, nutrient supply, temperature, humidity, soil pH and atmospheric CO2 levels. Plant health is also related to nutrients and the 4R strategy "right source at the right dose, at the right place, at the right time ", however, plant models, besides agri knowledge, are needed for nutrient content measurement and monitoring.

3.5.3.2.3 Livestock welfare and health

Livestock health is crucial for food safety. Different animal pathogens can be a serious threat for livestock management, because pathogens can be divided in those that can infect multiple species, and those that infect specific terrestrial and aquatic animal species (i.e., cattle, sheep, goats, equines, etc.). A great threat is represented by diseases that are highly transmissible, having the potential to spread rapidly across borders and cause significant socio-economic and public health consequences. All these lead to great economic loss to the farmers. Moreover, the use of antibiotics to treat animals increases the cost of production, as well as creating other problems like residues and resistance, which is of serious concern to public health.

In addition, better livestock management practices must reduce the release of pathogens into the environment and substantially reduce the risk of microbial contamination of surface and groundwater. As outlined in the literature[27], there is relevant impact of animal pathogens in four areas: animal health, economics, food safety and security, and public health. Consequently, there is strong interest in developing new advanced solutions systems with high sensitivity and specificity, for early detection of animal diseases and minimizing antibiotics use too.

Synergistic strategies can be applied to approach these challenges. Agronomic and technological solutions must be applied to:

- Minimise risks (e.g. release of pathogens into the environment, use of antibiotics for animals);
- Surveillance of the livestock environment through an efficient process of digitalization of livestock management to prevent diseases spread.

From a microbiological perspective, microorganisms can mitigate risk because specific beneficial microorganisms can be selected to work synergistically with other microorganisms already in the environment. Beneficial microorganisms can support the nutritional requirements of plants and reduce the incidence of pathogenic microorganisms, to solubilize minerals, to conserve energy, to maintain the

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[27] T. A. McAllister, E. Topp, Animal Frontiers, Volume 2, Issue 2, April 2012, Pages 17–27, https://doi.org/10.2527/af.2012-0039

microbial-ecological balance of the soil, to increase photosynthetic efficiency, and to fix biological nitrogen.

Research has also studied beneficial effects when these specific microorganisms are included in animal diets[28]. It has been shown that when they meet the organic matter that makes up the animal's diet, they secrete beneficial substances such as vitamins, organic acids, chelated minerals, and antioxidants, influencing an antibacterial effect through a selective blocking of pathogen colonization.

Animal welfare is also an important concern for a growing number of consumers.

We can assess that these synergistic strategies (risk reduction with agronomic solutions and surveillance) as explained above are drivers for investing in better sensing systems for animal monitoring. Combined with data analytics solutions, this will improve animal health and welfare, resulting in more animal-friendly production, higher efficiency, better quality, and improved food control safety:

- Wearable sensors at the farm/barn level, and ambient sensors during cattle transport.
- Smart sensor systems to monitor animal activity, such as individual or group behaviour, to provide useful information for early detection of diseases and to increase animal well-being.
- Smart sensor systems for rapid verification of bacterial infection together with behavioural observations to control disease spread and support clinical and veterinary stakeholders to effect suitable therapeutic interventions; body temperature can also be monitored for early disease detection to reduce antibiotics use.

A major source of GHG emissions in agriculture is related to livestock enteric emissions that must be reduced to achieve the 1.5°C pathway. The methane emissions from livestock increase atmospheric temperature approximately 80 times more than CO_2 on a 20-year outlook, but methane has a shorter atmospheric lifetime than other GHGs, making it an effective target for reducing global temperatures quickly.

New methods are emerging to reduce enteric emissions in livestock, and these should be largely introduced, particularly in grassland or mixed systems, where cattle might be centrally handled only once or twice a year for weighing and treatment, and where their feed rations are unpredictable and uncontrollable. In addition to the smart sensors systems mentioned above, the following tools can be added:

- Methane verification and monitoring tools to measure methane emissions and sequestration.
- Besides GHG emissions, monitoring nitrogen emissions is crucial due to the significant impact these emissions have on the environment and public health. Nitrogen emissions primarily arise from the application of nitrogen-based fertilizers and the management of livestock, and they occur in various forms, including ammonia (NH_3), nitrous oxide (N_2O), and nitrates (NO_3^-). Smart

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[28] D. Hidalgo, F. Corona & J.M. Martín-Marroquín Biomass Conversion and Biorefinery volume 12, pages 4649–4664 (2022)

sensor systems to monitor nitrogen emissions will play a pivotal role in addressing environmental challenges while optimizing agricultural productivity.

Taking into account the AI deployment in many sectors, the importance of a farmer-centric approach for livestock management is well highlighted within the digital livestock farming landscape[29].

When coupled with AI algorithms, all these data can provide real-time, objective, and holistic insights into animal welfare, but a farmer-centric approach is vital to ensure that technologies truly serve the needs of farmers and the welfare of animals. Therefore, every AI application should encourage this farmer centric approach, because the economic sustainability goal of the agricultural industry is also related to improve animal welfare and make informed decisions about disease prevention and management, leading to healthier herds and increased productivity.

3.5.3.2.4 Food Chain

Intelligent logistic systems including sensing and monitoring for food chains

Logistics are a critical component of the food chain. They not only determine the reach of distribution, but logistics delays and conditions profoundly affect the quality and safety of products reaching consumers and can result in food loss and waste in the supply chain.

Smart real-time sensing, monitoring and control systems in the food supply chain will safeguard food quality and food safety, while eventually reducing food losses in the supply chain. Therefore, technological solutions are required, but not limited to:

- Systems for monitoring and controlling the quality of food products and ingredients during transport and storage (e.g. temperature monitoring in cold chain, moisture, controlled atmosphere, ethanol, ethylene), which should be reliable, contaminant-free, secure, power efficient and interoperable along the logistics chain. Contact-less powering of the sensors placed in storage tanks could also avoid contamination of the food.
- Predictive systems to assess quality of (perishable) food products in the supply chain, providing real-time decision-support based on actual sensor measurements, supply chain data and AI models.
- Transport route optimisation, considering not only time and cost, but also external conditions and the intrinsic properties of the products being transported.

These needs are strongly related with traceability, as shown in the following section.

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[29] Neethirajan, S. Artificial Intelligence and Sensor Innovations: Enhancing Livestock Welfare with a Human-Centric Approach. Hum-Cent Intell Syst 4, 77–92 (2024)

End-to-end food traceability

Food and beverage manufacturers and producers are faced with increasingly complex and fragmented supply chains, stricter regulation, and more demanding consumers. Regulatory compliance, competitive advantage, brand reputation and costs have made product traceability a priority and end-to-end traceability a major challenge. In today's globalised world where people of any origin live across every country, the source of food products and ingredients, as well as their certification, are a major concern and priority for consumers, who want to be sure about the origin of food products. Therefore, traceability should also encompass certifying food origin, as well as making information available on any relevant process to which the food product has been submitted. This information should not be restricted to mere tracking across the supply chain. End-to-end traceability solutions are required, but should not be limited to:

- Integrating blockchain into current technology to increase safety while preventing fraud and counterfeiting.
- Traceability to increase alignment between production and individual consumer demands, leading to better provisioning and more personalised nutrition support.
- Traceability to optimise distance between farm and fork – although many products are produced preferentially in specific parts of the world, there are also many examples of food that could be produced economically closer to consumers.
- Smart tags.

To this end, as IoT/IIoT solutions are increasingly being deployed, integrated hardware systems need to deliver (apart from mobility and connectivity) long lifetime autonomous sensing and AI-based intelligence at-the-edge, as well as edge and/or cloud analytics and cybersecurity, complying with privacy regulations where applicable, on a plug-and-play, open, interoperable architecture, and platform.

Distributed Ledger Technologies (DLTs) such as blockchain allow secure storage and tracking of all kinds of information, including condensed sensing or monitoring data regarding crops and livestock. Examples include information on crop seeds, feed ingested by livestock (including medication and antibiotics), as well as recording of the whole process that any farm product is submitted to until it reaches the consumer, throughout the respective supply chain and involved actors. Such information increases the transparency of these supply chains and can reduce potential production issues, e.g. simplify the tracing of eventual product spoiling, or other issues, to the respective source, supporting possible decisions to recall product batches if necessary. Consumers can also benefit from such transparency, i.e., they can be given access to information to make better informed decisions about the offered goods they want or need to acquire, and they can use the information to provide feedback to farmers and producers incentivising their policies and practices further.

Nowadays, end-consumers are more concerned about the origin of the agriculture products that they consume. A complete system to manage traceability and to offer, to the end-consumers, a complete transparency of the actions taken in the farm (for instance in the vineyard) and during the transformation process (in the example of a winery) is required: a solution could use blockchain technology. However, it is important that small-scale farmers with low technological expertise, resources, and insufficient size to integrate blockchain could be supported, eventually through a dedicated ecosystem. This can be devised through blockchains implemented to include such farmers and respective food product chains, which would also allow the support of food safety assurance, namely in respective local markets, eventually involving less costs associated with logistics and distribution, and thus also contributing to sustainability and fair food systems. Nevertheless, the lack of regulations, standardization and interoperability are challenges for incorporating blockchain.

3.5.3.3 Major Challenge 3: Environmental protection and sustainable production

3.5.3.3.1 Status, vision and expected outcome

EU regulations together with consumers' increased interest in organic food, is compelling farmers to drastically decrease the use of pesticides to reduce risks and impact on human health and the environment, as well as to undercut the maximum residue levels of pesticides. Pesticides are found not only in drinking water[30] but also in food and beverages. Lively debates have shown that our society demands alternatives to pesticides to help preserve the environment and improve food quality.

Drastic reduction in the use of pesticides is one of the major goals of the EU's agricultural policy, with some countries planning to halve their pesticide use by 2025 (e.g. ecophyto plans[31] in France, and the Aktionsplan Pflanzenschutzmittel[32] in Switzerland). The EU Farm-to-Fork strategy also aims to implement an action plan that significantly reduces risks from chemical pesticides, as well as the use of fertilisers and antibiotics, and to increase the amount of organic farming carried out in Europe.

In general, the new EU agriculture policies put a major focus on preservation of landscapes, biodiversity, and environmental protection, in a results-oriented model aligned with the Green Deal[33]. For instance, the reform of the Common Agriculture Policy (CAP) introduces measures for fostering the adoption of sustainable farming practices ("eco-schemes"), such as agroecology or organic farming. Farmers will need to provide "digital evidence" of compliance to the CAP rules and the implementation of good practices. The CAP evaluations will be largely based on the use of high-quality data collected directly from the field. This will require measurement and monitoring technology (for environmental performance, biodiversity monitoring parameters, etc.) which is accurate, highly scalable, and secure (certified monitoring information).

Areas of interest are often remote without sufficient connectivity – new approaches are required to flexibly deploy sensors that harvest their energy and collect data.

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[30] https://www.notre-environnement.gouv.fr/themes/sante/la-pollution-de-l-eau-douce-ressources/article/les-pesticides-dans-les-eaux-souterraines?lien-ressource=5193&ancreretour=lireplus

[31] Ministère de l'Agriculture, Le Plan Ecophyto, qu'est-ce que c'est? https://agriculture.gouv.fr/le-plan-ecophyto-quest-ce-que-cest , 2020

[32] Aktionsplan Pflanzenschutzmittel, https://www.blw.admin.ch/blw/de/home/nachhaltige-produktion/pflanzenschutz/aktionsplan.html

[33] https://aioti.eu/wp-content/uploads/2022/02/AIOTI-Role-of-IoT-in-addressing-agroecological-focus-of-Green-Deal-Final.pdf

3.5.3.3.2 Soil Health

***In-situ* real-time monitoring of soil nutrients and herbicides**

The optimal use of chemical fertilisers and organic manures to deliver the ever-increasing food production requires a complete understanding of the nitrogen- and phosphorous-based nutrients applied in the fields with a much greater spatial and temporal resolution than is available today. Current methods of soil analysis do not provide real-time, precise and *in situ* nutrient analysis in fine detail, and delays in receiving soil results are common because of backlogs in commercial labs due to high sample volumes, thus reducing the value of the soil test results for the farmer. Moreover, herbicide application is another huge problem due to their environmental and health impact. To solve these issues, the following actions must be done:

- Intelligent sensors and bio-sensors (with miniaturised and ultra-low power consumption components allowing these sensors to harvest their own energy) must be developed to deliver measurements of soil quality and soil nutrients in situ and in real time at parts per million (ppm) concentrations. Such devices must have the appropriate packaging to extract water from the soil. Ideally, they should be buried in the soil for long periods of time or at least while sustaining operation capabilities for the entire growing season. To optimise effectiveness, low proximity sensors should be combined with optical sensors and high proximity sensors to retrieve the maximum amount of information on soil health.
- Likewise, smart actuators could prove to be highly beneficial. Such miniature units could be deposited on or buried into the soil. Coupled to sensing functionalities into the same module, critical actions (e.g. release of agrochemicals) could be triggered very close to the plant roots for maximized efficiency.
- Multidisciplinary approaches for developing novel sustainable smart ECS are needed. Indeed, current ECS contain a variety of toxic materials and chemicals. As such, they cannot be left in the soil. The optimization in the use of agrochemicals should not come at the expense of another ecological burden. New sustainable "green" ECS made of eco-friendly materials that will have benign environmental impact must be created.

IoT systems with edge and/or cloud-based data analytics are also necessary to provide farmers with decision-support regarding fertilisation strategies, by translating measurements into meaningful agronomic indicators and respective measures. These strategies should prioritise the use of organic fertilisers and the gradual reduction of chemical ones until eliminated to restore the biodiversity contribution in the preservation of soil health. Furthermore, this type of system should detect weeds, preserve the “good ones” and eradicate those that are competing with the crop in question. This requires low-cost vision technologies (not only plain optical red/green/blue (RGB), but also 3D, hyperspectral imaging, etc.) and edge AI for in situ prompt recognition and decision-making.

3.5.3.3.3 Healthy air and skies

Sensors and diagnostics for air quality monitoring (indoor, urban and rural)

According to the World Health Organization, the air we breathe is becoming dangerously polluted. Nine out of ten people now breathe polluted air, which kills seven million people every year. There has been much progress on identifying and reducing the sources of air pollution at lower concentrations and with higher spatial coverage. This is necessary to provide adequate data on what people are breathing, and to provide localised as well as holistic solutions. Microsensors and/or mini-stations can be used during fieldwork campaigns in cities, but there are technical problems relating to power source, data transmission, data storage, and data handling and assessment. Besides, local measures are not always effective since local concentrations of particulate matter may be influenced by long-range transported pollutants from agricultural activities occurring outside city boundaries.

Similarly, while indoor air quality has been shown to unambiguously impact the wellness, health and performance of people as shown for instance with Covid-19 in schools due to lack of indoor air quality measurement, there is also a lack of spatial granularity and a significant lag between exposures and sensing, actuation and management interventions for risk mitigation. In addition to indoors, air quality is made more complex by the interaction between indoor and outdoor air, emissions from buildings and their contents (paints, furniture, heating, and cooling systems, etc.), human activities (breathing, cooking, cleaning, etc.) and the effects of long-term exposure to low concentrations of volatile organic compounds. These issues necessitate development and deployment of real-time intelligent multi-sensor technologies with high selectivity and embedded (re-)calibration techniques. These should be combined with a monitoring network (edge-based) as part of the indoor infrastructure to provide the spatial and temporal information needed for specific, targeted and appropriate actions. A required ingredient of this monitoring solution is a digital twin platform able to predict in real-time the pollutant diffusion, considering the complex environment monitored. Such actions should also include public awareness and the promotion of behavioural changes.

Smart systems for controlling and preventing GHG emissions

Strong evidence has been accumulated on the climate emergency resulting from human activities that add GHGs to the Earth’s atmosphere. The EU is the world's third biggest GHG emitter after China and the US. Although several measures have been taken since the Paris Agreement, breakthrough technologies and state-of-the-art deployment are still needed across the transport sector and other industries with a high emission footprint to achieve a further reduction in emissions. These would be facilitated by the following:

- Smart systems and digitalisation to improve industrial processes performance and energy/resource efficiency towards a low-carbon economy, while reducing the impact of mobility and agricultural processes on the environment and human health, thereby controlling and preventing GHG emissions.
- A focus on the GHG emissions from animals by investigating microbiological sensing technologies on or in animals (in their rumens or breath, for instance) to increase efficiency while reducing environmental impact, as well as performing analysis of the gathered data to support decision-making for mitigation measures (for instance, leading to change in feed).

- GHG verification and monitoring tools to measure GHG emissions and sequestration.

3.5.3.3.4 Smart Waste Management

Integrated waste systems

Despite proactive European policies and regulations[34], effective bio-waste management remains a challenge. Reducing, recycling and reusing food/kitchen waste requires significant progress in technological solutions along with strong policymaking and shifting community behaviour. These solutions could be based on the following:

- Smart monitoring, controlling waste treatment units in real-time as well as gas emissions in landfills and anaerobic digestion monitoring. Data analytics should include gamification for behavioural triggers.
- Smart real-time quality control systems of the sorted waste (i.e., measure of the “purity” of the sorted waste) to ensure their proper recyclability
- Smart waste collection bins (radio-frequency identification (RFID) tags, self-compacting bins, fullness level sensors, automated waste segregation), even in remote locations, and without access to power supply, including automated robotic systems and optimised separation systems, which can be complemented by the upcycling of waste streams into usable resources and optimal routing systems, as well as vehicle tracking. These solutions should be integrated and interconnected into the product life cycle “from cradle to grave” to enable circular and resource-efficient methodologies.

Intelligent sustainable / biodegradable packaging

Intelligent and biodegradable packaging concepts have been gaining traction in the food industry to improve product safety and reduce environmental impact. Smart sensors in an IoT system can monitor environmental conditions and product quality, while communication devices can store and convey data throughout the product life cycle. While these concepts need to be further advanced for efficient, safe food production and waste management, intelligent packaging itself needs to become more sustainable. Novel ideas are required to solve the problem of the amount of plastic packaging produced by food manufacturers. The definition of biodegradable packaging should lead to a new generation of food packaging. Such novel ideas include:

- A synergetic interdisciplinary approach to cross the boundaries of novel materials for food packaging and smart sensors associated with analytical methods for the detection of harmful substances that can infiltrate into food, cause water contamination, etc.
- Fabrication and hybrid integration of eco-friendly nanostructured electrodes, sensors, energy harvesting and storage devices on rigid and flexible biodegradable substrates to reduce the waste from embedded electronics in smart packaging.

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[34] https://www.consilium.europa.eu/en/press/press-releases/2018/05/22/waste-management-and-recycling-council-adopts-new-rules/

3.5.3.3.5 Remediation

Efficient smart networks for remediation

Remediation processes aimed at converting harmful molecules into benign ones can be undertaken in different ecosystems, such as water bodies (e.g. biotic, and abiotic farming by-products), air (e.g. GHGs) and soil (e.g. pesticides). Remediation processes are mainly carried out in wastewater treatment plants. Although some pollution sources are static and sufficiently well-known such that treatment can be undertaken effectively, other pollution sources are more mobile in both time and/or space, making treatment at single points unsatisfactory. Another limiting issue is that remediation technologies are often power-intensive and cannot be deployed for long in remote locations. Alternative high-efficiency remediation methods are needed, such as to transform/reduce the levels of CO2 in chemical products. Current devices are also prone to fouling. This means remediation processes cannot be run constantly in remote locations, and there is thus a necessity to undertake them only when and where they are most required. In this regard:

- A network of smart sensors (an IoT system) that can monitor relevant status in real time, and inform on the necessity of remediation, would provide unique decision support invaluable for efficient water, air, and soil management.
- Techniques used in the measurement and analysis of carbon sequestration by soils could also investigate the current potential of soils as a remediation mechanism to improve the sequestration capacity – such investigation should include the initiative of “four per 1000”[35] presented at COP21 in Paris.
- Likewise, tools and methods able to evaluate the performance of the carbon sequestration techniques employed should be developed to guarantee their efficiency.

3.5.3.4 Major Challenge 4: Water resource management

3.5.3.4.1 Status, vision and expected outcome

The quality of groundwater, surface water bodies (oceans, seas, lakes), waterways (rivers, canals, estuaries) and coastal areas has a great impact on both biodiversity and the quality of water that people consume every day. While natural droughts may lead to increased salinity in freshwater systems[36] and along with floods, impact or endanger the quality of water bodies, human activities in energy production, data centers, manufacturing and farming industries have a major detrimental effect through thermal

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[35] Researchers from the French National Institute for Agronomic Research, mentors of the project, have observed that by increasing the organic matter in the soil by 4 grams per 1000 - hence its name - it would be possible to limit the current growth of CO_2 emissions to the atmosphere. Promoting good agricultural practice would combat climate change and, at the same time, guarantee the food security of the population.

[36] https://www.sciencedirect.com/science/article/abs/pii/S0012825214002086

pollution, chemical, microbiological and micro-plastic contaminants, and biotic and abiotic farming by-products. These human activities have released pollutants of emerging concern (such as PFAs and medicinal products) into water bodies, with detrimental consequences for human health and biodiversity. Moreover, the outdated and deteriorating water infrastructure is also having a detrimental impact on both water quality and the amount of water lost through leakage.

In the context of climate change, increased water temperatures may cause (apart from extreme evaporation) eutrophication and excess algal growth in surface water bodies. Moreover, heavy storms increase the amount of sediment nutrients and pollutants in water sources, and human activities release pollutant of emerging concerns that end up in all types of water bodies which have a direct impact on drinking water quality. Therefore, climate change jeopardizes the quality and safety of our water, making the development of new tools to deal with this problem more critical than ever.

3.5.3.4.2 Access to clean water (urban and rural)

Healthy Water

With the aim of reducing pollution-related health problems, water utilities, water associations, academia and private industry have focused on developing new methods, policies and procedures to secure drinking water distribution by (1) detecting in real-time any compound, contaminant or anomaly that may represent a health risk for the end-users and (2) taking the required measures to mitigate these issues. This necessitates online information on the status of water sources at a scale larger than ever before. To mitigate both accidental and intentional contamination of freshwater sources, the deployment of sensors and diagnostic and decision support systems with rapid communication technologies and data analysis capabilities are needed to secure water quality and its distribution over the network. Such actions shall provide:

Connected and highly integrated low power (or self-powered for maintenance/battery-free system) multi-parameter diagnostic sensors for real-time physico-chemical analysis (temperature, ionic electrical conductivity, pH, turbidity, inorganic pollutants as nitrates or heavy metals, etc.) in water distribution network and wastewater treatment plants, and biofilm growth monitoring in water pipes. Online monitoring systems at the edge, including devices with embedded AI for data analytics. The presence of a mesh of intelligent devices in drinking water networks will make it possible to identify and deal very quickly with drifts or anomalies (e.g, leaks, contamination events, etc.) while reducing the amount of data sent to the servers. Prediction in real-time of pollutant diffusion with simplified compact models, considering non-dense measurements from the multi-parameter diagnostic sensors and online monitoring that are developed and deployed.

Integrated systems for demand reduction and conservation of water

According to the UN Development Programme[37], dwindling drinking water supplies is affecting every continent. On the one hand, increased urbanisation and farming have amplified the demand of water for

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[37] https://www.undp.org/

human consumption and for domestic and agricultural use. On the other hand, an increasing number of countries are experiencing water stress due to longer drought periods and the spread of desertification. In addition, approximately 25% of all urban drinking water is being lost forever[38] in global water distribution systems, before it even reaches the end-user. Therefore, there is an urgent need to prevent losses from water abstraction as climate effects intensify. Leak localisation is currently very time-consuming, labour-intensive, and costly. Operators must manually place equipment that "listens" to the water flow during the night. Smart integrated systems can significantly contribute to key measures aiming at affecting consumer practices in water usage, delivering greater efficiency in detecting leaks and ultimately reducing water waste. Developments are needed in the fields of:

- Smart metering, time-of-use pricing and gamification to change habits in water consumption and control appliances, along with interoperable solutions for a truly connected smart household (taps, lavatories, showers, appliances).
- Low-cost self-powered/ low-power sensor nodes for flow control, leak detection and auto shut-off, along with inexpensive actuators to remotely control valves for limiting water usage by volume/time. IoT systems can optimise the control of household, agricultural and industrial infrastructure/equipment in water-intensive processes.
- Smart systems able to automate leak localisation, and to respond promptly and cost-effectively. This can be a combination of in-pipe inspection (to locate the leak) and a network of low-cost, fine-grained sensors to allow predictive maintenance of distribution systems.

Efficient and intelligent water distribution

The main challenge for improving the use of water is to guide its distribution depending on its final application (drinking water, water for industry, water for the cooling of data centers, etc.). However, the existing sanitary regulations always look to optimise water safety regardless of its final use. To apply the most effective measures to make water distribution more efficient, it is necessary to thoroughly review the different supply protocols and quality criteria for each sector. Moreover, by continuously monitoring the quality and availability of water, it would be possible to better regulate its distribution depending on the final use and to adjust the price accordingly. Intelligent systems connected to smart grids will allow water inputs to the network to be made at the right times, optimising the energy cost as a result.

To address these challenges, there is a need for developing:

- Novel smart metering solutions that include electrochemical multi-parameter sensors (pH, chlorine, conductivity, etc.) with high stability, anti-fouling, high accuracy capabilities and cost-effectiveness, as well as optical sensors based on different principles (fluorescence, absorbance, etc.) integrated into miniaturised systems at a low cost.

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[38] Leakage Reduction in European Water Mains; Layman Report https://ec.europa.eu/environment/eco-innovation/projects/sites/eco-innovation-projects/files/projects/ documents/-curapipe_layman_report.pdf

- Robust IoT systems with adequate data analysis processing power and AI capabilities to handle the large volume of data generated by the different water management processes to satisfy quality, usage type and associated pricing.
- Efficient year-round water management in terms of storage to deal with some of the most urgent shortages, with better forecasting and warning systems based on extensive measurements – e.g. intentionally flooded areas could be used to store water in times of expected scarcity.
- Prediction of pollutant diffusion in water distribution systems.

3.5.3.4.3 Resource Management

Smart systems for irrigation management

At a global level, agriculture consumes 69% of the world's freshwater[39]. Because of this, precise control of irrigation is essential to guarantee water and food security for all. Irrigation water management is the practice of monitoring and managing the rate, volume, and timing of water applications according to seasonal crop needs, considering the soil intake and water holding capacities with the objective of using water in the most profitable way at sustainable production levels. To this end:

- Smart sensors, with low-cost and self-powered characteristics, are increasingly required as tools to implement irrigation management and monitor water levels. Sensors should be more intelligent to support real-time applications and/ or reduce latency. Optimisation of the power consumption of the overall system shall be done to enable ultra-low power, ideally self-powered battery-free solutions that are cost effective and seamlessly deployed at the edge for both outdoor and indoor use.
- Integration of systems monitoring water deficiency or surplus is also required. These could be based on narrow-band spectral reflectance of water and land surfaces for vegetation/habitat mapping, along with UAV utilisation in remote areas.
- Smart low cost actuators will provide the "right dose (of water) at the right place".
- Appropriate simplified models should allow to limit the number of sensors spread over a given landscape and integration of various sources of data, included satellite ones, will expand the analysis capability of decision support systems. Also, leak detection in the irrigation management system shall be considered to ensure that water is not lost.

Smart systems for flood management

Flood management has been gradually integrating smart sensors. IoT systems with water-level sensors can also play a significant role in real-time monitoring and natural hazards predictive/forecasting capacity models. This requires:

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[39] http://www.fao.org/nr/water/aquastat/water_use/

- The monitoring of water levels and devising prediction models to identify areas at a high risk of flooding. This is possible through the development and deployment of more intelligent low power sensor nodes in combination with smart predictive algorithms that will act as digital twins to integrate information from various sources, such as weather forecasts and regional georeferenced data.
- IoT interoperable systems are key for provision of real-time information to first responders, civilians and companies to proactively take countermeasures.

Smart water treatments fostering circular use (wastewater, rainwater, storm water)

Around 80% of all wastewater is currently being discharged into the world's waterways, where it creates health, environmental and climate-related problems. Water from industrial, agriculture and domestic use contains organics, phosphates, nitrogen, cellulose, rare earth elements and other substances (including residues of medicinal products. In addition to its domestic use, purifying, distilling, or deionising water is essential for many agricultural and industrial uses – to ensure the consistency of products and to meet strict safety regulations. The global market for water and wastewater technologies reached US $64.4 billion in 2018 and is expected to rise to US $83 billion by 2023[40]. Commercial technologies that allow resource recovery from wastewater to be commercially feasible are increasingly being developed, making transitioning to a circular economy an opportunity to accelerate and scale-up the most recent scientific and technological advances that support greater efficiency in the water sector. However, this requires further advances in technologies such as:

- A range of sensors in water systems to monitor water levels, the flow of water through different channels, temperature changes, chemical leakage, pressure level, chemical residues, and biological residues, pH, etc., associated to smart decision support systems that allow to monito, take action in real-time and forecast the water treatment plant, considering multiple sources of data (from the sensors deployed on-site but also e.g., weather forecast).
- IoT-enabled water purifiers that can predict potential system failures to reduce downtime in water treatment plants, and to enable remote sensing for mapping groundwater resources and monitoring sustainable extraction levels.
- IoT-enabled increase of water recycling and development of the urban circular water economy. As examples waste water from industry and data centers can be used for district heating or treated and recycled to yield not only water but also energy, fertilizer, and organic inputs.
- IoT-enabled increase of water recycling in water-demanding industries (e.g., mining, semiconductor manufacturing) with reduction of the water footprint in manufacturing. Water-efficient processes must be implemented such as closed-loop systems, which capture and recycle the water used in the production process.

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[40] https://www.bccresearch.com/market-research/environment/water-and-wastewater-treatment-technologies-global-markets.html

3.5.3.5 Major Challenge 5: Biodiversity restoration for ecosystems resilience, conservation, and preservation

3.5.3.5.1 Status, vision and expected outcome

It has been stated that: "Biodiversity boosts ecosystem productivity where each species no matter how small, all have an important role to play"[41]. For example, increasing the number of plant species means a greater biodiversity ensuring natural sustainability for all life [42] Healthy ecosystems can better withstand and recover from a variety of disasters, anthropogenic or not. Healthy biodiversity offers many natural services for everyone.

It should be noted that there are many such services that we already get for free! However, the cost of replacing these, even, if possible, would be extremely expensive. More than ever, as noted in Section 3.5.4.3, the new EU agriculture policies promote sustainable farming practices that help to protect the environment, preserving landscapes and biodiversity. This is a consequence of the well-recognized correlation between the health of ecosystems and the health of farming production. It therefore makes economic and development sense to move towards sustainability. From this perspective, ECS will contribute to addressing some of the key challenges relating to biodiversity and sustainability for the four ecosystems described below.

3.5.3.5.2 Biodiversity restoration for the agriculture ecosystem

Among the key focus areas Agriculture is one of the economic activities that has the highest dependence on nature and biodiversity[43]. On average, global mean crop yields of rice, maize and wheat are projected to decrease between 3% and 10% per Celsius degree of warming above historical levels. All crops depend directly on soil health and fertility, and more than 75% of global food crop types rely on animal pollination. However, the impact of agriculture activity on the environment must be as low as possible to preserve biodiversity. Efforts to conserve existing land resources (e.g. forests) and expand natural-based solutions (e.g. peatlands restoration) are required to reduce the GHG emissions, or to improve resistance by microbial biofertilisers [44] [45].In this regard, the EU Biodiversity Strategy 2030 establishes several objectives[46], summarized in *sub-section 3.5.5* Timeline. To address these objectives, there is a need to develop:

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[41] Anup Shah « Why is biodiversity important? Who cares?
https://www.globalissues.org/article/170/why-is-biodiversity-important-who-cares

[42] https://www.pnas.org/doi/10.1073/pnas.2203385119

[43] European Commission. The business case for biodiversity. May 2020.
https://ec.europa.eu/commission/presscorner/detail/en/fs_20_907

[44] https://www.fao.org/3/nd651en/nd651en.pdf

[45] Prisa, D, Fresco, R, Spagnuolo, D. 2023. Microbial Biofertilisers in plant production and resistance: a review. Agriculture 13(9), 1666 - MDPI

[46] European Commission. EU Biodiversity Strategy for 2030: bringing nature back into our lives. May 2020.
https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1590574123338&uri=CELEX%3A52020DC0380

- Precision farming systems and services for optimal use of fertilisers and pesticides.
- Sensing and monitoring systems for *in situ* measurement of soil nutrients, connected insect traps and landscape monitoring.

3.5.3.5.3 Biodiversity restoration for the aquaculture ecosystem

Aquaculture impacts biodiversity negatively in several ways[47]: (i) where antibiotics and hormones are used to reduce farm stock mortality and improve growth rates, but their use has side effects for the flora and fauna of water bodies receiving farm effluents; (ii) through eutrophication and changes in flora and fauna in waters receiving effluents from aquaculture facilities; (iii) through the risk of excessive exploitation of wild fish stocks for use in farm fish feeds; and (iv) by transfer of disease and parasites from farm animals to wild animals.

To address these side effects, there is a need to develop:

- Precision aquaculture systems for optimal feeding (minimizing waste and feed residuals), optimal use of antibiotics/hormones, and optimal use of freshwater.
- Smart multi-sensors and smart systems for monitoring water quality in aquaculture facilities and their effluents.
- Smart systems combining data collected from different sources (IoT networks, satellite, and drones) and data analysis based on AI/ML techniques to create predictive models leading to more confident decision-making, timely alerts, and automated systems in general.

3.5.3.5.4 Biodiversity restoration for the fisheries ecosystem

The EU's Biodiversity Strategy has set an objective of protecting a minimum of 30% of its sea area. Like agriculture, fishing is an economic activity with a strong dependence on biodiversity. Keeping fish stocks healthy is critical to guaranteeing ocean biodiversity and thus the economic sustainability of fisheries. According to this strategy, the preservation of marine stocks could increase the annual profits of the European seafood industry by more than €49 billion.

Fishing activities impact biodiversity negatively in several ways, particularly by: (i) increasing fish mortality, so measures must be taken to keep this under maximum sustainable yield levels; and (ii) damaging the ocean ecosystem due to the use of certain fishing techniques, currently the most damaging activity to the seabed. In addition, the effect of by-catching from non-selective industrial fishing methods endangers many species of marine animals not being fished for. It is therefore necessary to evolve towards more selective and less damaging fishing techniques, as well as the more effective control of illegal fishing practices.

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[47] Claude E. Boyd, What is biodiversity and its relevance to aquaculture certification? https://www.aquaculturealliance.org/advocate/biodiversity-relevance-aquaculture-certification/

To reduce these negative impacts, there is a need to develop:

- Oceanographic sensing and monitoring solutions (including unmanned vehicles, UXVs) for fisheries ecosystems to estimate biodiversity indices, fish stocks and species distribution, and to build fishery management systems consistent with conservation objectives and rules, also related to the tropicalization process that it is becoming emergent in last times.
- Technologies to make fishing gear more selective and environmentally respectful.
- Technologies for checking compliance and detecting illegal activities (onboard cameras, RFID, traceability technologies, vessel monitoring, etc.).

3.5.3.5.5 Biodiversity restoration for the forestry ecosystem

The EU Biodiversity Strategy has set the objective of protecting a minimum of 30% of the EU's land area. At least one-third of protected areas – representing 10% of EU land – should be strictly protected. In particular, the strategy identifies the crucial need to strictly protect all the EU's primary and old-growth forests, which are the richest forest ecosystems removing carbon from the atmosphere, while storing significant carbon stocks.**Error! Unknown switch argument.** The strategy also calls for preserving the good health and increasing the resilience of all EU forests, especially against wildfires, droughts, pests and diseases. It is envisaged that the European Commission will develop a forest information system for Europe that integrates data from multiple sources and providers. To prevent more wildfires, we need to grow rural economies in a sustainable way and manage climate change, with a much better understanding and continuous assessment of EU forests. To this end, there is a need to develop:

- A precision forestry system with remote self powered sensing and AI/ML monitoring capabilities to map and assess the condition of the EU forests as well as early detection and prevention of threats to the forests (wildfires, pests, diseases, etc.).
- Smart systems for environment monitoring of forests as well as C02 footprint monitoring, remote monitoring of wildlife behaviour and habitat changes, and provide timely warning on illegal poaching activity.
- Customised services (similar to precision agriculture as a service as discussed earlier), not only to support the above-mentioned systems but also to further exploit the information they provide.

3.5.4 TIMELINE

MAJOR CHALLENGE	TOPIC	SHORT -TERM 2024 - 2028
Major Challenge 1: food security	**Topic 1.1:** intelligent and adaptative food production	• Advanced analytical processing based on several data sources. • IoT devices with integrated firmware for implementing big data solutions

	Topic 1.2: redesigning farming systems	• Advanced autonomous robotic systems and small robots for labour free, ecological friendly farming including smart sensors, edge AI • A farm management information system (FMIS) with decision support thoroughly integrated with IoT and automated systems; all the digital data should be gathered automatically
Major Challenge 2: food safety	**Topic 2.1:** crop quality and health	• IoT for monitoring the key parameters related to plant health including hydric stress. • Decision Support Systems (DSS) for recommendation/decisions related to agrochemical application; health and environmental care
	Topic 2.2: livestock welfare and health	• Advanced indicators of welfare, health and performance monitoring (integration of milking robot, wearable sensors, etc.) at the individual and herd scale • IoT devices (sensors) for monitoring livestock emissions of GHG, nitrogen
	Topic 2.3: food chain	• IoT devices monitoring food quality, safety and transport from production to the retailer; end-consumers to have full access to this information; AI (ML/deep learning) models based on the recommendations and decisions that the IoT devices could take to monitor the whole supply chain • Global accessibility for end-consumers to the traceability of the whole value chain – i.e. total transparency
Major Challenge 3: environmental protection and sustainable production	**Topic 3.1**: soil health	• Autonomous recommendation system related to fertilisation and phytosanitary application, considering measurements from multi-parameters IoT devices and other sources of information (e.g. weather forecast). • Sensor system to measure fertiliser content in manure prior to their application in fields
	Topic 3.2: healthy air and skies	• CO_2 capture materials in use • Advanced sensors for air quality (e.g. particular matters, GHG, nitrogen)
	Topic 3.3: smart waste management	• Forecasting models of potential waste that will be produced by the farm management system
	Topic 3.4: remediation	• Network of sensors for target pollutant with antifouling properties for use in real environments • Development of capture materials for targeted pollutants, including CO_2 capture materials

Major Challenge 4: water resource management	**Topic 4.1**: access to clean water (urban and rural)	• ICT solutions allowing greater societal involvement in water management through online knowledge of its consumption data (remote meter reading), and quality parameter monitoring for greater awareness about the optimisation of the freshwater as a limited resource • Water quality monitoring systems based on hybrid technology (mono-parameter bulky probes and some miniature chips) • Multi-parameter sensor solutions for *in situ* real-time measurement (included in remote locations): Sensors for basic parameters such as chlorine, conductivity and pH are available for real-time monitoring; more complex parameters require lab analysis • Cost and integration are still challenging for massive deployment in water distribution networks based on current IoT system applications • Limited amount of data (systems are installed only at critical locations) • Centralised control and data analysis based on AI on the cloud
	Topic 4.2: resource management	• Requirements identification and classification for biodiversity protection in the exploitation of aquifers for human supply • Monitoring systems for the water lifecycle, including supply and sanitation through the development of multi-parameter sensor nodes and digital tools allowing the intensification circular economy • Progressive transformation of wastewater into raw materials for the generation of products and services
Major Challenge 5: biodiversity restoration for ecosystems resilience, conservation and preservation	**Topic 5.1**: biodiversity restoration for agriculture ecosystem	• Sensing and monitoring systems for in situ real-time measurement of soil nutrients , connected Insect traps and landscape monitoring
	Topic 5.2: biodiversity restoration for aquaculture ecosystem	• Smart multi-sensors and smart systems for monitoring water quality in aquaculture facilities and their effluents
	Topic 5.3: biodiversity restoration for fisheries ecosystem	• Technologies for checking compliance and detecting illegal activities (onboard cameras, RFID, traceability technologies, vessel monitoring, etc.)
	Topic 5.4: biodiversity restoration for forestry ecosystem	• Precision forestry system with remote sensing and AI/ML monitoring capabilities to map and assess the condition of the EU forests, as well as early detection and prevention of threats to forests (wildfires, pests, diseases, etc.)

MAJOR CHALLENGE	TOPIC	MEDIUM-TERM 2029-2033
Major Challenge 1: food security	**Topic 1.1:** intelligent and adaptative food production	- AI applied to food production to define advanced analytical processing related to prescriptive and predictive analysis
	Topic 1.2: redesigning farming systems	- Semi-autonomous agronomic systems (irrigation systems, climate control systems, etc.) based on expertise and farmers' decision-support systems (DSS)
Major Challenge 2: food safety	**Topic 2.1:** crop quality and health	- AI for decisions and action support with self adaptation and learning capabilities; ML and deep learning related to agronomic models and algorithms
	Topic 2.2: livestock welfare and health	- Technoogy to enable the reduction in the use of antimicrobials for farmed animals by 50% by 2030
	Topic 2.3: food chain	- Interoperability among all the systems that manage the whole value chain - Normalisation and homogenisation of communication protocols and end-to-end security - IoT devices integrated in the food chain where the end-consumers will be able to read them by mobile phone and directly access for complete traceability
Major Challenge 3: environmental protection and sustainable production	**Topic 3.1**: soil health	- Combination of several data sources to establish and attain key performance indicators (KPIs) related to environmental protection and sustainable production
	Topic 3.2: healthy air and skies	- CO2 capture and conversion on site
	Topic 3.3: smart waste management	- Registration of the traceability related to residues management, including the residue management in food traceability and the environmental footprint
	Topic 3.4: remediation	- Coupled sensor and CO_2 capture/conversion system for CO_2 remediation - Solar/thermoelectric in situ driven pollutant removal
Major Challenge 4: water resource management	**Topic 4.1**: access to clean water (urban and rural)	- Smart monitoring systems at home to optimise household water spending and tools to improve performances through KPIs that allow for measuring progress at the microscale; water users must move from passive consumers to active management - New generation of more integrated and miniaturised multiparameter autonomous sensors (e.g. pH, chlorine, and conductivity parameters)

		• More complex sensors are available for real-time detection of pollutants in water, such as heavy metals and nitrates • Edge computing and multiparameter devices allowing decentralised data analysis and control • Massive deployment starts being cost-effective with more accurate solutions due to the availability of an increased amount of data
	Topic 4.2: resource management	• Improvement of knowledge through the accumulation of consolidated and valid data series, on the natural environment through the implementation of monitoring systems, for both the water and natural environment (fauna, ecology, sociological aspects, uses, etc.), as a basis for sustainable management through AI/ML tools, allowing for identification of the correlation between the evolution of the environment quality and water use • Design of environmental evolution models in different use scenarios • Industrial transformation of wastewater treatment plants in bio-factories
Major Challenge 5: biodiversity restoration for ecosystems resilience, conservation and preservation	**Topic 5.1**: biodiversity restoration for agriculture ecosystem	• Precision farming systems for optimal use of fertilisers and pesticides • Reduction of the use and risk of chemical and more hazardous pesticides by 50% by 2030 • Reduction of nutrient losses by at least 50% while ensuring no deterioration to soil fertility • Reduction in fertiliser use by at least 20% by 2030 • Reduction in the sales of antimicrobials for farmed animals and in aquaculture by 50% by 2030 • Boosting the development of EU organic farming areas to achieve a 25% increase in total farmland under organic farming by 2030
	Topic 5.2: biodiversity restoration for aquaculture ecosystem	• Smart systems combining data collected from different sources (IoT, satellite and drones) and data analysis based on AI/ML techniques and digital twin to create predictive models leading to more confident decision-making, timely alerts and automated systems in general
	Topic 5.3: biodiversity restoration for fisheries ecosystem	• Oceanographic sensing and monitoring solutions (including UXVs) for fisheries ecosystem to estimate biodiversity indices, fish stocks and species distribution
	Topic 5.4: biodiversity restoration for forestry ecosystem	• Smart systems for environmental monitoring of forests and fields, as well as CO_2 footprint monitoring, remote monitoring of wildlife behaviour and habitat changes, and provision of timely warnings about illegal poaching activity

MAJOR CHALLENGE	TOPIC	LONG-TERM 2034 AND BEYOND
Major Challenge 1: food security	**Topic 1.1:** intelligent and adaptative food production	- AI applied to food production, not only in pre-harvest areas but also post-harvest – i.e. applied to the whole value chain integrally
	Topic 1.2: redesigning farming systems	- Automation of labour; resource optimisation (further targeting environmental care and social impact)
Major Challenge 2: food safety	**Topic 2.1:** crop quality and health	- Robots with AI for managing plant health autonomously
	Topic 2.2: livestock welfare and health	- Fully automated herd performance control (growth and milk production, forage efficiency, early disease detection for antibiotics use reduction), and applications for genetic selection to optimise breeding performance and resilience
	Topic 2.3: food chain	- IoT devices making recommendations automatically and take autonomous decisions related to food safety, acting directly with the transport mechanism (cooling mechanism and others that impact food safety) - Systems automatically and autonomously act in all the machinery located at each step of the supply chain
Major Challenge 3: environmental protection and sustainable production	**Topic 3.1**: soil health	- Autonomous actions performed by IoT devices directly in systems related to fertilisation and phytosanitary applications
	Topic 3.2: healthy air and skies	- Low or no carbon fuel sources
	Topic 3.3: smart waste management	- AI and digital twin models providing recommendations for decision-making related to minimising farms waste
	Topic 3.4: remediation	- Real-time multiparameter sensing with AI and digital twin decision-support for management - Efficient and low-cost general pollutant removal and conversion systems using energy harvesting towards in situ remediation
Major Challenge 4: water resource management	**Topic 4.1**: access to clean water (urban and rural)	- Use of different water qualities for different usages (at home, industry, etc.) through secure monitoring systems, always guaranteeing the water quality (especially freshwater) - Advanced multiparameter sensors supporting new capabilities, such as stability, antifouling, accuracy, etc. - Real-time microbial- detection and removal are feasible

		• Large-scale deployment of multiparameter devices allowing advanced data analysis in water distribution networks for more intelligent water management • Freshwater quality prediction based on digital twin technology capabilities considering real-time environmental conditions
	Topic 4.2: resource management	• High-performance monitoring systems to identify and quantify the presence of emerging pollutants and high-risk chemical species derived from human action • Integrated vision for all aspects related to water in systemic and non-cyclical areas; process reengineering and redesign of monitoring, control and exploitation systems based on advanced tools for decision-making through the generation of models • Paradigm shift in the vision of water as a cycle to a system that must be optimised
Major Challenge 5: biodiversity restoration for ecosystems resilience, conservation and preservation	**Topic 5.1**: biodiversity restoration for agriculture ecosystem	• Reduction of European cumulated carbon and cropland footprint by 20% over the next 20 years, while improving climatic resilience of European agriculture and stopping biodiversity erosion
	Topic 5.2: biodiversity restoration for aquaculture ecosystem	• Precision aquaculture systems for optimal feeding (minimising waste and feed residuals), optimal use of antibiotics/hormones and optimal use of freshwater
	Topic 5.3: biodiversity restoration for fisheries ecosystem	• Technologies to make fishing gear more selective and environmentally respectful
	Topic 5.4: biodiversity restoration for forestry ecosystem	• Preserve the protected and restored forestry areas, as well as continuing to restore the remaining degraded forests