Alliance for IoT
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Innovation

6G SNS IA

White Paper
The role of 6G in agriculture

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Executive Summary

Agriculture is one of the key contributors to European GDP. Almost 40% of EU budget is spent for agriculture to sustain healthy food, meat and fish production is a sustainable way. In the current landscape of agriculture and aquaculture for food production, digital technologies have emerged as a transformative force leveraging cutting-edge technologies to enhance productivity, sustainability, and decision-making processes. Digital farming and precision agriculture are key trends which will leverage the evolution of IoT technologies and the evolution of connectivity services from 5G to 6G that will collect more high fidelity data to monitor soils, crops, animal wellness and trigger automation in this sector. The final aim is to produce more (quality food) with less (pesticides)to provide the food transformation industry, retail and restauration with higher quality and more sustainable raw natural material. The recent pandemics showed how important livestock monitoring is along with the paramount importance of reliable communications. The food production industry is demonstrating in its own high innovation as witnessed by recent advancements in meat culture.

Looking to the future, the demands on communication networks in digital farming are expected to grow exponentially. The farming industry will not only require more reliable, high-speed, and low-latency connectivity but also support the integration of artificial intelligence, machine learning, and sensing capabilities that 6G will offer natively from the edge cloud. Advanced analytics, digital twins, autonomous vehicles and drones are digital concepts that are already changing a traditional sector bases on centuries old procedures. New concepts like indoor farming based on advanced digital and communication services will change for ever the outlook of an industry dominated by hard work and tractors.

Policy measures such as the Biodiversity Strategy and the Farm2Fork Strategy will finally need advanced IoT capabilities that 5G and its evolution to 6G will support. 6G with its new features will step up the sector sustainability level (“6G for Green”) but attention must be put on 6G sustainability aspects such as energy consumption of networks and AI training, bio degradation of IoT devices etc. (“Green 6G”).

5GPPP and now SNSJ JU are funding research projects that make show concrete achievements in abovementioned statements. This document contains most relevant use cases investigated under European funded research projects and the level of impact of 6G.

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Introduction

In the current landscape of agriculture and aquaculture for food production, digital technologies have emerged as a transformative force leveraging cutting-edge technologies to enhance productivity, sustainability, and decision-making processes. Digital farming involves the integration of data-driven technologies, such as sensors, precision agriculture tools, and data analytics, to optimize various aspects of agricultural practices. The shift towards digitally-enabled precision agriculture allows for targeted application of fertilizers, pesticides, and water, reducing environmental impact while maximizing productivity and food quality. In short, the vision is to produce more food of high quality with less resources and carbon footprint, protecting nature and biodiversity while fostering a globally sustainable and resilient farming sector.

As digital farming continues to evolve supporting that vision, the need for robust and advanced communication networks becomes paramount. Communication networks are the backbone of digital agriculture, facilitating the exchange of data between sensors, actuators, machinery, and farm management systems. These networks enable real-time monitoring, automation, and data-driven decision-making, critical for optimizing agricultural operations.

Looking to the future, the demands on communication networks in digital farming are expected to grow exponentially. The farming industry will require even more reliable, high-speed, and low-latency connectivity going beyond the capabilities of current 5G networks. The future 6G networks should not only enhance data transfer capabilities but also support the integration of artificial intelligence, machine learning, and advanced services in future agriculture and aquaculture. Indeed, the main purpose of this document is, by taking a forward-looking approach, to figure out how the evolving needs of digital farming could shape the requirements of future 6G networks.

1. Precision agriculture & aquaculture

The scope of this section is outdoor & greenhouse agriculture, extensive & intensive livestock farming, inshore & offshore aquaculture. Modern agriculture and aquaculture are driven by the desire to become overall sustainable. Digital technologies and data-driven practices are indeed instruments transforming traditional farming into an advanced industry with a high degree of optimisation in terms of productivity, food quality, and use of resources. Hence, it is not surprising that farming is becoming a data-intensive industry. Objective and accurate data are needed to understand the status and needs of crops and livestock/fishes, in order to make informed decisions that can lead to the desired optimisation.

Data needs can be roughly grouped in three categories:

- **Crops monitoring**: the main objective is to obtain data related to crop growth, health and stress. Pest and disease data (detection and tracking[1]) is also of high interest, given their impact both in the health and growth of the crops, and thus in productivity. The trend is to monitor crops individually as much as possible.
- **Livestock and fishes monitoring**. The following parameters and aspects are of interest:
  - Growth: size and weight of the animals
  - Health: early detection of parasites and diseases is crucial not only for optimising productivity, but also for reducing the use of antibiotics [ECF2F20] and avoiding the transmission of diseases to humans
  - Behaviour: characterisation of activities like eating, resting, sleeping, walking, etc. which can provide for instance early clues for illness
  - Wellbeing: measuring the degree of stress, "social" interaction, freedom (e.g. the amount of time spent in open space)
  - The trend is to monitor animals individually as much as possible.
- **Environment monitoring**
  - On one hand, the surrounding conditions of crops and animals have a direct impact in their growth, health and wellbeing. The parameters of interest to be measured include air temperature, air humidity, soil and water condition (pH, nutrient levels, temperature, etc.), wind, light, CO2 concentration, space allowance, etc.
  - On the other hand, the farming activity produces an impact in the land and environment which should be minimised. Obviously, the first step is to have objective measurements of this impact. Variables of interest include water and soil pollution, GHG emissions… But also effects in the biodiversity, or indicators of carbon sequestration, or erosion control. The trend of promoting organic farming[2] and farming practices which are respectful/beneficial to the environment, increases the need for this kind of data.

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[1] Example of a commercial "pest detector & tracker": https://www.doktar.com/en/products/pheromone-trap-digital-pest-tracking/

[2] https://agriculture.ec.europa.eu/farming/organic-farming/organics-glance_en

The wide diversity of data which is needed must be obtained by means of different devices/technologies such as:

- **Earth Observation (EO) systems**, fundamentally satellite imagery but also images captured by aerial drones using LIDAR and hyperspectral imaging sensors.
- **Image sensors**, like livestock monitoring cameras, field cameras to monitor crops, or underwater cameras in aquaculture facilities.
- **Plant-mounted sensors** which can provide individualised information about crop growth and health conditions.
- **Wearable sensors in animals:** smart collars, health monitoring tags, GPS trackers, etc for livestock
- **Machinery** like tractors, harvesters, and feeders obtaining for instance geo-located yield data or variable rate application of pesticides and fertilisers,
- **Soil sensors and water sensors**, measuring variables such as nutrients concentration, moisture levels, temperature, and water quality.
- **Environmental sensors** and **meteo stations** capturing data about weather conditions,

The data produced by the different sensing systems is fed into **farm management systems** (FMS), with advanced data analytics and AI systems that provide recommendations, leading to decisions on the amount of food/fertiliser to be provided, irrigation, phytosanitary treatments, etc.

The next step in FMS is the use of **digital twins**. In short, a digital twin is a virtual, detailed and constantly updated representation of a physical object or system, coupled with advanced analysis, simulation and prediction capabilities. Farms are highly complex systems. Hence a **digital farm twin** [Nasira2022] must comprise the virtual representation of a large variety of elements: animals/crops, soil, machinery (tractors, harvesters,…), actuators (irrigation systems, feeding systems…), etc. The physical elements and the digital twin must be synchronised in real time with their virtual representation.

In farms and aquaculture facilities there is an increasing trend towards **work automation**, in tasks like seeding, feeding, weeding, harvesting, etc.

This requires a new generation of **smart actuators** (e.g. irrigation systems, advanced feeding machines) and **intelligent machines**. In particular, autonomous/cooperative machines which are able to complement the human labour or even to completely replace it, performing tasks like analysis of crops, soils, water, creation of irrigation/fertilisation maps, spraying of phytosanitary treatments, etc. This new generation of machines encompasses **autonomous tractors** and **autonomous drones**: Aerial vehicles (UAVs) + ground vehicles (UGVs) + aquatic vehicles (USVs). Highly **specialised robots**[3] are currently under development, oriented to complex tasks like weed detection/removal, crop harvesting and management, even for "delicate" crops like berries, grapes, etc.

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[3] https://flexigrobots-h2020.eu/

It is clear that communication networks play a crucial role in modern agriculture and aquaculture, enabling the exchange of data between the different sensing devices, machines and farm management systems. The target in the long term is to achieve **fully autonomous farms** with a total integration of monitoring, analysis, prediction, decision-making and actuation in a closed loop.

Table 1: Challenges in agriculture and aquaculture relevant to 6G networks

Area	Challenges relevant to future 6G networks
Sensing and monitoring	▪ Ultra-low-power communications to gather data generated by miniaturised and autonomous sensors in a sustainable manner ▪ Adaptive bandwidth to meet low (sensing) and high (monitoring) data rate requirements ▪ Ubiquity of communications, esp. in remote areas ▪ Accurate geo-location to allow high-precision application of treatments ▪ High spatial density of sensing devices (scalability) ▪ Improved device security ▪ Zero-energy devices that use energy harvesting capabilities. ▪ Environmental impact
Farm management systems	▪ High throughput for managing high-definition remote sensing imaging ▪ Decentralized data analysis and decision making (in autonomous sensors and actuators) ▪ Low latency and real-time deterministic capabilities for distributed critical device control. ▪ Communications networks interoperable with brownfield agricultural systems and devices. ▪ Energy Efficiency for IoT Devices
Digital farm twins	▪ Synchronisation of the physical measurements and virtual representations in real time[4] ▪ Real-time management ▪ Low latency and real-time deterministic capabilities for distributed critical device control. ▪ Flexible orchestration of Digital Twin services and algorithms through the Cloud-Continuum.
Autonomous and cooperative machines	▪ Accurate geo-location ▪ Autonomous decision making ▪ Safe operation in collaborative environment with human workers ▪ Inter-machines connectivity to enable cooperation ▪ Cybersecurity ▪ High-quality image/video communications: both for safety reasons and for automating farm tasks like health analysis, harvesting, etc.

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[4] The meaning of "real time" in farming applications must be understood in terms of providing adequate responses to the events detected in the farm. In general, extremely low latencies like those required in certain industrial applications are not needed.

2. Novel farming techniques

The scope of this section is on vertical & indoor farming, aka **"controlled environment farming" (CEF)**, which means indoor growing of vegetables/livestock without direct sunlight in controlled environments, typically industrial buildings. The main advantage of indoor farming over "traditional" farming is that a higher degree of control on the farming conditions allows for a more accurate management that results in higher productivity yet with reduced usage of resources, namely water and land. Researchers have estimated that CEF for vegetables cultivation can reduce water use up to 95% compared to greenhouses [Carotti23], reducing also significantly the growth cycles.

CEF is specially promising for regions with limited arable land and water scarcity. It can also bring farm production closer to (or even inside) urban areas, up to the point of being deployed at the point of sale, thus reducing the cost and carbon footprint of the logistics needed to take food to the consumers.

The intensive nature of CEF is obviously efficiency-oriented. Thus, its development has led to concerns about animal welfare. Most developments nowadays are being made in the area of agriculture. Currently there are two main techniques of indoor agriculture, aka. "vertical farming" [Birkby16]:

- Hydroponics: growing plants directly in water with the appropriate nutrients
- Aeroponics: growing plants without soil and not submerged in water

There exists a hybrid, yet not-so-developed technique called "aquaponics" which performs growth of plants and fishes together.

Indoor farms existing nowadays have been reported to provide excellent results in vegetables such as tomatoes, peppers, melons, and sweet corn[5]. As the main counterpart to all the benefits, CEA presents high CAPEX and still high production costs (mainly due to energy consumption by lighting systems). As such it is still oriented to high added value agricultural products, and is strongly reliant on economies of scale. One of the challenges for the sustainability of the business model is to reduce significantly the energy costs. In any case, and even if it is still an emerging industry, CEA is quickly gaining traction in Europe [Buttur20].

The key for successful CEF is the fine monitoring and control of all the growth and health parameters: nutrients, oxygen, CO2, light, humidity, temperature, water quality, pests, etc. The smart use of lighting (for instance varying its wavelength through the day according to certain patterns) has proven to be particularly important in the growth of indoor vegetables and as such this topic is being extensively studied [Wong2020]. Thus, indoor farming requires intensive use of **smart sensors and actuators**[6], together with accurate agronomic models and advanced **AI/analytics platforms** by the **farm management system**. The use of **AI and machine learning** offers a great room for improvement in future indoor farming, given the possibility to continuously improve the models and the growing strategies. Clearly, in the context of CEF the importance of the **Digital Twin** becomes even higher than for traditional farming. The sustainable operation of indoor farms will also demand an extremely high degree of **work automation**.

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[5] https://verticalfarmingplanet.com/vertical-farming-technology-how-does-it-work/

[6] https://www.hortidaily.com/article/9074499/the-role-of-sensors-and-data-collection-in-a-successful-vertical-farm/

Table 2: Challenges in Controlled Environment Farming relevant to 6G networks

Area	Challenges relevant to future 6G networks
Smart sensing	▪ High-throughput and scalable communications for massive (i.e. high-spatial-density) sensing of different parameters: o Crop/animal growth and health (ideally, at individual level) o Pest management o Environment conditions o Energy efficiency ▪ Integrating artificial intelligence (AI) and machine learning (ML) algorithms into smart sensing devices requires substantial computational power. ▪ Joint sensing, communications and lighting integrated into one single device.
Autonomous and cooperative machines	▪ Reliable communications for remote control of autonomous robots and actuators ▪ High-throughput communications for multispectral data ▪ Inter-machines connectivity to enable cooperation ▪ Accurate indoor geo-location ▪ Cybersecurity
Digital twin	▪ Continuous monitoring for synchronisation of the physical measurements and virtual representations ▪ Low latency and deterministic communications for precise control of CEF devices from Digital Twins ▪ Dynamic and flexible orchestration of services between 6G MEC, devices and Cloud.

3. Environmental and biodiversity monitoring

As noted in a recent AIOTI paper [AIOTI2023], the interrelation between farming activities and biodiversity is gaining increasing attention and is indeed at the core of the European policies for protecting the environment, namely the Biodiversity Strategy [ECBDSW20] and the Farm to Fork Strategy [ECF2F20]. The interdependence of nature's health and sustainability of the agriculture sector has become clearer in recent years, so it is not surprising that the new policy measures are strongly promoting the preservation of landscapes and biodiversity. Within this context, a number of objectives are being set out for the next years, like the following:

1. Legally protect at least 30% of the EU's land area and 30% of the EU's sea area
2. Strictly protect at least a third of the EU's protected areas
3. Effectively manage all protected areas, including proper monitoring measures
4. Reverse the decline in pollinators
5. Reduce the use of chemical pesticides by 50%
6. Bring at least 10% of the agricultural area under high-diversity landscape features
7. At least 25% of the agricultural land is under organic farming, and significantly increase the uptake of agro-ecological practices.
8. Reduce the use of fertilisers by at least 20% and reduce the losses of nutrients from fertilisers' use by 50%
9. Eliminate the use of chemical pesticides in sensitive areas such as EU urban green areas

A consequence of these objectives is the need for different measurement and monitoring capabilities that are scalable, reliable and practical. In summary, the aspects to be monitored can be grouped in:

- **Biodiversity monitoring** refers to measuring the number, variety and variability of living organisms: animal and plant species, fungi, micro-organisms.
- **Environmental monitoring** comprises also of **surveillance** to detect illegal activities which are harmful for the environment, for instance making use of remote cameras in areas of special protection needs such as marine reserves. It includes but it is not limited to measuring:
    - Soil health: nutrients, pH, organic matter content, microbial activity, etc
    - Water quality: nutrients, pH, bacteria concentration, etc. This is particularly important in surrounding areas of aquaculture facilities, but also in farms.
    - Existence and concentration of chemical pesticides and fertilisers
    - Existence and concentration of other pollutants in air, water and soil
    - Existence and tracking of pests and diseases

- **Forests monitoring**: forests are one of the specific focus areas of the new environmental policies of the European Commission, having its own strategy since 2021 [ECFS21]. The EU Forest Strategy envisions systematic monitoring and data collection related to the development of forest biomass, tree growth, detection and monitoring of pests and diseases. It also envisages the detection of fire risks, early detection of fires, and similar aspects.

This monitoring framework fits into the EU Destination Earth (DestinE) initiative[7], which aims at developing a digital twin of the Earth on a global scale. However, at least a fraction of environmental and biodiversity monitoring will have to be performed at a more local scale, at farm level, in order to comply with certain requirements of the new Common Agricultural Policy [ECCAP21]. All of this will demand in the long term extensive deployments of **IoT-based monitoring and surveillance tools**, bringing new challenges from the perspective of the underlying communication networks.

Table 3: Challenges in environmental and biodiversity monitoring relevant to 6G networks

Area	Challenges relevant to future 6G networks
Monitoring	▪ Collection of ground-based monitoring data in remote areas in efficient, low cost and sustainable manner ▪ Extended coverage network, e.g. via non-terrestrial networks (satellite, unmanned systems) ▪ Geo-location ▪ Zero-energy/very-low power consumption devices that use energy harvesting capabilities. ▪ Zero-touch AI/ML-based surveillance
Surveillance	▪ Enabling of surveillance (including the capture of audio and video) in remote areas ▪ Extended coverage network, e.g. via non-terrestrial networks (satellite, unmanned systems) ▪ Real-time Processing and Analysis - Surveillance systems often require real-time processing and analysis of data to respond quickly to potential threats.

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[7] https://digital-strategy.ec.europa.eu/en/policies/destination-earth

4. Sustainability: energy consumption, carbon/pollution footprint

As explained in previous sections, the overall trend in agriculture and aquaculture is towards practices which are more sustainable and environmentally-friendly. A recent AIOTI paper [AIOTI2022] explored the role that ICT technologies, and IoT in particular, play in supporting the transition towards this new model, leveraging on the use of data, analysis and monitoring tools. Indeed, in recent years the scientific literature has been particularly focused in showing the positive impact of IoT in farming, for instance enabling optimisation of water resources, or the reduction of pesticides and fertilisers.

However, as noted in [AIOTI2022], it is necessary to look at the wider sustainability picture and take into account the full ecological footprint of IoT technology in farming. We need to consider at least the following aspects:

- Energy cost of communication networks, which increases with the number of connected devices and network traffic.
- Pollution due to the IoT devices lifecycle, generating electronic waste which may end up degrading the natural environment. This is specially concerning if we consider the trend towards massive sensing.
- High energy cost of training the AI models needed to perform inference on the captured data.

To the best of our knowledge, benchmarking frameworks for quantifying the impact and full footprint of IoT and digital solutions in farming do not exist yet. This is particularly important in the domain of organic farming, which by definition must be an environmentally-friendly food production system which relies only on natural substances and processes[8]. Arguably, the massive use of electronic components in the production process could compromise organic certifications.

Biodegradable compounds for electronic devices and circuits are already being investigated[9]. Technical advances are being achieved, although it is still far from being a mature technology that will reach mass production shortly.

Table 4: Challenges in sustainability relevant to 6G networks

Area	Challenges relevant to future 6G networks
Communications and computing	▪ Energy-efficient communication networks ▪ Energy-efficient ML and AI integrated in the network ▪ Energy-efficient optimization and orchestration of support services and network virtualization functions ▪ Over-the-air computation (Air Comp) that integrates communications and computing to increase system efficiency
Sensing and communications	▪ Zero-energy devices relying solely on energy harvesting and passive communications ▪ Fulfilling sensing and communications needs with environmentally-friendly, biodegradable electronic components and devices

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[8] https://agriculture.ec.europa.eu/farming/organic-farming/organics-glance_en

[9] https://eandt.theiet.org/content/articles/2022/06/compostable-crop-sensors-aiming-to-keep-fields-green/

5. Use cases/pilots

This section provides an overview of use cases and pilots in digital agriculture which are being investigated or demonstrated in recent EU-funded innovation projects. A brief description of the projects referenced in the table below can be found in the Annex. The third column in the table highlights the main issues related to 6G networks that are relevant to the corresponding use cases. The last column represents the estimated impact of the issues in the feasibility of the use case (Critical, high, medium, low), according to the reported information, provided by participants in these projects.

Table 5: Summary of use cases/pilots in EU projects, relevant to 6G networks

Use case(s)	Project	Main issues related to 6G	Impact of 6G
▪ Potato precision agriculture, including crops monitoring and spraying in the Balearic Islands (Spain) using UAVs ▪ Forestry inventory, forest harvest and forest operations in Southern Norway using UAVs ▪ Livestock grazing and health monitoring in Greece using UAVs	SPADE	▪ Connectivity in rural/remote areas ▪ UAV to UAV communications for cooperative operation ▪ Autonomous decision making ▪ Accurate geo-location ▪ Landscape/crops sensing ▪ Cybersecurity	Critical
Real-time monitoring for increasing production of tomato in greenhouses in the Balearic Islands (Spain) using IoT sensors	PLOUTOS	▪ Ultra-low-power connectivity ▪ Connectivity in rural/remote areas ▪ Real-time management ▪ Autonomous decision making ▪ Cybersecurity	High
IoT-based monitoring and irrigation for water optimisation in banana plantations in the Canary Islands (Spain)	Quantifarm	▪ Ultra-low-power connectivity ▪ Connectivity in rural/remote areas ▪ Real-time management ▪ Autonomous decision making ▪ Cybersecurity	High
Analysis of the movements of pests, droughts, heat maps, etc... in the Balearic Islands (Spain) by means of a data space	Data4Food	▪ Integration with data spaces	Low
Creation of multicriteria interactive decision maps for urban food production by using real-time IoT monitoring and edge processing	U-GARDEN	▪ Ultra-low-power connectivity ▪ Autonomous decision making	Medium
Real-time monitoring of grapevine crops using UAVs and IoT sensors	NGI-UAV-AGRO	▪ Autonomous decision making ▪ Accurate geo-location ▪ Landscape/crops sensing ▪ Cybersecurity	High
▪ Improving yield of arable crops in GPS-unfriendly of orchard fields in Greece through UGVs' mounted sensors ▪ Reducing impact of diseases and pests in Portuguese tomatoes through UAVs with multi-spectral cameras ▪ Improving productivity of Italian vineyards through automated machinery guidance, acquisition of multispectral imagery from UAVs and machinery-transported cameras	AgriBIT	▪ Connectivity in rural/remote areas ▪ Autonomous decision making ▪ Accurate geo-location ▪ Landscape/crops sensing ▪ Cybersecurity	Critical
Intelligent distributed energy management in indoor farms, relying on wireless connectivity	I-SWARM-X	▪ Reliable communications for remote control of autonomous robots and actuators ▪ Continuous monitoring	High
Milk quality and animal welfare tracking	DEMETER	▪ Connectivity in rural/remote areas ▪ Ultra-low-power connectivity ▪ Accurate geo-location	Medium

Use case(s)	Project	Main issues related to 6G	Impact of 6G
Testing and experimentation services for ag-tech companies, including: - Test fields for autonomous ground and aerial robots (guidance, anti-collision, geo-fencing, etc) provided with advanced connectivity technologies like 5G - Benchmarking of edge computation devices	AgrifoodTEF	- Ultra-low-power connectivity - Autonomous decision making - Accurate geo-location	High
Real-time monitoring of soil nutrients and gaseous emissions in Romania and France	SARMENTI	- Connectivity in remote/rural areas - Ultra-low-power connectivity - Real-time management	High
Five Living Labs for testing the integration of innovative, cost-effective, and energy-efficient connectivity solutions: - Digitalisation of viticulture in Luxembourg - Connected forestry in Norway - Connected livestock transport in Denmark - Smart olive tree farming in Turkey - Sustainable agriculture and preservation of natural environment in Serbia.	COMMECT	- Connectivity in remote/rural areas - Ultra-low-power connectivity	Critical
Connected forestry in Norway. Open call 1, project AI-4-Forest Precision agriculture. Open call 1, project AGRO4 + 5G	IMAGINE-B5G	- Ultra-low latency and high throughput - Network slicing and ultra-low latency	Critical

6. Conclusions

Communication networks are the backbone of digital agriculture, facilitating the exchange of data between sensors, actuators, machinery, and farm management systems. These networks enable real-time monitoring, automation, and data-driven decision-making, critical for optimizing agricultural operations.

In this document we have taken a forward-looking approach to figure out how the evolving needs of digital farming in different domains could shape the requirements of future 6G networks. Looking to the future, the demands on communication networks in digital farming are expected to grow exponentially: more reliable, high-speed, and low-latency connectivity going beyond the capabilities of current 5G networks. Future 6G networks should not only enhance data transfer capabilities but also support the integration of artificial intelligence, machine learning, and advanced services in future agriculture and aquaculture.

In Section 5 we have looked to on-going EU innovative projects in digital farming. Even if the sample is small, the preliminary overview show, as expected, the dependence of the viability of the digital innovations on the proper delivery of the communications network. Often, digital farming innovation projects are not focused specifically on network services, but they are rather assumed to be available and ready to use. The reality is that these projects are finding challenges and limitations in line with the prospective analysis in sections 1-5, which call for relevant improvements to fully realise the benefits of digital farming in the years to come.

- Those projects focused on robotics or autonomous vehicles suffer from the highest impact due to non-properly performing network services. In general, autonomous vehicles/robots are expected to collect data and perform actuations after taking decisions based on the analysed data, which usually takes place in the edge. One of the conclusions of the SPADE project, for instance, regarding the initial perspectives derived from UAV practices in precision agriculture or remote regions, is that the integration of 6G technology could significantly enhance real-time decision-making, potentially enabling truly autonomous operations.

- Some projects face serious limitations in connectivity aspects. In the SARMENTI project, for instance, the LoRa gateway was sensitive to the topology of the fields and as such, data recorded at the individual sensors needed to be manually retrieved. This became tedious as there were multiple sensors in the fields. Furthermore, significant amounts of data were lost, as if the retrieval was not done in a timely manner it was overwritten by the next data package. The loss of historic data is significant as it prevents the ability to look at trends within farming land. There is thus a need for improved connectivity technologies to overcome this kind of limitation.

- In indoor farms: no clear idea about ideal connectivity solutions. Cloud-edge deployment of distributed automation systems for the farm energy assets, observe connectivity performance of various wireless connectivity such as LTE, Wifi, or 5G.

- Contemporary agricultural and remote areas face a lack of wireless networks coverage. It is not uncommon to find areas devoid of any cellular connectivity. Non-terrestrial networks are the only choices nowadays, however this alternative is yet far from being fully deployed or even available.

- Few digital farming innovation projects are already considering/using advanced 5G networks to implement and test their use cases. As a result, the real performance/benefit of these networks for agriculture and aquaculture is not being yet assessed in a systematic manner.

Opportunities for 6G smart networks and services

As recognised in [vanHilten22] and checked in the use cases overview (Section 5), the application of 5G to agriculture is still in an early stage, with the technology still being deployed as proof of concept. Hence, it is still too early to grasp the full picture of benefits and limitations of 5G in the agricultural domain. However, having in mind the inherent limitations of 5G, together with the preliminary evidence found in the use cases/pilots, we try to envision the enabling aspects where 6G should deliver in order to address the different challenges.

- **Global coverage**: 6G is likely to integrate satellite communications more extensively into terrestrial networks. This can extend coverage to remote and underserved areas, including rural regions and maritime environments, where traditional terrestrial networks are less economically viable. Besides, new distributed and more economic architectures based on Open RAN and Integrated Access and Backhaul (IAB) may extend terrestrial coverage to underdeveloped areas. This could be of paramount importance for wider adoption of advanced services in the agricultural domain without requiring the cost from extensive deployment of base stations in rural areas. This digital inclusion can empower small-scale farmers and help bridge the urban-rural digital divide.

- **Seamless spectrum access**: a global coverage in terms of 6G networks means the utilization of very different spectrum bands, comprehending traditional sub-6GHz bands, new mmWave bands, future THz frequencies and optical access. While spectrum access must be optimized to guarantee high spectral efficiency, devices and terminals for digital farming should balance the access to multiple bands, energy efficiency and low cost.

- **Throughput**: The use of drones, and autonomous vehicles (driverless trucks and tractors) require significant transmission bandwidth on the uplink (e.g., using high-definition and multispectral cameras) and sustainable downlink (e.g., for reception of NTRIP corrections for high-precision GNSS receiver). For such applications, it is widely accepted that the uplink spectral efficiency of 5G networks needs further improvements. Also, the overall capacity of the network, especially for delay-critical applications e.g., remote operation of equipment, need further considerations. High uplink bandwidths will also help in faster transmission of high-resolution images from on-board imagers for offline processing in real-time applications.

- **Ultra-massive Machine Type Communication (MTC)**: the trend towards increasingly granular monitoring (up to individual crop/animal level) leads to ultra-dense networks that will demand new technical approaches to deliver communication services with high scalability in sustainable manners. This brings the need of providing connectivity to a massive number of devices avoiding collisions in the channel access and interference.

- **Edge computing**: Edge computing is one of the 5G features that can be used to support real-time data processing, faster decision-making, optimized resource management, and the scalability needed for modern farming practices. However, there is still work to be done to ensure that these services will have the correct level of security and redundancy especially in cases where services will require the support from multiple operators.

- **AI as a service**: AI as a service (AIaaS) offered by telecom operators can have a significant positive impact on agriculture by providing access to AI capabilities and resources that are typically beyond the reach of individual farmers and organizations. Although 5G networks have taken the first steps towards AI, 6G networks are expected to offer native AI solutions taking into consideration a plethora of points like reliable AI framework, trustable AI in terms of security and privacy, energy-efficient AI, etc. Furthermore, applicability of **digital twinning** to farms can be supported only by 6G networks as the amount of data to be exchanged, the response time and the native integration of AI can no longer be supported to the sufficient levels by 5G networks. Additionally, AI/ML mechanisms can be applied to optimize the network, e.g. AI-based end-to-end network configuration.

- **Security**: agriculture and aquaculture environments are typically isolated areas with low or null level of surveillance, and the devices deployed in these areas may well be very simple with low levels of security protection. Significant advances should be made in the field of cybersecurity, not only in the protection of communications by means of techniques such as robust ciphering and the reinforcement of physical layer security, but also in the protection of the physical infrastructure.

- **Integration with data spaces**: The integration of 6G networks with data spaces can enable the creation of new use cases and applications that require data sharing in conjunction with high-speed, low-latency, and reliable connectivity. Thus, new use cases can be devised regarding these aspects. Data spaces infrastructures in conjunction with 6G networks may enable fast reaction channels for weather sharing, pest control alerting or improving traceability through the use of real-time information coming from high throughput devices such as cameras or sensors that may provide high quality information regarding the status of animals, crops or other assets.

- **Energy consumption**: 6G networks have as one of its primary goals the minimization of the energy consumption of the network infrastructure, aiming to reduce the environmental impact of wireless communication. This is expected to be achieved through a series of advanced solutions, e.g., advanced antenna technologies, improved spectral efficiency, dynamic spectrum sharing, energy harvesting, energy-efficient protocols and the extensive use of AI and ML for the operation of the network. Moreover, new achievements are expected for short range communications that would reduce energy requirements for IoT devices, allowing them to operate for extended periods of time, even indefinitely by means of energy harvesting.

- **Joint communication and sensing**: combination of communication, sensing, precise positioning and advanced data processing technologies could be immensely valuable for agricultural services, providing innovative solutions to improve efficiency, productivity, and sustainability in the agriculture sector (e.g., crop/livestock monitoring and management).

The Way Forward

One of the main conclusions extracted from the preliminary analysis performed in this document is that a more systematic approach is necessary to identify use cases and needs in EU agrifood projects related to advanced communication networks, and to proactively detect the opportunities in this area. In this regard, it is interesting to highlight the approach by projects like COMMECT, involving end users of the agri-forest value chain and ICT experts working together to discuss end users' "pain" and (connectivity) "gains", from different perspectives.

In this regard, it is highly recommended to approach recently closed and on-going innovation projects in the agri-food domain to better understand the real pains, challenges and needs found out in those projects that could be used to consolidate and refine the prospective analysis made in this paper. In particular, the table of Section 5 should be enlarged to have a wider picture of the challenges and their impact, to prioritise future 6G developments.

On the other hand, it is important to have clear figures about the utilisation of connectivity technologies and their shortcomings in the farming industry, not in innovation projects but for production purposes. In particular, measuring the penetration of current 5G networks in the sector.

Annex – EU projects featured in the use cases

A.1 SPADE

The SPADE[10] project (Multi-purpoSe Physical-cyber Agri-forest Drones Ecosystem for governance and environmental observation) started in September 2022 and will last 4 years.

The strategic objective of SPADE is to develop an Intelligent Ecosystem to address the multiple purposes concept in the light of deploying UAVs to promote sustainable digital services for the benefit of a large scope of various end users in the sectors of agriculture, forestry, and livestock. This includes individual UAV usability, UAV type applicability (e.g., swarm, collaborative, autonomous, tethered), UAV governance models availability and trustworthiness. Multi-purposes will be further determined in the sensing dataspace reusability based on trained AI/Machine Learning (ML) models. These will enable sustainability and resilience of the overall life cycle of developing, setting up, offering, providing, testing, validating, refining as well as enhancing digital transformations and 'innovation building' services in Forestry, Cropping and Livestock Farming. Pilot prototypes will contribute towards greater challenges such as deforestation, precision cropping and animal welfare. First, SPADE will create a digital platform that is able to realise the potential benefits to be reaped from the use of drones. This platform is making drone operations better accessible and controllable, as well as providing a service channel for value added services enabled by drones. Second, SPADE is demonstrating three innovative use cases of drones making use of the digital platform. While demonstrating the use cases, the benefits coming from the use of drones are analysed and quantified, on a detailed stakeholder level basis. This will demonstrate the new business opportunities. The demonstrations/pilots will also serve as an analysis platform to investigate the regulatory framework at international and national level. Open calls will provide 12 further use cases.

A.2 PLOUTOS

The PLOUTOS[11] project (A sustainable innovation framework to rebalance agri-food value chains) deals with the application of IoT and new technologies in agriculture, demonstrating the beneficial effects. In the Balearic Islands in 2019, the Ploutos project was launched where sensors were deployed in tomato greenhouses. Thanks to the use of technology, engineers had real-time information on the parameters and conditions that were occurring in the crops.

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[10] https://spade-horizon.eu/

[11] https://ploutos-h2020.eu/

A.3 QuantiFarm

The QuantiFarm[12] project (Assessing the impact of digital technology solutions in agriculture in real-life conditions) deals with the deployment of digital technologies in agriculture and food production. It started in July 2022 and will end in December 2025.

The objective of QuantiFarm is to support the deployment of digital technologies (DATs) in the agriculture sector, as they are key enablers for enhancing its sustainability performance and competitiveness. However, despite the promised benefits of DATs, their adaption by farmers in Europe has been slow and limited. In this context, QuantiFarm aims to bridge the gap between farmers and DATs by delivering an Assessment Framework that measures the impact and effectiveness of these technologies. The project involves 30 test cases on organic, sustainable, and conventional commercial farms to assess DATs under real-life conditions.

The project implements a test case in the Canary Islands to measure the impact of using digital technologies (IoT, Precision Irrigation, Monitoring, Sensors, and automatizations) in banana plantations and a winery. The objective of the test case in the Canary Islands is, to optimize the use of resources by improving water management for banana plantations and digitalization processes in the winery. After 3 years of the project, a 20% reduction in water and fertiliser consumption has been observed.

A.4 Data4Food2030 EU Project – Data Economy for Food Systems

The Data4Food2030[13] project (Pathways towards a fair, inclusive and innovative Data Economy for Sustainable Food Systems) aims to enhance the data economy for food systems by addressing the existing gap in our understanding of various aspects of this economy. Its objective is to broaden the definition of the data economy, map its development and performance and generate new insights and opportunities. Therefore, Data4Food2030 advocates for the use of big data as a powerful tool to make European food systems more sustainable, provided that adequate governance of big data is in place. The project started in September 2022 and will end in August 2026.

The project includes real-life examples that are represented by nine case studies deploying data and technologies. These case studies aim to map and enhance the data economy while promoting data-enabled business models in areas such as production, supply chain, and circular economy.

One of the use cases takes place in the Balearic Islands, emphasizing the use of cooperative digitalisation to map all existing data sources that can support the agri-food data economy. The case study primarily centres on almonds and wineries creating a data space by collecting all available information on the producers, in order to be able to accurately analyse the movements of pests, droughts, heat maps, and more. The collected data will be shared with stakeholders through the NADIA platform.

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[12] https://quantifarm.eu/

[13] https://data4food2030.eu/

A.5 U-GARDEN

The urban gardens are a key component of the traditional urban and peri-urban landscapes of the main European cities. Beyond food production and consumption, urban gardens provide a wide range of ecosystem and social services, with a positive impact on the urban and socio-residential environment. The main aim of the U-Garden project[14] is to promote the implementation of urban gardens and agroforestry experiences as key components of the strategic framework for sustainable urban development in European cities, from an interdisciplinary approach.

To this end, the project will try to achieve several objectives: 1) to identify needs, problems and opportunities concerning urban garden and agroforestry experiences; 2) to promote, through Urban Living Labs, the stakeholders' capacity building in terms of green governance for food production and consumption in cities; 3) to drive citizens' capacity building for the involvement in sustainable urban development experiences; 4) to foster innovative business models around sustainable and local food production; 5) to evaluate the impact of the implementation of agroforestry/urban garden experiences in their social, cultural and environmental dimensions; and 6) to set up a multi-criteria framework to support decision-making in the location of urban gardens and agroforestry plots.

A.6 NGI-UAV-AGRO

In the NGI-UAV-AGRO project[15] (Next Generation Internet platform based on 5G and UAVs for precision agriculture), a monitoring and prevention platform for precision agriculture was developed and optimized, a platform that functions using NGI 5G (Next Generation Internet) principles. The platform consists of an autonomous UAV (Unmanned Aerial Vehicle) DJI Phantom 4 Multispectral, a wireless dedicated sensor network, a Libelium Waspmote Plug & Sense device! Smart Agriculture PRO, as well as other hardware and software components that ensure its correct operation and reliability. Grapevine crops were real-time monitored, detecting changes in soil and crop parameters to automatically activate the soil irrigation mechanisms and identify the stages of certain diseases (black rot, downy mildew, and powdery mildew (flourishing)) that can occur due to air pollution, insufficient or excess precipitation, etc. Based on sensor's data merging, phenological calendars and effective treatment recommendations were issued to the beneficiaries. Deep Learning (DL) algorithms were used to perform predictability on diseases occurrence.

Using the DJI Phantom 4 Multispectral drone, flights were made to collect multispectral images based on which coverage maps were made. The generation of these maps is useful to easily identify the areas of the vineyard where there is viable crop (green vegetation) and where there is no viable crop (area covered with other plants not of interest for monitoring or weeds).

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[14] https://u-gardenproject.eu/
[15] https://beiaro.eu/ngi-uav-agro/

A.7 AgriBIT EU Project – AI applied to precision farming

The AgriBIT project[16](Artificial intelliGence applied to pRecision farming by the use of GNSS and Integrated Technologies) is about the usage of GNSS services and sensors installed on the field to improve decision taken by farmers that will exploit the capabilities of precision faming technologies, is a project that started in July 2021 and will end in June 2024. The project is coordinated by Engineering Ingegneria Informatica that is mainly involved in the farm management system and the cross-platform visualization of the information coming from GNSS enablers applications (namely the sensors and the mobile platform on the field) and the precision agriculture services.

The project aims to increase the precision, accuracy and continuity of services to empower farmers to benefit from improved precision agriculture services. This will lead to reduction in costs through decreased use of inputs, a lower environmental impact and increased production yields. AgriBIT improves synergies with GNSS and EO and combines such information with on-field and on-machine sensors and actuators, as well as expert agricultural knowledge, to deliver simple, high-precision and continuously available services. AgriBIT improves the agriculture chain in terms of optimised use of resources, increased crop diversity across smaller land areas, and extended availability of precision agriculture services, even in challenging conditions.

The AgriBIT project involves three use cases: the Greek Orchards, Portuguese Tomatoes and Italian vineyards fields, a cross-platform visualization that allows the farmers to monitor the crops and to inform them with early warning about potential pests, to provide estimation on the crop yield, to do prescription mapping through Copernicus data. The Farm Management System moreover allows to monitor the fields health through weather stations distributed on the field, the level of glucose of the grapes through brix sensors for the vineyards, the level of pollution through custom sensors nodes.

A.8 I-SWARM-X project

The I-SWARM-X project is carried out by Aalto University, which aims to establish higher degree of intelligence of controlled environment agriculture, e.g., indoor vertical farm or greenhouse energy assets, facilitating self-adaptation of indoor farming energy assets to fit and optimize energy management to fit with energy availability while respecting the need to maintain the growth of plants in the greenhouse / indoor farm space. The farm energy assets rely on wireless connectivity as the farm takes decentralized control architecture where network cabling/wiring is expensive or difficult to install. The project incorporates various farm energy assets such as Heating Ventilation, Air Conditioning (HVAC), watering and nutrient dosing system, lighting, and also battery energy storage. Part of the project is to investigate cloud-edge deployment of distributed automation systems for the farm energy assets, observe connectivity performance of various wireless connectivity such as LTE, Wifi, or 5G, and investigate feasibility of farm energy assets participation in electricity demand response/ancillary market.

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[16] https://h2020-agribit.eu/

A.9 DEMETER

The DEMETER project [17] aims to lead the Digital Transformation of the European agri-food sector based on the rapid adoption of advanced technologies, such as Internet of Things, Artificial Intelligence, Big Data, Decision Support System (DSS), Benchmarking, Earth Observation, etc., to increase performance in multiple aspects of farming operations, as well as to assure the viability and sustainability of the sector in the long term. It aims to put these digital technologies at the service of farmers using a human-in-the-loop approach that constantly focuses on mixing human knowledge and expertise with digital information. DEMETER focuses on interoperability as the main digital enabler, extending the coverage of interoperability across data, platforms, services, applications, and online intelligence, as well as human knowledge, and the implementation of interoperability by connecting farmers and advisors with providers of ICT solutions and machinery.

DEMETER focuses on the deployment of farmer-centric, interoperable smart farming-IoT (Internet of Things) based platforms, to support the digital transformation of Europe's agri-food sector through the rapid adoption of advanced IoT technologies, data science and smart farming, ensuring its long-term viability and sustainability.

One of the pilots implemented in DEMETER is aimed at building a digital eco-system that allows the farmer to monitor animal welfare to improve milk quality, while the processor optimizes the supply chain process by innovating the way to use its data. The use of some wearable devices entered the breeding several years ago but, more recently, their connection via web to computers in-cloud opened alternatives to otherwise unsuccessful business, unable to compete in a global market where even cents have great value. For example, these wearable devices allow to identify the animal, to monitor its activity and report any abnormalities to a reliable and accurate alert system.

The Pilot is deployed in the premises of Maccarese Spa and of Latte Sano Spa. The pilot envisaged both hardware and software components. The former includes wearable collars to monitor animals' behaviour, two different devices to measure milk components and analyse them, one used at farm level and one at processor level, and one tool for milk tracing used during the milk collection to create representative sampling and transport recording.

Figure 1: DEMETER Project – Pilot 4.2 Some hardware components used in the pilot

The software components refer to the development of a traceability system to inspect on a dashboard all the phases of the milk life cycle, and two Decision Support System to estimate animal welfare and predict milk quality, all of them based only on DEMETER Enablers.

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[17] https://h2020-demeter.eu/

A.10 AgrifoodTEF

To foster sustainable and efficient food production, the AgrifoodTEF project[18] empowers innovators with validation tools needed to bridge the gap between their brightest ideas and successful market products. Built as a network of physical and digital facilities across Europe, the project provides services that help assess and validate third party AI and Robotics solutions in real-world conditions aiming to maximise impact from digitalisation of the agricultural sector.

The project focuses on five impact sectors and proposes tailor-made services for the testing and validation of AI-based and robotic solutions.

- For the Arable sector, AgrifoodTEF will propose services for testing and validation of robotic, selective weeding and geofencing technologies to enhance autonomous driving vehicle performances and therefore decrease farmers' reliance on traditional agricultural inputs.
- For the Tree Crop sector, AgrifoodTEF will propose services for testing and validation of AI solutions supporting optimisation of natural resources and inputs (fertilisers, pesticides, water) for Mediterranean crops (Fruit orchards, Olive groves).
- For the Horticulture sector, AgrifoodTEF will propose services for testing and validation of AI-based solutions helping to strike the right balance of nutrients while ensuring the crop and yield quality.
- For the Livestock sector, AgrifoodTEF will propose services for testing and validation of AI-based livestock management applications and organic feed production improving the sustainability of cows, pigs and poultry farming.
- For the Food Processing sector, AgrifoodTEF will propose services for testing and validation of standardised data models and self-sovereign data exchange technologies, providing enhanced traceability in the production and supply chains.
- For the Viticulture sector, AgrifoodTEF will leverage facilities in the vineyards of some of the most productive wine regions in Europe, where AI can deliver value by improving the quality of the final product and the sustainability of practices.

A.11 SARMENTI

The SARMENTI project aimed to develop a multi-sensor, low power IoT secure node to provide decision support to farmers by monitoring in real-time and in situ soil nutrients and gaseous emission. Deployment of the SARMENTI system was envisioned to enable farmers the ability to perform appropriate actions regarding fertilisation, with direct impact on crop growth, soil & water quality and farmer income. The SARMENTI system embed electrochemical sensors to measure NO_3, dissolved oxygen and pH. These stayed buried in the soil during the crop lifecycle with appropriate packaging to protect them from their environment. To lower the power demands of the system, a hygroscopic membrane passive pump was used to attract water from the soil, a significant improvement over the more commonly used active pump typically employed to exact water from a soil sample.

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[18] https://www.agrifoodtef.eu/

Furthermore, SARMENTI was also used to monitor CH_4 (generated by decomposition of manure under anaerobic conditions) just above the ground. This is a greenhouse gas with a higher warming potential than CO_2.

SARMENTI was designed to be a part of the IoT, with a view on enabling remote and real time analysis of farming land. The data generated was readily available to farmers, allowing for decisions to be made regarding, for example, optimum time to fertilise, in much shorter timeframes than conventional approaches. Data was transmitted to the end users by means of a LoRa gateway, which in theory makes the data accessible anywhere. The SARMENTI system was deployed in Pilot sites based in Romania and France. The sensors were found to last up to 6 months in active use, with the data being comparable to the conventional laboratory approaches.

A.12 COMMECT

Over the last few years, the importance and need for broadband and high-speed connectivity have constantly increased. The Covid-19 pandemic has even accelerated this process towards a more connected society. But this holds mainly true for urban communities. In Europe, a 13% lack of access persists and mainly concerns the most rural and remote areas. Those are the most challenging to address since they are the least commercially attractive. The COMMECT project[19] aims at bridging the digital divide by providing quality, reliable, and secure access for all in rural and remote areas. The goal of extending broadband connectivity in rural and remote areas will be achieved by *integrating Non-Terrestrial Networks with terrestrial cellular XG networks and low-cost Internet of Things (IoT). Artificial Intelligence, Edge and Network Automation will reduce energy consumption both at the connectivity and computing level.*

A participatory approach with end-users and ICT experts working together on development challenges will be the key to the digitalization of the sector. To ensure the rich exchange of best-practice and technical knowledge among the actors of the agri-forest value chain, COMMECT will set up five Living Labs across and outside Europe, *where end-users' "pain" and (connectivity) "gains" will be largely discussed, from different perspectives.*

In particular, COMMECT aims to contribute to a balanced territorial development of the EU's rural areas and their communities by making smart agriculture and forest services accessible to all. COMMECT will facilitate that by developing a decision-making support tool to advise on the best connectivity solution according to technical, socio-economic, and environmental considerations. This tool, incorporating collaborative business models, will be a key enabler for jobs, business, and investment in rural areas and for improving the quality of life in areas such as healthcare, education, and e-government, among others.

The COMMECT project started on the 1st September 2022 and is targeted to end by the 31st August 2025.

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[19] https://www.horizoneurope-commect.eu/

Challenges:

- OBJECTIVE 1: Empower rural and remote communities and train them toward digitalization:
    - COMMECT will adopt a twofold approach toward digital inclusion of rural communities: (1) easy access to fast and reliable broadband Internet (making it affordable for all and able to meet different end-user needs*)- including IoT and edge computing features*, and (2) educate rural communities and business toward the adoption of the digital technologies.
- OBJECTIVE 2: Increase the competitiveness of rural communities and give them access to new services and business opportunities:
    - COMMECT will design innovative, cost-effective, and energy-efficient (5G, last mile, and *edge*) connectivity solutions that can increase the attractiveness of rural and remote areas to businesses and individuals. COMMECT will enhance the communities' capability to create and innovate business models to impact remote and rural areas socially and economically in a sustainable way. New forms of entrepreneurship in agriculture and forestry, based on environmental and social values, will also be promoted.
- OBJECTIVE 3: Facilitate decision-making in the selection of the most appropriate Internet connectivity:
    - The choice of the most appropriate technology (*including IoT and Edge computing features*) depends on economic, geographic, and technical factors, the type and number of services required, the infrastructure already available, etc. COMMECT will validate such a concept in five Living Labs deployed in five countries with different regional, socioeconomic, and environmental conditions. *Technical and non-technical actors will closely work together in the Living Labs, exchanging their complementary knowledge (scientific and practical).* COMMECT will develop a DST that advises farmers, forestry, municipalities, and decision-makers on the best connectivity solution, according to technical requirements and the foreseen socio-economic and environmental impact.
- OBJECTIVE 4: Contribute to climate change mitigation and increase the resilience and sustainability of rural communities:

Connectivity solutions *(including IoT and Edge computing feat*ures) will be designed considering criteria such as energy efficiency, climate change impact and total cost of ownership to improve their sustainability performance. The benefits of the connectivity solutions (i.e. Green ICT and ICT for Green) will also be assessed and compared to sustainability targets (European Green Deal and Fit for 55 package) for the agricultural and forestry sectors (e.g. reaching climate neutrality by 2050 in the EU). The socio-economic and environmental indicators will be included in the DST to guide the end-users towards more sustainable choices.

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About AIOTI

AIOTI is the multi-stakeholder platform for stimulating IoT and Edge Computing Innovation in Europe, bringing together small and large companies, academia, policy makers and end-users and representatives of society in an end-to-end approach. We work with partners in a global context. We strive to leverage, share and promote best practices in the IoT and Edge Computing ecosystems, be a one-stop point of information on all relevant aspects of IoT Innovation to its members while proactively addressing key issues and roadblocks for economic growth, acceptance and adoption of IoT and Edge Computing Innovation in society. AIOTI's contribution goes beyond technology and addresses horizontal elements across application domains, such as matchmaking and stimulating cooperation in IoT and Edge Computing ecosystems, creating joint research roadmaps, driving convergence of standards and interoperability and defining policies.

About 6G IA

The 6G Smart Networks and Services Industry Association (6G-IA) is the voice of European Industry and Research for next generation networks and services. Its primary objective is to contribute to Europe's leadership on 5G, 5G evolution and SNS/6G research. The 6G-IA represents the private side in both the 5G Public Private Partnership (5G-PPP) and the Smart Networks and Services Joint Undertaking (SNS JU). In the 5G-PPP and SNS JU, the European Commission represents the public side. The 6G-IA brings together a global industry community of telecoms & digital actors, such as operators, manufacturers, research institutes, universities, verticals, SMEs and ICT associations. The 6G-IA carries out a wide range of activities in strategic areas including standardization, frequency spectrum, R&D projects, technology skills, collaboration with key vertical industry sectors, notably for the development of trials, and international cooperation.