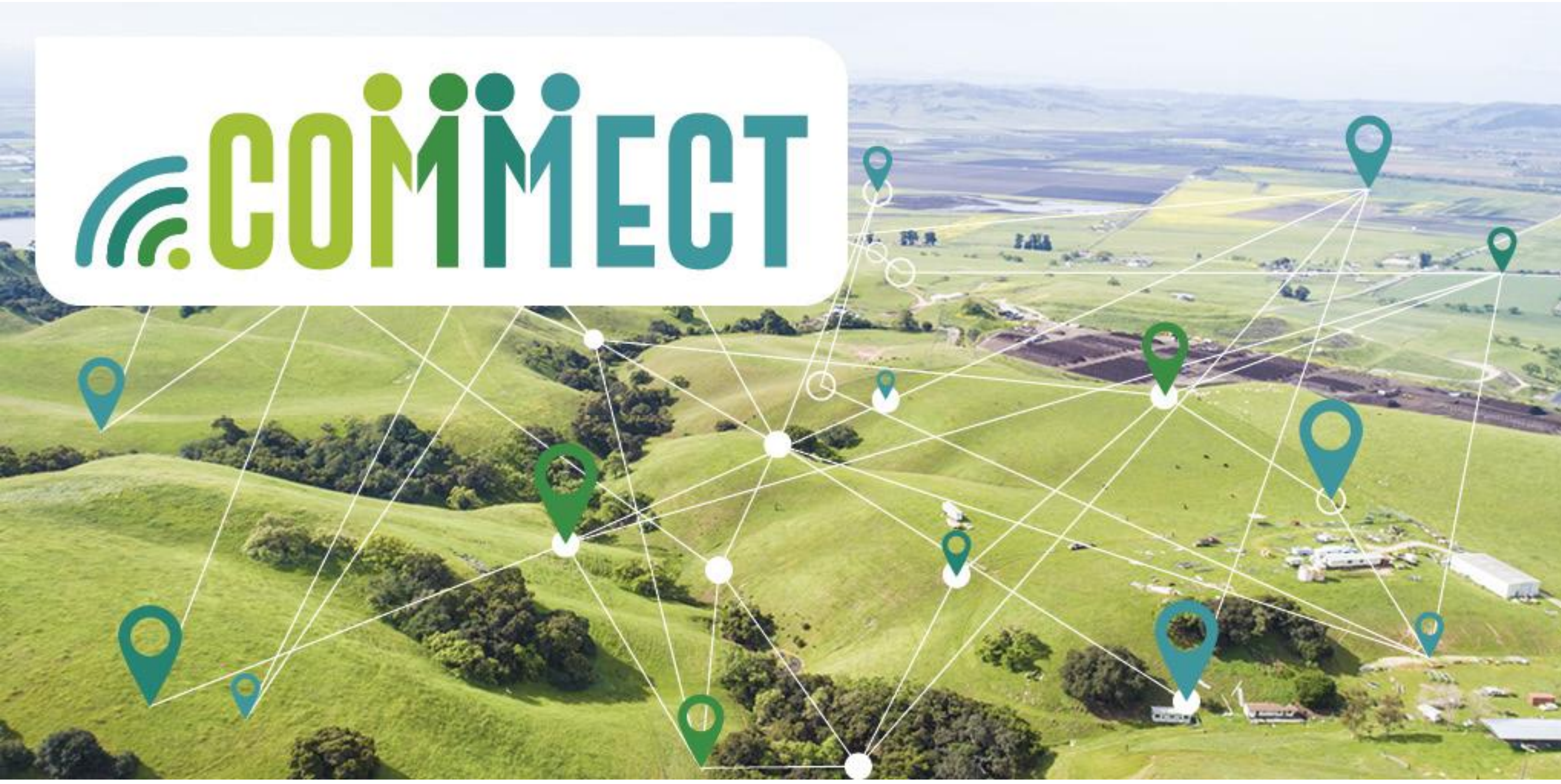
Bridging the digital divide and addressing the need of Rural Communities with Cost-effective and Environmental-Friendly Connectivity Solutions



Deliverable 1.2
Report on COMMECT requirements and KPIs

February 2024

PUBLIC

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COMMECT

Bridging the digital divide and addressing the need of Rural Communities with Cost-effective and Environmental-Friendly Connectivity Solutions

Grant agreement No. 101060881

Report on COMMECT requirements and KPIs

WP1 - End-User Needs, COMMECT Requirements and Architecture

Deliverable ID	**D1.2**
Deliverable Name	**Report on COMMECT requirements and KPIs**
Lead Partner	Aalborg University (AAU)
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COMMECT Project Abstract

Over the last years, the importance and need for broadband and high-speed connectivity has 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 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. COMMECT 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 connectivity and computing level.*

Participatory approach with end-users and ICT experts working together on development challenges will be the key **for the digitalization of the sector**. To ensure the rich exchange of best-practice and technical knowledge among the actors of the agro-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.*

COMMECT aims at contributing 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** able 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, as well as for improving the quality of life in areas such as healthcare, education, e-government, among others.*

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Executive Summary

COMMECT aims at bridging the digital divide and addressing the need of rural communities with cost-effective and environmental-friendly connectivity solutions. With that in mind, it is necessary to define a set of technical requirements and KPIs that will allow to evaluate the feasibility of the proposed connectivity solutions to serve the identified use cases.

This deliverable describes the outcome of task *T1.2 – Definition of COMMECT Requirements and KPIs* of WP1 of the COMMECT project. The document aims at describing a set of technical requirements for each of the chosen use cases and services, and a group of and Key Performance Indicators (KPIs) to be supported by COMMECT. The use cases addressed in this document have been defined in deliverable *D1.1 – Report on end-users' needs and use cases* [1] according to the user needs gathered from end users, during interviews and workshops. Technical requirements that reflect closely the end-user experience for the selected representative services are identified in this document and will be adopted as the basis for the technical evaluation and validation carried out in WP5 of the COMMECT project. Since the definition of the different use cases and the implementation of the corresponding technical solutions might be reassessed throughout the project, some KPIs may be redefined, added, or removed during the evaluation process (in *T5.2 – Technical Validation in the Living Labs*).

Apart from radio connectivity technical requirements, other relevant technological indicators will be defined to reflect network quality and service automation levels.

Additionally, this deliverable also specifies the corresponding technical requirements that will be used to measure performance and energy efficiency to support environmental sustainability against requirements, following the European Green Deal and Fit for 55 package targets. Further work on this topic is developed in WP3 and will be validated in WP5.

The technical requirements described in this document provide the basis for the COMMECT architecture (T1.3), for its development in WP2 and WP3, and implementation within the Living Labs (WP4), and finally for its validation (WP5).

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Glossary of Terms

3GPP	3rd Generation Partnership Project
DL	Downlink
DST	Decision-making Support Tool
EF	Environmental Footprint
eMTC	Enhanced Machine Type Communications
EU	European Union
GEO	Geostationary Earth Orbit
HDR	High Dynamic Range
ICP	Intelligent Connectivity Platform
ICT	Information and Communication Technology
IP	Internet Protocol
IoT	Internet of Things
KPI	Key Performance Indicator
LCA	Life Cycle Assessment
LEO	Low Earth Orbit
LL	Living Lab
LoRaWAN	Long Range Wide Area Network
LPWAN	Low Power Wide Area Network
ML	Machine Learning
MVP	Minimum Viable Product
NB-IoT	Narrowband-Internet of Things
OEF	Organisation Environmental Footprint
ORP	Oxidation Reduction Potential
PDR	Packet Delivery Ratio
PEF	Product Environmental Footprint
PoC	Proof of Concept

QoS	Quality of Service
RAN	Radio Access Network
RS	Remote Sensing
SF	Spreading Factor
SLA	Service Level Agreement
SDR	Standard Dynamic Range
UAV	Unmanned Aerial Vehicle
UL	Uplink
XG	Extended Generation

1. Introduction

This document describes the requirements and Key Performance Indicators (KPIs) of the Horizon Europe COMMECT project, which aims at bridging the digital divide existing in rural communities by providing high-quality and reliable connectivity in rural and remote areas. To that end, COMMECT has set up five different Living Labs (LLs) across and outside the European Union (EU), involving different actors and end-users from a selection of the agro-forest value chains. Throughout a series of interviews, workshops, and meetings, the COMMECT project has collected information on the end-users' needs and difficulties, and identified a series of use cases that will address them. This information is collected in deliverable *D1.1 – Report on end-users' needs and relevant use cases* [1]*.* A summary of the identified COMMECT use cases for each LL can be found in Table 18 of *Appendix 1: Summary of Identified Use Cases.*

In this deliverable, we define the COMMECT technical requirements and KPIs for each of the defined use cases. To avoid confusion with the COMMECT KPIs defined in the Grant Agreement, this document will use the term *technical requirements* to refer to the performance metrics that will be used to evaluate the feasibility of the proposed connectivity solutions to serve the identified use cases. The technical requirements should reflect the expected Quality of Service (QoS) for each use case defined in WP1, and they will be used in WP5 for the technical evaluation and validation of the proposed connectivity solutions. The technical requirements defined in this document may be *quantitative* or *qualitative*, as not all the requirements can be evaluated through tangible numerical values. The technical requirements definition is performed separately in Section 2, adapting them to the specific requests of the end-users in each of the five LLs.

The COMMECT project aims to establish a Decision-making Support Tool (DST) that serves as an interface connecting end-user requirements to the underlying solution. Additionally, the project will define an Intelligent Connectivity Platform (ICP) designed to seamlessly integrate various connectivity technologies and networks within the proposed solutions, catering to the different use cases and corresponding requirements across different Living Labs (LLs). Section 3 of this document outlines the requirements used for evaluating the efficacy of both the DST and ICP. These requirements are crucial in enabling Living Labs members, organizations, and communities to comprehensively assess the value of their DST and ICP platforms. The assessment encompasses factors such as effectiveness, efficiency, impact, adoption, technical performance, and return on investment.

Discussions between the LLs' technical responsible persons suggest that there are several commonalities among the different use cases. Section 4 will further elaborate on how the COMMECT project will exploit these similarities.

Additionally, this document will shortly introduce in Section 5 the KPIs that will be used to measure the performance and energy efficiency of the proposed solutions from an environmental perspective. Relevant KPIs for evaluating the socio-economic perspective of the solutions will be defined in WP3 and are only summarized in Section 6 of this document. Lastly, Section 7 draws the conclusions of this deliverable.

2. Living Labs Technical Requirements

2.1 LL N.1 – Luxembourg – Digitalization of Viticulture

The management of the vineyards in Luxembourg is still most of the time based on "best practices", i.e., on the winegrower's experience. According to the feedback collected from the winegrowers, they would be highly interested in digital tools that could provide them support in the decision-making, related to different activities such as disease detection, irrigation, and fertilizer applications. The tools could help them in predicting/managing effects of climate changes, such as the spread of grapevine diseases, common in Luxembourg. In fact, it is difficult to identify or even predict in advance those diseases, when relaying only on human monitoring. The current situation of the viticulture sector in Luxembourg calls for digital solutions, which can provide winegrowers with timely data about their vineyards, and suggestions to act promptly in a constantly changing environment.

Extending connectivity in the Remich area, along the Mosel, where most of the Luxembourgish vineyards are located, is the first prerequisite to enable adoption of digital solutions. In particular, the deployment of Internet of Things (IoT) networks to collect *in-situ* data, about soil and weather conditions is the first step toward a real-time monitoring of the vineyards. Besides small IoT sensor data, Remote Sensing (RS) data can be relevant for the winegrowers, to have a digital map, and a view at different scale (row, tree, leaves) of their vineyards. RS data (e.g., videos acquired with cameras, mounted on drones, or on tractors), and IoT sensor data have different requirements, in terms of bandwidth (big vs. small data). While Long Range Wide Area Networks (LoRaWAN) can offer enough uplink (UL) and downlink (DL) bandwidth for the sensor data, other technologies (terrestrial – Wi-Fi, 3G/4G/5G, and NTN – satellite, UAV-based), should be used to accommodate the higher needs of bandwidth for uploading videos. This suggests the need of multi-connectivity in the Radio Access Network (RAN) to support heterogenous data traffic, with different requirements. A gateway supporting multiple technologies could be a cost-effective solution for the Luxembourgish LL, to provide seamless connectivity for multiple sensors, as well as stable acquisition and timely transmission of high-quality videos.

Besides solving connectivity issues in the RAN, data collection over the core network should be ensured to offer the final services to the end-user (e.g., prediction of grapevine diseases via the VitiMeteo application, and visualization of the vineyard map via applications, like the one developed by LuxSense). Integration of several terrestrial and satellite networks for the backhauling link could be the best approach to ensure reliable access to the service. Based on network conditions and service requirements, Wi-Fi, 4G/5G and/or satellite could ensure the upload, and transmission of the data, within the acceptable delay.

2.1.1 UC 1.1: In-Field Microclimate and Crop Monitoring in Vineyards

The use of IoT technology for remote monitoring of the vineyards, holds the potentials of offering relevant data for supporting winegrowers in their decision-making.

Multiple sensors can be deployed in the vineyard. Leaf wetness sensors, and weather stations measuring air temperature, air humidity, wind speed direction, rainfall, soil moisture content, water volumetric content, can generate data relevant for promptly detecting the symptoms of downy mildew disease. This is an acknowledged method for more plants to be protected from the infection. Generated data needs to be sent periodically (every 15 min) and efficiently to remote servers. To support data transmission, an IoT platform that collects measurements from sensors spread all over the vineyard needs to be carefully designed. Energy supply, distances, obstructions in the field and density of sensors define different requirements for the access and backhauling networks.

Regarding sensor data collection, the following requirements have been identified on the RAN:

- *R1.1: PDR (Packed Delivery Ratio)*

Since IoT devices are supposed to be spread in the field, it is important that the proposed connectivity solution is able to cover all the sensors in terms of long distance (signal attenuation) and density (interference). For this, we target a packet delivery ratio of 90% as the rate of successful transmissions.

- *R1.2: Energy efficiency (Battery lifetime)*
  Energy resources in the field are constrained, and devices will be using limited batteries to collect and transmit data. Transmission parameters (modulation, transmit power, packet size) should be optimized in order to reduce energy consumption and extend the battery lifetime (Battery life > 1year).

LoRa is one of the IoT Low-Power Wide Area Network technology (LPWAN) that can be used in the context of LL Luxembourg to extend connectivity in rural areas. Low-cost and low-power devices can collect data in real-time and transmit it to several gateways in their coverage range.

According to Jiang *et al* [2], the coverage of LoRaWAN can easily reach 5 kilometres for the urban deployment of LoRa sensors, and up to 10-20 kilometres for rural regions, which depends strongly on the initial configuration of LoRa devices with specific Spreading Factors (SF) being selected. Those devices are usually battery-equipped, and thus, energy consumption must be optimized, to ensure they are operational for long time, without the need of replacing the battery. The authors of [2] indicated that for the transmission of each bit of data under 8 B payload, the energy consumption ranges from less than 1 millijoules to several joules depending on the value of the SF. Thus, transmission parameters must be properly configured, considering energy constraints.

The gateways in a LoRaWAN network are responsible of forwarding data to a remote network server and application server via a backhauling network. Data coming from different sensors in the field is sorted and routed to distant servers over IP, using a reliable and robust network.

For achieving proper and timely data forwarding, the following requirements on the backhauling network are identified:

- *R1.3: Latency*
  Data exchange with servers (UL data, DL ack) define requirements for the network in terms of latency. It represents the tolerable elapsed time from packet generation at source (packet forwarder) to reception at distant application (< 400 ms).

- *R1.4: Network availability*
  Sensors are sending periodical updates to the server via LoRaWAN gateways. For this the backhauling network should be available whenever a transmission occurs (> 99%).

A summary of the technical requirements for UC 1.1 can be found in Table 1.

Table 1. Technical requirements for UC 1.1 of the LL in Luxembourg.

Requirement ID	Description	Technical Requirement(s)	Target Value
R1.1	Sensor data collection	Packet Delivery Ratio	> 90%
R1.2	Sensor data collection	Battery lifetime	> 1yr
R1.3	Data forwarding	Latency	< 400 ms
R1.4	Data forwarding	Network availability	> 99%

To deploy the backhauling segment of the communication platform, several terrestrial networks (cellular, Wi-Fi, Ethernet) or/and NTN (satellite), can be adopted, depending on connectivity requirements and performances in field. In the LL Luxembourg, different backhauling connectivity solutions (terrestrial vs satellite) will be compared, to identify the one that can provide better performance, not only from the technical network requirement perspective, but also in term of cost, and energy efficiency. A summary of all the requirements for UC1.1 can be found in Table 1.

2.1.2 UC 1.2: Digital Twin for Digitalized Management of Vineyards

To build a digital map for dynamically monitoring the growth and health status of crops, it is indispensable to rapidly upload the videos collected by Unmanned Aerial Vehicles (UAVs) or from smartphones installed on the tractors. Based on the feedback collected by end-users and stakeholders, the time duration spent on video's acquisition and transmission from the field to the remote server (i.e., through the RAN and backhauling networks) is an important criterion for the selection of connectivity solutions.

The requirements identified for achieving video uploading are the following:

- *R1.5: Uplink Throughput*
  The collection of RS videos is done with cameras installed on the tractor. The tractor moves between rows in the field and records videos. It takes around 2-3 minutes for the tractors to film all the plants, which are evenly distributed 80-100 meters in length for each row (~ 2 km/h operation speed). In practice, a video of an entire row is 200 MB of data, and tractors can collect up to 20 rows in one hour. In the best-case scenario, the winegrowers would like to receive the processed data within 6 hours from the data acquisition. In other words, they would like to download the digital map generated at the beginning of afternoon, after driving a tractor in the field in the morning. The data processing takes 1-2 hours, which means that collected data (200MB x 20rows) needs to be uploaded in maximum 4h. This results in a minimum UL throughput of 2.23Mbps. Considering disconnections that may happen when the tractor is moving in the field, we target for this use case a network deployment with a minimum UL throughput of 5Mbps.

- *R1.6: Latency*
  In order to build the digital map, some requirements in terms of delay and latency are also important for image/video transmission. The aim is to reduce delays between the device recording the video in the field, and the remote server. Lower latency ensures delivering multiple synchronized video tracks in parallel, while avoiding network congestion resulting from packets buffering. The following table summarizes the requirements for this use case.

Table 2. Technical requirements for UC 1.2 of the LL in Luxembourg.

Requirement ID	Description	Technical Requirement(s)	Target Value
R1.5	Uploading video	Uplink Throughput	5 Mbps
R1.6	Uploading video	Latency	< 400 ms

A summary of the requirements established for UC1.2 can be found in Table 2. To meet the requirements of this use case, LL Luxembourg evaluates diverse communication technologies.

Wi-Fi can provide stable and real-time data uploading for high-resolution RS videos collected with cameras installed on drones [3] and/or tractors. The ideal transmission rate of Wi-Fi 6 can reach at least 300-500 Mbps. However, considering the outage due to the tractor's disconnection and its potential packets drops, the average achievable transmission rate can only reach around 80Mbps in realistic situation. This average rate allows the smartphone installed on the tractor to upload 200MB data per row within 20 seconds, which is still meeting the predefined requirements in terms of throughput. However, in case that the buffering unit of Wi-Fi gateway encounters a long queue of data (buffer overflow), the packet delivery rate will drop down. Due to the buffering congestions and the jitters resulting from the variable delay among the packets, the QoS can be seriously degraded for consistent video acquisition by Wi-Fi.

In addition, to collect the data over the wide area of vineyards, some Wi-Fi repeaters should be deployed to extend the coverage range. In fact, with a single Wi-Fi router in a fixed location, the camera on the tractor may get disconnected as the tractor moves far away from that location. To achieve seamless connectivity, LL Luxembourg can investigate the introduction of Wi-Fi repeaters, for instance installed on tractors or other machinery. In this way, the Wi-Fi repeater can extend the coverage range generated by the Wi-Fi router, and support videos collection all over the field, regardless of the current location of tractor. Then, the Wi-Fi router is responsible for the internal collection of videos from all the Wi-Fi repeaters within the Wi-Fi network, and it ensures Internet connectivity for uploading the RS video to the remote server.

Satellite communications respond to the urgent need to extend broadband coverage in rural and underserved areas, they provide another alternative for connectivity in this use case. They offer a wide bandwidth to support the transmission of RS videos and a large coverage. An overall satellite throughput between 6 Mbps to 3 Gbps can be achieved depending on configuration and constellations (Low Earth Orbit (LEO)/Geostationary Earth Orbit (GEO)). However, the latency and delay in satellite networks is more significant than in terrestrial networks, given the distance between transmitter and receiver. Also, the deployment, rental, and maintenance of the network are expensive. In this context, SES, the satellite communication operator, and LL's partner, is providing a satellite capacity through the ASTRA 2F satellite of 12 MHz, hence, it is expected that 5 to10 Mbps UL throughput will be achieved for uploading the videos.

LL Luxembourg will evaluate these connectivity solutions in WP5 and provide criteria of selection between these networks depending on the coverage, network performances, as well as costs of deployment.

2.2 LL N.2 – Norway – Connected Forestry

The Connected Forestry LL covers the forest industry ecosystem in South-East of Norway. Preliminary studies uncover a value chain consisting of six major stages: planting, care, thinning, logging, transport, and sawing. The timespan from planting to logging is between 60 and 80 years. In general, the industry lacks digitalization, with a low degree of automated and robotized processes.

When planting, doing it in the right place is crucial. 15% of the plants die after the first 1-2 years in Norway, most often due to temperature and drought as well as beetles attack. Care involves removing forest/deciduous trees around planted trees, or trees that were sown too tightly. It is very important to keep those that have the greatest chance of survival. Planting and care are mostly performed with manual labor. Thinning refers to smaller forestry machines taking out trees that are least suitable to be used in premium products such as planks. Today, the machine-operator must assess very quickly (approx. 100 trees are removed per hour) based only on visual sight, the quality of the trees before deciding whether it should be left for further growth. Logging involves cutting the trees according to specifications from the buyer of forest/sawmills (length, and "quality"). Loggings are done using forest machines, e.g., log harvesters. Later, different machines pull the trees to the trucks waiting at the forest road. Fertilization of forests increases the volume of trees/harvest value and occurs every 10 to 20 years before logging. It is performed by helicopter (accurate), forest-walking machines and by hand. Transport refers to transporting the logged trees from the drop point at the logging site to the sawmills (usually by truck, alternatively by train or boat). The logs are measured (the bulk of logs on a trailer) at fixed autonomous measuring stations on their way to the sawmill. Sawing refers to sawing the logged trees in different shapes of wooden planks for the buyer/user at the sawmill.

The LL in Norway aims at bringing digitalization to all the processes abovementioned, providing improved connectivity and real-time transfer capacity in the forest areas.

2.2.1 UC 2.1: Remote Operational Support from Expert for Forest Machine Operators

The use of remote operational support and remote vehicle control has the potential to revolutionize various industries, such as transportation, construction, mining, and forestry by enabling remote support and remote operations of machinery in hard-to-reach locations. Here a human (expert) operator can provide expert advice to the operator or control a vehicle remotely over a network (with or without a person sitting in the machine).

The main requirements for UC 2.1 can be divided into two parts. The first concerning video streaming from a remote location to facilitate remote assistance, and the second involving controlling the vehicle from a distant site. To enable remote assistance and control, the forestry vehicle must be equipped with cameras capable of capturing high-quality video.

- *R2.1: Uplink Throughput*

  The video captured by the forestry machinery needs to be transmitted over a network that can support higher throughput values with low latency, ensuring timely delivery of video streams to the remote expert. Typically, high-definition video demands a throughput of 3 to 10 Mbps, contingent on factors such as compression and encoding efficiency. For scenarios involving 360-degree video or virtual reality content, throughput requirements may extend from 10 to 20 Mbps or even higher. For the remote expert use case, we will initially focus on real-time streaming of HD video, with a potential consideration for testing 360-degree video streaming if time permits.

- *R2.2: Latency*

  Similarly, latency requirements also vary depending on the specific application and use case. For instance, video conferencing and communication necessitate a latency of less than 100 ms, whereas live streaming of content can tolerate latency ranging from 1 second to 10 seconds. These figures are contingent on various factors, including network latency and the latency introduced by different encoding techniques. In this context, we specifically refer to glass-to-glass latency, which encompasses all components contributing to latency.

  For the remote control of a vehicle, the remote operator must have a view through the vehicle's cameras and send control signals to manoeuvre the vehicle in different directions. The remote operator employs a joystick to transmit these control signals over a network. To respond effectively to live situations from a remote location, the glass-to-glass1 latency should be less than 100 milliseconds, ensuring reliable vehicle control from distant locations.

[1] Glass-to-glass latency is a term typically used for video streaming to refer to the time delay between the moment light passes through a camera lens and the moment it appears on a viewer's screen.

- *R2.3: Service Reliability*

  Considering seamless service is required for remote operation of vehicles, a service reliability of 99.9% is targeted.

The technical requirements for UC 2.1 are displayed in Table 3, along with the corresponding target values that have been defined according to literature and lessons learned from previous projects [4] [5] [6].

Table 3. Technical requirements for UC 2.1 of the LL in Norway.

Requirement ID	Description	Technical Requirement(s)	Target Value
R2.1	High quality video feedback to remote operator	Uplink Throughput	10 Mbps
R2.2	High quality video feedback to remote operator	Latency	< 100 ms
R2.3	Seamless service for vehicle manoeuvre/maintenance	Service Reliability	99,9%

The network coverage and connectivity are usually scarce in distant locations like forests. Thus, to support the technical requirements of the UC, a 5G private network could be deployed. The 5G private network provides high-speed connectivity, low latency, and high reliability, making it ideal for real-time remote assistance and control of vehicles. The low latency of 5G private networks ensures that the operator can control the vehicle in real-time, without any significant delay. The high-speed connectivity allows for high-quality video streaming and fast data transfer, providing the operator with a clear view of the vehicle's surroundings and enabling the transmission of other critical data.

Overall, the 5G connection for remote assistance and vehicle control should provide sufficient throughput and low latency to support real-time control signals and high-quality video streaming for safe and reliable operation.

2.2.2 UC 2.2: Complex Situation Awareness Services in the Forests

The forestry industry is a vital component of the global economy, providing a range of products such as timber, pulp, and paper. However, managing vast forested areas can be a complex and challenging task, requiring accurate data collection, and monitoring.

Traditionally, forestry management involved manual data collection methods, such as walking through the forest and taking measurements of tree growth and health. However, this approach can be time-consuming and labour-intensive, making it difficult to collect data on a large scale. With the advent of drone technology, forestry management has become more efficient and effective. Drones can fly over forested areas and capture high-quality images and videos, allowing operators to assess tree health and growth, identify potential threats such as wildfires and pests, and monitor changes in the forest over time.

Therefore, similarly, to UC 2.1, the following requirements are defined:

- *R2.4: Uplink Throughput/ R2.5: Latency*

  The drones need to stream back high-quality video and images over a network along with drone’s control signals. Thus, the throughput and latency requirements for video streaming and drone control will be approximately similar to the ones described in UC 2.1. Furthermore, drones connected over 5G networks provide even greater advantages. With 5G's high bandwidth and low latency, operators can transmit high-quality video from the drone's cameras in real-time, allowing for precise monitoring and data collection. This real-time monitoring is particularly important in situations where the drone needs to be manoeuvred around obstacles or where quick decision-making is required.

- *R2.6: Service Reliability*

  As for the previous use case, seamless service with 99.9% service reliability is targeted.

The technical requirements for UC 2.2. are displayed in Table 4 along with the corresponding target values, which have been defined according to literature and lessons learned from previous projects [7], [8].

Table 4. Technical requirements for UC 2.2 of the LL in Norway.

Requirement ID	Description	Technical Requirement(s)	Target Value
R2.4	High quality video feedback to remote operator	Uplink Throughput	>10 Mbps
R2.5	High quality video feedback to remote operator	Latency	< 100 ms
R2.6	Seamless service	Reliability	99,9%

Overall, using drones controlled over 5G networks provides the forestry industry with a powerful tool for data collection and monitoring. With high-quality video, low latency, and wide coverage areas, 5G technology enables more efficient and accurate data collection, leading to better forest management practices and a more sustainable industry.

In most cases, the drone control is done with a proprietary controller and on designated frequency ranges. However, the controller in turn is then connected over 5G network to provide edge computing capabilities on the site. Alternatively, there are drones accessible today that can be directly connected and controlled over 5G.

2.2.3 UC 2.3: Digital Decision Support for Forest Machine Operators

This use case addresses digital assistance for operation and includes no external expert support as described in UC 2.1. The digital tools should provide access to digital maps, IoT sensors information, or video feed from drones and cameras mounted on forest machines. This will prevent the operator from entering “forbidden” forest areas (real time map update of position of machine/vehicle) and smart tracks (to reduce abrasion of terrain and energy consumption). Drones can also spot potential sparks in the terrain that may lead to forest fires.

In UC 2.1, either the forest vehicle is controlled remotely (no operator in vehicle) or machine is controlled locally (guided and supported) by another expert (operator in machine). In UC 2.3 the forest operator is solely guided by digital support tools to perform the work. No external expert support is involved.

The forestry industry can benefit greatly from the use of IoT sensors to gather important environmental data, such as temperature, humidity, air quality, soil moisture, and water quality. These sensors can be deployed throughout the forest to provide real-time information on environmental conditions, allowing for more effective forest management and early detection of potential threats.

To facilitate the transmission of data from the sensors, a reliable and robust network is required. Network requirements and technical requirements for an IoT sensor network in the forest include coverage, reasonable latency and bandwidth, and reliable operation in challenging environments. While the specific requirements for an IoT sensor network in the forest may vary depending on the particular use case, ensuring that the network can provide reliable and timely data transmission is critical for the success of the system. The sensor data do not have very stringent requirements in terms of latency and throughput, as the sensors require few kilobits of bandwidth to transfer the required information. Similarly, the case with latency where sensors do not need very low latency for a data transmission. The most important parameters for digital assistance could be sensors and network availability all the time along with long battery times to be operated in distant forestry area. Therefore, the following technical requirements have been defined for this use case:

- *R2.7: PDR (Packed Delivery Ratio)*
  The connectivity solution for the IoT sensors should effectively cover all sensors, considering both distance coverage and density. To achieve this, a packet delivery ratio of above 90% is targeted, indicating a high success rate for transmissions.

- *R2.8: Battery lifetime*
  Considering that energy resources in the forest are limited and devices rely on restricted batteries for data collection and transmission, energy consumption should be optimized. Therefore, a minimum battery lifetime of 1 year is targeted, which will be achieved through the optimization of certain transmission parameters.

- *R2.9: Latency*
  As previously indicated, the transmissions involved in uploading data and receiving confirmation from the server do not imply highly strict requirements. Hence, a targeted latency requirement of less than 400 ms has been established for these transmissions.

- *R2.10: Network availability*
  For sensors to consistently transmit data to the server at regular intervals, it is essential that the backhauling network be reliably accessible during each transmission event, with a reliability rate exceeding 99%.

A summary of the technical requirements for UC 2.3. is displayed in Table 5.

Table 5. Technical requirements for UC 2.3 of the LL in Norway.

Requirement ID	Description	Technical Requirement(s)	Target Value
R2.7	Sensor data collection	Packet Delivery Ratio	>90%
R2.8	Sensor data collection	Battery lifetime	>1 year
R2.9	Data forwarding	Latency	< 400 ms
R2.10	Data forwarding	Network availability	>99%

The Norwegian LL has identified three use cases for Connected Forestry (UC 2.1 - Remote operation support, UC 2.2 - Complex Situation Awareness and UC 2.3 - Digital Decision support), where high-speed broadband connectivity is foreseen to make an impact. The corresponding defined technical requirements are associated to network features such as throughput, latency and availability. The technical requirements and target values are defined with reference to literature and lessons learned from previous trials, but they might be redefined according to the work performed in WP4 and WP5.

2.3 LL N.3 – Denmark – Connected Livestock Transport

The Danish LL focuses on providing better connectivity solutions to the livestock transport sector (pigs, specifically). To ensure animal welfare before, during and after transportation, the European Union (EU) defined a series of regulations, compiled in the Council Regulation (EC) 1/2005 [9]. These regulations require monitoring of certain parameters during the transportation, explained in detail in the following sub-sections. Additionally, country-dependent regulations such as the ones imposed by the DANISH transport standards, require constant reporting of the truck's location during the transport journey.

Conversations with multiple stakeholders involved in the livestock trading process also suggest that, generally, this sector could strongly benefit from further digitalization in the logistics, which would allow increasing cost-efficiency. The livestock transport companies envision a future where big amounts of data are shared constantly with the transport centre and other regulatory bodies so that safety is increased, and a higher optimization of the trading process can be achieved. However, the poor cellular coverage currently available in the main transport routes of Europe and in some rural areas where the farms or transport centres are located, does not always allow to meet the requirements, or enhance the digitalization of the livestock trading industry.

After a thorough evaluation of the end-user needs', obtained through a series of interviews and meetings with the main stakeholders of the livestock transport industry, four different use cases have been defined for the Danish LL. However, only three of them will be addressed in the COMMECT project. These, and their corresponding technical requirements are defined in the following sub-sections.

2.3.1 UC 3.1: Monitoring of Livestock Transport along Rural Routes

The regulations on the protection of animals during transport defined in [9] require constant reporting of the truck's location within a fixed interval of 10 to 30 minutes. The systems collecting and transmitting location data, currently work over 2G since it provides reliability and it is known to be the widest deployed technology in Europe, according to [10]. However, interviews with end-users indicated that the transmissions of the location reports from the truck to the coordination centre do not always succeed due to poor cellular connectivity.

Additionally, constant monitoring of the animals' health conditions and other parameters during the journey is required: onboard sensor information (CO_2 levels and temperature in the livestock trailer compartments), load weight, and loading ramp status, among others. This information is currently registered manually, and it is not transmitted while the vehicle is on the route, but uploaded to the database established by the regulatory bodies after the journey is completed. However, livestock transport companies claimed during the interviews that they would like to have the monitoring information transmitted along with the position of the truck every 10-30 minutes.

The packet size for transmitting the required location information only is 286 Bytes. In the COMMECT project, we will address the user needs assuming that all the telemetry data will be transmitted to the hauler centre along with the location information, as requested by the livestock transport companies. An additional packet with location data will also be transmitted to the database of the corresponding regulatory bodies. Based on this, we define the following requirement:

- *R3.1: Uplink Throughput*

  We consider that a packet containing relevant location, onboard sensor information, will be sent to the transport center every 15 minutes, and we assume that there will be a transmission window of approximately 2.5 seconds (as per current configuration). Based on that, and an estimated packet size of 5 KBytes we establish that an UL throughput of 16 kbps should be enough to perform this transmission and potential additional packets that may be required in the future if more data needs to be transmitted (e.g., data-driven solutions for intelligent transport systems mentioned in Section 4 of deliverable D1.1 [1]).

Furthermore, regulations state that livestock transport journeys should not exceed a 24-hour limit. There are yellow, red, and black zones indicating the risk of infection for diseases spreading in Europe that can be dangerous for the livestock. Therefore, truck drivers need to plan their journey accordingly to avoid passing by dangerous areas while keeping the travelling time below 24 hours. However, this is sometimes challenging due to unexpected e.g., traffic jams, road cuts, increasing/decreasing temperatures, or other unplanned events. The end-users require a service that provides seamless cellular connectivity with enough capacity to load the navigation maps with current traffic conditions, consult live traffic cameras, load information on dangerous areas, or even consult weather forecast information to re-plan the route according to the corresponding situation. The sparse cellular coverage and poor connectivity performance in the main transport routes do currently not allow these services to be available along the whole journey. Therefore, we distinguish between two different requirements:

- *R3.2: Downlink Throughput*

  User needs defined in deliverable D1.1 [1] request an application that is able to calculate the optimal route considering all relevant information: current traffic, risk infection areas, and even weather forecast. This need will not be addressed during the COMMECT project. However, we will work on providing appropriate connectivity solutions so that any future application providing these services has access to the required data rates.

  In order to compute the required DL throughput, we take into account the download content size, the equation *throughput = downloaded_size / load_time*, but also the bursty nature of HTTP traffic (big peak rates, etc.), the impact of TCP/QUIC congestion control on different networks and access conditions, and the device type. We consider the following content:

  - The size of the files to be downloaded from Google Maps, if a driving route between Denmark and Germany (of 5-7 hours duration) is requested is around 4 MB for mobile devices (tablet type, with 820x1180p resolution, similar to the current ones used in the transport trucks), but only 1.6 MB are downloaded due to file compression.
  - Adding google maps satellite view: 0.5 MB
  - Adding Google Maps Road status: 0.5 MB
  - Extra information on Google Maps (e.g., service areas, gas stations): 0.6 MB
  - Weather Forecast: 0.7 MB
  - Risk areas content: 1.1 MB
  - *Total:* 5 MB

  Considering a tolerable loading delay of 3-5 seconds according to Google recommendations for mobile sites [11] we set an 8-14 Mbps DL throughput range as target to be able to load the optimal route calculated based on the current traffic conditions, risk areas and weather forecast information.

- *R3.3: Service Reliability*

  To ensure that the service is consistently available to end-users, the Danish LL partners are committed to offering a connectivity solution that guarantees a minimum of 99.9% uptime, providing the necessary throughput for livestock transport applications to function seamlessly throughout the entire route.

The technical requirements set for UC 3.1 are outlined in Table 6. Ideally, end-users would prefer higher throughputs, aiming for load times below 1 second. To guarantee a seamless service, these defined requirements also encompass considerations for reliability.

Table 6. Technical requirements for UC 3.1 of the LL in Denmark.

Requirement ID	Description	Technical Requirement(s)	Target Value
R3.1	Non-continuous telemetry transmission (< 2.5 s)	Uplink Throughput	16 kbps
R3.2	Online navigation systems (3-5 s)	Downlink Throughput	8-14 Mbps
R3.3	Seamless Service	Service Reliability	99.9 %

2.3.2 UC 3.2: License Plate Recognition

Only trucks authorized for livestock transport are permitted access to the farms for pick-up and delivery. Presently, this process, which involves reading the license plate, verifying if the vehicle is authorized, and lifting the barrier upon confirmation, is manually executed by the farmer. Automating this process would significantly enhance efficiency. Existing solutions employ cameras to capture license plate data, check against an authorized truck database, and transmit a signal to open the barrier. However, tests conducted with this system have demonstrated that the current cellular deployments' low data rates in certain areas are insufficient for this application.

Hence, the primary challenge lies in the absence of suitable connectivity solutions that can fully leverage existing applications. Given this context, we need to assess the network requirements to ensure the seamless provision of the service:

- *R3.4: Uplink Throughput*

  License plate recognition for vehicles in a parked position typically needs just one image. To set this technical requirement, a minimum image resolution of 1920 x 1080 pixels is considered, which implies that a 6 MB size file should be transmitted every time that a truck is seeking access to the farm premises. Considering that, and a delay tolerance of about 10 seconds, an upload throughput of approximately 5 Mbps would be required.

- *R3.5: Downlink Throughput*

  Once the images have been processed and cross-referenced with the regulatory body's database to determine the authorization status of the truck's license plate for livestock transport, the server communicates with the application. If the response is affirmative, the boom gate is raised. As the response is binary, signifying either a positive or negative outcome, a 64 B packet is considered adequate. Given the small packet size and a delay tolerance of 5 seconds, a downlink throughput of 100 kbps is deemed suitable.

The technical requirements set for UC 3.2 are summarized in Table 7.

Table 7. Technical requirements for UC 3.2 of the LL in Denmark.

Requirement ID	Description	Technical Requirement(s)	Target Value
R3.4	Uploading Image for license plate recognition	Uplink Throughput	5 Mbps
R3.5	Downloading Response for license plate authorization status	Downlink Throughput	100 kbps

2.3.3 UC 3.3: Monitoring of Livestock Loading/Unloading Processes

As the trade of livestock relies on agreements between farms regarding the quantity of animals to be exchanged, it becomes imperative to maintain a precise record of the animals loaded and unloaded into/from the truck. Responsibility for this, as well as ensuring the pigs' health remains consistent throughout the transportation process, falls on the transport unit driver. Consequently, the trading companies expressed a desire to streamline these tasks through an automated system that can tally the pigs during boarding and identify any pigs in poor health conditions. Additionally, they seek the capability to retrieve video footage from the departure location at the destination in the event of complaints from the purchasing farmer concerning a pig's health. This allows for verification of whether the pig's health status changed during transport or was already compromised at the departure location.

While there are numerous solutions accessible from research with potentials for carrying out these tasks, the first challenge arises when attempting to upload the video feed for processing in the cloud (or edge-cloud) due to the limitations in data rates, as previously mentioned.

- *R3.6: Uplink Throughput*

  According to [12], a minimum UL throughput of 5 Mbps is necessary for uploading Standard Dynamic Range (SDR) video, and 10 Mbps is required for uploading High Dynamic Range (HDR) video. Although some applications may not demand high-quality video for image recognition, for this use case, we opt for the more stringent requirement.

- *R3.7: Downlink Throughput*

  Download speeds in this use case are taken into account for two distinct purposes. The first pertains to retrieving counter information, a task that is considered time-critical, with a response time target of under 1 second. However, as the packet containing the loaded pig count information is small, it does not necessitate high data rates. The more stringent downlink throughput requirement is associated with the retrieval of video footage. Assuming an HDR video (1080p at 30 fps) lasting approximately 15 minutes, this would result in a file size of approximately 0.9 GB. Given that this retrieval is not time-critical and a delay of up to 3 minutes is permissible, a downlink throughput of 5 Mbps is considered adequate.

A summary of the technical requirements for UC3.3 is shown in Table 8.

Table 8. Technical requirements for UC 3.3 of the LL in Denmark.

Requirement ID	Description	Technical Requirement(s)	Target Value
R3.6	Uploading video for pig counting and health monitoring	Uplink Throughput	10 Mbps
R3.7	Downloading counter information / Retrieving video footage	Downlink Throughput	5 Mbps

Given the use cases stated in deliverable D1.1 [1], we defined the requirements of the Danish LL and stated the corresponding technical requirements and target values that will allow us to evaluate the performance of the proposed solutions. The use cases covered in this LL are generally not latency critical, and therefore they depend mainly on providing adequate UL/DL data rates and service reliability.

2.4 LL N.4 – Türkiye – Smart Olive Tree Farming

Olives have been cultivated in the Mediterranean basin for thousands of years and today, Türkiye is one of the most important olive-producing countries in the world. Olive production is done by traditional methods in Türkiye and most of the producers are part of communities living in rural areas. Improving harvest quality and reducing the cost per kilogram of olives are the most critical challenges in Turkish olive agriculture and farming activities. Interviews with end-users suggested that there is a need for higher automatization in the irrigation and pesticide application systems. However, the lack of connectivity in the rural areas where olives are being cultivated hampers the digitalization of these systems, among others. Additionally, Türkiye lags behind developed countries in integrating technology into olive farming.

The LL Türkiye will focus on the olive tree garden and explore how soil and other conditions can be closely monitored in olive cultivation using connectivity solutions from the 3rd Generation Partnership Project (3GPP) and enabling disease risk management and optimal spraying decisions. Narrowband-IoT (NB-IoT) and enhanced Machine Type Communication (eMTC) will be implemented for offering digital solutions to farmers, foresters, and refugees in the LL Türkiye. The data collected from the sensors installed in the field will feed early warning systems that notify end-users of the most effective control time for diseases and pests. The use of early warning systems will support environmental sustainability. The yield and quality of the product can be increased with the proper, timely and adequate olive farming techniques.

Two use cases were identified for the LL in Türkiye, which are further explained in the following sub-sections, along with the definition of their technical requirements.

2.4.1 UC 4.1: Microclimate Monitoring for Early Disease and Pest Detection

Rising temperatures and changing rainfall patterns, consequences of climate change, pose a significant threat to olive trees by fostering the proliferation of pests and diseases. Having information on certain climatic data, such as relative humidity, air temperature, leaf wetness, soil moisture, and wind speed and direction, can be helpful to effectively combat the ring spot disease *'Spilocaea oleagina (Castagne) Hughes'*. Obtaining this data from meteorological stations is crucial for disease prevention. To further enhance monitoring capabilities, soil-plant-atmosphere sensor stations can trigger spray and irrigation warnings, which can avoid low olive yields due to factors such as drought or the *Spilocaea oleagina (Castagne) Hughes* disease.

For seamless disease monitoring, climatic data should be periodically transmitted to a server without interruptions. One of the primary challenges faced by IoT devices in this context is limited battery capacity, as their required service availability may change based on the use case. Soil-plant-atmosphere sensor stations, which sleep most of the time and only awake occasionally, must have batteries that can reliably switch on for those short bursts of warnings.

This use case also requires better coverage than that of the current RAN for the agricultural sensors located in remote places. Since the extension of the RAN through the deployment of new 4G base stations (eNodeBs) or 5G base stations (gNodeBs) can be costly, the use of the NB-IoT coverage enhancement feature will be investigated.

The technical requirements defined for this use case are aligned with the standards set by the Turkish Information and Communication Technologies Authority [13], informed by insights gained from previous deployments. However, it should be noticed that these target values may be subject to change based on feedback received from the diverse stakeholders involved in the Türkiye LL value chain. The following technical requirements are considered for UC 4.1, and a summary can be observed in Table 9.

- *R4.1: Random Access Success Rate*

  The random-access procedure is employed during the initial establishment of communication between IoT devices and XG radio access networks. Its primary objective is to facilitate swift access without causing disruptions to existing connections. The Random-Access Success Rate technical requirement establishes a target value for the network's accessibility to subscribers. This metric reflects the frequency with which transmitted messages are successfully received across different coverage levels. The accessibility target is mandated at 90% according to the regulations set by the Turkish Information Technology and Communication Authority [13].

- *R4.2: Power Consumption Decrease*

  Power efficiency is considered a fundamental principle in XG radio access networks. This requirement minimizes energy consumption for radio access while providing the highest possible coverage. The target is to design the system with the ability to efficiently access the network and provide sufficient availability, so that transmission can be discontinued when there is no data to transmit. Power saving mode and extended idle discontinuous reception (DRX) are standardized by the 3GPP to decrease the power consumption of IoT sensors like the soil-plant-atmosphere sensors in LL Türkiye [14]. The average power consumption value of the base stations in İzmir Türkiye Smart Olive Tree Farming LL is approximately 60 kWh per day, and a 8-12% power decrease is set as target value for this technical requirement. The energy consumption may vary depending on the mobile network operator's equipment power efficiency, the technology and capacity of air conditioning units, the climate, and the location of the base station, etc. The target value has been decided according to the Next Generation Mobile Networks Alliance (NGMN) project that Turkcell contributed [14] and previous optimization activities in both the network and UE sides. For example, a base station micro shutdown shows approximately 10% of energy saving in a less-loaded scenario.

- *R4.3: Network availability*

  The percentage of time that a network coverage is available for service is defined as the network coverage availability. This is considered as the availability of a cell coverage in a given state to perform a required function at a given instant of time or at any instant of time within a given time interval. The network coverage availability requirement is set to 90%, according to the regulations imposed by Turkish Information Technology and Communication Authority [13].

- *R4.4: Warning Accuracy*

  There is a close relationship between disease agents in plants and climatic data. Fungal diseases increase at high humidity and optimum temperature. With the effect of climate change, disease development has changed in recent years. The collection of climate data is important for assessing disease risk. Climate instruments allow us to obtain data on air temperature, relative humidity, precipitation, wind speed in the region. These data allow us to predict the risk of possible spread of the disease. Olive ringspot disease is the most important olive disease in Turkey. Ringspot disease spreads faster under optimum temperature (23-25° C) and high humidity conditions. Leaf wetness due to rainfall increases the occurrence of the disease. Wind affects the spread of disease vector organisms (fungal spores). With the early warning system, the optimum climatic conditions that may occur for ringspot disease will be determined by the climate device and will enable rapid measures to be taken. This technical requirement aims at measuring the accuracy of the early warning systems in detecting when spray needs to be applied, which is set to 90%.

Table 9. Technical requirements for UC 4.1 of the LL in Türkiye.

Requirement ID	Description	Technical Requirement(s)	Target Value
R4.1	Sensor data collection	Random Access Success Rate	90%
R4.2	Sensor data collection	Power Consumption Decrease	8-12%
R4.3	Sensor data collection	Network Availability	90%
R4.4	Early warning system against ring spot disease	Warning Accuracy	90%

2.4.2 UC 4.2: Monitoring of Pest Insect Traps

The Olive fruit fly (*Bactrocera oleae* – Gmelin, Diptera: Tephritidae) is the main pest of olive both in Türkiye and in the whole Mediterranean basin where olive production takes place. It causes a significant amount of yield and quality losses. Following the olive fly population is important for pest control. Olive fly has the potential to multiply and cause damage in a very short time under favourable conditions. For this reason, the olive fly population in nature should be monitored frequently. Thanks to the photos that digital traps can take 2-3 times a day, it is possible to detect the sudden population increase in nature remotely through the digital system before the damage to the fruits begins.

Considering the above, the following requirements have been defined for this use case:

- *R4.5: Fly Detection Accuracy*

  XG-connected electronic traps are yellow sticky traps that contain pheromones that attract adult flies. These traps can take pictures two or three times a day with the integrated camera and transfer the image to a mobile phone, tablet or computer application. The electronic system automatically counts how many olive flies are on the sticky board. Each image is saved, and past images can be checked. Every picture file has approximately 12 MB depending on the complexity of the image. The data plan in the LL XG network should be calculated according to the number of pictures taken per day. In addition, together with digital traps, daily recorded weather data (air-soil temperature and humidity, precipitation, wind) play an important role in determining the sudden population increase for the early warning system. The target accuracy for fly detection in this use case is set to 90%.

- *R4.6: Uplink Throughput*

  Integrity is the degree to which the LL service, once obtained, is provided without excessive impairments in uplink or downlink direction, like throughput. This requirement is related to the estimation of the Bytes transmitted with some queuing in the base station and the throughput of the data limited by the radio capability of the base station. The value has been chosen based on theoretical calculations for transmitting a machine vision pest monitoring picture, which depending on the complexity of the image can be between 10 and 12 MB.

- *R4.7: Power Consumption Decrease*

  Connected mode power efficiency enables DRX for the IoT devices in normal coverage-connected mode to enhance power consumption like machine vision pest monitoring sensors. The target value has been decided according to the Next Generation Mobile Networks Alliance (NGMN) project [12] and the previous optimization activities in both the network and UE sides. The average power consumption value of the base stations in İzmir Türkiye Smart Olive Tree Farming LL is approximately 60 kWh per day, and a power consumption decrease of 8-12% is targeted for this use case. For example, a symbol shutdown shows approximately 10% of energy saving in a less-loaded scenario.

Table 10. Technical requirements for UC 4.2 of the LL in Türkiye.

Requirement ID	Description	Technical Requirement(s)	Target Value
R4.5	Potential Risk Analysis Based on Olive Fruit fly Population	Fly Detection Accuracy	90%
R4.6	Uploading of machine vision pest monitoring photo	Uplink Throughput	0.3 Mbps
R4.7	Extended battery durability of sensors equipment	Power Consumption Decrease	8-12%

Türkiye smart olive tree farming LL defined the technical requirements for the use cases shared in the deliverable D1.1 [1]. Both measuring drought stress, determining potential irrigation need and collecting of weather information is sensitive to the accessibility and availability of the XG network. Machine vision pest monitoring needs to transfer the images to the XG network [15].

2.5 LL N.5 – Serbia – Sustainable Agriculture and Preservation of Natural Environment

The agriculture sector in Serbia plays a crucial role in the country's economy and employment, particularly in the Vojvodina province. Land suitable for agriculture represents around 70% of total area, mostly located in Vojvodina province, northern part of Serbia. The current agriculture practice still mostly relies on experience influencing on negative environmental impact including soil degradation and biodiversity loss. Improving agriculture practice by introducing digital services will lead to production optimization, less pesticide usage, optimal water usage and consequently less negative environment footprint. Introducing digital solutions will be done throughout the fields at LL in Gospodjinci village, located in Vojvodina province, surrounded by a nature park where agriculture has a huge impact on the environment. The LL will utilize mobile solar generators, edge technology and renewable energy sources to establish a community based Low Power Wide Area Network (LPWAN) that covers extended rural areas. Additionally, sensors for environmental and soil parameters, air quality, noise level, and cameras will be installed to provide real-time insights into environmental conditions throughout the agriculture and nature park area.

2.5.1 UC 5.1: Creation of a Shared Rural Infrastructure

Powering up electrical irrigation pumps, providing network connectivity, processing data on the edge, etc., requires electric energy. To that end, mobile solar generators, designed as foldable tractor trailers capable of generating up to 30kW of electricity, will be used for multiple purposes: 1) to power up a LoRaWAN gateway providing connectivity to the deployed sensors, 2) to power up irrigation pumps replacing fuel-run pumps, 3) to power up one or more video cameras to monitor the status of the crops, and 4) to power up an edge Machine Learning (ML) device responsible for processing video and audio streams, and sensor data. Considering the need for creation of a shared infrastructure as a basis for digitization of agriculture in Gospodjinci village, different requirements have been defined for this use case:

- *R5.1: Maximal power output capability*

  The electric power generator must provide sufficient power to enable simultaneous use of networking and computing devices, and irrigation pumps. Based on field experience, the use of mobile solar generators has proven to be highly effective in meeting the diverse energy requirements on the field. In practical terms, the solar generator must consistently deliver between 5kW and 30kW of electricity, accommodating the simultaneous operation of networking and computing devices, as well as irrigation pumps. Regarding this requirement generator should have the capability to deliver up to 30kW of power when needed.

- *R5.2: Stable power supply*

  The power plant must be equipped with batteries of sufficient capacity to power-up the connected devices for at least 12 hours. This will provide stable power supply during the night or cloudy days.

- *R5.3: Mobility and roadworthiness*

  The electric power generator must be mobile and roadworthy. It should be sufficiently robust to withstand use on rural and dirt roads without any significant issues or damage throughout the entire growing season. The target value for this technical requirement is set at 95% which reflects the expected effectiveness of the electric power generator.

- *R5.4: Server uptime*

  LoRaWAN server must ensure high availability and reliability with a target goal of 99% uptime indicating the desired level of continuous operation without disruptions.

- *R5.5: Device connectivity*

  The primary objective of this requirement is to achieve a 100% connectivity rate for all deployed devices. This means that each sensor, video camera, and edge Machine Learning (ML) device should consistently establish and maintain a connection to the LoRaWAN network. The LoRaWAN infrastructure will be configured to support the characteristics of the devices, considering factors such as data storage capacity before transmission and the frequency of data transmission. This approach ensures that the devices can operate efficiently without impacting the agricultural operations they support.

- *R5.6: A standard, enterprise-grade platform*

  The edge computing infrastructure must use a standard, enterprise-grade platform for both hardware and software components.

- *R5.7: Battery lifetime*

  The sensors in the sensing infrastructure must be battery-powered, utilize LoRaWAN and be housed in durable outdoor enclosures, with a minimum battery lifetime exceeding 2 years.

Table 11 summarizes the technical requirements established for UC 5.1.

Table 11. Technical requirements for UC 5.1 of the LL in Serbia.

Requirement ID	Description	Technical Requirement(s)	Target Value
R5.1	Providing sufficient power	Maximal power output capability	30 kW
R5.2	Battery power storage	Stable power supply	Min. 12 hours
R5.3	The electric power generator must be mobile and roadworthy	Mobility and roadworthiness	95%
R5.4	LoRaWAN availability and reliability	Server uptime	99%
R5.5	Establishing constant LoRa connectivity	Device connectivity	100%
R5.6	Standardized edge computing platform	A standard, enterprise-grade platform	True
R5.7	Battery powered sensors	Battery lifetime	>2 years

2.5.2 UC 5.2: Securing Crops and Equipment

This use case is centred around implementing edge ML computing algorithms to enhance the security of crops and equipment on the field. The primary objective is to detect and respond to potential threats, such as theft, while also providing valuable insights into crop development and field activities. The required actions for implementing the edge ML computing involve deployment of cameras and development of machine learning algorithms for each edge device, encompassing tasks such as detecting people, vehicles, monitoring crop progress, and recognizing audio patterns.

Having in mind that the edge computing devices are powered by a renewable energy source with battery backup, the energy consumption profile of the edge devices is important which, in turn, impacts the type and the number of ML inferencing that can be done in parallel.

Technical requirements defined for this UC are listed below:

- *R5.8: Real-time video processing*

  Edge computing infrastructure must be capable of processing video streams in real-time (ML inferencing to detect/count people and vehicles in the scene). At least two video streams should be processed in real time. Deploying a minimum of two cameras allows for optimal coverage on at least two sides of the monitored area. In an ideal scenario, having four cameras in every direction provides a 360-degree surveillance capability, minimizing blind spots and enhancing the security perimeter.

- *R5.9: Edge ML remote configuration*

  Power consumption, battery status, and power requirements of active ML algorithms should be monitored. Edge devices must be remotely configurable.

Table 12 summarizes the technical requirements established for UC 5.2.

Table 12. Technical requirements for UC 5.2 of the LL in Serbia.

Requirement ID	Description	Technical Requirement(s)	Target Value
R5.8	Edge ML computing infrastructure	Simultaneous video streams processing	>=2
R5.9	Power consumption and power requirements monitoring	Edge ML remote configuration	Remote configuration supported and enabled

2.5.3 UC 5.3: Shared Environment Monitoring Platform

This use case is focused on monitoring of air quality, water quality and noise levels in the nature park, contributing to its preservation and the prevention of activities harming the environment (like the use of fuel-run boats). To support the environment monitoring efforts in Mrtva Tisa Nature Park, devices for air quality monitoring and noise sensors will be installed. The collected data from devices will be stored centrally, and the measurements made available via the shared Mrtva Tisa environment monitoring platform. This data will be accessible to all users, increasing transparency and supporting preservation of the park and prevention of activities that harm the environment. The devices must use a LoRaWAN network for data transferring and be solar (optionally battery) powered. Installed devices will be able to measure air quality (CO, CO_2, NO, NO_2, SO_2, O_3, PM1, PM2.5 and PM10), noise level and water quality (pH, dissolved oxygen (DO), water temperature, Oxidation Reduction Potential (ORP), EC/salinity).

Defined requirements for this use case are:

- *R5.10: Network capacity (air quality)*

  The air quality monitoring system requires transferring of minimum 20 measurements per day per monitoring site.

- *R5.11: Network capacity (water quality)*

  Water quality monitoring system requires transfer of more than 4 measurements per day per site.

- *R5.12: Network capacity (noise level)*

  The monitoring system must measure noise levels with defined technical characteristics, requires transferrin of more than 20 measurements per day per site.

The capacity limit specified in Table 13 (24 transfers per day for R5.10, R5.11 and R5.12) is not intended as a maximum threshold but rather as a minimum requirement. It ensures that the network has to be able to transfer a minimum of 24 status updates from each monitoring site. This limitation is due to potential constraints when using a single LoRaWAN gateway when monitoring multiple sites, as there may be limitations on the number of concurrent messages that can be transferred. To address this, options like message repetition, scheduled transfers, or additional gateways can be explored. However, the essential requirement is that the central application should receive information about sensor measurements at least once per hour.

- *R5.13: Network capacity*

  The system should be able to push notifications to all citizens in the region with ability to deliver more than 10000 notifications within 15 minutes.

Table 13 summarizes the technical requirements established for UC 5.3.

Table 13. Technical requirements for UC 5.3 of the LL in Serbia.

Requirement ID	Description	Technical Requirement(s)	Target Value
R5.10	Air quality monitoring	Network capacity* *(air quality)*	>20 measurements/day/site received
R5.11	Water quality monitoring	Network capacity* *(water quality)*	>4 measurements/day/site received
R5.12	Noise level monitoring	Network capacity* *(noise level)*	>20 measurements/day/site received
R5.13	Alerts/notifications distribution	Network capacity	>10000 notifications delivered in less than 15 minutes

** Minimal 24 transfers per day per monitoring site*

2.5.4 UC 5.4: Shared Digital Agriculture Platform

UC 5.4 is focused on the establishment of a community-shared platform for digital agriculture in this LL to overcome the cost barrier faced by farmers and promote the adoption of digital agriculture practices.

A set of data acquired from in-field installed devices for monitoring environmental and soil conditions will be stored and analysed by the agroNET platform, providing irrigation advice, disease predictions and advice, machinery tracking/utilization optimization, etc. Environmental parameters (air temperature, air humidity, etc.) will be used as inputs in prediction models for pests and disease appearance. Hourly measurements are required. As the output, farmers receive advice on optimum time of using pesticide. Soil parameters (soil moisture and temperature, soil salinity) are measured and analyzed together with relevant information provided by farmers to define the optimum time for irrigation. This all leads to improvement of agriculture practice, saving the natural resources (soil and water) and overall decreasing the negative environmental footprint.

The network should be able to transfer at least 24 status updates from each monitoring site. However, required average response time for accessing different information are used as a basis in defining the requirements that are listed below:

- *R5.14: Network capacity (environment)*

  Hourly measuring of environmental parameters is required for proper running of the pests' and disease' prediction models. While the network should allow 24 transfers per day per monitoring site, more than 20 measurements per day per site are required for creating the timely advice.

- *R5.15: Network capacity (soil)*

  Measuring of soil parameters at least once each 6 hours per day is required.

- *R5.16: Network capacity (alerts)*

Notifications and alerts for pest and disease management and irrigation management are created in the form of advice. It is necessary that the network can support transfer of alarms/notifications in a timely manner for all users.

Table 14 summarizes the technical requirements established for UC 5.4.

Table 14. Technical requirements for UC 5.4 of the LL in Serbia.

Requirement ID	Description	Technical Requirement(s)	Target Value
R5.14	Environmental monitoring	Network capacity* *(environment)*	>20 measurements/day/site received
R5.15	Soil monitoring	Network capacity* *(soil)*	>4 measurements/day/site received
R5.16	Alerts/notifications distribution	Network capacity	>10000 notifications delivered in less than 15 minutes

** Minimal 24 transfers per day per monitoring site*

2.5.5 UC 5.5: Shared Rural Community Platform

This use cases focuses on development of community platform that will serve as a central place for exchange of data, best practices and advice.

This centralized platform serves as a hub for data exchange, sharing best practices, and offering advice among the farming community. The shared platform fosters collaboration and knowledge sharing, creating a supportive community network.

Defined requirements for UC 5.5 are listed below:

- *R5.17: Expandability*

  The system must be flexible and expandable, i.e., open to addition of new features (identified through interaction with stakeholders). Initially, the platform has to support provision of information about the average yields in the region/world, selected crop prices, pesticides available/approved for use in the region, available agriculture consultants, guidelines for the allowed levels of air and water quality levels. Target value is more than 5 distinct data points available on the platform.

- *R5.18: Multilanguage support*

  The system must support easy implementation of the end user facing interface in different languages. Initially, the system must support at least Serbian and English.

- *R5.19: Access to platform*

  The platform must be accessible through different communication channels. At least the following communication channels must be supported: web browser, mobile app, and a messaging app.

- *R5.20: Accuracy of responses*

  The system must incorporate local data whenever applicable to ensure response accuracy, with a target value of more than 90%.

Table 15 summarizes the technical requirements established for UC 5.5.

Table 15. Technical requirements for UC 5.5 of the LL in Serbia.

Requirement ID	Description	Technical Requirement(s)	Target Value
R5.17	Flexible and expandable system	Expandability	>5
R5.18	Multi-language interface	Multi-language support	>3
R5.19	Accessible through different communication channels	Access to the platform	>3
R5.20	Accuracy and relevance	Accuracy of responses	>90%

3. DST and ICP Requirements

The COMMECT project aims to develop a Decision-Making Support Tool (DST) designed to provide users with informed guidance on candidate connectivity solutions tailored to their specific requirements. Comprehensive insights into the DST can be found in two key deliverables: *D1.3 - COMMECT Solution Architecture* [16] and *D3.3 - Decision-Making Support Tool, Version 1* [17].

In assisting the DST, there is the Intelligent Connectivity Platform (ICP), which will integrate the different technologies and networks that are part of the proposed connectivity solutions. The evaluation of both the DST and the ICP encompasses an assessment of their effectiveness, efficiency, and impact on decision-making and connectivity.

To measure the value that the DST and ICP platforms bring to the end-users, different KPIs have been established. The effectiveness of the platforms can be quantified by examining their proficiency in offering accurate advice on suitable connectivity solutions. This is done through two crucial parameters:

- **Decision Accuracy**: Measure the precision of decisions facilitated by the DST by quantifying the percentage of correct decisions made with its support. This metric serves as a direct indicator of the tool's ability to guide users effectively.
- **Solution Relevance**: Evaluate the frequency with which the DST and ICP provide solutions that align with the specific needs and challenges of end-users or use cases. This parameter assesses the practical applicability and appropriateness of the solutions recommended by the platforms.

To measure the efficiency of the platforms, we employ a metric centred on quantifying the time saved by end-users or administrators with the assistance of the DST and ICP, expediting decision-making processes. This is included in the following metric:

- **Time Savings**: Quantify the amount of time saved by users or administrators when leveraging the DST and ICP in contrast to traditional manual decision-making or connectivity management processes. This metric serves as a tangible measure of the platforms' efficiency in accelerating key operational aspects.

Lastly, the evaluation of the impact of the DST and ICP spans two crucial perspectives: network reliability improvement and adoption and usage. The specific KPIs for each perspective are detailed below:

Network Reliability Improvement

- **User Satisfaction**: Gather qualitative feedback from users and stakeholders to assess their satisfaction with the DST and ICP. This evaluation encompasses factors such as ease of use, overall effectiveness, and the perceived impact on decision-making. Qualitative insights provide a nuanced understanding of user experiences.
- **Network Reliability Improvement**: Measure the extent to which the DST and ICP have improved network reliability using the chosen connectivity solutions. This involves measuring the performance and stability of chosen connectivity solutions, offering a quantitative measurement of the platforms' contribution to enhancing overall network reliability.
- **Quality of Service Improvement**: Measure the extent to which the DST and ICP have enhanced the quality of service, specifically focusing on improvements in data rates and latency resulting from the implementation of selected connectivity solutions. This quantitative metric assesses the platforms' impact on improving user experience through enhanced service quality.

Adoption and Usage KPIs:

- **User Adoption Rate**: Track the rate at which users within the organization or community adopt and actively use the DST and ICP. This KPI provides insights into the acceptance and integration of the platforms within the user community.
- **Feature Usage**: Monitor and analyse the usage patterns of different features and functionalities within the DST and ICP. This involves identifying which aspects are most frequently utilized, offering valuable information about user preferences and aiding in the tailoring of future developments to meet specific needs.
- **User Engagement:** Assess the level of user engagement by tracking metrics such as the frequency of logins, data input, and utilization of decision support features. This KPI provides a holistic view of how actively and meaningfully users interact with the DST and ICP, reflecting the platforms' effectiveness in supporting decision-making processes as well.

For a more comprehensive understanding of these KPIs, detailed explanations and analyses can be found in deliverable *D3.3 Decision-making Support Tool, Version 1* [17].

4. Potential Connectivity Solutions

This section aims to map the connectivity solutions defined in WP2 to the technical requirements defined in this document for the various use cases in the COMMECT project. While Section 2 provides a detailed breakdown of the technical requirements for each LL, this section focuses on identifying commonalities across these use cases and offers a concise summary of the COMMECT technical requirements and potential connectivity solutions.

A visual representation of these solutions can be found in Figure 1, helping the reader to better grasp an overview of the connectivity solutions addressed by COMMECT.

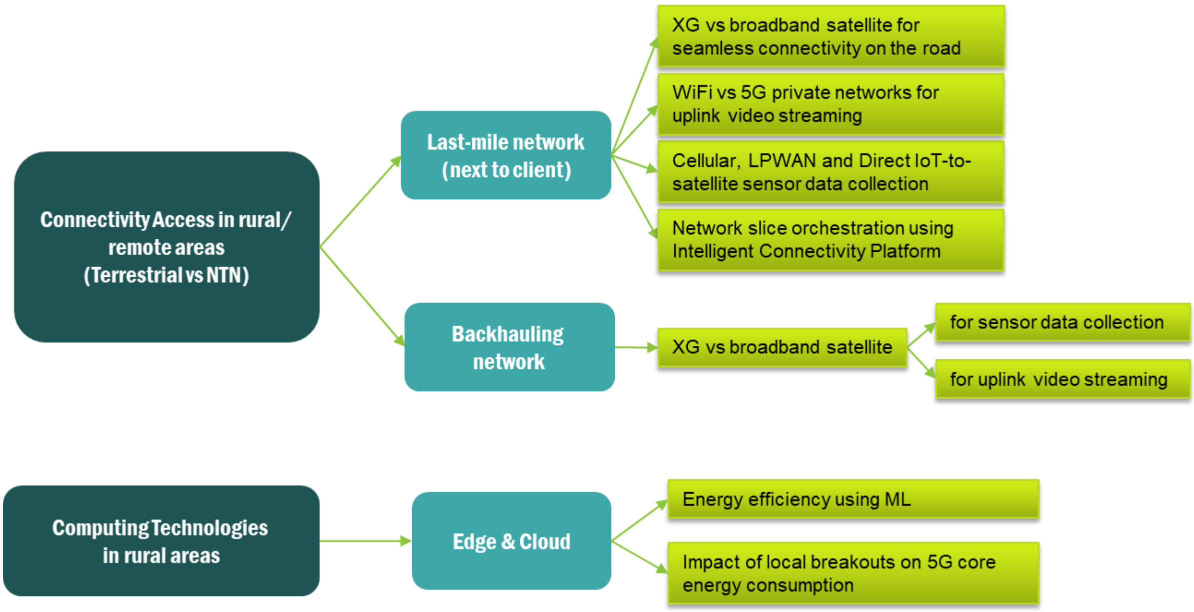

Figure 1. Summary of potential connectivity solutions for COMMECT use cases.

Based on the work carried in WP2, COMMECT aims to provide connectivity solutions (in two segments: the last-mile, and the backhauling) and improve energy efficiency in the computing (with edge vs cloud). Therefore, we distinguish:

<u>**Connectivity Access in Rural/Remote Areas (Terrestrial vs. Non-Terrestrial Networks)**</u>

This category focuses on addressing connectivity challenges in rural and remote areas. It includes two segments: the last mile / access networks, and the backhauling, as described below.

Last-Mile or Access Network

COMMECT will investigate in the five LLs different connectivity solutions for ensuring reliable connectivity to end-users, over the last mile. In this context, three main classes/categories have been established:

XG vs. Broadband Satellite

The Denmark LL, in UC 3.1, will explore the choice between XG and broadband satellite technologies to provide seamless connectivity. This is especially relevant for addressing the challenges faced by stakeholders involved in livestock transportation, where continuous connectivity is crucial.

WiFi vs. 5G Private Networks

The Denmark LL will investigate the use of WiFi versus 5G private networks. This study aims to optimize the livestock loading and unloading processes in remote locations, as seen in UC 3.2 and UC 3.3.

Cellular, LPWAN, and Direct IoT-to-Satellite Sensor Data Collection

All five LLs (Luxembourg, Norway, Denmark, Türkiye and Serbia) will delve into the choice between cellular, LPWAN, or direct IoT-to-satellite solutions for collecting sensor data for environment monitoring purposes. While the specific use cases may vary, the connectivity solutions proposed by the LLs can be cross evaluated since the objective remains the same: the continuous transmission of sensor data.

Network slice orchestration using Intelligent Connectivity Platform (ICP)

In Norway LL, the ICP prototype (see section 3 for more detail) will be integrated to a network orchestrator at TNOR's Lab (described in deliverable *D2.1 – 5G Connectivity Platforms, version 1* [18]) in order to select the best connectivity solution and perform resource reservation.

Backhauling Network

The use of XG networks versus the use of broadband satellite as backhauling networks will be investigated by different LLs as well. The backhauling comparison will be performed for two specific uses: sensor data collection (forwarding sensor data, as in the UC 1.1 and 2.3 of Luxembourg and Norway, respectively) and video uploading (UC 1.2, in the Luxembourg LL, for uploading the video recorded by the drone, UC 2.1, 2.2 and 2.3 of Norway LL).

Computing Technologies in rural areas

The COMMECT project also aims at assessing the benefits of leveraging Edge computing as opposed to cloud computing, with a specific focus on scenarios where a substantial volume of data from IoT devices requires real-time processing and analysis. The primary targeted applications include video processing, execution of ML algorithms, and the aggregation of network traffic from different base stations, among others. The aim is to conduct a comparative analysis between Edge computing and Cloud computing, evaluating factors such as energy consumption, latency, bandwidth utilization, and more. This evaluation will provide insights into the efficiency and performance of Edge computing, particularly in contexts where prompt and resource-efficient data processing is paramount. These aspects are not directly addressed by any of the use cases defined in WP1 but will be studied within the framework of WP2. Further information on the investigation and results can be found in D2.2 and D5.1, respectively.

A summary of the COMMECT technical requirements can be found in Table 16.

Table 16. Summary of COMMECT Technical Requirements.

Connectivity Category	Connectivity Solution	Use Case Applicability	Technical Requirement(s)	Range Values
Last-mile or Access Networks	XG vs. broadband satellite for seamless connectivity	• Continuous connectivity on the road for livestock transport units (UC 3.1).	a) DL Throughput b) Service Reliability	a) 8-10 Mbps b) 99.9 %
	WiFi vs 5G private networks	• Video uploading for digital management of vineyards (UC 1.2). • Video drone video uploading in the forest (UC 2.2). • Video uploading for automated processes in livestock loading/unloading locations (UC 3.2, UC 3.3).	a) UL Throughput	a) 5-10 Mbps
	Direct IoT-to-satellite vs. cellular-based sensor data collection *(LoRaWAN, NB-IoT, eMTC, etc.)*	• Remote monitoring of vineyards (UC 1.1). • Forest environment data transmission (UC 2.3). • Soil-plant-atmosphere for spray and irrigation optimization (UC 4.1). • Environment monitoring in natural parks (UC 5.1).	a) Packet Delivery Ratio b) Battery life	a) >90% b) >1 year
Backhauling Networks	XG vs. broadband satellite	• For sensor data forwarding (UC 1.1, UC 2.3). • For video uploading in remote locations (UC 1.2, and UC 2.1, 2.2 and 2.3).	a) Latency b) UL Throughput c) Network Availability	a) < 400 ms b) 5 Mbps c) > 99%

5. Environmental Requirements and KPIs

To evaluate the environmental sustainability of the digital solutions tested, derive environmental KPIs and compare them with benchmarks, the standardised life cycle assessment (LCA) methodology [19] will be used. The latter aims at evaluating the potential environmental impacts of a product or a process along its life cycle, in a comprehensive manner (including a large panel of environmental effects). At European level, the European Commission (EC) developed the Product Environmental Footprint (PEF) and Organisation Environmental Footprint (OEF) to further harmonize LCA results within products and organisations in the European Union[2].

For the calculation of environmental KPIs in COMMECT, the LCA standards ISO 14040/44, as well as the Environmental Footprint (EF) recommendations will be thus followed. This implies to adopt a life cycle perspective where any exclusions should be transparently reported and justified, and to assess the impacts on 16 categories with the recommended assessment methods [20].The latter include the effects on climate change, human health (human toxicity, particulate matter, ionising radiation, ozone depletion), ecosystems (ecotoxicity, ozone formation, eutrophication, acidification) and resources (land, water, fossil, mineral and metal).

The calculation of environmental KPIs should be done for a reference unit, which should translate the quantified function satisfied by the compared scenarios (called the functional unit). For example, the impacts of different network solutions can be compared based on data traffic (e.g., reference unit of 1 GB transferred). When deploying digital solutions, the impacts will involve the supply chain of the terminals (e.g., sensors, smartphones), servers and network. These generated impacts are also called the first order effects [21], and can be compared for connectivity solutions based on the amount and quality of transferred data.

The use of connectivity solutions can nevertheless affect the rest of the economy, e.g., by optimizing transport, industrial processes, and agricultural or farming activities. The differences of impacts between the baseline (no digital solutions) and new scenario (with digital solutions) correspond to the so-called second-order effects, which generally are meant to reduce environmental burdens of the targeted sector (avoided impacts). A comprehensive evaluation of digital solutions should thus include both the induced impacts by their deployment (first-order effects, generated impacts) and the changes induced by their use (second-order effects, avoided impacts). In that case, the reference unit to compare scenarios depends on the application. For example, when using connectivity solutions to optimize viticulture in LL1 (Luxembourg), scenarios with and without digital solutions could be compared for the production of 1 kg of grapes. All the material, energy and transport flows (e.g., water irrigation, lorry distance travelled, electricity consumption, waste generated) affected by the digital solutions should be identified, and the difference between scenarios quantified to assess the environmental impacts.

In COMMECT, environmental KPIs will be calculated on an appropriate reference unit for each Living Lab, covering both generated and avoided impacts. Sub-analyses could be performed to compare digital solutions on a data traffic level (only generated impacts).

As mentioned before, the EC recommends assessing 16 impact categories. Such a large number might be complicated to interpret and include in e.g., decision support tools. While the 16 indicators will be analysed to fully understand the environmental profile of the use case scenarios, a focus could be on climate change (i.e., greenhouse gas – GHG – emissions, carbon footprint) and on an aggregated score using the normalization and weighting sets

[2] https://environment.ec.europa.eu/publications/recommendation-use-environmental-footprint-methods_en

developed by the EC [22]. Two environmental KPIs could be thus defined: carbon footprint and EF single score of ICT solutions.

To put the obtained KPIs in perspective, the environmental requirements defined at European level for the targeted sectors (in particular the expected GHG reduction) will be used, and a benchmarking exercise with literature data will be made to understand the benefits of COMMECT technologies.

The evaluation methodology for environmental KPIs is detailed in deliverable *D3.1 - Socio-economic Impact and Environmental sustainability Assessment* [23].

6. Socio-economic Requirements and KPIs

To evaluate the socio-economic impact generated through digital solutions deployed and tested as part of COMMECT, we will adopt a two-fold approach:

1. On the one hand, we will investigate the macro socio-economic effects of network deployment, which represents effect that span the contextual boundaries of the Living Labs and capture the high-level impact of digital solutions on a national level. Accordingly, the objective is to understand the impact of improved connectivity on socio-economic outcomes. This can be related to the effect it has on households, levels of employment and firm productivity. We will support this assessment through statistical data through public and private databases to study the effects of connectivity on employment, settlement, commuting and firm performance and connectivity.
2. On the other hand, we will conduct a micro-level investigation of the socio-economic effects of network deployment. This will be positioned within the context of improving the socio-economic conditions of end-users targeted for these use cases. This analysis will be supported through interviews and interactive workshops with Living Lab stakeholders to elicit this information. This is complemented by a survey approach in which we intend to complement this information to draw broader conclusions.

To guide our assessment, KPIs should be defined that help us structure and define what information should be collected to assess socio-economic impact. In this regard, the following KPIs are defined per level of investigation:

Macro level

For the macro level, we focus on general KPIs related to high-level socio-economic impact. Note that we intend to consider differences between regions to correctly express the impact of network connectivity access. As a result, we will include KPIs related to:

- Usability of connectivity for organizations (including access to connectivity by organizations, and use of connectivity to support organizational activities);
- Firm performance as a result of access to connectivity for organizations;
- Increased employment for (regional) inhabitants as a result of connectivity;
- Increased sense of well-being for (regional) inhabitants as a result of connectivity;
- Increased attractiveness of area as a result of connectivity.

Micro level

For the micro level, we focus on stakeholders in the Living Labs and their perceptions on socio-economic impact: it clarifies how digital solutions contribute to enabling use cases, which in turn create value for end-users. Through initial discussions with the Living Lab stakeholders, the KPIs shown in Table *17* have been identified. We will further define these KPIs through interactions with the LLs.

For more information on how the methodology is employed, the reader is referred to COMMECT deliverable D3.1 [23].

Table 17. Socio-economic KPIs identified through interviews.

Living Lab	Stakeholders considered	Socio-economic indicators identified	Business indicators identified
Luxembourg	• Vineyard farmers • Agronomists • Research organizations • Government bodies, municipalities • Viticulture value chain stakeholders • Technology providers	• Reduced environmental impact as a result of less spraying (farmers, government bodies) • Level of decision support through farming solution (farmers) • Well-being of area through digital twin (municipalities, government bodies) • Access to agricultural data (research organizations, agronomists)	• Reduced inputs needed (farmers) • Profitability (technology providers, viticulture value chain stakeholders, farmers) • Improved grape quality (farmers, viticulture value chain stakeholders)
Norway	• Forest preservation • Contractors • Wood value chain stakeholders • Technology providers • Public services (fire dept.) • Municipalities • Forest visitors (tourists)	• Environmental well-being (protection of forests) • Decreased pollution (reduction of emissions) • Improved connectivity in forest (tourists visiting) • Attractiveness of area, access to connectivity (municipalities, tourists) • Ease of use of technology deployed (for contractors)	• Operational efficiency (logging, protection) • Improved quality of wood to be sold (forest preservation, contractors, wood value chain stakeholders) • Profitability (technology providers, contractors)

Living Lab	Stakeholders considered	Socio-economic indicators identified	Business indicators identified
Denmark	• Logistic companies • Truck and trailer manufacturers • Municipalities • Technology providers • Farming companies / farmers • Authorities • Veterinarians	• Ease of use of technology (hauler companies and associated truck drivers) • Improved collaboration with veterinarians and farming companies, as well as authorities	• Profitability (technology providers, logistic companies, truck and trailer manufacturers) • Quality of livestock (farming companies)
Türkiye	• Farmers • Technology providers • Olive production value chain actors • Farmers association • Municipalities • Refugees	• Access to digital technology (farmers, refugees, municipalities) • Education on technology (refugees, farmers) • Attractiveness of region (municipalities, farmers) • Reduced emissions and environmental impact (municipality, farmers) • Ease of use of technology (farmers, refugees)	• Reduction of inputs needed (farmers, farmers association) • Increased quality of olives produced (value chain actors, farmers, farmers association) • Increased profitability (farmers, farmers association, technology providers)

Living Lab	Stakeholders considered	Socio-economic indicators identified	Business indicators identified
Serbia	• Farmers • Technology providers • Farmers association • Municipalities • Rangers (Nature park preservation)	• Access to digital technology (farmers, municipalities, rangers) • Access to education on technology (refugees, farmers) • Attractiveness of region (municipalities, farmers, rangers) • Reduced emissions and environmental impact (municipality, farmers) • Environmental well-being (rangers, municipalities) • Ease of use of technology (rangers, farmers)	• Reduction of inputs needed (farmers, farmers association) • Increased quality of produce (farmers, farmers association) • Increased profitability (farmers, farmers association, technology providers)

7. Conclusions

This deliverable outlines the technical requirements for the COMMECT project, which are essential for validating the performance of the proposed connectivity solutions in Work Package 5 (WP5) for the different use cases that have been defined in WP1 considering the user needs at each Living Lab (LL).

First, the technical requirements for each of the LL use cases are defined and then a summary is provided along with a categorization of the connectivity solutions that will be investigated in the COMMECT project. While these requirements are specific to the identified use cases, the partners would like to emphasize their applicability to other pilot projects with similar needs. This can be particularly noticed in the use of IoT sensors within the agro-forest and transport industries. Four of the LLs (Luxembourg, Norway, Türkiye, and Serbia) have identified use cases where IoT sensors can enhance the management and productivity of agro-forestry businesses. Additionally, video uploading, for various purposes, is also relevant to the industry but currently lacks an optimal connectivity solution for rural and remote areas. Similarly, the transport industry as a whole, not limited to just livestock, could benefit from the solutions proposed for the Danish LL. Therefore, the definition of these requirements and the proposed connectivity solutions in the next project phase hold significant value for the digitalization of rural communities.

In addition to the technical connectivity requirements, this document provides a brief description of the criteria for validating the decision-making support tool. It primarily focuses on the tool's ability to provide users with the necessary feedback, with more detailed information available in deliverable *D3.3 – Decision-making Support Tool version 1* [17].

Furthermore, this deliverable briefly outlines the COMMECT requirements that will be used to assess the proposed solutions from both socio-economic and environmental perspectives. Detailed assessment frameworks for these aspects are provided in deliverable *D3.1 – Socio-Economic Impact and Environmental Sustainability Assessment* [23].

Appendix 1: Summary of Identified Use Cases

Table 18. Summary of use cases identified by each LL.

LL N. 1 - Luxembourg – Digitalization of Viticulture	
UC 1.1	In-Field Microclimate and Crop Monitoring in Vineyards
UC 1.2	Digital Twin for Digitalized Management of Vineyards
LL N. 2 - Norway – Connected Forestry	
UC 2.1	Remote Operational Support from Expert for Forest Machine Operator
UC 2.2	Complex Situation Awareness Services in the Forests
UC 2.3	Digital Decision Support for Forest Machine Operators
LL N.3 – Denmark – Connected Livestock Transport	
UC 3.1	Monitoring of Livestock Transport Along Rural Routes
UC 3.2	License Plate Recognition
UC 3.3	Monitoring of Livestock Loading/Unloading Processes
LL N. 4 - Türkiye – Smart Olive Tree Farming	
UC 4.1	Microclimate Monitoring for Early Disease and Pest Recognition
UC 4.2	Monitoring of Pest Insect Traps
LL N. 5 - Serbia – Sustainable Agriculture and Preservation of Natural Environment	
UC 5.1	Creation of Shared Rural Infrastructure
UC 5.2	Securing Crops and Equipment
UC 5.3	Shared Environment Monitoring Platform
UC 5.4	Shared Digital Agriculture Platform
UC5.5	Shared Rural Community Platform

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