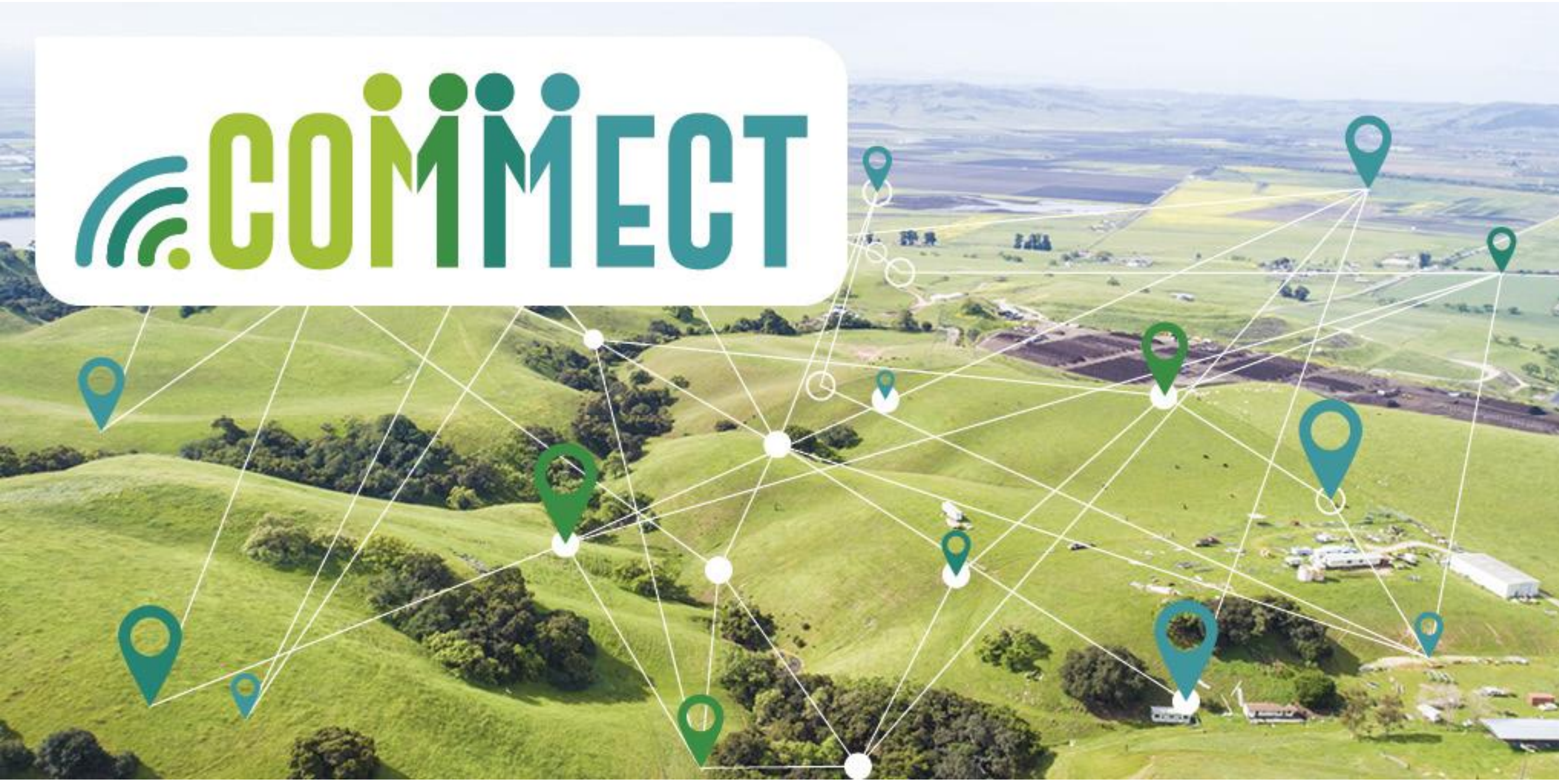
Bridging the digital divide and addressing the need of Rural Communities with Cost-effective and Environmental-Friendly Connectivity Solutions



Deliverable 4.1
Set-up and design of Living Labs

November 2023

PUBLIC

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COMMECT

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Set-up and design of Living Labs

WP4 COMMECT Living Labs

Deliverable ID	**D4.1**
Deliverable Name	**Set-up and design of Living Labs**
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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

The COMMECT project aims at bringing connectivity to remote and rural areas to address the needs of local communities. COMMECT adopts a participatory approach where end-users, researchers and experts work together to identify the pains and develop efficient solutions inside each Living Lab. COMMECT Living Labs cover five sectors and are set in five countries: Viticulture in Luxembourg, Forestry in Norway, Livestock Transport in Denmark, Olive Tree farming in Türkiye and sustainable agriculture and preservation of natural environment in Serbia.

This deliverable describes the activities carried out by the consortium members and project stakeholders to set up the five Living Labs and create the ecosystem connecting all the actors. The stakeholders advise on the local, societal, economic, and environmental challenges, and facilitate reaching the end users and understanding their needs. For each LL this deliverable presents the engagements of several stakeholders that have been closely working with the COMMECT partners, for the set-up of the LLs. The co-creation in the LLs starts with a series of workshops, aimed at understanding users' needs (WP1), and defining relevant use cases accordingly (as described in deliverable D1.1, and D6.3). It follows, the definition of connectivity solutions (in WP2) by the project partners to meet the network coverage and capacity demands of the local rural communities, farmers, foresters, winegrowers, livestock traders, among others, using existing network infrastructure, or deploying new ones (e.g., private 5G networks, private LoRa networks, Wi-Fi, etc.).. For each LL, the document first provides an overview (location, size, type of crops, consortium partners involved, external stakeholders, end-users, etc.), then, it shortly recaps the use cases, and describes the plan for the deployment of the connectivity solutions that were designed, through the co-creation process. Note that the plan for deployment may be subject to possible changes in the coming months, due to different factors (change of priority for the end-users, unavailability of network infrastructure, unforeseen issues, etc.).

The connectivity and computing solutions identified along this document defined a clear trend in term of common needs of the different rural communities, addressed by COMMECT.

- IoT **Low Power Wide Area Networks** and **5G Private Networks could** extend **last mile coverage** networks over the Living Labs, to enable real-time remote transmission of small (sensor) and big (video, images) data.
- Different non-terrestrial networks, in particular **UAVs** and **satellite** communication systems (LEO, GEO) could guarantee **broadband connectivity** in unconnected areas, lacking terrestrial infrastructure.
- **Edge computing** is the key to meet the energy-efficiency requirements, by reducing costs for data processing, and bandwidth demand for transmission of big data (e.g., images and videos).

The regular exchange between the Living Labs have been insightful: answers of some specific challenges of a given Living Lab could be found in the lesson learned from the other Living Labs. This was the case not only for LLs addressing similar scope (e.g., climate and crop monitoring in Luxembourg, Türkiye, and Serbia), but also for LLs focused on different sectors (e.g., livestock transport in Denmark, and forest surveillance in Norway), having common needs (e.g., acquisition and transmission of videos recording of pigs, and forests).

This document D4.1 presents the outputs of all the tasks of WP4 from the beginning of the project till M15, focusing on the setup and design of the Living Labs. It describes the connectivity solutions that were designed and implemented ad-hoc for each LL, based on the needs of the local rural communities. While they could look specific for the precise needs of end-users and stakeholders directly involved in each LL, it emerged that the proposed

solutions are scalable and are applicable in other countries, for other rural communities, facing similar issues in their daily work and life. This document describes how COMMECT impacted the digital landscape within each LL. The technical implementation of the designed connectivity solutions will be evaluated and validated in WP5, in Task 5.2. An updated version of this deliverable, D4.2, is due at M34. It will describe how COMMECT contributed to extend (broadband and narrowband) connectivity in the target rural areas, and to promote adoption of digital tools, and services by the local rural communities, through the continuous exchange with stakeholders, and end-users, resulting from workshops and trainings organised in WP6. Moreover, the deliverable D4.2 will also describe the impact of COMMECT results and activities on the rural communities in each LL (from socio, economic and environmental perspective), and thus, provide evidence of how COMMECT empowered those communities, and helped them in becoming more competitive and sustainable.

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Glossary of Terms

AI	Artificial Intelligence
AP	Access Point
ASTA	Administration des Services Techniques de l'Agriculture
DL	Downlink
DT	Digital Twin
eMTC	enhanced Machine Type Communication
GIS	Geographic Information System
ICT	Information and Communication Technology
IoT	Internet of Things
ITS	Intelligent Transportation Systems
IVV	Institut Viti-Vinicole
KPI	Key Performance Indicator
LL	Living Lab
LoRa	Long Range communication
LoRaWAN	LoRa Wide Area Network
LPWAN	Low Power Wide Area Network
LTE	Long Term Evolution
MAGW	Multi-Access Gateway
MAAV	Ministère de l'Agriculture, del'Alimentation et de la Viticulture
MCX	Mission Critical
ML	Machine Learning
MPPT	Maximum Power Point Tracking
MQTT	Message Queuing Telemetry Transport
NB	Narrow Band
NDVI	Normalized Difference Vegetation Index
NPK	Nitrogen (N), Phosphorus (P) and Potassium (K)
NSA	Non-Standalone
NTN	Non-Terrestrial Networks

PFEC	Program for the Endorsement of Forest Certification
PH	Potential of Hydrogen
PTT	Push to talk
RS	Remote Sensing
RTK	Real Time Kinematics
RTMP	Real-Time Messaging Protocol
RXRM	Real time eXtended Reality Multimedia
SA	Standalone
SatCom	Satellite Communication
SDK	Software Development Kit
UAV	Unmanned Aerial Vehicle
UC	Use Case
UI	User Interface
UL	Uplink
UV	Ultra Violet
Wi-Fi	Wireless Fidelity
WLAN	Wireless Local Area Network
XG	Extended Generation

1. Introduction

WP4 is the core of COMMECT project. It defines the activities carried out by the project partners to create the Living Labs (LLs), to connect citizens, firms, and rural communities in an efficient framework to enhance their socio-economic position and environmental impact. *COMMECT Living Labs are the ecosystem where end users and different actors across the agro-forest value chain will exchange and collaborate to identify the challenges, to address the needs, and to extend connectivity into rural areas for enabling the digital transition of the rural communities.* To select the LLs, COMMECT adopted a multi-sector and multi-actor approach; different activities in the agro-forestry chain are analysed in LLs across and outside Europe: digitalisation of viticulture in Luxembourg, connected forestry in Norway, connected livestock transport in Denmark, smart olive tree farming in Türkiye and sustainable agriculture and preservation of natural environment in Serbia. Figure 1 illustrates the COMMECT LLs.

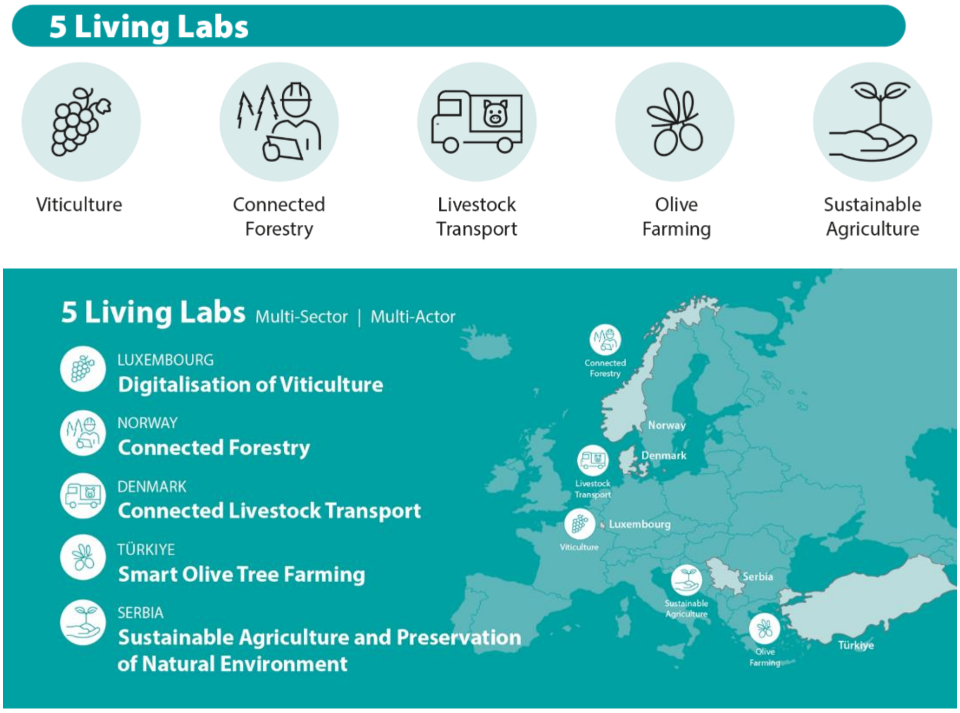

Figure 1 COMMECT Living Labs

1.1 Document objectives

The objective of this deliverable is to summarize the activities carried out by the members of the consortium for the actual set-up of the COMMECT Living Labs, and the key role played by the end-users and stakeholders in the definition and co-creation of the LLs' ecosystem. Details about developments and experimental deployment of connectivity solutions in field to address user needs among all the LLs are provided, as evidence of how COMMECT has extended connectivity in rural areas. Potential impact of the LL results is discussed, with first analysis of the stakeholders that could be interested in adopting and exploiting the proposed solutions.

The coordination, and exchange between activities carried out in the five different LLs is also summarized to highlight the synergies and reusability of the proposed solutions, in different context, and sectors.

1.2 Structure of the document

The document is organised as follows. For each LL, first a short overview of the LL is provided, recalling the *open innovation ecosystem* created by the project, by closely exchanging with the end users and stakeholders (in WP1, and WP6). Then, the deployment plan for the implementation of the COMMECT solutions identified in WP1-WP2 is presented, in terms of connectivity needs, technology, devices, network infrastructure, and data exploitation. An analysis of available connectivity in deployment areas will motivate the selection and deployment of new technological solutions. Finally, possible impact of the proposed connectivity solutions is discussed, based on their level of innovation, and future exploitation of the enabled digital services by interested parties, within the created ecosystem.

1.3 Link to other Work packages

WP4 represents the core of the COMMECT Work Plan, since the LLs are the place connecting the members of the consortium (researchers, Information and Communication Technology (ICT) experts, Telco and Satellite Communication (SatCom) operators, Internet of Things (IoT) services providers, advisors, etc.) with the rural communities (farmers, winegrowers, foresters, etc.) and other relevant actors across the value-chain. The LLs have ensured the co-production of the knowledge, with constant participation and involvement of the end-users, in WP1 to gather their needs. WP2 has identified a set of relevant connectivity platforms and technologies, spanning from 5G (public, and private), IoT long-range technologies (LoRa, NB-IoT, LTE-M), Non-Terrestrial Networks (NTN), i.e. drones and satellite; and computing technologies (cloud, edge). Some of those have been selected for actual deployment in the LL, in WP4.

WP4 will coordinate activities among the Living Labs to deploy selected connectivity solutions from WP2, according to the requirements and architecture defined in WP1. This implementation will be evaluated and validated in WP5 according to test plans that will be defined in deliverable D5.2 (by M18).

The work in WP4 takes also inputs from WP3 to guide the deployment of connectivity solutions from business and societal perspectives, and to create value for end users in rural areas while considering the environmental potential and impact. Finally, the activities taking place in the LL will be anyhow useful for the design and the implementation of the Decision-Making Support Tool (DST), and for the creation of its Knowledge Base, in Task 3.4.

All the exchanges, trainings, and workshops with stakeholders to identify the needs and discuss running activities in the Living Labs will be managed in WP6. Also, the exploitation and dissemination of WP4 activities and results will be done in WP6.

2 Living Lab N.1 – Luxembourg- Digitization of Viticulture

2.1 LL user-driven open innovation ecosystem

Viticulture plays an essential role in the agricultural sector of Luxembourg. - It takes place on a 42-kilometer stretch between Rosport and Schengen and has a total of 1295 hectares of vines cultivated by about 450 full-time and part-time winegrowers. The wines are produced by the members of the cellar cooperatives Domaines Vinsmoselle (58% of the national production), the private winegrowers Organisation Professionelle des Viticulteurs Indépendants (28% of the production), and the wine trade (14% of the production).

The COMMECT partners have been in touch with wine estates from each professional category. It allows the researcher to work with a representative sample of the different structures: small family-owned wine estates, cooperative member who are not making wine themself and bigger wine estate, which are making trade too and must manage a large vineyard surface. Figure 2 provides an illustration of the independent winegrowers in Luxembourg. Some of them were approached by the COMMECT partners and had an active participation in the LL.

Governmental support is given by the Institut Viti-Vinicole (IVV), part of the “Ministère de l’Agriculture, de l’Alimentation et de la Viticulture (MAAV)“. They provide information and advice with respect to plant protection, administration and regulation, new challenges like new diseases or pest and any question regarding their work. Winegrowers are supported in their activities by different advisors, including IBLA, part of the COMMECT consortium.

Figure 2 Main Independent Wine Makers in Luxembourg

The LL Luxembourg has connected experts from different areas, as part of the COMMECT consortium: IoT, and RS scientists (LIST and LXS), viticulture experts (LIST and IBLA), satellite providers (SES), data service providers (LXS), and farmer advisor (IBLA). All together, they have established a framework for effective and efficient interaction and intelligence gathering, mixing technical knowledge with best practice (Figure 3)

(a) Members of the LL Luxembourg from LIST, IBLA, LXS and SES.

(b) Members of the LL Luxembourg discussing connectivity solutions, for vineyards based on end-users' and stakeholders' needs.

Figure 3. LL Luxembourg: co-creation and exchange among different experts.

The members of the consortium have engaged with IVV, the governmental entity in charge of viticulture, leveraging on an already long-term established collaboration with LIST. Moreover, IBLA has reached several winegrowers association and private winegrowers, and invited them in taking part in the LL ecosystem. The core of the LL location has been established in **Remich**, **at IVV**, where several vineyards are made available for trials, and experiments to LIST researchers. Through the voluntary participation of private winegrowers, the LL has been **extended along the Moselle valley**, including some of their field farms.

Figure 4. LL Luxembourg main location in Remich at IVV.

Surveys and personal interviews have been hosted by IBLA to investigate the needs of winegrowers. 41 winegrowers participated in the first interviews, aged between 21 and 65 years old. They expressed their main needs. *Climate change* is affecting their daily life in an unseen manner and due to the permanent culture, vine is exposed to extreme weather conditions and frequent disease occurrence. Drought stress and higher disease severities (mainly Downy Mildew pathogen) can damage the total crop; thus, its control is mandatory to guarantee the quality of viticulture. All these aspects call for digital innovation into the farmers daily life. Digital tools can be a chance to plan work more precisely and efficiently but can also be frightening and overburden for winegrowers, when not used to computing and communication technologies. Having these aspects in mind, the LL viticulture is supporting winegrowers in the digital transition, first developing solutions tailored to their needs, and second training them, toward easy adoption of the technologies.

After collecting the end-users needs, the LL Luxembourg defined two main use cases (detailed in deliverable D1.1 [1]).

The first use case in the LL Luxembourg aims to support farmers to choose the optimal timing and dose for disease treatment to protect plants. Currently, winegrowers rely on information on disease severity received through the *VitiMeteo application*, which estimates the risk of diseases based on the meteorological data (T, H, rainfall, and leaf wetness), generated by several weather stations installed in the country by ASTA, part of the MAAV. Due to the more frequent occurrence of micro-climate events, the LL Luxembourg identified the need to install additional weather stations, and IoT devices, equipped with multiple sensors in the winegrowers' vineyards, to provide them more precise and timely information. It has to be noticed that the Vitimeteo model is commonly used by winegrowers, not only in Luxembourg but also in other European countries (Germany, Austria or Switzerland). Thus, the proposed solution is not limited to the COMMECT LL Luxembourg, but it is scalable in other countries, and can impact a larger rural community.

The second use case identified in this LL aims to provide a digital inventory and image data of the vineyard that can support the creation of a Digital Twin (DT). The digital replica, with high spatial resolution remote sensing data can provide rapid disease maps that will help experts and farmers diagnose and classify plants, detect drought or disease, and predict and advise on actions to perform in field, at micro and macro scale.

Following the collection of the end-users' needs, the members of the LL designed connectivity solutions (encompassing IoT LoRa technology, Wi-Fi, cellular, satellite backhauling) to enable the deployment of the use cases (see Sec. 2.2 for details). Then, a second Workshop was organised with winegrowers and stakeholders to collect feedback on the proposed connectivity solutions. The workshop was also an opportunity to engage them in the co-creation and definition of the business models, which could show the added value (potential investment, new business opportunities) for them in adopting digital solutions. More details about the workshops are available in Deliverable D6.3 [2].

To ensure the continuous participation of the winegrowers in the COMMECT project, and co-creation in the LL, IBLA, serving as farmer advisor, has participated in several official events, organised by the viticulture institute (IVV), and in dedicated meeting with winegrower's associations. In particular, IBLA has presented regular updates of the COMMECT project within the framework of the monthly meeting of the institute with winegrower's organizations. The objective was to inform them officially about the project activities, like the intention of deploying additional weather stations, and to make a call of participation (testing) for end-users willing to take a more active role in the LL. Following such exchange, the LL partners identified 5 winegrowers interested in installing weather stations and/or soil and leaf wetness sensors in their vineyards, to better monitor micro-climate effect in their farm. After this meeting, IBLA kept the end-users (winegrowers) informed about further progress on the installation, network deployment, and data collection, through the internal communications tools (Newsletter, LinkedIn).

Besides end-users (winegrowers, and winegrowers associations), other relevant stakeholders were involved in the co-creation process, within the LL Luxembourg, in particular, Frontier Connect, GEOsens and Moosle.

Frontier Connect is a technology innovating company, located both in Luxembourg and Romania, developing end to end IoT solutions for smart agriculture. They are providing the LL with tailored technological solutions for the different deployments: hardware (weather stations, soil sensors), software and services (Lumbara platform). The company is collaborating and adapting their offer, in terms of sensors, communication technology and data integration and visualization, to fit the different requirements and needs of the LL.

The VitiMeteo application, providing information about disease severity, is the result of a collaboration between the Weinbauinstitut Freiburg/Germany and Agroscope in Switzerland providing the simulation of diseases based on meteorological observation and algorithms on pathogen biology and epidemiology [3]. The company GEOsens is offering the model calculation as a service. LIST is closely working with GEOsens for the exploitation of the data collected from the additional weather stations, and soil sensors, to support winegrowers.

Representatives from LIST (Miriam Machwitz), IBLA (Segolene Charvet, Jörg Pauly) and LXS (Gilles Rock) investigate the interest of the company Moosle as a potential stakeholder exploiting the project results, and met the CEO Marius Krämer. This company is providing an online GIS (Geographic Information System) service for the digital management and documentation of vineyards. Marius Krämer was in general interested on the in-situ image analysis developed by LXS and in UAV images, collected by LIST. Beside a first 1:1 meeting, he also joined the COMMECT LL workshop organised in November 2023. The company is settled in Germany and has already many clients both in Luxembourg and Germany. While they are not partner in the consortium, they are very much interested in the project activities (mainly related to UC2), and they could be among the stakeholders, interested in exploiting the project results in the future.

Representatives of the Administration des Services Technique de l'Agriculture (ASTA) have been also part of the LL ecosystem. ASTA is the administrative entity in charge of the deployment of the weather stations in the country, made available to farmers for managing their fields and crops. The ASTA weather stations installed along the Mosel are already integrated into the VitiMeteo network and forecast system. The LL members presented the COMMECT activities to ASTA which showed interest in extending the Luxembourgish network of sensors and weather stations. To integrate the COMMECT weather stations in the official network of weather forecast from the ministry, ASTA requested first to demonstrate the accuracy of the IoT devices and sensors, and second to show the added value (e.g., better detection of micro-climate conditions). LIST will work toward the achievement of such results, with the final aim to provide evidence to ASTA, and promote the exploitation of the project results by the Ministry, beyond the project duration.

In the following sections, we describe how the coverage and network infrastructure demand of the Luxembourgish winegrowers have been addressed, based on the identified users' needs and use cases.

2.2 Use case 1.1: In-Field Microclimate and Crop Monitoring in Vineyards

2.2.1 Connectivity needs

To support in-situ data collection from different sensors (soil moisture, leaves wetness, and air temperature, etc;) in the field, it is important to design an efficient communication infrastructure, which can ensure reliable data collection, and thus, continuous monitoring of meteorological and soil conditions. Selected connectivity solutions should meet the requirements defined in deliverable D1.2 [4] in terms of performance, but also take into consideration network availability in the LL, and deployments costs. LoRaWAN technology is one of the solutions that can be used in this use case to extend connectivity in rural areas. It is a low power, low cost, and wide area communication technology that can cover a dense and long-range network of sensors while ensuring energy efficiency. In other scenarios where cellular coverage is available and efficient, XG networks (mainly3G/4G) will be used to collect IoT data.

Figure 5 illustrates the candidate communication technologies proposed by LL Luxembourg to address the users' needs in use case UC1.1. It relies on IoT technologies: LoRaWAN or cellular XG for the access network, depending on the density and distance between sensors. For the backhauling network, cellular network will be used, when available, otherwise satellite backhauling will be adopted as alternative solution.

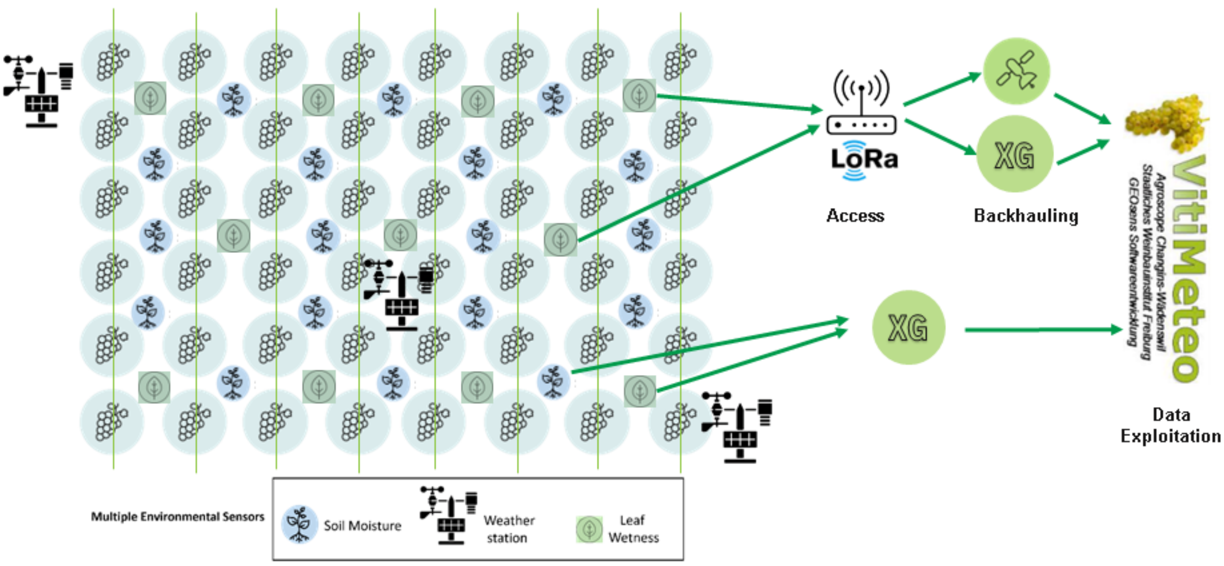

Figure 5 connectivity for environmental sensors deployed in the vineyard.

The technical members of the LL had to make a selection among several sensors and IoT devices available on the market. The IoT experts at LIST could benefit from previous experience in deploying other Pilots in Luxembourg, in the framework of national (Lux5GCloud [5]) and EU (DEMETER – HEMS Pilot [6]) projects, and from established collaboration with stakeholders, selling IoT devices for smart agriculture (e.g., Frontier Connect). Detailed information about the devices and gateway selected for the set-up of the LoRaWAN network in the LL Luxembourg are provided in the Annex.

2.2.2 Co-creation for the use case implementation

Climate change is jeopardizing the winegrowers' routines of management. Very local weather phenomena can lead to different severities of diseases or drought stress in almost neighbouring vineyards. 35 weather stations are already deployed by ASTA all over the country, [7], However, the current distribution and number of weather stations in the Moselle valley, as shown in

Figure 6, is not representing these small-scale effects. Thus, it follows the need for having an extended network of IoT devices (weather stations, and soil devices), equipped with different sensors as a first step towards the implementation of UC1.1.

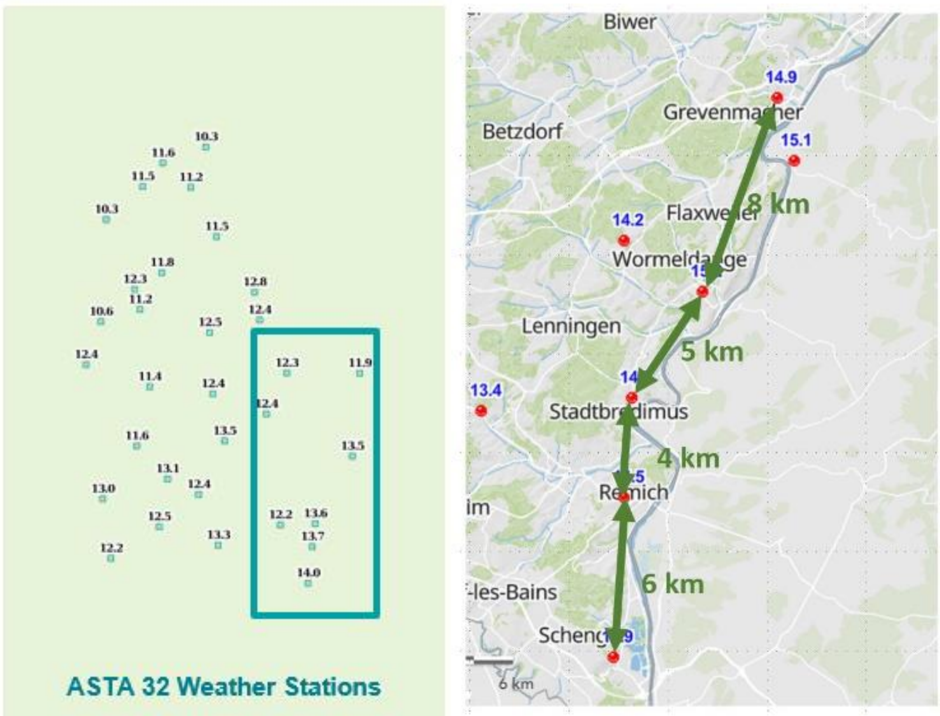

Figure 6 Distribution of current weather stations in the Mosel valley

To effectively forecast the progression of infections like downy mildew, it is crucial to collect precise weather data on a small-scale, site specific, focusing on areas where robust infections are both likely and favoured. This approach helps prevent the underestimation of the infection severity and ensures the accurate scheduling and implementation of plant protection measures.

In practical terms, this entails the strategic placement of weather stations and leaf wetness sensors, with a primary focus on west and south-west facing slopes. Additionally, positioning them at the base of the slope and in proximity to rivers holds more significance than siting them in higher slope regions.

The connectivity solution to deploy this use case depends on the density and distribution of sensors, and on the specifications of the deployment field. Two network configurations were identified for the deployment in the LL, as described in the following.

LoRaWAN networks

In this scenario, COMMECT is deploying a LoRaWAN infrastructure in a vines field in Remich, with the support of our stakeholders IVV ([8]) and MAAV ([9]), to collect data from Lumbara Base devices configured for LoRaWAN transmission. The 4 devices are installed in the field (Figure 7) and include environmental module, soil module and leaf wetness module. These devices are battery powered and have *solar panels* to ensure continuous connectivity. They are configured to collect measurements every 10 minutes and send collected packets to the server every 30 minutes. Installation activities of the weather stations in the LL Luxembourg are presented in Figure 8.

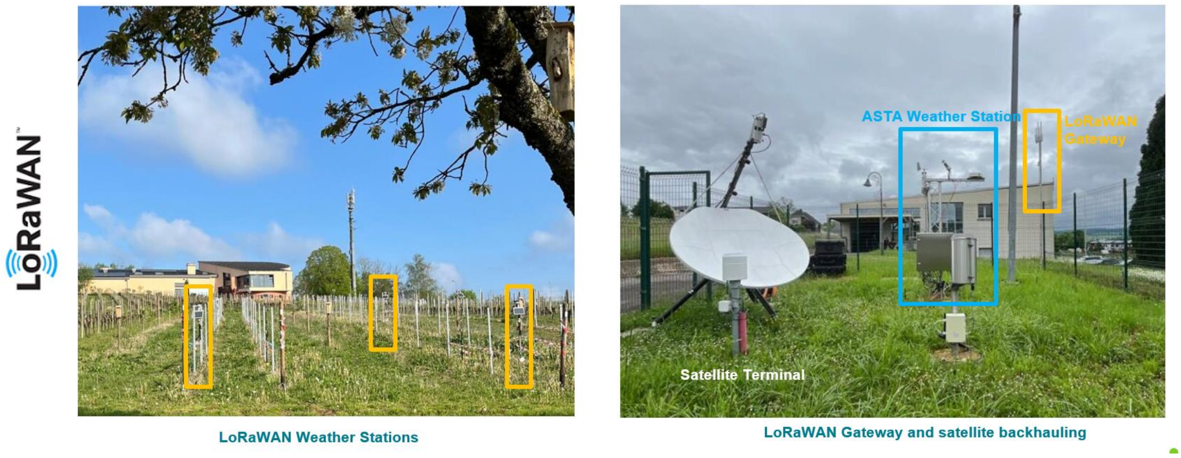

Figure 7: LoRaWAN based deployment in the LL at IVV Remich

The LoRaWAN gateway was also installed, thanks to the support of our stakeholders (ASTA), on a 4m mast within ASTA's premises with a main power supply to achieve permanent availability. The gateway will cover the different devices in the field. It will collect and forward data packets to the server via 4G/Wi-Fi backhauling, where it will be processed and downloaded to appropriate servers.

Figure 8 Installation of weather station, and soil moisture sensors in the LL1 (IVV Remich, Luxembourg)

Cellular networks

In this scenario, 2 full weather stations with environmental modules and solar panels, and 4 leaf wetness and soil sensors, will be deployed along the Moselle valley to increase the network of weather stations and sensors, and allow more accurate fine-monitoring of microclimate conditions in the region. *The locations to install the COMMECT weather stations, the leaf wetness and temperature sensors, as shown in* Figure 9*, have been the result of the co-creation between the viticulture experts at LIST (Daniel Molitor), and relevant stakeholders: representatives of IVV, IBLA members, and private winegrowers.* The selected locations represent different samples of environmental conditions leading to high risk of infection:

- *Wasserbillig*: This location is close to the river Sauer, which represents a high risk for downy mildew disease. Installing a weather station here will insure also the coverage of the **North** of the Moselle valley.
- Dreiborn: It is a cool valley, with **late phenological** development, monitoring this region can provide a representation of other similar conditions with late phenology, owned by IVV.
- *Bous*: A **cool** location with late frost, presenting high risk of contamination.
- Wellenstein: It is a **warm** and south exposed location, with a gap between ASTA's weather stations installed in Remerschen and Remich. Installing a new sensor in this location will close this gap and allow tracking microclimate in this special region.
- *Schengen*: This is a terrasse plantation region, also installing a sensor here will insure the coverage of the **South**.
- *Ahn*: This is a warm location with **early phenological** development, and there is a gap between Grevenmacher and Wormeldange. Installing a sensor here will close this Gap and allow a presentation of microclimate conditions in early phenological regions.

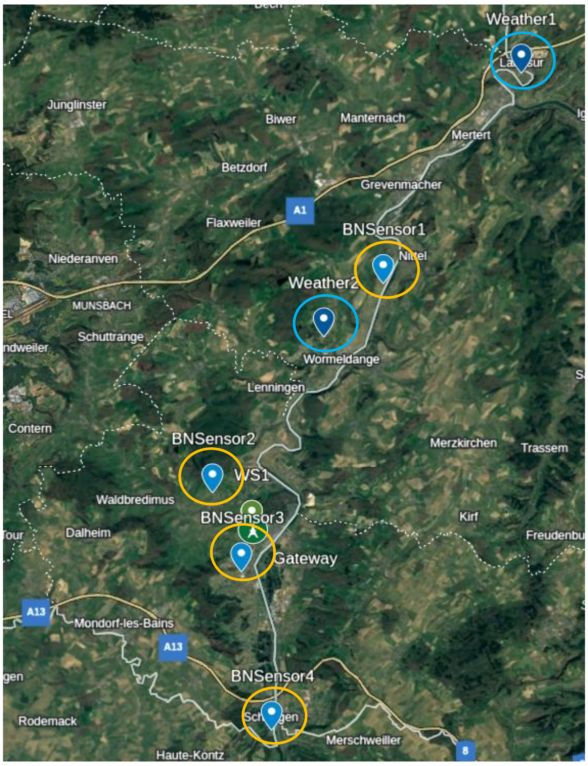

Figure 9: Locations of XG based weather stations in the Moselle valley.

The identified positions are distributed along the Moselle valley as presented in Figure 9 . The distance between the northern and southern positions is more than 30 Km as the crow flies, thus these sensors and weather stations cannot be covered with one Gateway, which mean that LoRaWAN network is not efficient in this scenario. The 4G coverage provided by the main Telco Operator (POST Luxembourg) is extended in this area, as illustrated in Figure 10 . Thus, we can adopt 4G for this deployment.

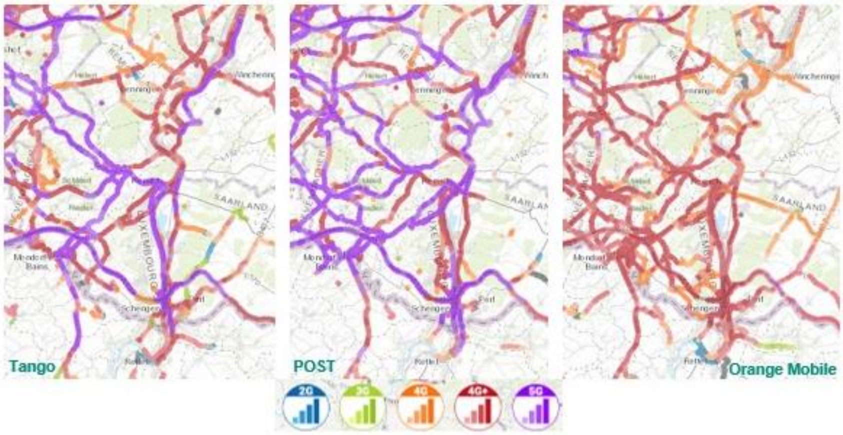

Figure 10 XG coverage from different operators in the Moselle region.

In these locations, the weather stations and sensors will be configured to send measured data to the server using cellular network. Devices are equipped with SIM cards with a roaming option and an optimized transmission algorithm. The communication modules look for the nearest operator's base station (best coverage quality) to send packets of data to the server with the lowest transmit power. Thus, improving energy efficiency of the device.

2.2.3 Data exploitation and expected impact

The extended network of meteorological stations along the winegrowing region allows for more local simulation of potential infection events of major diseases in viticulture such as downy mildew. The simulation of infection events in the decision support platform VitiMeteo [10] based on local meteorological conditions is used by winegrowers for the timing of pesticide treatments. In other words, due to the more precise simulation of infection events, the timing of plant protection treatments might be optimized, and unnecessary applications reduced, which is potentially leading to a reduction of pesticide use in viticulture as requested e.g. in the European Green Deal.

The data collected from sensors will be transferred to the server of the company Geosens [11], which is using this data to run the decision support platform VitiMeteo including models for the most important diseases in viticulture such as powdery mildew, downy mildew and black rot.

VitiMeteo uses the leaf wetness as the main parameter in combination with air temperature, humidity and rainfall to calculate the infection risk of downy mildew. The output of the model is visualised either with a private account access on the VitiMeteo homepage or can be integrated into the Vitimeteo network of stations which is jointly used by the German and Luxembourgish winegrowers (www.vitimeteo-rlp.de). The fee for running the model as well as for the integration into the official website is nowadays paid by ASTA for the governmental weather stations. Thus, to keep the COMMECT weather stations in the field, beyond the end of the project, and to exploit the related data in the interest of the winegrowers, it would be important that ASTA take over the fees for the VitiMeteo integration, and for the stations' maintenance. By keeping the additional stations and sensors, it will be possible to improve the coverage and forecast accuracy in the region significantly and support the disease forecast and plant protection efficiency.

2.3 Use case 1.2: Digital Twin for Digitalized Management of Vineyards

2.3.1 Connectivity needs

In the second use case, we consider collection of images at different scales, from plant, field, and region, using cameras installed on tractors (smartphones), Unmanned Aerial Vehicles (UAVs), and satellites respectively, with the final aim of combining them to build the digital map of the vineyard. For the first scale, high-resolution pictures with their precise geolocations are collected with the *InstantMapper application* provided by LXS. It includes a smartphone and a RTK (Real Time Kinematics) Antenna. *The precise synchronization of the video and the RTK Antenna geolocation, in addition to the transfer of high-quality videos and images from smartphones mounted on tractors to the remote servers ask for a reliable broadband backhauling network. Moreover, the access connectivity solution should provide a wideband uploading link and smooth handovers for the moving onboard cameras.*

Wi-Fi networks can provide stable and efficient network coverage for this use case. And to overcome the degradation of connectivity or even the network outage due to limited coverage constraints when the tractor is moving in the field, Access Points (APs) and Wi-Fi repeaters can be evenly placed throughout the field to extend the coverage range. The smartphones can be connected to the Wi-Fi network via multiple APs and repeaters deployed in the field for video uploading, enabling reliable data transmission in the field. Another option to achieve high connectivity is to install Wi-Fi APs on the tractor, which maintains a fixed distance between the smartphone and the AP. However, this requires specific configurations for connecting APs to Internet, which relies on wireless connections, instead of physical cable connections as the APs installed in the field.

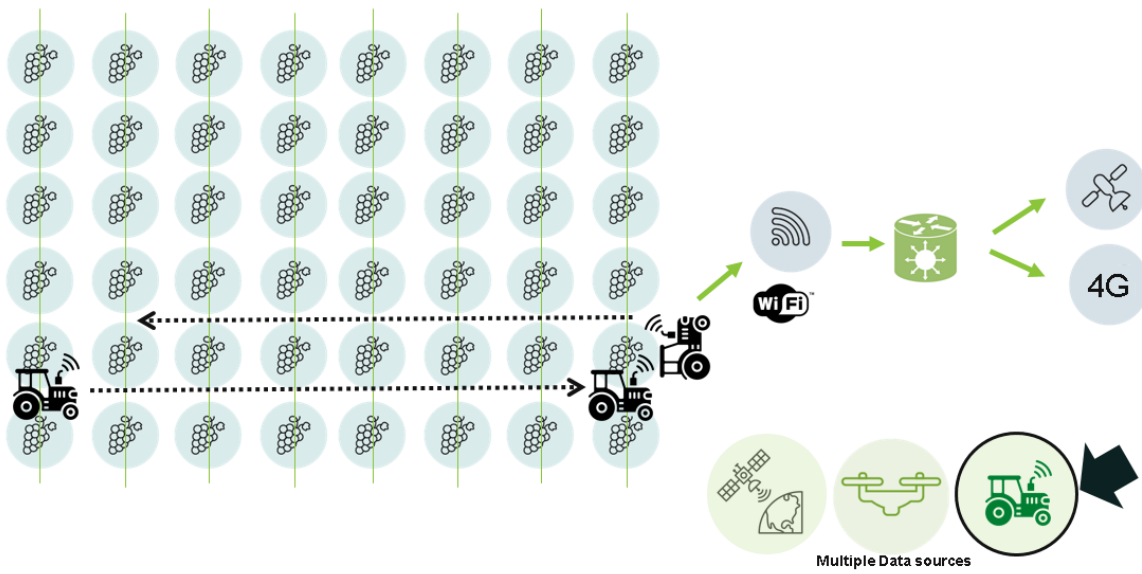

Figure 11: Connectivity for Digital Twin of vineyards.

A Digital Twin (DT) of a vineyard is a perfect instrument for any kind of planning, modelling, analysis or management. It can be of various complexity and scale. We plan a simplified version of a DT on three scales of remote sensing data collection: (1) the single plant scale, (2) the field or vineyard scale (3) the regional scale considering all vineyards in Luxembourg along the Mosel valley. For each of the scales, different data collection and processing are necessary.

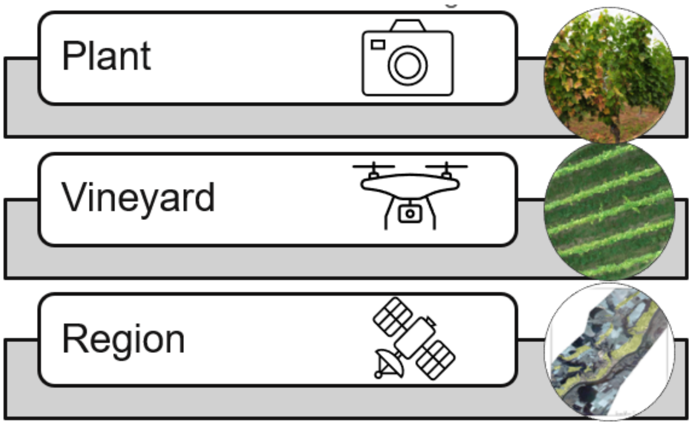

Figure 12 Data collection scales for the Digital Twin of vineyards.

(1) the single plant scale

On the plant scale, video streams are created. Aim is to have the camera (e.g. integrated in a smartphone) mounted on a tractor which is collecting and sending the in-situ information (videos) in parallel to the routine work. Images are of high resolution and allow the accurate representation of stems and leaves.

(2) the field or vineyard scale

On the field scale, UAVs are used to collect data at canopy level from a bird eye perspective. The aim is to detect patterns and heterogeneities in the field and map them to the concerned plant or row.

(3) the regional scale

Satellite data is an objective data source at low costs. An entire region can be captured by satellites and regional planning can be supported. Some data like Sentinel-2 are free with 10m resolution and a high theoretical frequency of 5 days if no clouds are present. Processing this data allows the detection of drought stress and sum burns.

2.3.2 Co-creation for the use case implementation

The connectivity solution for the second use case is composed of Wi-Fi, Access points (APs), and satellite/4G backhauling as presented in Figure 11.

Data is collected by the phone camera mounted on the tractor while the tractor is doing the routine work and navigating between rows. Wi-Fi network allows to get the precise geolocation of each recorded video frame with a high spatial accuracy from the RTK antenna and route fast data thanks to several APs deployed in the field, whereas the satellite backhauling network ensures the throughput for transferring the big amounts of data to the remote data center.

Besides, 5G network is another broadband backhauling network option. It can provide higher data transmission rate and lower latency compared to satellite backhauling. However, the coverage availability and quality of 5G networks in the Moselle valley is less reliable. The Moselle region is in the borders between Luxembourg and Germany and the coverage quality from different operators in the Moselle region is not as good as in central cities. (Figure 13) shows the coverage quality of cellular networks from different operators (Tango, POST and Orange Mobile) in this region (source of coverage plans [12]).

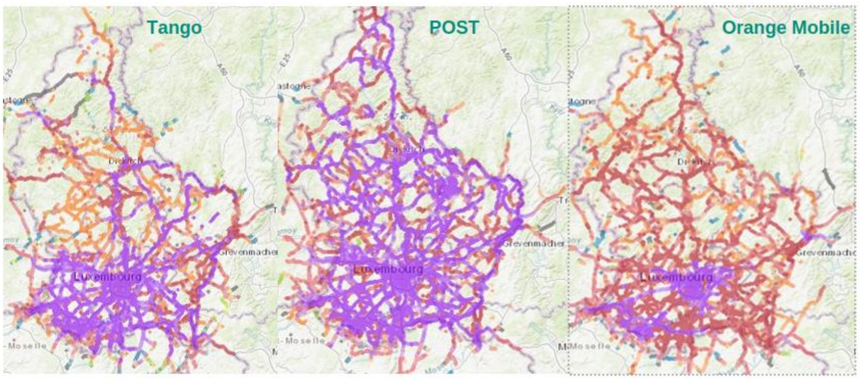

Figure 13 XG coverage from different operators in Luxembourg.

Both backhauling technologies will be tested in WP5, and the performances will be compared. Thus, the backhauling technology for deployments in the Living Lab will be decided based on the performance results, to satisfy the requirements for video uploading (high traffic, congestion).

2.3.3 Data exploitation and Expected Impact

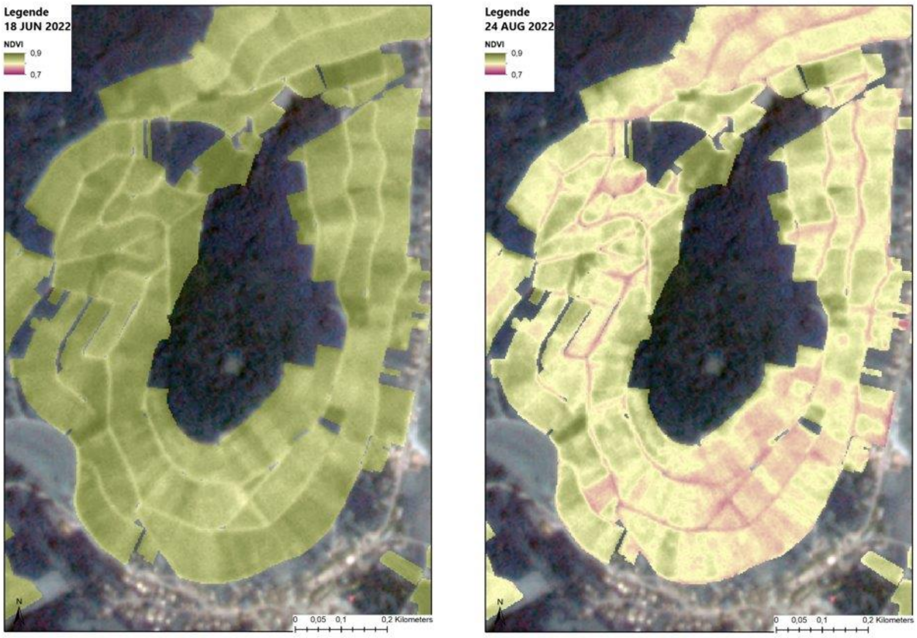

Figure 14 Satellite data from different dates to monitor climate change in the region

The DT allow to provide monitoring and analysis of the plants from diverse scales, against the threats of climate change and leaf diseases. More precisely, the high-resolution satellite can provide 1-10 meters spatial resolution which analyses and further defines the local difference (e.g., microclimate, hill scopes) among the geographic zones, as illustrated in Figure 14.

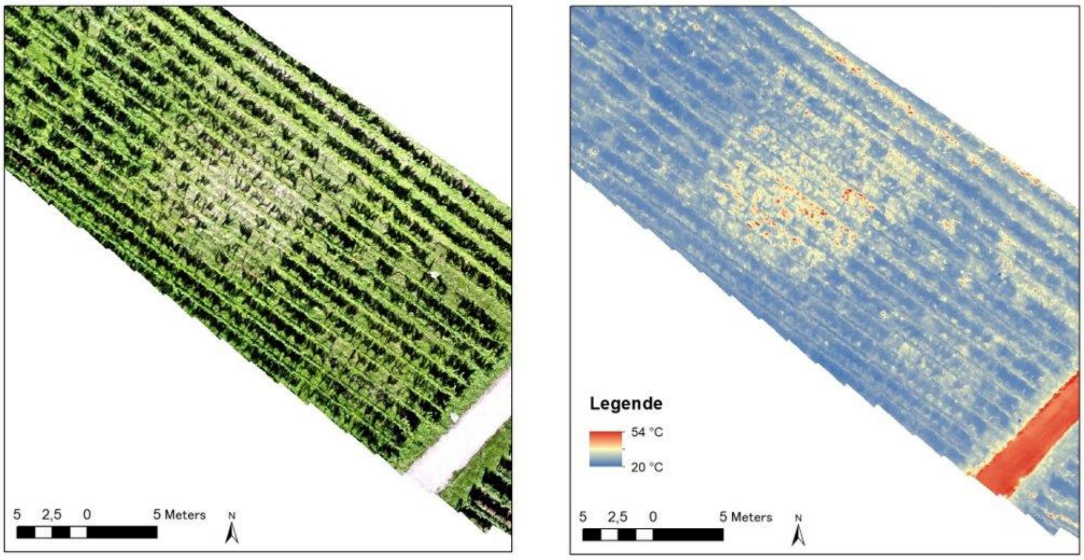

Figure 15 UAV images to detect heterogeneity in the field.

In contrast, the high-resolution UAV can collect the vitality information by analysing the canopy imagery of each individual plant, this can help detect heterogeneities in the field and map them easily (see Figure 15. Following the dissemination of the project activities, through close exchange with winegrowers, through IBLA's and ASTA's newsletter, and project workshops, some winegrowers showed interest in getting a digital map of their vineyard, using drone data.

In particular, one winegrower had planted some trees (so called vitiforst) in three of her fields, and was interested in evaluating their effect on temperature and radiation (to mitigate drought effect). Another end-user that showed interest in getting support from COMMECT LL is a manager of a big wine producer who is worried about some fields with poor growth and heterogeneous development. He would like to use drone data to monitor and document the development during several years. An example of the images of fields with poor growing condition is shown in Figure 15. The interest was very high and we received positive feedback from the winegrowers, which are pioneers in the region, willing to adapt new tools and measures. Thanks to the established COMMECT LL ecosystem, the LL partners will collect further thermal and true colour UAV data for these sites, besides the regular monitoring done in Remich, at IVV (main location of the LL).

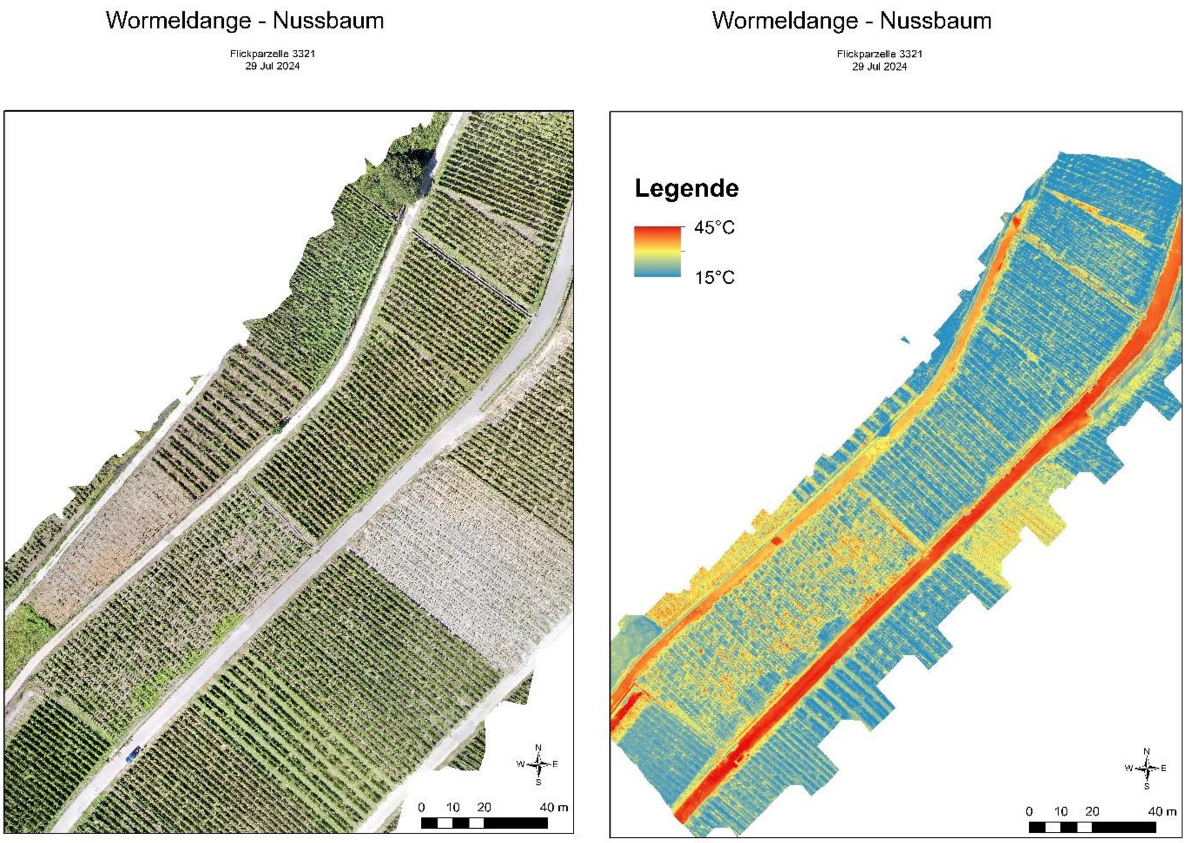

Figure 16: True colour and thermal image of a vineyard with poor development and heterogeneous growing conditions.

Collecting data from additional sites will enlarge and add more diversity to the data collected in the LL Viticulture, and help monitoring disease occurrence and drought severity in the region. Clearly, the project activities are supporting winegrowers in Luxembourg toward the digital transition, motivating them in adopting digital tools that can support them in managing their farm in a more sustainable and resilient manner.

Moreover, close-to-plant cameras on tractors can provide more precise leaf-level characteristics (e.g., disease symptoms), which are analysed from high-quality video streams by Machine Learning (ML) techniques, see Figure 17 . Online Geographic Information System (GIS) is expected to be further developed by companies like Moosle as a visualized data management tool to present the collected RS data at different levels of the vine's crops. For the time being, no sub-field management is realised but with increasing pressure by climate change and the increasing availability of information, management strategies might change in the near future.

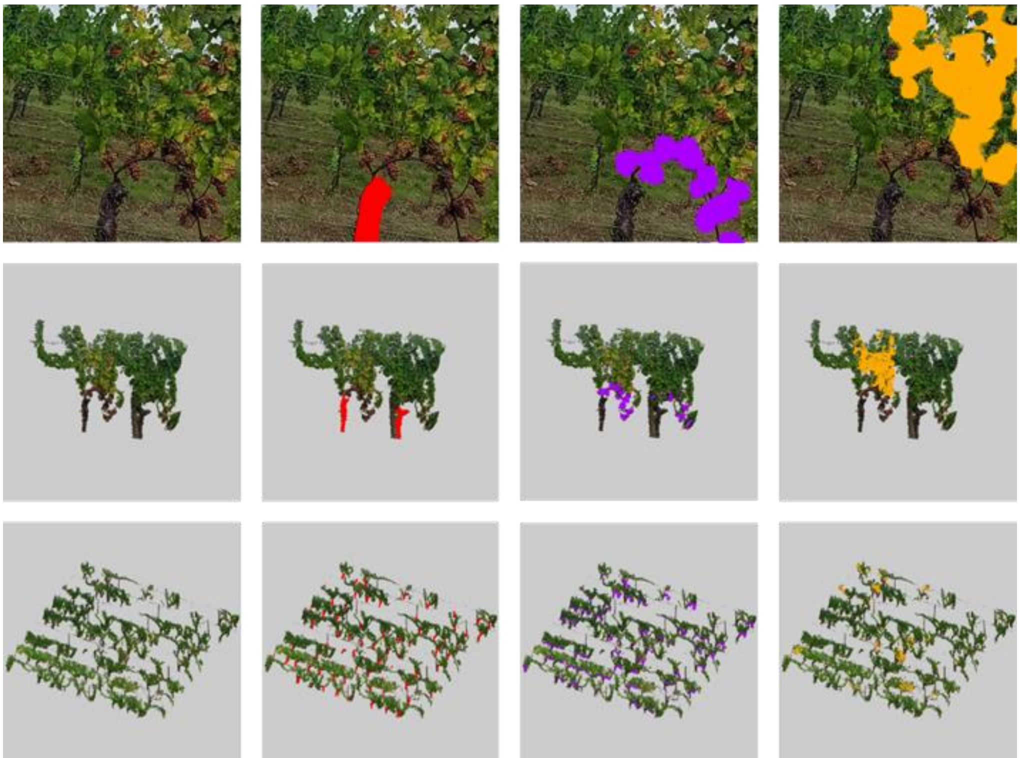

Figure 17 3D Reconstruction of vineyard from plant-level images

The data collected at the digital replica of the vineyard can be used to simulate the growth and development of vines in real time. Thus, the operations done in field can be optimized and preventive actions can be performed in advance. The models developed in the DT can predict disease occurrence, fertilization needs drought severity, and consequently provide timely recommendation to the winegrowers to optimize the interventions and protect their vines.

3 Living Lab N.2 – Norway- Connected Forestry

3.1 LL user-driven open innovation ecosystem

The forestry (logging) and forestry industry (sawing and value creation of logs) is one of the oldest industries in Norway. In 2020 the total volume of logging was 12 Mill.m^3 [13]. Kongsvinger, where the COMMECT LL2 Connected Forestry is located, is the second largest (approximately) municipality in Norway when it comes to the volume of logging per year (m^3). The forest industry is an important creator of value in the rural areas of Norway. Processing timber also creates large economic value increasing the value of the logs with approximately 10 times before it reaches the customer as a product [14]. The forest industry is a highly relevant industry in the context of society’s current focus on increased sustainability. Demand is high for the correct type and amount of timber. Precision and taking care of the surrounding areas in the forest is also strongly emphasized now due to protecting biotopes and cultural monuments. The Norwegian PEFC (Program for the Endorsement of Forest Certification) puts requirements towards the management and governance of the forest.

The forestry value chain consists of different phases spanning over 60-80 years (from planting to logging) following transport and sawing of the logs for further processing of wood products (see Figure 19). In the planting phase, new trees are planted right after logging. In 2021, 39,4 million trees were planted in Norway, up 70.5% compared with the decade before [13]. Caring for young forests consists of removing forest and deciduous trees around planted trees, or sown trees sowing too tightly. The thinning phase includes taking out trees that are least suitable to use in premium products (planks). The logging takes place according to specifications from the buyer of forest/sawmills (length, and “quality”). After logging, the timber is transported to the sawmills where the logs are cut in different shapes of wooden planks for the buyer/user. Figure 18 gives an illustration of collaboration between one machine operators logging trees and another bringing the logs to the road for further transport to sawing mills.

Figure 18 Two machine operators collaborating on logging and bringing logs to road for transport. The picture was taken during the demonstration done in October 2024, during the consortium visit to the Living Lab Norway.

The regional cooperatives of Norwegian Forest Owners Federation are a major owner/stakeholder in the forestry industry in Norway with a market share of approximately 80% of the logging market [14] .

Logging and planting take place over large areas and over a large timespan. The time from planting to logging can be 30 years or more. Hence *the very nature of the forestry activity is not limited to one site*. It follows that the LL Norway cannot have a fixed location, as rather possible for other LLs (e.g., Luxembourg, Türkiye, and Serbia), where sensors and IoT devices have been (or will be) installed permanently in the field. Besides that, the core location of the LL is the **forestry in the Kongsvinger region of Norway** where most of the stakeholders involved in the LL ecosystem are located. Moreover, it must be noticed that the connectivity solutions proposed by COMMECT are therefore suited to **follow the machine operator as he works in different locations at different times** as per the defined needs of this end-user group.

The LL Norway leverages on the complementary expertise of three project partners: Telecom Operator (Telenor Norway), Innovation and development company (Klosser Innovation, KI) and Education and Research faculty (Inland School of Business and Social Sciences, INN), all necessary to drive innovation in the forest sector. Since the start of the project activities, they have engaged with several stakeholders (mainly Norwegian Forestry associations, among them: Nordtømmer and Glommen Mjøsen Skog). Table 1 lists all the actors involved in the LL, both partners of the consortium, and external end-users and stakeholders. Details on the size of the companies with respect to number of employees, are also provided. We see that they are mostly small to medium large companies. However, some of the stakeholders are part of a larger company, e.g Telenor R&I being a department in Telenor with a total amount of 16.000 employees worldwide. Furthermore, Nordtømmer AS is also a part of the Norskog company which constitutes of multiple subsidiaries and represents in total 15% of the total production of forestry resources in Norway. Finally, Klosser Innovation AS is located in four cities/townships in the Inland County south east of Norway, where Kongsvinger is one of these locations. Klosser has worked closely with multiple partners within the forestry industry both domestically and internationally on various innovation projects previously. Such as the project on circular use of wood with Forestia, the largest producer of chipboard in Norway as well as hosting the annual “Forestry in the future conference” in Kongsvinger. These collaborations allow them to bring an in-depth knowledge on the industry along with their expertise on innovation and commercialisation of research projects primarily within big industry and AgriFoodTech.

Table 1. Overview over stakeholder/company profile in the Connected Forestry LL

Company name	Type of company	Company size
Holth Skogsdrift AS	Forestry operator/services	28 employees
John Deere Forestry AS	Forestry machine vendor	27 employees
Glommen Mjøsen Skog AS	Forestry owner association	59 employees
Nordtømmer AS	Forestry owner association	60 employees
Eidskog Stangeskovene AS	Wood processing producer	57 employees
Skogbrand Forsikringselskap	Forest insurance company	11 employees
Skogbrukets Kursinstitutt	Forestry training institute	63 employees
Telenor Research and Innovation	Research and innovation center on telecommunication	40 employees

Klosser Innovasjon	Competence and innovation center on regional development	35 employees
Inland School of Business and Social Sciences	Education and Research faculty	300 employees

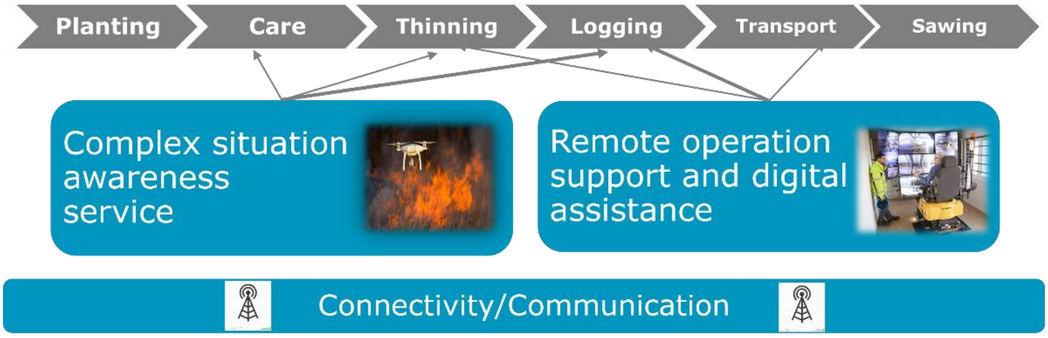

Figure 19 Forestry value chain and use cases.

After several rounds of interviews and workshops with forest owners, forest machine operators (performing the thinning and logging activities) and other value chain actors the general need for a more digitalized value chain with the opportunity to share data across and amongst themselves was expressed. Moreover, two major use cases were focused – emergency awareness and remote operation support. The former relates to better handling of accidents and injuries of the operators or other major disasters such as forest fires, floods, and landslides. The latter related to more precise and accurate thinning and logging through the assistance of expert remotely connected. The connectivity needs and deployment plans for proposed solutions to support these use cases needs and requirements will be presented more in detail in the following sections. The expectation is that the solutions will enable more efficient, safe and cost-effective processes for workers and businesses as well as operations that are more environmentally friendly, according to PEFC regulations.

Both use cases are created from inclusive end-user-based feedback and needs. Both the value that will be created and the implementation of the solutions proposed will have a cross-sectorial impact including but not limited to end-users (machine operators), Machinery developers, connectivity providers, forest owners and government agencies.

3.2 Use case 2.1: Remote operational support from expert for forest machine operators

3.2.1 Connectivity needs

This UC2.1 involves remote guidance and support for forest operators using high quality video transmissions from forest machinery over 5G networks. The support is facilitated through online cameras setups mounted directly on machinery, allowing immediate help for on-site operators. The remote support is specifically linked to thinning and logging activities, wherein an expert from the forest operator’s company advises and supports the on-site operator in decision-making through remote means. The use of remote operator support faces limitations in forestry, primarily due to the inadequate performance of cellular networks in forested areas. Thus, deployment of local private 5G networks specifically tailored for forestry areas will help realizing the UC2.1. Additionally, assistance in maintenance, detection, and repair of engine or machine errors is also considered. In these instances, a vendor’s expert, situated nationally or internationally, supervises the operator through online cameras utilizing high quality video feeds at the vendors location. Figure 20 shows the overall concept of this UC2.1.

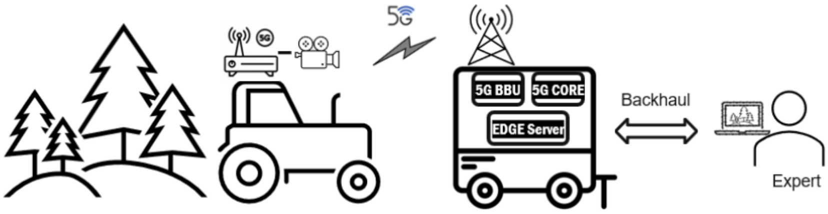

Figure 20 Remote Operations Support.

To realize the UC2.1, expected video cameras will be deployed on the forestry machinery, that will stream the live high-quality videos to the remote experts for support. Remote experts after analysing the videos will guide the machinery operators on the field.

To this aim, a high-quality network will be required to for transmission of live video streams from the cameras.

A **5G private network** will be used as **access network** to provide connectivity to the cameras mounted on the forest machinery. 5G private network trailer will be deployed, that is all in one solution containing 5G core, 5G radio and an edge server for on premises processing of different applications like video renderer software. The video renderer software will significantly reduce the data to be relayed over the low performance backhaul connectivity options.

5G private networks are localized and exclusive communication infrastructures that leverage the capabilities of 5G technology. Unlike conventional mobile networks, these networks are dedicated to specific entities, providing tailored solutions for diverse applications. They harness the high data speeds, low latency, and massive device connectivity of 5G to facilitate innovative and customized functionalities. Key features include the ability to customize network parameters, ensuring optimal performance, and enhanced security through isolation from public networks. These networks play a crucial role in transforming connectivity, supporting real-time interactions, automation, and improved efficiency. Overall, 5G private networks mark a significant advancement in connectivity solutions, offering organizations the flexibility and performance required for their specific use cases.

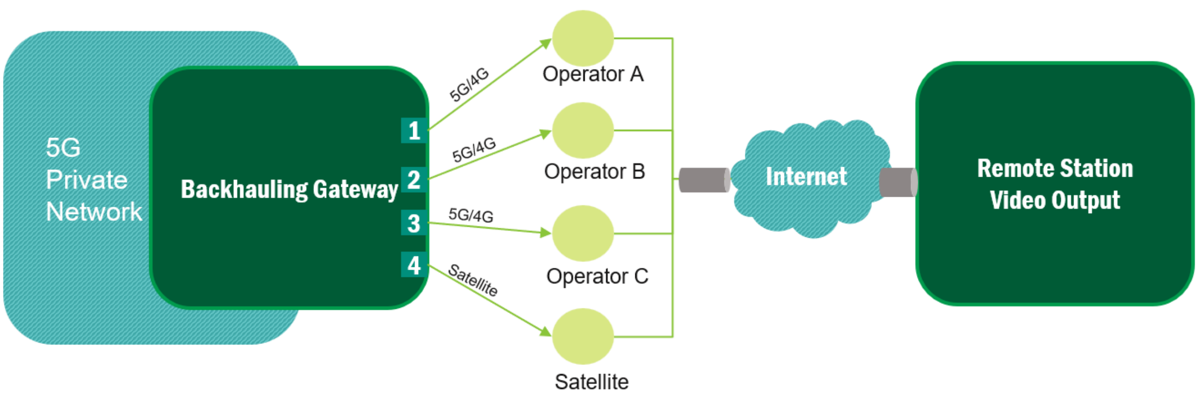

Figure 21 Connectivity Solutions along with Backhauling option

To connect a 5G private network to a remote operator, a robust **backhaul solutions is needed**. COMMECT is targeting two backhauling solutions, illustrated in Figure 21.

First solution is via utilizing the multichannel router system. It is equipped with multiple channel/sim slots that can provide seamless and reliable switching between them and simultaneous use of the best available broadband data networks, ensuring uninterrupted connectivity. The main benefits include combining the availability of up to four freely selected networks for broadband access along with Link aggregation. It also maximizes data connection capacity by flexible network usage, prioritizing a network or always choosing the best performing link. It also supports a wide variety of wireless network technologies e.g., 5G/4G/3G/2G, LTE450 and WLAN by embedded mobile terminals. In addition, the idea is to park the transportable solution in an area where there is significant commercial network coverage for backhauling whereas the coverage in the forest will be provided by a transportable 5G private network solution.

The second solution if the time and budget allow will be to foresee the usage of satellite backhauling via Starlink satellite constellation, this will be considered as a backup solution in case if connectivity from commercial operators is not available.

3.2.2 Co-creation for the use case implementation

The UC2.1 deployment will start in first quarter of 2024. For video streaming, and to provide the interactive remote support, number of solutions will be discussed, including Nokia's Real time eXtended Reality Multimedia (RXRM) [15]. RXRM offers genuinely immersive, Realtime experiences that have the potential to reshape collaborative work dynamics. Utilize cutting-edge 360° video and spatial 3D audio to boost industrial efficiency, elevate employee safety and well-being, and contribute to the establishment of a more sustainable work environment. This comprehensive solution encompasses all the necessary components for a seamless start-up, including software, hardware, and project implementation. The product can cover numerous use cases including remote inspections, remote supervisions, and remote expert assistance.

If the time and budget allow, the LL Norway will be exploring the opportunities for remote control of forestry machinery over a 5G network. The aim is to develop a proof of concept using a toy car. As in practice, to remote control the forestry machinery over 5G require tremendous efforts and budget and is considered out of scope of this UC2.1. Figure 22 shows the basic concept where a person sitting remotely can control the forestry machinery for either logging or cutting process.

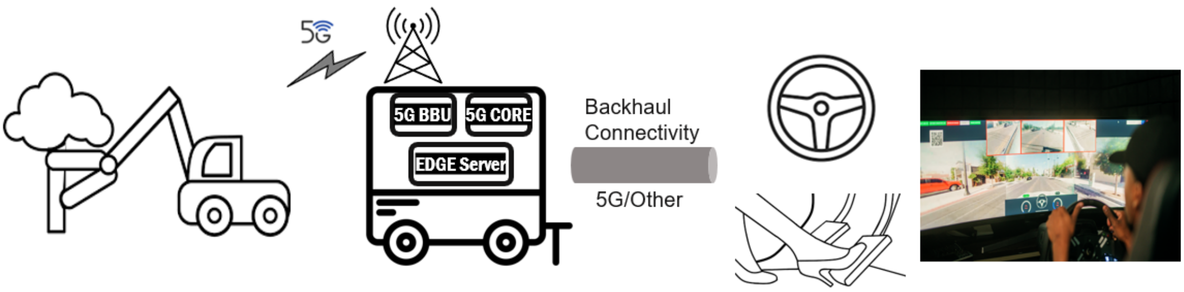

Figure 22: Remotely controlled Forestry Machinery concept

3.2.3 Data exploitation and expected Impact

Collected data is not automatically exploited in this use case, it is sent in real time to the operator. However, it is used to provide on-line assistance to machinery operators in the forest; experts from the forest operator's company will monitor camera video and advise and support the on-site operator in decision-making through remote means.

Additionally, assistance in maintenance, detection, and repair of engine or machine errors is also considered. In these instances, a vendor's expert, situated nationally or internationally, supervises the operator through online cameras using high quality video feeds at the vendors location.

The project partners have identified the relevant stakeholders to be involved in the first use UC2.1 case: the machine operators, the machine producers and drone producers. All of the above mentioned have been involved in one or more of the workshops and are being continuously followed up to establish their role and engagement in the deployment of the use cases. Holth Skogdrift, one of the machine operator companies, has been particularly motivated and shown interest in investing in adoption of digital technologies. The machine producer John Deere Forestry has also been very responsive and motivated to move forwards with the use cases, but it is necessary to plot out the whole plan and establish the business model in order to progress.

3.3 Use case 2.2: complex situational awareness services in the forest

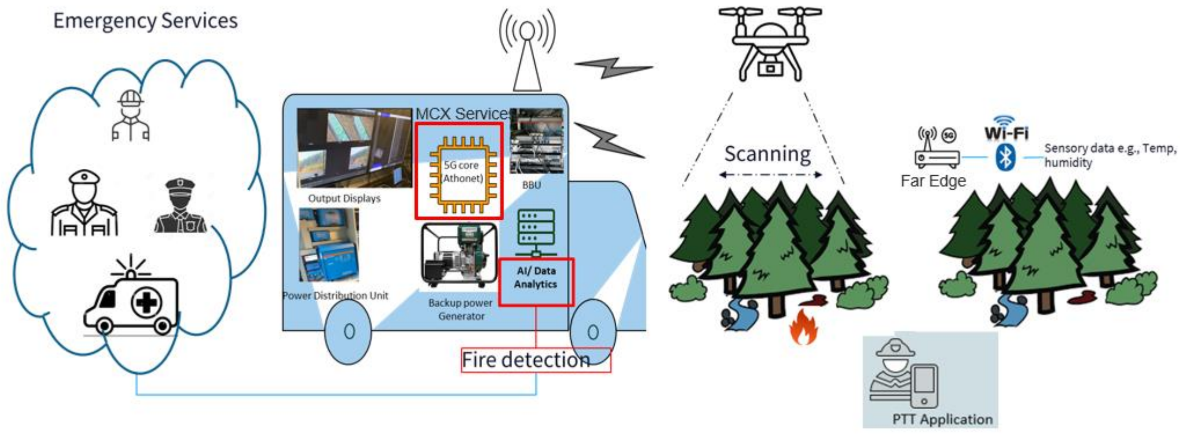

Figure 23 Situational awareness UC2.2 scenario

This UC2.2 aims to provide the monitoring and surveillance environment to protect forests from different accidents like forests fires. It will also enhance the efficiency and safety of emergency personnel (police, ambulance, fire, and volunteers) by providing real-time digital information during critical forest situations like landslides, or floods. The UC2.2 will use drone technology along with deployment of different on ground sensors.

Figure 23 illustrates the UC2.2, where drones and on-ground sensors provide the forest monitoring and surveillance and notify the emergency personnels in case of any emergency incidents resulting in efficient response. The use case will also establish a real time monitoring setup to evaluate a forest health.

The proposed forest monitoring methodology in UC2.2 uses drones equipped with advanced cameras to capture high-resolution and multispectral aerial images of the forest. The goal is to stream these images and videos to an external edge server in real time over private 5G network, integrate on-map analytics for forest metric visualization, and enable an immediate response to alarming changes. In case of detection of any forest accidents like fire, the alarm will be generated to the emergency service organizations. The emergency personnel will visit the onsite location to provide the emergency services, this could include the fire brigade services, ambulance or any other emergency response organization. The UC2.2 will also equip the solution with mission critical (MCX) applications that will allow emergency personnel's to continuously coordinate with each other via MCX application like Push To Talk (PTT).

3.3.1 Connectivity needs

To realize the UC2.2, following three main connectivity solutions are required: Wi-Fi/Bluetooth connectivity will be required to connect the ground sensors with far edge router; 5G Private network to provide control/video streaming from drone to edge server; and Commercial 5G Network or Satellite backhauling to backhaul the data to cloud storage. We will utilize the commercial 5G system from different commercial service providers like (Telenor, Telia/ICE) or will also explore the option of backhauling the data over Starlink satellite.

The implementation of 5G technology plays a crucial role in establishing effective and swift alert systems. Utilizing the high bandwidth and ultra-low latency of 5G networks, both ground sensors and aerial drones will optimize data transfer and communication across nodes, ensuring seamless operations.

3.3.2 Co-creation for the use case implementation

To realize the UC2.2, the LL will deploy the following major components.

- Drones
- Ground Sensors
- Edge Computing (Near Edge and Far Edge)
- Private 5G Network

Figure 24 shows the overall network architecture where the drone surveillance the forest sends video/image feeds to the Edge server. Similarly, the far edge node, collecting the sensory data over Wi-Fi or Bluetooth also process that data locally on far edge and relays this data to the Edge server. The data is being processed in edge server using AI and machine learning algorithms and suitable actions are taken based on the decisions. In addition to that the data may also be pushed via backhaul connectivity to the cloud servers.

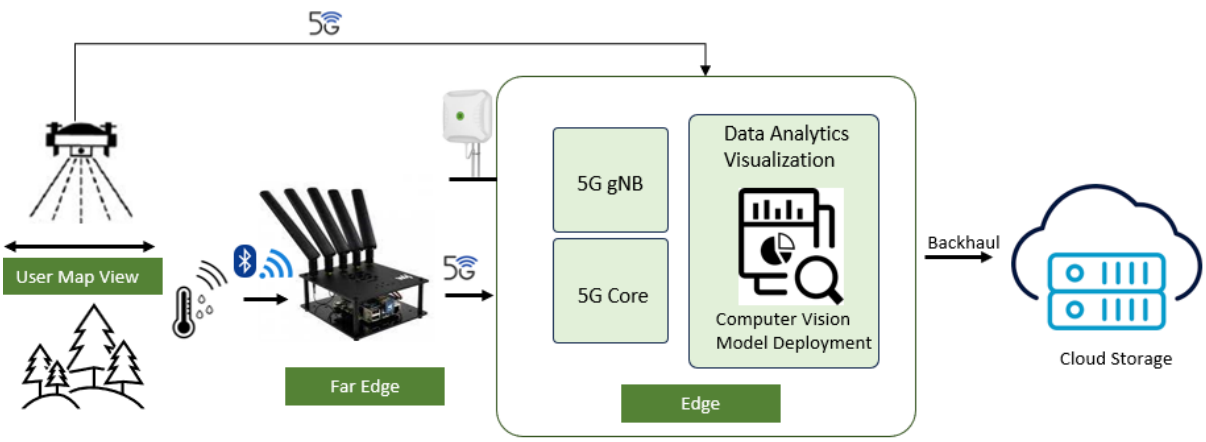

Figure 24 Network architecture of UC 2.2

The UC2.2 intends to employ drones equipped with advanced cameras for capturing high-resolution and multispectral aerial images of forested areas. These cameras will stream the real time images and videos to an external edge server using the RTMP (Real-Time Messaging Protocol) communication protocol over a 5G network. Additionally, the plan involves integrating on-map analytics for visualizing forest metrics, facilitating an immediate response to alarming changes. For the mentioned purpose, the DJI Mavic 3 Multispectral drone will be deployed, featuring both RGB and multispectral cameras.

The DJI Mavic 3 Multispectral drone specifications, as provided by the manufacturer, encompass a range of capabilities including Mobile SDK 5 (MSDK5) with fully open-source production code sample, Max wind speed resistance of 12m/s, Max flight distance of 32km, Max flight time of 43 minutes, Max hover time of 37 minutes and equipped with GPS + Galileo + BeiDou + GLONASS (GLONASS supported only when RTK module is enabled).

The drone assumes a pivotal role in the proposed methodology. As in any country, also in Norway, to fly the drone, specific rules and regulations must be followed, as detailed in [16]. Aerial images captured by the drone's camera will also be crucial in assessing the overall health and thickness of each forest section. Thickness measurement will leverage Artificial Intelligence (AI) computer vision models for image segmentation and object counting on each segment. This approach enables the determination of whether a thinning process should be applied and to which forest part.

The methodology also involves assessing the health of the forest by calculating the Normalized Difference Vegetation Index (NDVI) parameter for each part. This metric relies on values of reflectance in the near-infrared (630–690 nm) and red (760–900 nm) bands. The use of multispectral cameras is essential for obtaining these values accurately.

The drone's trajectory will be predefined at a relatively high altitude. Multispectral camera images will be transmitted to the edge server and fed to AI models, subsequently stored in the database. In the event of anomaly detection by the models, the drone will receive an immediate notification via the ultra-low latency 5G network. It will then conduct a lower altitude scan of the abnormal area, collecting additional data for further analysis. Similar actions will be taken if sensor network data indicate abnormal behaviour, prompting instant notifications to the drone for further investigation of specific forest areas.

To improve the efficiency of data processing, the UC2.2 intend to deploy edge computing enablers as decision-making nodes within the system. Utilizing the Raspberry Pi 4 Model B in conjunction with the 5G Hat, we aim to facilitate data conversion and preprocessing at the far edge (forest points). The selection of this specific processor is based on its high capabilities in data processing, coupled with a range of modular units that support various processes. Beyond features such as Wi-Fi, BLE, 8GB RAM, USB ports, and a UI emulator, numerous other technical specifications add significant value to our UC2.2 deployment. This configuration will enable real-time data analysis and seamless integration with AI models.

Simultaneously, the IoT sensors positioned on the forest floor will employ a 5G network to transmit data to the edge server. The Raspberry Pi console, located at the far edge, will receive the IoT data. Immediate processing will occur at the far-edge device (Raspberry Pi) to identify critical patterns through the combination of IoT data, such as detecting fires or unexpectedly low humidity. If a critical condition is identified, the far-edge server will use a 5G network to promptly notify the authorities for further actions. IoT data will periodically be transmitted from the far-edge device over the 5G network to the edge server for storage and additional processing. Specifically, the Raspberry Pi will be equipped with a "HAT" module providing 5G capabilities to the far-edge node. This 5G/4G/3G Raspberry Pi communication HAT adopts the SIMCom 5G module SIM8200EA-M2, supporting 5G NSA and SA networking with data rates up to 4 Gbps (DL) / 500 Mbps (UL).

TNOR, partner of the COMMECT LL Norway is collaborating with the IMAGINE-B5G project on the drone-based situational awareness use case (UC2). Third-party service providers "iLINK" and "Local AI" are supporting the development of the drone related functions in the situational awareness use case. Their contribution is funded through an open call in IMAGINE-B5G project.

3.3.3 Data exploitation and Expected Impact

The mobile application will display IoT metrics as an extra visual layer, integrating spatial data captured by the drone (forest images) with specific IoT metrics at various forest locations. The combination of drone imagery and IoT metrics creates a comprehensive monitoring tool for real-time forest conditions.

In addition to the Far edge processing, process at edge will also take place based on AI and machine learning models. Extensive set of deep learning models tailored for edge enablers will be implemented to facilitate real-time forest detection and monitoring. The initial model will be a deep neural network for image segmentation, specifically designed to conduct precise segmentation on frames captured by the multispectral camera mounted on the drone. This process involves breaking down the image frame into enclosed pixel areas (referred to as blobs) with consistent colour, and texture attributes. The colour data of each identified segment will be utilized to calculate the Normalized Difference Vegetation Index (NDVI), a crucial metric for assessing forest health. Consequently, the segmentation module holds potential for both short-term (leveraging 5G capabilities) and long-term forest health monitoring. The segmentation model will be based on the widely adopted Mask RCNN paradigm used in RGB image segmentation but fine-tuned with innovative unsupervised domain adaptation methods to effectively process aerial multispectral images.

Additionally, the second model is an object detection neural network proficient in recognizing various tree species within aerial imagery frames. By using this model, the system generates precise bounding boxes for each identified tree in images captured by the UAV's multispectral camera. This information will be utilized to estimate the extent of thinning or deforestation required for specific forest locations.

Furthermore, a neural network will be trained using the maximum likelihood training framework, utilizing data from ground sensors. The model's learning process involves understanding the distribution of normal parameter values observed in ground sensor measurements. This equips the trained model to excel in detecting anomalies. Specifically, when a set of ground sensor measurements for a designated forest area yields a low probability according to the model, it indicates an abnormal event. Upon identifying such an event, the system triggers the drone, via 5G, to approach the specified area at a lower altitude for a more detailed inspection. The subsequent analysis is conducted in real-time using an event detection module operating on multispectral images obtained by the UAV during its low-altitude pass. The entire processing will take place on the Edge.

The project partners have identified the main stakeholders that could benefit from this use case, and be interested in exploiting the results.

The most relevant stakeholders in the value chain for UC2.2 are the machine operators as they will be the ones in large utilising the setup. Further the forest owner associations are highly relevant as well, as they represent the forest owners. And since this UC2.2 is tied to monitoring and surveillance, it all should go through and be approved by the property owners. However, in order to achieve the full potential of the UC2.2 civilian emergency services also need to be involved. The latter is important since they need to be linked up to the system in order to be contacted if and when there is an emergency. They would need to be involved early on, in order to establish how the connections can be setup to best suit all security requirements.

3.4 Use case 2.3: Digital decision support for forest machine operators

Use case 2.3 can be considered as subpart of UC2.1 and UC2.2 where the aim of the use case is to provide the digital support to forest operator in terms of digital maps, applications, pre-installed digital data, route information or even live updates. Thus, the same connectivity solutions along with deployment plan for UC2.1 and UC2.2 will be used in for UC2.3.

As in UC2.2, where drone will take an arial flight and send images and live stream back. We will also try to utilize the drone to construct a digital image of the entire forest, with estimated tree count and height. This information will be fed into the mobile application along with sensory data collected from on-ground sensors. It will allow the forest operator an additional visual layer of information combining drone images/video with IoT metrics will provide an integrated monitoring tool of the real time conditions of the forest.

4 Living Lab N.3 – Denmark- Connected Livestock Transport

4.1 LL user-driven open innovation ecosystem

For over a thousand years, the pig industry has been one of the major sources of income in Denmark. As it is shown in Figure 25, approximately 90% of the production of the country is exported, out of which around 30% is livestock [17].

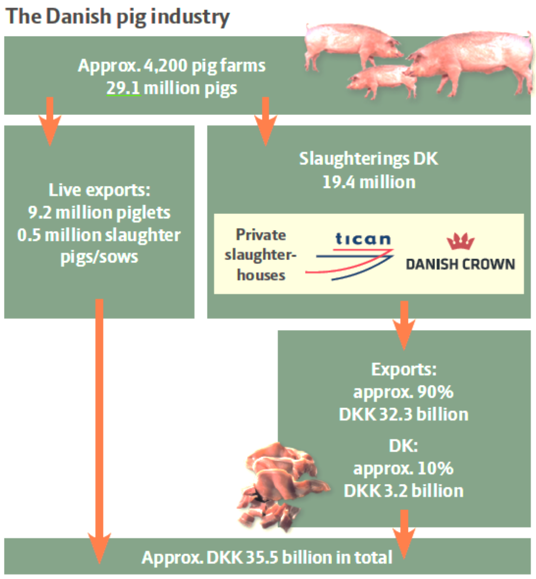

Figure 25 Danish Pig Industry Exports. Figure extracted from [17].

In recent years, a massive industry has grown up around the export of live Danish pigs abroad. In 1990, the Danish pig breeders exported almost 9,000 pigs abroad. In 2018, the figure had risen to 14.5 million live pigs, and Denmark is now the EU's largest exporter of live pigs. In most cases, the transported animals are 12-week-old piglets of approx. 30 kg, which are sent for feeding and later slaughter in countries such as Poland, Germany and Italy, but also as far away as Romania. One truck pulling a livestock compartment trailer can transport around 600 pigs over a long distance. There is a small increase in the direct employment on pig farms in Denmark, which constituted 6600 employees in 2021. Pig breeding was done by 1297 sow farms in 2020 in Denmark. The pig farming has a positive impact on the local society, creating jobs for many sectors like service, transport, manufacturing, and construction and other craft firms.

The EU, as well as the Danish authorities, have established a series of regulations that should be followed in order to ensure the animals welfare before, during and after transport [18], [19]. These regulations can be summarized as follows:

- Livestock transport units are not allowed to leave or enter the facilities (transport centre, source/destination farms) until it is checked in the corresponding database that the unit is certified for livestock transport (it has been properly disinfected, and the paperwork is under regulation).
- Transport periods should not exceed 8 hours. This means that after 8 hours of driving, the driver of the transport unit should find a resting stable, where the pigs can be unloaded and rest.
- The overall livestock transport (from pick-up location to destination location) should not exceed 24 hours, excluding resting periods.
- During transport, location of the transport unit must be reported every 15 minutes, and the truck driver must avoid driving through areas that pose a risk infection for swine fever disease.

Padborg Transport Center (PTC), member of the COMMECT consortium and the LL Denmark, is a collection of companies, their facilities and offices that offer services related to transport, logistics and freight transport. PTC covers a total area of 7 km^2. PTC located at the Danish border to Germany, sees around 3000 truck visits per day. Companies at the PTC location handles approximately 60% of all live animal transport to and from Denmark. They also handle the washing, disinfection, veterinary inspection, and control for disease for 92% of the livestock trucks and trailers in Denmark. Out of a total of 21 assembly stables Denmark, three of them are located at PTC.

The main location of the Danish LL is the assembly stable owned by the main stakeholder, DTL A/S, and located at PTC (Figure 26). The second location of the LL is a pig farm in the Netherlands (Figure 27).

The LL Denmark has connected experts from different areas, as part of the COMMECT consortium. PTC is the main initiator of contact to stakeholders in the domain of hauler and pig trading companies as these are shareholders of the PTC. TNO, VITECH and AAU are all experts on private 5G network on farms, as well as multi connectivity and broadband satellite for seamless connectivity on the move. Expert on the agricultural, digitalisation and operations management of livestock trading and transport is AU. The partners have established a framework for interaction and understanding of the complexity of trading, hauling and digitalisation of livestock export and transport, by the mix of technical knowledge with the daily practice.

Figure 26 Orthophoto of the two DTL A/S assembly stables located at Industrivej 44, 6330 Padborg, Denmark (Dataforsyningen Skråfoto, The Danish Agency for Climate Data)

Figure 27 photo of the Dutch pig farm

The Danish LL deals primary with the value chain of trading and transport of pigs. The transport of livestock is a vital link in the supply chain of animal breeding and production.

Relevant discussions with the stakeholders engaged in the gathering of COMMECT end-user needs, led to the conclusion that there is the need for better network infrastructure along the road, and at the farm location, to adopt digital solutions in the livestock sector. According to these discussions, there are a series of applications that require connectivity and are currently not being used due to the poor or inexistent coverage in certain rural areas. Some of these applications were included in the three use cases, which are explained in the following.

Online route optimization programs for livestock transport navigation, that consider multiple factors such as risk infection areas, current traffic and weather conditions, and time restrictions imposed by regulations. A related application is the online and continuously reporting of sensor data that allows proactively detecting potential problems in the trailer by the trading company, to remotely support/control the truck drivers in their decisions during transport of livestock. The objectives of the use case 3.1 was derived from this application, and the use case is studying the value of implementing multi connectivity for the future solutions of route optimisation and remote support to livestock transporting units on the move and under the always changing physical conditions.

Another two applications were concluded for further investigation in the project, which are 1) digital solutions on farm for automatic counting and weight estimation of pigs before loading to the livestock trailer compartment, and 2) on farm automatic license plate recognition as a security measure during farm access for livestock transport units with correct quarantine certificate (for control of disease spreading). The applications comprise computer vision-based solutions that allows detecting licence plates, the pigs' status and evaluate the departure and arrival conditions and number of the pigs, ensuring that their health status remains unchanged during transport. Only trucks that have been officially authorized for livestock transportation are granted entry. The necessary clearance information is exclusively accessible through real-time checks with the updated database maintained by regulatory authorities, emphasizing the need for connectivity. This ensures that the destination farm for the livestock has convenient access to the status video recorded during the loading process. While non-connectivity-reliant solutions are available, stakeholders express a preference for cloud storage of the video footage from both applications. The use case 3.2 and 3.3 are therefore implementing and studying on a farm broadband connectivity solutions consisting of private 5G and satellite backhauling, as well as coverage analysis of WiFi.

Based on the above mentioned application, the Danish LL has defined three use cases (see D1.1 [1]). The UC 3.1 is entitled 'Monitoring of Livestock Transport along Rural Routes' and the objective is to support the next generation livestock transport telemetry systems for i) highly frequent and stable data transmission of location and sensor data to the hauler operations center, as well as for ii) Intelligent Transportation Systems (ITS). The UC 3.2. is entitled 'License plate recognition', where the objective is to investigate connectivity solutions that efficiently enables the existing systems for license plate scanning by digital cameras, online database check for the disease quarantine certificates associated to license plates, and automatic boom barrier lifting for allowing accepted livestock transports to enter pig farms automatically. The UC 3.3 is entitled 'Monitoring of Livestock Loading/Unloading processes', and is concerning the connectivity solutions for on-farm automated counting of pigs, health detection and weight estimation before loading by deployment of the desired future technologies based on computer vision and cloud Machine Learning (ML).

The COMMECT project will propose connectivity solutions for all three use cases, mostly aiming at improving the connectivity in the main livestock transport routes and in the rural areas where the farms and resting stables are located. This is the outcome of multiple interviews, workshops and meetings held with different end-users and stakeholders, and within the members of the consortium involved in this LL.

The main stakeholders of the UC3.1. are the pig trading and hauling company DTL A/S. It is the company that provides the truck and livestock trailer for mounting of equipment, and for providing the routes. The company is also helping to understand the everyday problems within and around this specialised business sector. They introduced the LL to the livestock trading companies and their organisation (SamMark), and pig farmers and their organisation (Danish Agriculture and Food Council). Other stakeholders identified were suppliers of data logging devices on trucks and trailers, truck and trailer manufacturers and technicians, hauler companies and their organisations (ITD and DTL). Carrier is the current telematic provider for DTL trucks and trailers. The Carrier company is useful for understanding how the current telematic solutions works for DTL A/S owned livestock trailers and trucks. Mobicom Pro and ZF Group are both suppliers of data logging devices on trucks and trailers and are developing and producing a lot of the end user solutions for the hauler business. The two companies have experience in embedding connectivity solutions in their end user solutions for logistic planning, monitoring and documentation. The companies will support the LL to understand the way the tech companies work together with the livestock trading and hauling companies in both developing phase and sale of logistic solutions that require connectivity. The two companies have expressed high interest in the results of the proposed connectivity solutions.

The livestock trading and transport business also involves authorities for both livestock registration and welfare (The Danish Veterinary and Food Administration), authorities for data supply and infrastructure, and animal science institutions. After issuing a press release in August 2023, more stakeholders contacted the LL, for example manufacturers of animal feeding systems that require internet connection inside and outside farm buildings.

In the context of UC3.2 and UC3.3 the main stakeholders are the farmers organisation. The Danish Agriculture & Food Council contributes with knowledge about the challenges for farmers which delivers livestock to the livestock trading and hauling business sector. The pig farmers have an interest in making sure that their farm delivers batches of pigs in accordance with the trading agreement, and the trading company has an interest in an automated control of the batches. There are negative practical and animal welfare consequences that can occur if the loading of pigs accidently does not follow the trading agreement, for instance wrong number of pigs, injuries, umbilical hernias, etc.

The main stakeholder of the Danish LL, DTL A/S, will support the searching for consignee customers in Germany and nearby the Dutch border, that can be used for the testing and validation of the proposed multi-connectivity solution, encompassing 5G private networks, public 4G/5G, Wifi and satellite networks.

PTC collaborates with the local community in the south part of Denmark through strong alliances with the GateDenmark organisation and the ecosystem around Aabenraa Municipality, where transport and logistics by road, sea and rail is a regional focus area to enrich the society with jobs and good public services.

4.2 Use Case 3.1: Monitoring of Livestock Transport along Routes

This use case aims at developing and evaluating solutions to provide continuous connectivity while livestock is being transported. The analysis of the end-user needs leads to the conclusion that seamless connectivity is not only needed now but will be a key factor in a future where the transport industry evolves towards digitalization.

4.2.1 Connectivity Needs

The solution proposed to provide seamless connectivity along the route consists of the use of multi-connectivity. In this communication mode, the user (the livestock transport unit, in this case) can have more than one active link simultaneously. The secondary link may be connected to Internet through the same technology or through a different technology than the primary link.

Two different solutions will be investigated for this use case:

- *Cellular-satellite multi-connectivity: C*onsidering the cellular link as the primary link, using a satellite network to provide a secondary link guarantees the availability of the network due to the global coverage usually provided by this technology. This solution will be only evaluated in a controlled environment and will not be tested in the LL premises. For further information, the reader is referred to deliverable D5.1 [20].
- *Cellular-based multi-connectivity:* Cellular-based multi-connectivity can enhance signal level. We consider evaluating two configurations:
  - *Same Operator:* Having two cellular modems with two active links with the same operator has been proven to enhance service availability and performance [21]. This will be further investigated in this use case.
  - *Multi-operator:* Having two cellular links connected to two different operators may increase the chances of having cellular coverage available. This will also be investigated in this use case.

4.2.2 Co-creation for the use case implementation

The equipment that will be used to evaluate the proposed solution is currently being tested and consists of a small box that will be placed on top of the trailer of a truck of one of the stakeholders of the Danish LL (the DTL A/S livestock trading company). More details about the equipment are available in the annex.

As illustrated in Figure 28, the box will be placed in the trailer of one of the trucks from DTL's fleet. It will start driving from Denmark and will follow different routes towards Germany and the Netherlands. This measurement campaign is currently being planned to start in Q4 of 2024, and further details will be provided in deliverable D5.2, with the description of the results obtained in this campaign.

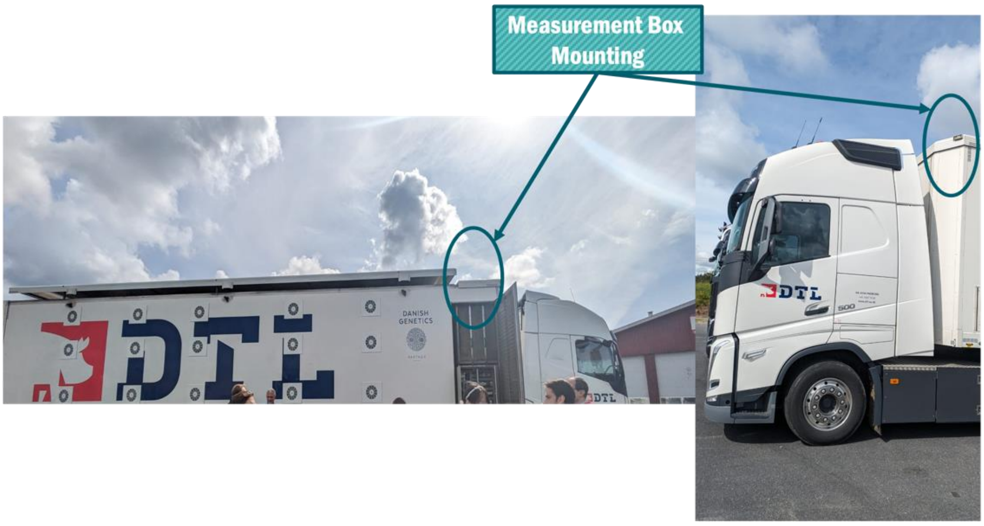

Figure 28. Location for mounting of measurement box (MAGW) on the trailer.

4.2.3 Data exploitation and expected Impact

The implementation of the connectivity solution is slightly different to the one presented in other COMMECT LLs, since the proposed solution aims at providing seamless connectivity rather than implementing the data reporting and downloading systems required by the stakeholders. Therefore, no sensors will be deployed in the LL, and the only data that will be collected aimed at evaluating the performance of the proposed connectivity. This includes:

- Radio Key Performance Indicators (KPIs) such as received signal or interference levels and GPS position as part of the coverage analysis that will be performed in the main transport routes.
- Round Trip Time/Latency values along the main transport routes.
- Uplink and Downlink throughput values along the main transport routes.

This data will be used to evaluate the feasibility of multi-connectivity as a solution to provide seamless coverage along the main transport route for livestock transport units.

4.3 Use Case 3.2 and 3.3 License Plate Recognition and Monitoring of Livestock Loading/Unloading processes

According to the interviews and workshops performed with the livestock transport companies, farmers, the truck drivers, and the providers of connectivity solutions for the trucks/trailers, the uplink connectivity with sufficient throughput at the loading/unloading locations is an issue. The stakeholders claim that they would also like to transfer live video-stream of the loading/unloading process and be able to make automated video monitoring process for e.g. piglets counting and wellbeing, as well as license plate recognition and authorisation to avoid disease spreading. Additionally, easy access and authorisation for the truck's video camera to access the local network at the loading/unloading location is found very important.

LL Denmark identified two other use cases related to the loading and unloading of the piglets as follows:

- Use case 3.2 Truck License Plate Recognition/Authorisation, see Figure 30, where the truck approaching the loading or unloading location is authorised to access the facility via automatic license plate recognition/authorisation.

- Use case 3.3 Real-time video monitoring of the loading or unloading process (see Figure 31) that facilitates either an expert or a computer vision-based solutions and further enhances the digitisation of the livestock transportation.

4.3.1 Connectivity Needs

The connectivity solution for the two use cases UC3.2 and UC3.3 should support a real-time video monitoring stream with sufficient uplink wireless coverage (and capacity) nearby the location of the farm and the livestock transportation truck. For example, for a real-time video streaming with HD quality it is expected that 10 Mbps throughput for the uplink wireless access link would be required [4].

The farm locations might be in remote areas where the availability of good wireless network coverage from MNOs and sufficient uplink wireless capacity can be challenging. Therefore, it is important to realize a local wireless network coverage at those remote locations by creating local 5G private networks or local Wi-Fi networks, see Figure 29. Furthermore, depending on the farm's location the local wireless network could be complemented with either terrestrial networks or in some cases with satellite networks for transporting the real-time video stream to the desired remote destination.

The video monitoring might require timely analysis and decisions, for example to open the barrier and let the transportation truck approach the location (when authorized) or to identify particular piglets with injuries, illness etc. From connectivity point of view the current understanding is that the video analysis should be still done 'in the edge' i.e. nearby to the farm locations such that the whole decision loop is within seconds.

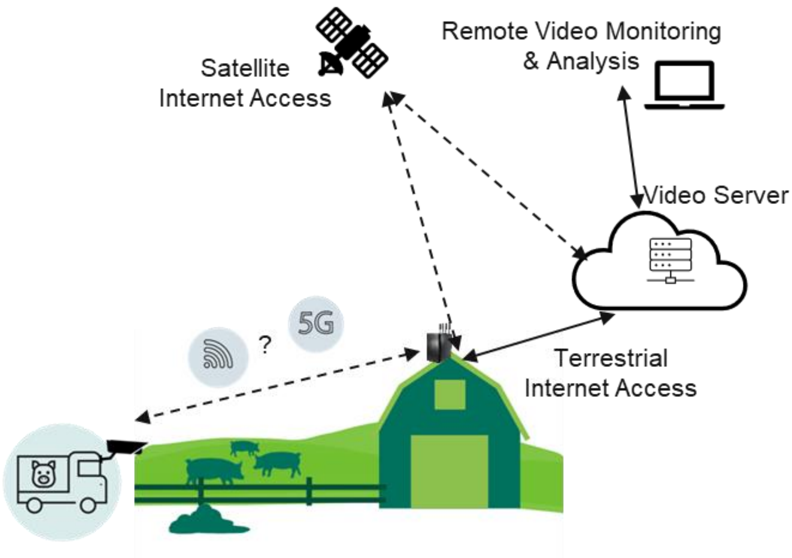

Figure 29. Connectivity needs for UC3.2 and UC3.3

4.3.2 Co-creation for the use case implementation

The proposed connectivity solution for the local wireless network is a 5G local wireless access or alternatively a Wi-Fi local wireless access. The 5G and Wi-Fi local wireless network modules that are expected to be used at the farms location for COMMECT's investigation are detailed in the annex.

A candidate deployment for the UC3.2 regarding the truck license plate recognition and authorisation is depicted in Figure 30. At the barrier that blocks the approaching road for the livestock transportation plan a video camera for the live-stream can be installed. The latter is capable of communicating the video stream via the 5G or Wi-Fi wireless link as provided by the local/private wireless access network at the farm's location. Then as the transportation truck approaches and stops by the barrier the video image is processed at the authorisation server and the truck's credential can be checked to authorize the access.

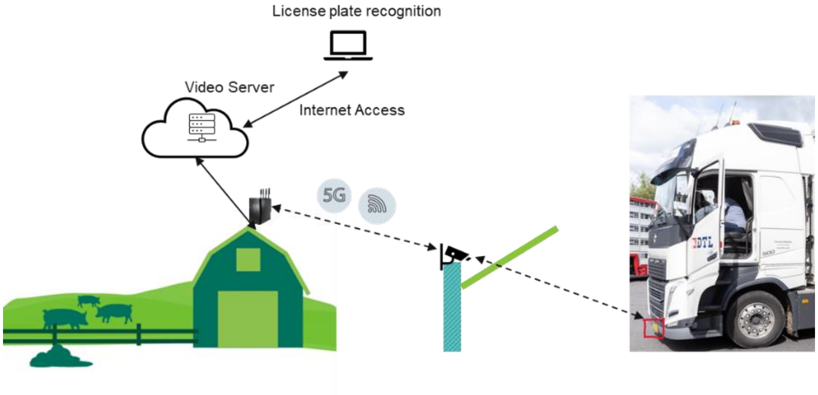

Figure 30. Local wireless coverage for truck license plate recognition/authorisation UC3.2

A candidate deployment for the UC3.3 regarding the video monitoring of the loading/unloading process for the livestock transportation truck is depicted in Figure 31. A video camera capable of 5G or Wi-Fi wireless communication will be mounted on the truck (or the entrance of the loading/unloading facility) and a video-stream will be communicated via the local/private 5G or Wi-Fi network. The video-stream can then be monitored at a remote location either by an expert or a computer vision algorithm in order to perform the various tasks such as counting, injuries or illness detection etc.

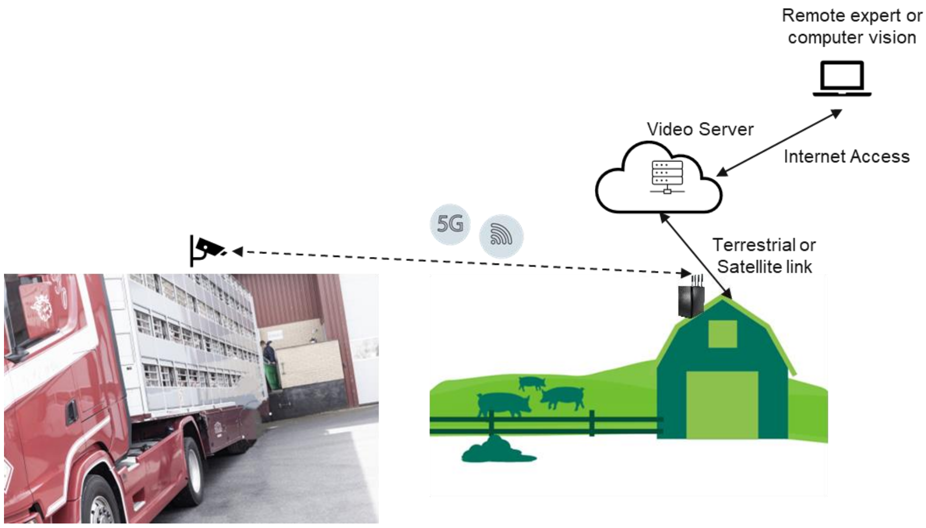

Figure 31. Local wireless coverage for video live-stream livestock loading/unloading monitoring UC3.3

The actual set-up at the selected farm's location in the Netherlands will depend on the local conditions at the farm, and in worst case an approximated mock-up of the scenarios in Figure 30 and Figure 31 will be pursued. Further, next to the fixed/terrestrial internet access for the farm, the option of having satellite internet access at the farm location will be investigated depending on the satellite terminal availability within the COMMECT project.

This measurement campaign is currently being planned to start in Q2/3 of 2024. The measurement results from the field tests will be presented in deliverable D5.2 [22].

4.3.3 Data exploitation and expected Impact

In the course of the COMMECT project it would be difficult to exploit at the end-to-end application level the quality of the video monitoring service, either by expert or automatic via a computer vision. Therefore, the focus of the investigation is to test if the connectivity solution can enable such a real-time video monitoring service. The data that can be exploited for evaluating the connectivity solution in this context is as follows:

- Uplink throughput performance (i.e. from the video-camera towards the network) in Mbps of the wireless links in various locations around the farm location when there is local 5G or Wi-Fi coverage.
- The coverage area around specific locations within the farm's facility where this uplink throughput excesses a desired performance target of e.g. 10 Mbps.
- The end-to-end delay (either one-way or round trip) for the communication link between the video camera and the remote monitoring location. This delay can be investigated for different configurations e.g. when the video camera is provided with 5G or Wi-Fi at the access link, and in combination with the terrestrial or satellite links for the internet at the farm's location.

The feasibility of end-to-end video monitoring in this deployment will be assessed given: the measurements of the UL achievable throughput (from different configurations of local 5G or Wi-Fi networks), the size of the coverage area with a minimum throughput, and the measured end-to-end delay.

5 Living Lab N.4 – Türkiye- Smart Olive Tree Farming

5.1 LL user-driven open innovation ecosystem

Olive tree is a plant native to the Anatolian region, and its main products (table olive and olive oil) have been considered important food and commercial products since ancient times. With the increasing interest in healthy life and nutrition, the importance of the producing and consuming of table olives and olive oil is increasing.

Olive production in Türkiye directly or indirectly concerns approximately 10 million people. Türkiye ranks 2nd in the world with the number of 195 million trees on 899 million hectares [23] and an average annual raw olive production of 3 million tons [24].

Modern planting systems, mechanisation, and digitalisation are rapidly occurring in olive agriculture worldwide. While innovative production systems are increasing daily worldwide, they are progressing slowly in Türkiye. It is not easy to talk about integrating technology and agriculture in Türkiye, which historically relied on traditional olive cultivation methods.

The olive fly is the primary pest in Türkiye and in the Mediterranean region where olive production takes place. It causes significant yield and quality losses. It is of great importance to carry out a successful fight against this harmful insect. Using modern agricultural systems in the fight against insects may also increase the success rate.

Additionally, there has been an increase in diseases in recent years due to climate change. This increase may cause some difficulties in the timing of spraying. Pest forecasting and early warning systems may accurately determine spraying times using weather data to control diseases and pests in olive groves.

To address these challenges, LL Türkiye identified 2 use cases that will be deployed in the LL with the participation of stakeholders. The first one focuses on the monitoring of microclimate conditions that make olive trees more vulnerable to attacks from pests and disease. The second use case will be tracking the olive fly population in the environment to control pest and plan insecticide applications efficiently.

LL Türkiye includes actors from different sectors: Researchers (Hatay and Izmir Olive Research Institutes, Ministry of Agriculture and Forestry General Directorate of Agricultural Research and Policies, Alata Horticultural Research Institute), satellite, telecom and data service providers (TURKCELL), and end users (Olive growers and olive oil producers). They all collaborate in an open innovation ecosystem to identify needs in LL Türkiye and design and implement connectivity solutions that meet such needs.

Surveys and interviews were organized by TOB to investigate the needs of olive growers. 65 olive farmers attended the first meetings and expressed their basic needs for digitalization in olive farming regarding agricultural activities. It emerged that it is of foremost importance for them to diagnose ring spot disease and olive fly from a distance, especially in difficult field conditions, without going to the field. Moreover, it was revealed what the benefits of spraying at the right time and in sufficient amounts will be.

LL Türkiye is geographically distributed in three different regions of the country, with the aim of monitoring the effectiveness of the proposed connectivity solutions in different terrain and geographical conditions. The 1st location is in the Olive Research Institute application area in **Izmir**. There are 4 tractors, 2 spraying tanks, 1 olive oil factory, 1 table olive production unit, 8 laboratories and all related equipment within the 65 hectares land. The 2nd location is in Antalya**,** Zeytinpark, located on 200 hectares of land, and it consists in a complete olive grove. Advanced agricultural operations are not applied on the land where there are 2 tractors and 1 spray tank. The 3rd location is on the land of Alata Horticultural Research Institute in **Mersin** region. The LL is located in an 8 hectares olive grove. The institute has 6 tractors and 3 spraying tanks, as well as all agricultural equipment.

Figure 32. Turkish living lab use cases 4.1 and 4.2 locations

All the activities in the LL were carried, in close discussion with the end users. Two workshops were organized to increase the participation of olive farmers, rural farmers and refugees in the COMMECT project.

In the first workshop, the need of introducing digital agriculture for olive farmers, based on their needs and pains was discussed. Some first solutions were also presented. The second workshop took place in the form of a working session, organised together with TNO, for the definition of the business models. The workshop discussed the environmental and socio-economic effects of digitalization in olive agriculture with cooperative representatives connected to many olive farmers, Ministry of Agriculture and Forestry officials, agricultural insurers and other stakeholders. In addition, studies were carried out on other issues discussed in the first workshop and updates on the COMMECT project were presented.

In this context, in-depth information was given to the managers of MARMARABİRLİK [25] and TARİŞ [26], Türkiye's largest olive producer cooperatives. Agricultural insurance representatives clarified that using different IoT technologies in olive farming is essential for them and that it will be an important data provider regarding the control of pest propagation and reduction of the impacts that these insects may have on olive trees production. Data received from the sensors deployed in the LL Türkiye will be evaluated and analysed, and advice on spraying scheduling will be shared with end users.

5.2 Use case 4.1: Microclimate Monitoring for Early Disease and Pest Detection

5.2.1 Connectivity needs

Weather and soil sensors installed in the olive tree orchard can provide pest, air temperature, and soil data. Seamless connectivity is essential to monitor meteorological and soil conditions continuously. This data can feed models providing accurate disease severity predictions. Thus, offering table olive and olive oil produces comprehensive and precise information for their decision-making. Figure 33 illustrates the connectivity solution proposed to address the users' needs in UC 4.1. It relies on NB-IoT machine-type communications technology.

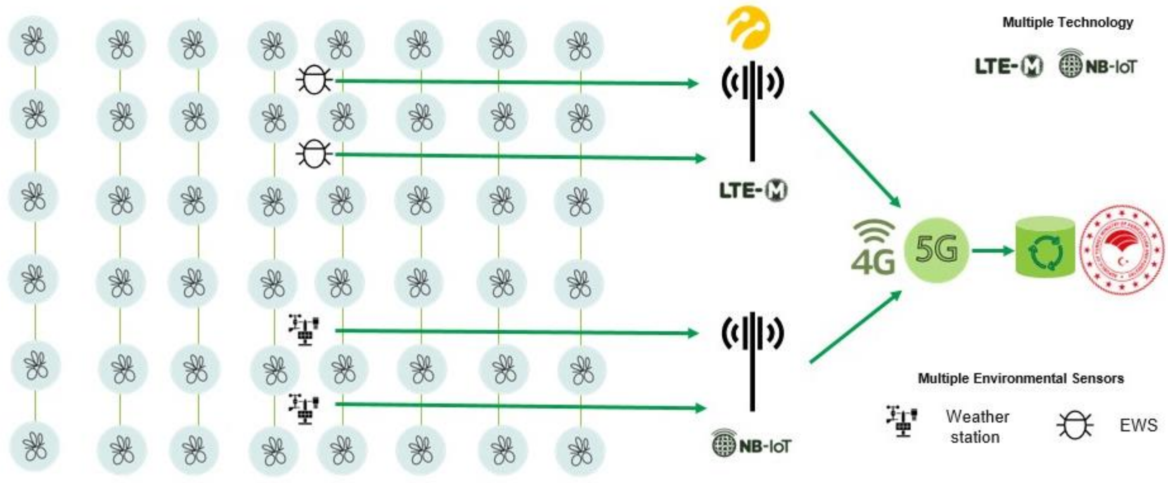

Figure 33 The connectivity solution proposed to address the users' needs in LL Türkiye

5.2.2 Co-creation for the use case implementation

The first use case requires the collection of data from weather stations and soil sensors. Thus, it asks for very low-cost devices requiring a long battery life, deployed in large numbers. The setup of NB-IoT data architecture and the configuration of specific features can affect the performance of an NB-IoT sensor, its cost, and even its ability to well perform in the Türkiye smart olive tree farming LL. The impact of different features' and parameters' setups on NB-IoT base stations and sensors will be investigated to achieve the best performance in the first use case.

NB-IoT and eMTC are prioritized technologies in the Türkiye smart olive tree farming LL. Their cellular Internet of Things radio access technologies are specified by 3GPP to address the fast-expanding low-power wide-area connectivity markets. Their specification started from 3GPP Release 13 [27]. The current Release is Rel-17 [28] and the enhancement related to power saving and coverage extensions come in the later 3GPP releases to achieve global coverage and wide adoption of IoT services.

When deploying the weather stations, soil sensors, work trackers and early warning systems, it is essential to consider energy consumption, coverage, and connectivity constraints together. In addition to NB-IoT and eMTC, Türkiye smart olive tree farming supports former XG technologies like 2G and 3G. The olive oil or table olive producer/farmers can use any XG technology. Figure 34 shows the initial network architecture of Türkiye smart olive tree farming LL.

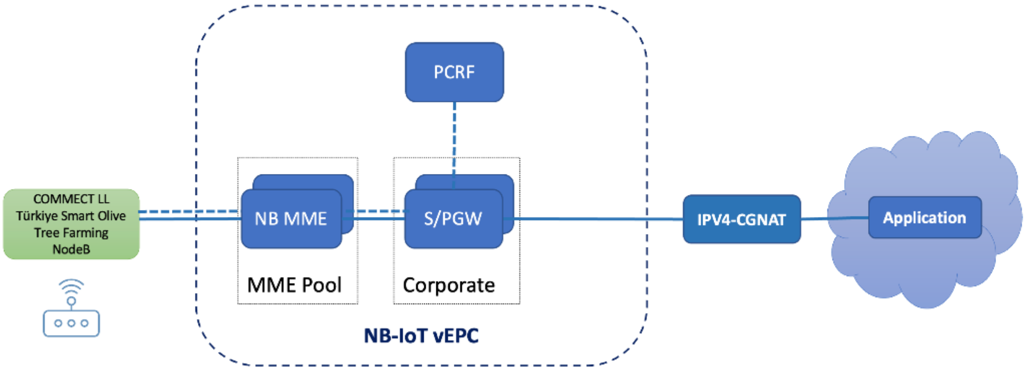

Figure 34. The initial network architecture of Türkiye smart olive tree LL

In Türkiye living lab, the deployment of the first use case for microclimate monitoring and early disease and pest detection is planned in two different olive production locations. These locations are in Izmir and Antalya, see Figure 32. Production amounts and different climatic conditions were taken into consideration when selecting these cities.

In the Izmir (65ha) and Antalya (200ha) campuses, where the **installation is completed**, two climate stations, two delta traps and cameras, two yellow sticky traps and cameras, two manual traps without cameras, two tractor tracking devices, and one phenology tracking camera were deployed. Some calibration and connectivity problems were resolved during the process. An example of digital traps and weather station deployed in the LL is shown in Figure 35.

Figure 35. Digital traps and weather station installed in the LL

It is essential to position the devices away from other external factors (buildings, trees) that may skew the measurements. In Türkiye LL, climate stations were optimally positioned to represent accurate conditions of the garden and away from these effects.

The data received from weather stations may play a role in using an early warning system against essential diseases and providing complementary information about the pest's life cycle. Critical processes such as flowering and harvest time may be monitored remotely with phenology cameras. They can help us make decisions remotely without going to the area in case the land conditions are unsuitable for transportation. With tractor tracking devices, information may be obtained about what kind of traffic process our vehicle is involved in, work intensity and working processes during a production season. In this way, it may be evaluated whether the equipment is used effectively or not and whether new equipment is needed.

5.2.3 Data exploitation and expected Impact

Agriculture experts should evaluate the data obtained from the first use case. As a result of the evaluation, calculations are made regarding the pesticide application and its dose. This information must then be conveyed to the technicians working in the towns. These personnel may be working in town organizations of the Ministry of Agriculture and Forestry, and they should also be shared with cooperatives and agricultural insurance companies operating in the region. These people can deliver the pesticide warning and dose to rural farmers via SMS or mobile applications. Thus, by spraying at the right time and in the appropriate dose, less environmental damage can be caused, and the quantity and quality of the product can be increased.

5.3 Use case 4.2: Monitoring of Pest Insect Traps

5.3.1 Connectivity needs

Early warning or pest trap monitoring systems were installed in the olive tree orchard to follow the pest population. Good quality broadband connectivity is essential to monitor the pest population continuously. This data can feed models providing accurate disease severity predictions. Thus, offering table olive and olive oil produces comprehensive and precise information for their decision-making. Figure 33 illustrates the connectivity solution proposed to address the users' needs in the use case U.C4.2. It relies on enhanced machine-type communications (eMTC) technology.

5.3.2 Co-creation for the use case implementation

The second use case collects the early warning systems data, such as pictures of pests and olive trees. eMTC is another low-power wide area network technology that provides broad coverage, low power consumption, and direct connection to a 4G or 5G cellular network, facilitating seamless Internet connectivity for IoT devices. eMTC can offer higher data rates and lower latency compared to NB-IoT. It makes it more suited to IoT applications that require real-time response and more extensive data transmission, a key distinction when comparing eMTC vs NB-IoT for IoT devices.

To deploy the second use case of LL Türkiye, the production amounts of olive and special climatic conditions were considered to select the LL locations. Three different regions were initially selected: Izmir (65ha), Antalya (200ha) and Hatay. (see Figure 32).

However, a violent earthquake happened in February 2023, which impacted the area of Hatay. The manual traps, one delta trap and camera and one yellow sticky trap and camera could not be installed, but th devices were not destroyed, and were kept in Hatay. A new deployment of these devices has been discussed among the LL partners and stakeholders.

After some field inspections, it was decided that Mersin province could be a suitable location. And the installation will be finalized in the upcoming months (Q1/Q2 2024).

The devices in the second use case are digital traps that enable an effective fight against the olive flies. The reason for choosing this type of device was to use compelling usage scenarios of remotely connected traps and camera systems that will provide remote diagnosis and eliminate the problems encountered in the effective fight against the olive fly. If the controversial areas in the effectiveness of these currently used systems are clarified, and an economical and environmentally friendly solution is found, it could be a massive gain for the olive oil industry. In addition, it may be used widely by many manufacturers.

To deploy the digital traps within the olive grove, an optimal positioning in the field is essential. Conditions that will affect the population of the olive fly in the garden must be eliminated. Moreover, in order to represent the entire field, direction and height of the trap must be meaningful. In Türkiye LL, digital traps were positioned to represent the conditions of the garden and away from any external influence.

Figure 36. Digital trap station

When deploying the work trackers and early warning systems, it is also essential to consider energy consumption, coverage, and connectivity constraints together. In addition to NB-IoT and eMTC, the devices deployed in Türkiye smart olive tree farming supports also former XG technologies like 2G and 3G. The transmitters can use any XG technology to send data.

5.3.3 Data exploitation and expected Impact

Agriculture experts should evaluate digital trap images taken from the second use case. It is essential to detect this, especially when the number of olive flies reaches the economic damage threshold. As a result of the evaluation, the spraying time can be decided. This information must then be conveyed to the technicians working in the towns. These personnel may be working in town organizations of the Ministry of Agriculture and Forestry, and they should also be shared with cooperatives and agricultural insurance companies operating in the region. These people can deliver pesticide warnings to rural farmers via SMS or mobile applications. Thus, by spraying at the right time and in the appropriate dose, less environmental damage can be caused, and the quantity and quality of the product can be increased. On the other hand, unnecessary spraying during periods when harmful insects do not reach a critical population can be prevented.

6 Living Lab N. 5- Serbia- Sustainable Agriculture and Preservation of Natural Environment

6.1 LL user driven open innovation ecosystem

Agriculture is a key part of Serbia’s economy. Land suitable for arable is mostly located in Vojvodina province. Gospodjinci village, where LL5 will deploy the identified use cases, is in the Vojvodina province. There are around 5500 ha of land cultivated through about 600 agriculture households. It is a community where agriculture is the primary source of employment and the community’s livelihood depends on the success of their crops and livestock production. There are two nature parks in the area, Mrtva Tisa and Jegrička, with agriculture fields which make a complex ecosystem, where agriculture has a significant impact on the environment. Pearl Island, bordering the Mrtva Tisa nature park, is an agricultural area, cultivated by farmers from the surrounding villages. The area lacks community infrastructure (dirty roads, no electricity). While being surrounded by water, there is an increased need to irrigate the fields due to increasingly warmer summers. The current agriculture practice relies mainly on the experience resulting in sub-optimal practices, increasing production costs and negative environment impact. Fossil fuel-based generators are used for powering irrigation systems, thus generated high level of CO2 emission and noise.

Farmers need decision support in defining the right time for different activities based on crop needs and current environment and soil conditions and a solution to replace fossil-fuel generators with renewable energy source to enable nature park preservation and decreasing of environmental footprint.

The LL Serbia involves actors from different sectors: mobile solar generators provider (AluMarkom), farmers (Solar Agro association, local farmers), service provider (DNET), local mobile operator (A1/Telekom), local community, tourists. The key stakeholders play distinct but interconnected roles in the LL5 deployment. Alu Markom company has been involved in discussions from the very beginning of the project, providing technical requirements related to the mobile energy generators, based on their interactions with farmers and other users of the technology. The local mobile operators (A1/Telekom) have a role in providing mobile network coverage enabling interaction with the cloud-based parts of the system. DNET, as a service provider, is responsible for selection of devices and components comprising communication, computing and sensing infrastructure, its integration, deployment and maintenance as well as for implementation and validation of required ML algorithms. In addition, DNET will act as the main driver of the LL5, providing training, collecting feedback and promoting the designed solutions.

The end-user, farmer Association SolarAgro (ZZSA) supports the involvement of farmers, adoption of new technologies, knowledge sharing among farmers and collecting the feedback. The association gather 13 farmers cultivating around 500 ha of land. They will serve as pilots for implementing technology and sharing results with local farmers cultivating around 5500 ha of land. Farmer Association SolarAgro together with local farmers have been actively engaged in discussions, providing insight into their current agricultural practices and challenges in adopting new technologies. Workshops gathering 44 participants (farmers, representatives of farmer association Solar Agro and representative of a solar trailer supplier) together with on-site meetings have been organized to facilitate this engagement. After collecting the end-users needs, five use cases were defined. Additionally, lesson learned during execution of DEMETER project activities [29] and insight gathered from the end-users’ survey have contributed to a better understanding the challenges that farmers are faced with.

The LL area is well known as tourist attraction, especially during the summer period. Actively involving the community in LL’s initiatives such as information sharing and participating in conservation efforts, will enhance the surrounding nature parks. This engagement will attract more tourists to the region, optimizing tourist capacity and boosting efforts towards nature park preservation. Accessible environmental data will be provided to the entire community, rangers, local authorities, and tourists through shared environmental platform.

Hardware vendors represent another important stakeholder impacting availability and affordability of the deployed infrastructure. Stakeholders like seed, chemical and fertilizers vendors working directly with farmers provide necessary inputs in the different stages of agriculture production.

Agricultural advisors and experts in different areas of agriculture domain (plant protection, fertilizers, machinery, etc.) focusing on sharing experience, advice, knowledge as well as information about current trends in agriculture production and usage of digital technologies will be able to provide the service through Community shared platform.

To address end users' needs collected through face-to-face interviews and discussion during the workshop organized with farmers and their association representatives, the LL Serbia focuses first on creating an adequate energy, communication and computing infrastructure providing stable power supply, communication, and computing capabilities where and when needed, and then on implementing and deploying services identified as being of interest to the community.

6.2 Connectivity needs

Digital farming and environment monitoring relies on a combination of several inputs of which field measurements are among the most important ones. To facilitate continuous and reliable acquisition of the measurements, the sensor devices deployed across the LL5 region require availability of one or more communication networks providing good coverage and adequate throughput, while being suitable for battery powered devices. To that end, establishment of a LPWAN network with a backhaul connection to the Internet (primarily via mobile network; other types of communication are acceptable as well) is required. The acquired data is forwarded to the edge and cloud functional components and modules, enabling centralized storage, advanced analysis, and access to data and generated insights.

The deployed LoRaWAN network must cover at least 90% of the LL5 area, see Figure 37, considering the characteristics of the used devices and requirements of the deployed solutions (i.e., how many records the devices can store before transmitting, how often the data has to be transmitted without impacting the supported agriculture operation). As the Living Lab evolves and expands, the connectivity infrastructure should be scalable to accommodate growing data volumes and increasing device deployments. This infrastructure will be used for all the five use cases identified in the LL5 Serbia.

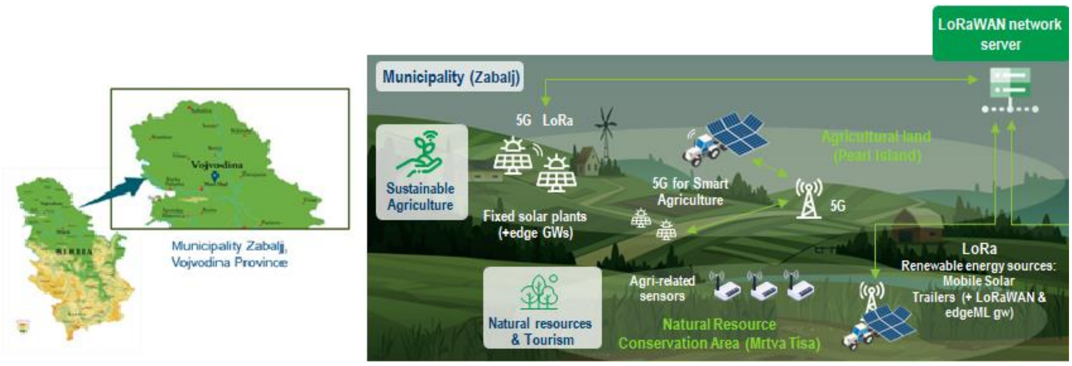

Figure 37 Municipality Zabalj (map) and LL Serbia architecture

6.3 Co-creation for the use case implementation and data exploitation

The deployment of devices (described in the annex), is scheduled for spring 2024, with the plan to ensure that all devices and the network are operational before the start of the vegetation season. The network architecture of the system planned for deployment in the LL5 is presented in Figure 38.

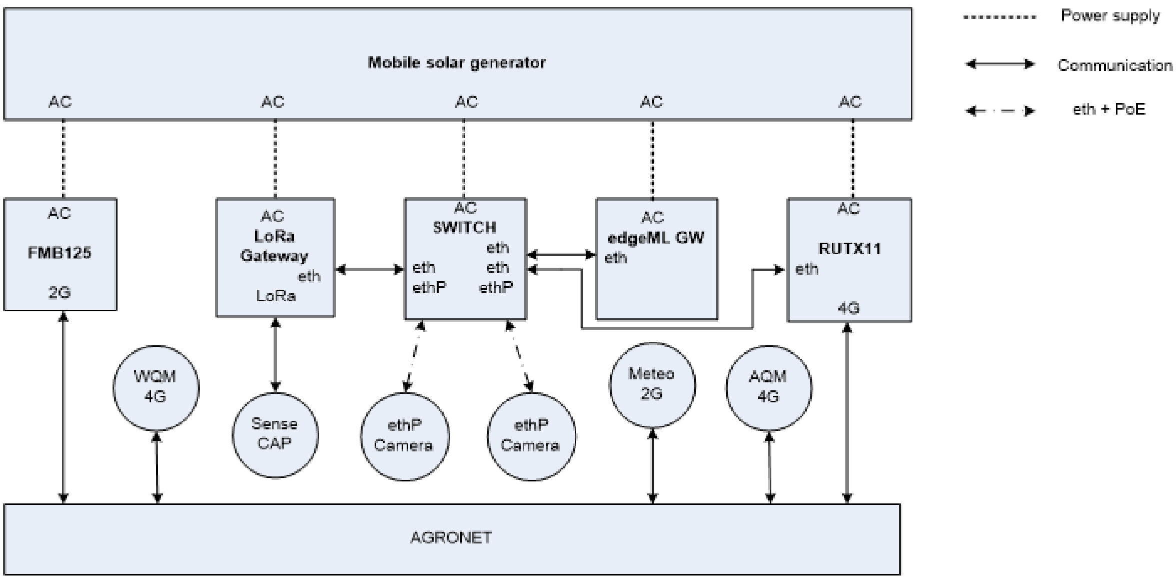

Figure 38 LL N.5 network infrastructure

In the following, the different five use cases will be detailed in terms of implementation of this infrastructure and data exploitation.

6.3.1 Use case 5.1: Creation of a shared rural infrastructure

UC 5.1 aims to address the need to enable connectivity for sensors as well as computing environment at the edge (in the field, on-site). To that end, a stable power supply is required. As the electric grid is not readily available in the agriculture fields, an alternative solution is required, preferably based on renewable energy sources to support the sustainability of the approach and to contribute to the sustainability of the agriculture operations as well.

The measurements collected by the sensing infrastructure are used to provide a range of value-added services, i.e., farm management and decision support systems, environment monitoring solution as well as more general community platform, and, potentially, to create the basis for the future community data spaces which will act as a source of additional revenue for the communities. More details on how the acquired data is used is provided in the descriptions of the remaining LL5 use cases.

6.3.2 Use case 5.2: Securing crops and equipment

This use case is focused on implementing edge ML computing algorithms for detection of events and processes taking place in the field.

The shared communication, computing and sensing infrastructure provided by UC 5.1 will be used in this case to acquire relevant video and audio streams and process them on the edge. The outcomes of the processing will be forwarded to the cloud where the central system functionalities will generate relevant alerts, notifications, and reports.

Gathered audio and video streams (people/vehicles present/moving, crops' status, noise generated) will be analysed through ML algorithms to gain the following insights: (i) detection of people and vehicles present/moving in the field and around the equipment to prevent thefts as well as to automatically create a log of activities; (ii) detection of the status of the crops (growth status, height, size) to support execution of agricultural operations; (iii) recognition of audio/noise to detect activities in the surrounding area.

6.3.3 Use case 5.3: Shared environment monitoring platform

UC5.3 is focused on continuously monitoring environment conditions in the protected nature park and the surroundings, creating the basis for more efficient protection.

Communication and sensing infrastructure established in UC 5.1 will be used for gathering relevant parameters (air quality, water quality and noise level) and transferring them to the environmental monitoring platform.

The collected data (air temperature, air quality: CO, NO_2, SO_2, O_3, PM; water quality: water temperature, pH, dissolved oxygen, EC/salinity, oxidation-reduction potential, and noise level) will be used by the deployed environment monitoring platform and made available to the community, visitors as well as to other interested parties like tourist promotion agencies, local administration responsible for maintenance of nature protected areas, etc. The data will provide transparency into the status of the protected areas and will create the basis for detecting and, eventually preventing activities harming the environment (like the use of fuel-run boats), thus leading to the preservation of the natural environment.

An example of the GUI of the Monitoring Platform is provided in Figure 39.

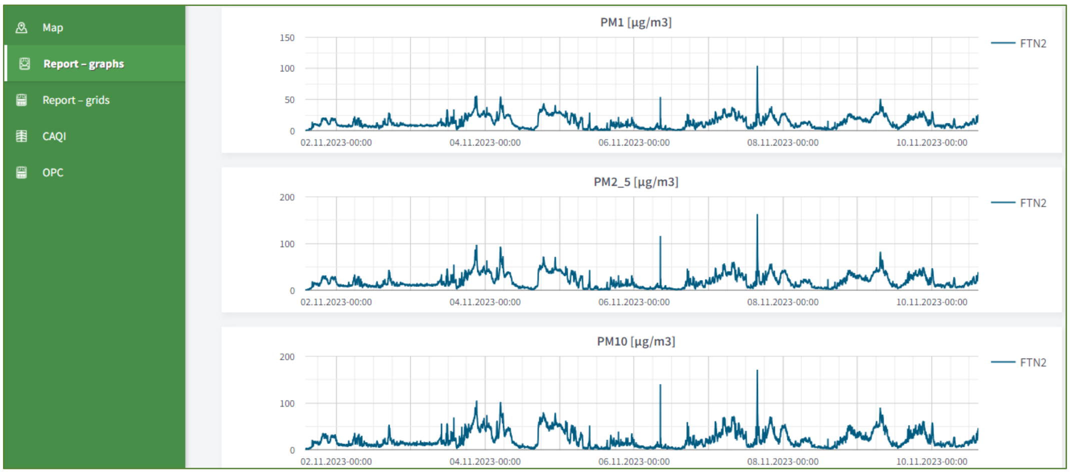

Figure 39 Shared environment monitoring platform

6.3.4 Use case 5.4: Shared digital agriculture platform

This use case will provide decision support advices to the farmers helping them to timely apply adequate agriculture measures and to increase efficiency of the irrigation management.

Communication, computing, and sensing infrastructure established in UC 5.1 will be used for gathering relevant parameters, processing and transferring them to the farm management/decision support system.

The acquired data (air temperature, air humidity, precipitation, solar radiation, barometric pressure, leaf wetness, wind speed and direction) will be used to generate adequate decision support insights and recommendations to the farmers. For that, the LL5 will rely on agroNET (DNET's proprietary solution) platform as the basis. The focus will be, taking into account the crops primarily cultivated in the LL5 region, on **optimization of the irrigation and pesticide spraying**. Functionalities implemented in UC 5.2 will be integrated with the platform and validated in collaboration with the farmers.

Access to the platform and the data of interest to the farming community (e.g. environmental conditions, when to spray against crop diseases, frost alarming) will be provided to all farmers in the region, while the data related to specific fields and recommendations/insights will be accessible to the respective field owners only.

Data collected across the fields belonging to the community, will be aggregated, contextualized, anonymized, and prepared for use by the relevant domain data spaces, serving, potentially, as an additional source of income for the community.

Figure 40 provides an example of data visualization in the agroNET platform, proprietary of DNET.

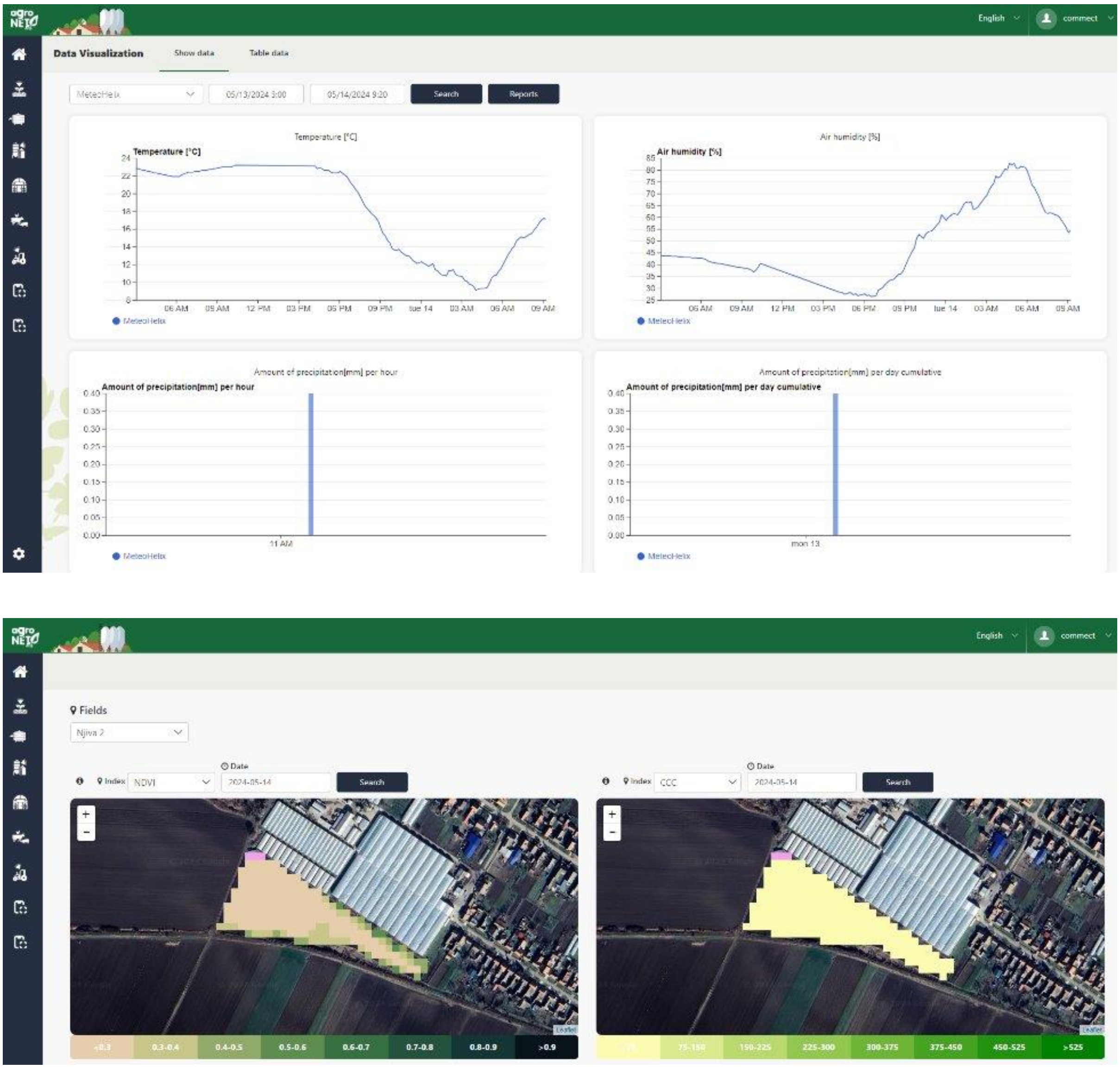

Figure 40 Shared digital agriculture platform

6.3.5 Use case 5.5: Shared community platform

This UC focuses on development of the shared platform that fosters collaboration and knowledge sharing, creating a supportive community network. The platform will evolve based on the feedback from the community, the availability of data and interested partners/third parties providing additional content and services.

This use case will collect data from the shared platforms implemented by UC 5.3 and UC 5.4 as well as from Internet sources and direct contributions from farmers and other stakeholders.

The platform will act as a central place for community collaboration, exchange of data, sharing best practices, and offering advice among the farming community. Leveraging modern AI technologies, the platform will evolve toward a community co-pilot, facilitating easier adoption of digital technologies in the rural areas.

7 Living Labs Synergies

After a series of workshops and interviews with stakeholders and partners, the 5 COMMECT LLs identified some relevant use cases that can address end users' needs, by extending connectivity in rural areas. A clear pattern of the network and computing need was defined across the use cases: Different deployments of **Low Power Wide Area Networks** (LPWAN) or **5G Private Networks** (PN) are needed to extend **last mile coverage** networks in the LLs. Also, the integration of **satellite** communications in access or backhaul networks to ensure **broadband connectivity** was also identified for the needs of some UCs. Moreover, **edge computing** techniques are developed in several LLs to meet the requirements of the use cases in terms of communication efficiency and data exploitation. These motivated research activities carried out in WP2.

Despite the difference between the LLs - focused on various sectors, located in different countries, facing different challenges - the exchanges between the teams raised some common points between the UCs and LLs from perspectives of: i) Provided solution, ii) collected data and iii) connectivity solutions.

From the first perspective, all the Living Labs provide **automated monitoring solutions** to track environmental parameters in agricultural fields (LL Luxembourg: vineyard, LL Türkiye: olives and LL Serbia: arable lands) in forest (LL Norway) or in Livestock transportation (LL Denmark). Data processing and exploitation from different solutions are discussed among the consortium to exchange the lessons learned and evaluate if some methodologies can be reused in other LLs.

From the perspective of collected data, two main categories identify different requirements in terms of connectivity solutions: (1) **IoT data** collected from sensors (UC1.1: microclimate and field monitoring in vineyards, UC2.2: environmental monitoring to protect forest, UC3.1: monitoring of animals' health during transportation, UC4.1: microclimate monitoring for olive farming, UC5.1 and UC5.3: environmental monitoring for sustainable agriculture); and (ii) **Image and video data** collected from cameras (UC1.2, UC2.1, UC2.2, UC3.3, UC4.2 and UC5.2).

The selection of hardware, positions to install devices and configurations to collect, process and transmit data are discussed during the WP4 meetings where all the LLs participate to give advice and learn from the experience of other LLs deployments. Moreover, data processing solutions presented in some LLs (UC2.2 and UC2.3: near edge vs far edge, UC5.2: edge computing), can be tested in other LLs collecting the same type of data (UC1.2, UC3.3 and UC4.2)

The last classification to identify exchange and synergies between LLs is related to **connectivity solution** deployed to extend the coverage in rural and remote areas. LoRaWAN technology was selected by LLs Luxembourg and Serbia to provide access for IoT devices, while eMTC and NB-IoT were selected by LL Türkiye. As another alternative, LL Luxembourg and LL Türkiye will use also XG to enable sensors data collection in some specific regions. These technologies can be replicated in other LLs, in other countries, if they prove their efficiency after first tests in the initial target LLs.

For broadband connectivity, LLs Norway and Denmark will be deploying 5G PNs with terrestrial and satellite backhauling using different configurations and hardware. LL Luxembourg also will be testing satellite backhauling. Comparisons between these different deployments will give important lessons about the efficiency of each solution and how and where it can be optimally reproduced.

Some examples of win-win collaboration between LLs are already identified, at this stage of the project, and can be further explored in the next version of this deliverable (D4.2 due by M34). For instance, the RS data collection at field scale for UC1.2 of LL Luxembourg aims at collecting UAV video of the vineyard and process it at server level to provide DT services. At this stage, no connectivity platform is deployed for this operation, data uploading from the UAV camera is done offline. In a similar use case (i.e.UC2.2), LL Norway uses UAVs for real time monitoring of the forests, and aspires to deploy a DT of the forest in the context of UC2.3, if the duration of the project allows that. An exchange of expertise between the LLs can help reproduce the connectivity platform in UC1.2 and DT implementation in UC2.3. Similar exchanges can be identified also with LL Serbia from UC5.2, many LLs will be interested in securing the equipment deployed in the field.

The following table summarises the common points between the UCs in COMMECT LLs:

Table 2 Summary of COMMECT Solutions

<table>
<tr><th>Collected Data Type</th><th>Use Case</th><th>Living Lab</th><th colspan="2">Connectivity Solution</th></tr>
<tr><td rowspan="5">IoT sensor data</td><td>UC1.1</td><td>LL N.1 Luxembourg</td><td colspan="2">LoRaWAN
XG</td></tr>
<tr><td>UC2.2, UC2.3</td><td>LL N.2 Norway</td><td colspan="2">Wi-Fi
Bluetooth
5G Private Network</td></tr>
<tr><td>UC3.1</td><td>LL N.3 Denmark</td><td colspan="2">5G Private Network</td></tr>
<tr><td>UC4.1</td><td>LL N.4 Türkiye</td><td colspan="2">NB-IoT
eMTC
XG</td></tr>
<tr><td>UC5.1, UC5.3, UC5.4, UC5.5</td><td>LL N.5 Serbia</td><td colspan="2">LoRaWAN</td></tr>
<tr><td colspan="3"></td><td>Access</td><td>Backhaul</td></tr>
<tr><td rowspan="5">Video/ Image</td><td>UC1.2</td><td>LL N.1 Luxembourg</td><td>Wi-Fi</td><td>Satellite
XG</td></tr>
<tr><td>UC2.1, UC2.2, UC2.3</td><td>LL N.2 Norway</td><td>5G Private Network</td><td>Satellite
XG</td></tr>
<tr><td>UC3.2, UC3.3</td><td>LL N.3 Denmark</td><td>5G Private Network</td><td>Satellite
XG</td></tr>
<tr><td>UC4.2</td><td>LL N.4 Türkiye</td><td colspan="2">XG</td></tr>
<tr><td>UC5.1, UC5.2</td><td>LL N.5 Serbia</td><td>LoRaWAN (edge ML)</td><td>XG</td></tr>
</table>

8 Conclusions

This document describes the activities carried out in the LLs in WP4, and the status of their deployment, till M15 (November 2023). After performing many workshops and exchanges with end-users and stakeholders, the consortium identified specific Use Cases and requirements to address the users' needs in each LL.

Five LLs are set up and 15 UCs are identified for deployment. For each use case, detailed analysis of the requirements for connectivity solutions was performed in the activities of Task1.2. Based on those requirements, specific technologies -among those defined in WP2- are selected to bring connectivity to rural area.

This first deliverable of WP4 describes how the project partners created the LL ecosystem, in close collaboration with end-users, and different actors of the agro-forest value chain. The engagement of several stakeholders that have been closely working with the COMMECT partners, was translated in the set-up of the five LLs. It followed the implementation of the 15 use cases in the LLs with the final aim of demonstrated the expected impact, and promote the adoption and exploitation of the proposed solutions by the engaged stakeholders.

LL N.1 Luxembourg identified 2 use cases to be deployed, the deployment for the first one is already ongoing, with the support of the stakeholders (IVV, MAAV), in the vineyards of end-users. Several tests are planned for the demonstrations of the two connectivity solutions. Moreover, several discussions are ongoing, for the co-creation of appropriate solutions for the implementation of the second use case.

LL N.2 Norway identified 3 use cases with 3 connectivity solutions that will be deployed starting from the first quarter of 2024. Support from different stakeholders will be fundamental for implementing and testing the solutions.

LL N.3 Denmark also identified 3 use cases; these UCs will be deployed using 2 different connectivity solutions starting from the first quarter of 2024. Several discussions are ongoing with the livestock transport companies, to get the right support in the next phase of the project.

LL N.4 Türkiye identified and already deployed 2 use cases, using three connectivity solutions, in different regions in Türkiye and started collecting data. The activities are strongly supported by TOB, the Ministry of Agriculture, in close collaboration with different actors.

LL N.5 Serbia identified 5 use cases that will be deployed in Spring 2024 to ensure that the platform is operational before the vegetation period.

Use cases and connectivity solutions were designed based on the needs of local communities, end users and stakeholders involved in each LL. However, these solutions are scalable and can be applied in other countries with similar needs.

The impact of these solutions as well as the evaluation of the performances of these deployments in the LLs is carried out in the activities of WP5. A second deliverable of this WP4, i.e. deliverable D4.2, due by M34 will update this document with the final implementations and the contributions of COMMECT LLs to the extension of connectivity and expansion of the digital landscape in rural and remote areas. Feedback from stakeholders and end users will be collected to define the socio-economic and environmental impact of each LL.

Annex: Enabling technology in the LLs

A - LL Luxembourg

Weather Station (Lumbara base)

To monitor weather conditions in the vineyards, LL Luxembourg selected the “Lumbara base” weather station [30], presented in Figure 41; a multi-sensor weather station, supporting several connectivity solutions. It is composed by 5 main modules:

- Transmission module: offering a versatile connectivity that can be configured according to the use. It can send collected data via cellular network (2G/4G), Wi-Fi, NB-IoT or LoRaWAN. In the context of this LL, we configure transmission via LoRaWAN interface or XG interface (more details are provided in network architecture)

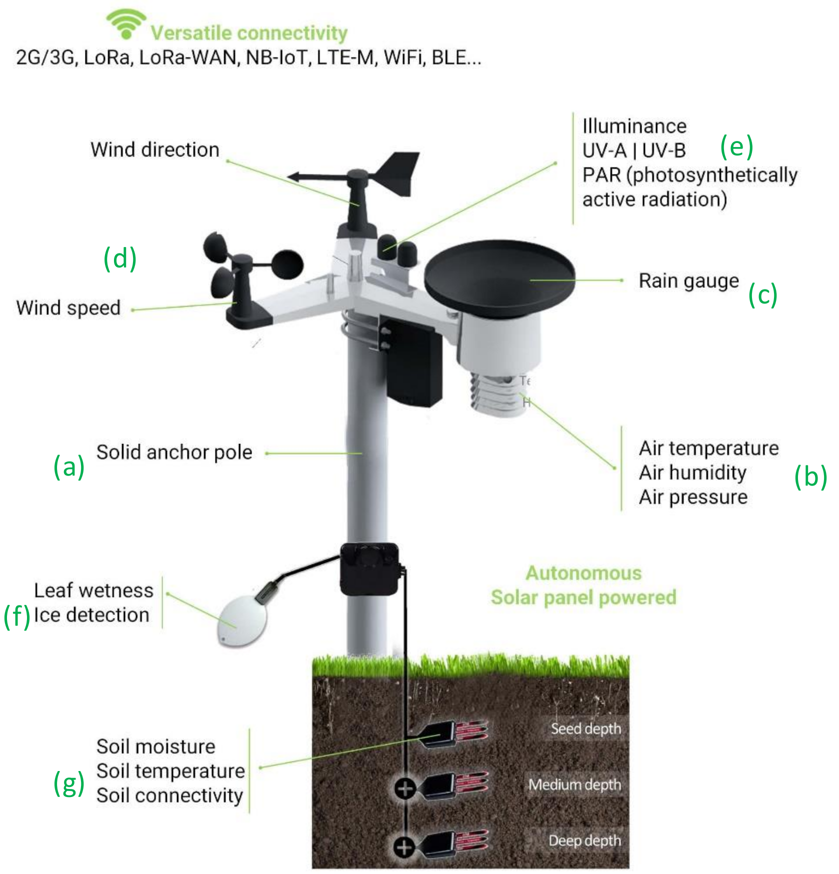

Figure 41 Weather stations used in LL1.

- Power module: The Lumbara base will be installed in this LL with a solar panel connected to a smart Maximum Power Point Tracking (MPPT) regulator with battery charging protection. The solar panel (see Figure 42) is installed vertically on the holder of the base (a), in the direction of south.

Figure 42 Solar panel of the weather station.

- Environment module: This module is an aggregation of various sensors for environmental monitoring. It collects data related to air temperature, humidity, and pressure (b), rainfall (c), wind direction and speed (d), and illuminance and UV index(e). This module should be installed at a distance from objects (vine rows and buildings), and at a height of 1-2m from the ground, to avoid interaction with surroundings and get accurate readings.
- Leaf wetness module: This module (f) collects data related to leaf temperature, moisture, and conductivity. It can also detect ice and water drops on the leaf. This sensor has the shape of the leaf and will be installed on the plant canopy (See Figure 43)

Figure 43 Leaf wetness module.

- Soil module: This module (g) integrates professional soil sensors to measure temperature, moisture, and conductivity, and PH and NPK concentrations at different depths. The sensor probe will be plugged deep in the rooting crops (30cm) of a vine row for accurate monitoring.

<u>LoRa Gateway (RAK wireless)</u>

To collect data from sensors in the field, the LL Luxembourg selected the RAK7249 [31] outdoor gateway (see Figure 44). It is an industrial equipment with high reliability and flexibility for deployments in the field. Its software and UI sits on top of OpenWRT, offering the possibilities to develop customized applications via SDK.

The main board of the Gateway includes hardware and software to collect LoRa/LoRaWAN frames from devices in the coverage range, via 8 to 16 channels. The transmit power of the gateway is configurable up to 27dBm and can receive with a sensitivity down to –142dBm. It is also deployed in this LL with an 868MHz LoRa antenna with 3dB gain.

The data backhauling with this gateway can be done using cellular networks (4G), Wi-Fi or Ethernet.

The gateway can be powered by direct plug or can use the integrated backup battery (autonomous for 10 hours under typical conditions) plus optional solar kit.

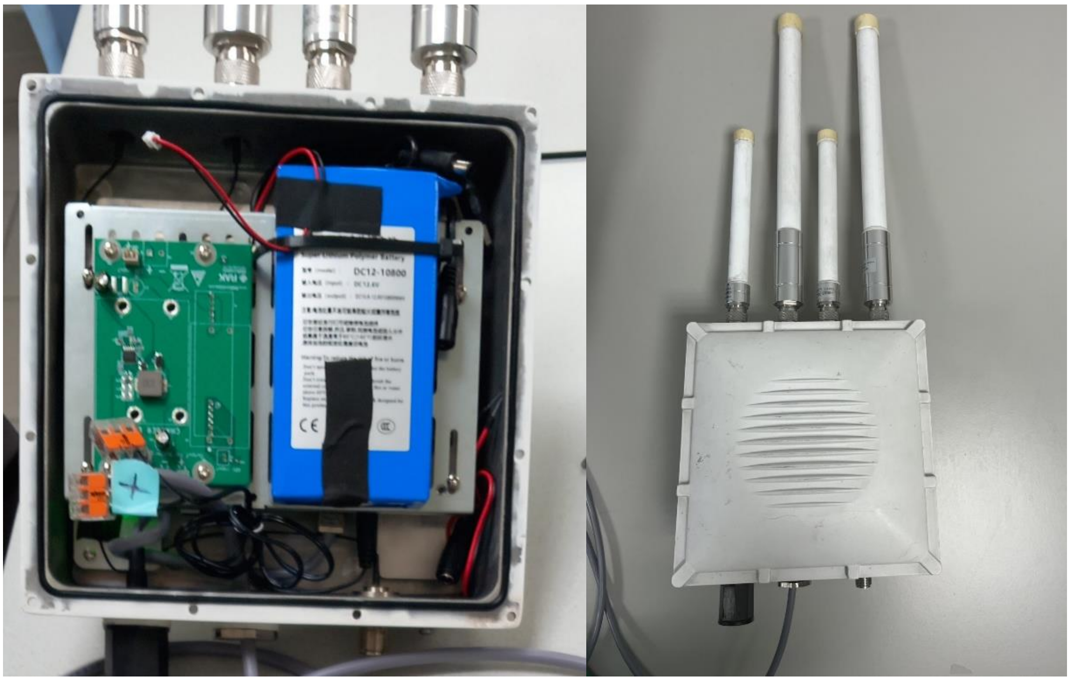

Figure 44 LoRaWAN RAK7249 gateway.

B - LL Denmark:

The multi-access gateway

The baseline element of the multi-access gateway is an ARM-based Gateworks GW6400. It consists of a small size industrial computer that supports up to four mini PCIe extension cards and has 5 Gbit Ethernet ports and integrated GPS support [32]. Two SIMCOM SIM 8380G-M2 modems will be connected to the computer through two of the mini PCIe ports in order to obtain the cellular samples from either one or two operators. These multiband modems support 3GPP Release-16 5G Non-Standalone (NSA) and standalone (SA), and up to four antennas each [33].

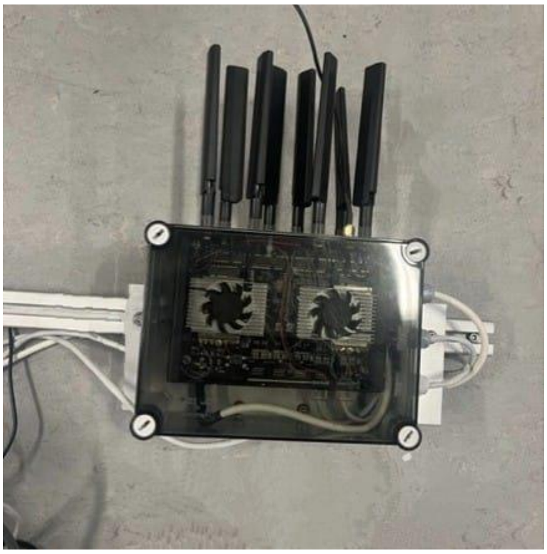

Figure 45. Measurement Box: Multi-Access Gateway (MAGW).

Installed in the MAGW is *mpconn*, a tunnelling program developed by Aalborg University that allows performing packet duplication at Layer 3 [34]. The tool receives packets from an entity, generates a new UDP packet by encapsulating the latter and adding a sequence number, and duplicates the packet to send it through all the interfaces configured (e.g., two 5G interfaces connected to two different operators). The same tool should be installed on the receiving end, where the packets will be received and processed consequently, as shown in Figure 46.

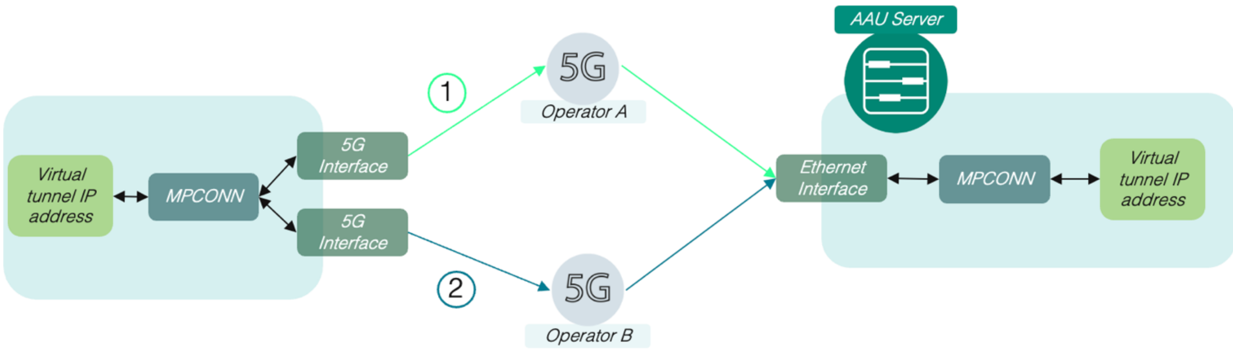

Figure 46. Multi-connectivity tool (mpconn) scheme.

Amarisoft Callbox Classic:

The Amarisoft's Callbox Classic can provide for local 5G coverage by using a local 5G frequency license typically in the n77 band (3.3 GHz to 4.2 GHz) and can be configured with bandwidths up to 100 MHz wide [35]. The Callbox Classic has also MIMO support (2x2 or 4x4) and depending on the bandwidth configurations as well as terminal capabilities the achievable throughputs are in order of magnitude of few hundreds of Mbps. These throughputs should be sufficient for the digitisation and video monitoring of the livestock transportation and loading/unloading.

TP-Link's Archer AXE75:

The local Wi-Fi network coverage can be provided by e.g. TP-Link's Archer AXE75 Wi-Fi router [36]. It is important to note that this commercial device supports the WiFi6E option that is capable to operate at the 2.4 GHz and 5GHz, in addition to the new Wi-Fi 6GHz band. The throughputs achievable with this device again depend on the configuration, interference conditions, band usage as well as terminal support, and can easily achieve few hundreds of Mbps, which should be sufficient for the purpose of the use case.


Figure 47. Amarisoft's 5G node (left) and TP-Link's WiFi node (right)

video camera:

A video camera, e.g. GoPro Hero product lines [37], connected to the road barrier or the transportation truck and connected to the local 5G or Wi-Fi network is suitable for providing the real-time video streaming.

C- LL Serbia:

To implement the use cases in the LL Serbia, a set of devices listed below will be deployed setting up the required infrastructure:

Mobile solar generator: to provides power supply to all consumers (communication and computing equipment, sensors, irrigation systems, etc.). The prototype designed for COMMECT by the partner ZZSA is illustrated in Figure 48

Figure 48 Mobile solar generator

Communication infrastructure: mobile router with a mobile network (4G) interface for the backhaul connectivity and acting as a Wi-Fi access point, LoRaWAN gateways, GPS location trackers (see Figure 49).

Figure 49 LoRaWAN gateway and GPS tracker

Computing infrastructure: edge ML gateway with adequate GPU hardware and software framework to provide edge processing capabilities that will enable creation of autonomous systems capable of controlling and automating agricultural operations, while reducing traffic load through advanced data processing, and making advanced services more accessible even in areas with poor network coverage.

Figure 50 EdgeML device

(Environmental) sensing infrastructure: sensors for continuous monitoring of air quality (air temperature, CO, NO2, SO2, O3, PM), water quality (temperature, pH, dissolved oxygen, EC/salinity, oxidation-reduction potential) and noise level. Same examples of those type of sensors are illustrated in Figure 51.

Figure 51 Environment monitoring sensors

Weather station for monitoring environmental parameters (air temperature, air humidity, precipitation, solar radiation, barometric pressure, leaf wetness, wind speed and direction) relevant for agriculture decision support advices.

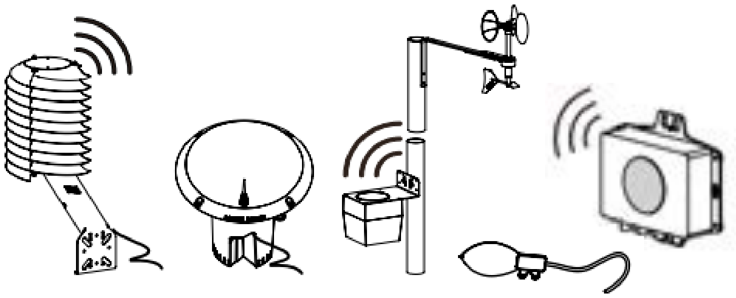

Figure 52 Weather station

(Agriculture) sensing infrastructure: sensors for monitoring soil conditions (moisture, temperature, electroconductivity).

Figure 53 Soil sensor

Security and agriculture sensing infrastructure: video cameras to monitor plant growth, machinery activities, and safety hazards in the field, enabling real-time analysis of crop progress, identification of abnormalities, optimization of machinery operations, and enhanced safety measures.

Figure 54 Security sensing infrastructure

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