



Innovation and Capacity building

in Agricultural Environmental and Rural UAV Services



ICAERUS

D3.1: Use Case Plan **Version A**

WP3: ICAERUS Use Cases and Demonstration Activities

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Executive Summary

The ICAERUS project proposes an "application-oriented" approach through the selection of five (5) specific drone applications to explore the multi-purpose application potential of drones in agricultural production, forestry and rural communities. The selected drone applications represent the main sectoral and societal uses of drones in Europe and cover multiple applications that are interconnected within Europe's complex rural landscape. The vision of ICAERUS is to explore opportunities and provide a more comprehensive and interconnected representation of the potential and impact of drones as multi-purpose vehicles in agriculture, forestry and rural areas of the European Union (EU). The aim is to demonstrate and support the effective, efficient and safe use of drones through their application and to identify the risks and added values associated with their use. "Taking off" from the current state of the art in the drone ecosystem, ICAERUS will "rise up" by further developing existing software technology, platform components and knowledge related to drones to harness the potential of drones and strengthen capacities to reduce their risks, achieve better informed decision-making and improve sustainability performance and competitiveness in agriculture, forestry and rural areas. This will be done in two ways: a) basic 'eye in the sky' applications using the drone as a positioning system for visual observation and recording, and b) a "hand in the sky" application for spraying and delivery of goods. ICAERUS plans to create an efficient, trusted and safe environment for the EU drone services market through research, technology optimisation, demonstration and education on drones to achieve the EU's decarbonisation, digitalisation and resilience goals. ICAERUS consists of a balanced, cross-sectoral and experienced consortium including research institutions, SMEs (small and medium-sized enterprises), technology providers, associations and non-profit organisations.

Deliverable "D3.1 Use Case Plan", aims to provide a general overview of the activities to be carried out through the Use Cases (UCs) during the lifetime of the project and a report detailing the plan for the development and implementation of these UCs. The aim of this document is to provide general guidance for all UCs to be implemented. This deliverable is based on the individual plans of the following UCs: 1) Crop monitoring in Spain; 2) Drone spraying in Greece; 3) Livestock monitoring in France; 4) Forestry and biodiversity monitoring in Lithuania; and 5) Rural logistics in North Macedonia. The ICAERUS UCs are strategically selected to cover multiple applications, which can be interconnected within the complex rural European landscape (i.e., areas with numerous neighbouring small settlements, towns and villages, of reduced population mostly dedicated to agricultural activities, open field production and livestock, adjacent to forest areas). This is based on the project's specific interest of combining multiple drones uses for the benefit of remote rural areas with specific characteristics, where drones can simultaneously be applied to multiple tasks. This report contains tailor-made guidelines and concludes with a detailed overview of the planning for each of the UCs. The information was provided directly by the UC leaders to ensure the specificity of the guidelines and the smooth running of the activities. This deliverable will be updated periodically to reflect additional methodologies, measurements and data adopted during the life of the project. This is the first version of Deliverable D3.1. An updated version of this report, including refined plans for the five UCs, are planned for M34 of the project duration.

Table of Contents

Executive Summary	5
1. Introduction	9
1.1 Purpose.....	9
1.2 Abbreviations	11
2. Individual Use Case Plans	12
2.1 Use Case 1: Crop Monitoring.....	13
2.1.1 Introduction.....	13
2.1.2 Key Activities	15
2.1.3 Technical Requirements.....	17
2.1.4 Expected Results.....	20
2.1.5 Replicability	21
2.2 Use Case 2: Drone Spraying.....	22
2.2.1 Introduction.....	22
2.2.2 Key Activities	24
2.2.3 Technical Requirements.....	26
2.2.4 Expected Results.....	32
2.2.5 Replicability	33
2.3 Use Case 3: Livestock Monitoring	34
2.3.1 Introduction.....	34
2.3.2 Key Activities	40
2.3.3 Technical Requirements.....	45
2.3.4 Expected Results.....	48
2.3.5 Replicability	48
2.4 Use Case 4: Forestry and Biodiversity	49
2.4.1 Introduction.....	49
2.4.2 Key Activities	53
2.4.3 Technical Requirements.....	57
2.4.4 Expected Results.....	67
2.4.5 Replicability	69
2.5 Use Case 5: Rural Logistics.....	70
2.5.1 Introduction.....	70
2.5.2 Key Activities	74
2.5.3 Technical Requirements.....	78
2.5.4 Platforms & Mounted Technological Components	79
2.5.5 Expected Results.....	83
2.5.6 Replicability	83
3. Summary	85
References	86

Table of Figures

Figure 1: Selection of drone application areas in ICAERUS and their geographic distribution	9
Figure 2: Illustration of the workflow plan of the key activities in UC1	15
Figure 3: Timeline of the key activities in UC1	16
Figure 4: Map of Mas Martinet vineyard in Tarragona (Catalonia, Spain).....	17
Figure 5: Mas Martinet vineyard viticulture analytics.....	17
Figure 6: Example of a plant growth curve	18
Figure 7: Example of the platforms and mounted technological components required for the UC1	19
Figure 8: Illustration of the workflow plan of the key activities in UC2.....	25
Figure 9: Timeline of the key activities in UC2	26
Figure 10: The pilot area of UC2 in Spata, Greece	27

Figure 11: The experimental design of the spraying quality trials	28
Figure 12: The WSPs collectors deployed and collected in field trials	28
Figure 13: Example of WSPs used to sample spraying droplets.....	29
Figure 14: The filter paper collectors used at the first 5 sampling distances (1 to 5 m from the last vine row) 30	
Figure 15: Retrieval of the tracer deposits in the laboratory	30
Figure 16: Example of the technological components deployed in UC2	31
Figure 17: Map of the pilot area (Farm A, 70 ha), which is divided into 28 paddocks so that several lots can rotate grazing. In general, up to 5 batches of animals can graze in different paddocks at the same time	38
Figure 18: "Bocage" landscape (left) and a group of animals (cows and calves) in a paddock (right).....	38
Figure 19: Illustration of how the use of drones can facilitate daily routine work in a grassland. The farmer has to check daily on foot the different batches of animals (white cows) scattered around the farm and assess the availability of the grass (top) or alternatively perform the same checks with the use of a drone from the main settlement of the farm (marked with the letter H) without much effort (bottom).....	39
Figure 20: Lowland pastures (left), woody rangelands (centre) and summer mountain pastures (right)	40
Figure 21: Illustration of how the use of drones can ease the daily routine work on a lowland pasture. Every day, the farmer has to use a car to check the various flocks of sheep scattered around the farm and assess the availability of grass (above). Alternatively, he can carry out the same checks with the use of a drone from the main settlement of the farm (marked with the letter H) without much effort (below)	41
Figure 22: The drone is an eye-in-the-sky providing visual feedback in places where the shepherd has a low visibility on his flock	43
Figure 23: Illustration of the workflow plan of the key activities in UC3.....	44
Figure 24: Timeline of the key activities in UC3	44
Figure 25: Map of the area of Farm A. The coloured polygons represent areas where a drone can perform a continuous flight. The green polygons denote 3 main regions for monitoring cattle with drone use. The blue polygons denote regions where drone use is less beneficial due to various constraints (roads, proximity to other facilities or residents). The orange markers represent potential launch sites suitable for efficient drone flight planning, covering the entire surrounding area (green polygons), while the blue markers indicate the main settlement of the farm.....	45
Figure 26: Map of the area of Farm B. The coloured polygons represent areas where a drone can perform a continuous flight. The green polygons indicate 2 main areas for monitoring cattle with drone use in winter. The red polygons indicate large forested grazing areas of more than 500 ha. The orange markers represent potential launch sites for drone flights within the green polygons. Both launch sites are located in the main settlement of the farm.	46
Figure 27: Map of the summer mountain lands of farm B. Highlighted polygons represent areas where a drone can perform continuous flight	46
Figure 28: Distribution of potentially beneficial use cases of crewed aircraft and different UAV types for remote sensing in forestry	50
Figure 29: Illustration of the UAV mission activities' workflow plan for the UC4.....	56
Figure 30: Illustration of the general workflow plan of the key activities in UC4.....	56
Figure 31: Timeline of the key activities in UC4	57
Figure 32: Test area for the scenario 1 of the UC4	57
Figure 33: Test site for the scenario 2 of the UC4.....	58
Figure 34: Map of the African swine fever spatial distribution	58
Figure 35: Flowchart of the employed methodology for the identification of the trees damage level	60
Figure 36: Flowchart of the employed methodology for the identification of the forest fuel types	62
Figure 37: Example of the developed prototype models and algorithms for boars' detection	63
Figure 38: Illustration of the boars counting model.....	63
Figure 39: Illustration of the workflow plan of the key activities in UC5.....	77
Figure 40: Timeline of the key activities in UC5	78
Figure 41: Map of the pilot area for the scenario 1 implementation within UC5 (Ohrid, North Macedonia)	79
Figure 42: Map of the pilot area for the scenario 2 implementation within UC5 (North Macedonia)	79
Figure 43: Example of a plant growth curve	80
Figure 44: Illustration of the system's workflow that will be developed within UC5	80

Table of Tables

Table 1: Examples of potential barriers for the UC1 implementation.	15
Table 2: Key activities of UC1	16
Table 3: Examples of potential barriers for the UC2 implementation.	24
Table 4: Key activities of UC2.	24
Table 5: Total iterations for the experiment within UC2.....	29
Table 6: Examples of potential barriers for the UC3 implementation	36
Table 7: Key activities of UC3	42
Table 8: Examples of potential barriers for the UC4 implementation	53
Table 9: Key activities of UC4	53
Table 10: Preliminary list of the hyperspectral indices used in UC4.....	59
Table 11. Preliminary mission plan for wildlife monitoring in mixed forest areas (autumn-winter) within UC4.	66
Table 12: Preliminary connection points for the drone logistics testing within UC5	71
Table 13: Examples of potential barriers for the UC5 implementation	73
Table 14: Key activities of UC5	75

1. Introduction

1.1 Purpose

ICAERUS is taking an “application-oriented” approach in selecting UCs, to explore the multi-purpose application potential of drones in rural European areas. Therefore, the ICAERUS UCs will cover five (5) appropriately selected drone application areas, which represent the most important sectoral and societal drone usage purposes in Europe (crop monitoring, drone spraying, livestock monitoring, forestry and biodiversity, and rural logistics) as shown in **Figure 1**.



Figure 1: Selection of drone application areas in ICAERUS and their geographic distribution

The ICAERUS UCs are strategically selected to cover multiple applications, which can be interconnected within the complex rural European landscape (i.e., areas with numerous neighbouring small settlements, towns and villages, of reduced population mostly dedicated to agricultural activities, open field production and livestock, adjacent to forest areas). This is based on the project’s specific interest of combining multiple drones uses for the benefit of remote rural areas with specific characteristics, where drones can simultaneously be applied to multiple tasks. The following use cases have been selected: 1) Crop monitoring in Spain; 2) Drone spraying in Greece; 3) Livestock monitoring in France; 4) Forestry and biodiversity monitoring in Lithuania; and 5) Rural logistics in North Macedonia.

WP3 of the ICAERUS project aims to develop and implement key Use Cases (UCs) and demonstrate the effective and efficient use of drones and data analytics models in agricultural production, forestry and rural areas. The specific objectives are:

- Develop a plan for the UCs explaining how the UCs will be designed and deployed.
- Deployment, testing, monitoring and evaluation of the UCs.
- Assess socio-economic and environmental impacts.
- Demonstration of innovative approaches to the use of drones and evaluation of end-user experiences.

More specifically, the main purpose of “T3.1 Use Case Planning”, is to develop the plan for five (5) defined ICAERUS UCs and explain how they will be designed and deployed according to the needs identified in

“T1.1 Understanding the Drone Market”. The UCs will select the drone platforms and mounted technological components to be used during their deployment. This will utilise the findings from “T1.2 Stock-taking of Drone Technologies” and the drone data analytics models and algorithms from “T2.1 Identify Existing Drone Data Analytics Models”. The datasets to be used in the UCs will undergo a preparation process to meet the requirements and use the appropriate data analytics models for WP2.

The UCs of T3.1 are briefly described below:

Crop Monitoring Use Case

- Demonstrate the capacity of drones in disease and plant stress identification and weed detection in vineyards by building on existing and implemented solutions and avoiding duplication of effort.
- Assess drones as a tool for 3D canopy reconstruction in vineyards, using aerial (top) and ground (side) image acquisition.
- Develop a user-friendly dashboard as a DSS for the analysis and visualisation of drone data and for recommendations for action.

Test site: Camp de Tarragona, Spain | **Key partners:** NMN & EI

Drone Spraying Use Case

- Test and assess spraying configurations for optimal drone spraying applications under field conditions.
- Compare existing conventional with drone spraying practises in terms of efficiency and environmental impact.
- Identify risks and develop mitigation strategies associated with drone-based plant protection applications.

Test site: Attica and Viotia Regions, Greece | **Key partners:** AUA & HCPA

Livestock Monitoring Use Case

- Evaluate drone solutions for monitoring different grazing cattle and sheep systems, building on existing and implemented solutions and avoiding duplication of effort.
- Assess their labour-reduction capabilities for drone-based herd monitoring.
- Investigate governance models and brakes and levers for drone adoption.

Test site: Alpes-de-Haute-Provence and Saône-et-Loire, France | **Key Partner:** IDELE

Forestry and Biodiversity Use Case

- Monitor forest tree health through the use of drones, satellites and data science.
- Identify and inspect areas of potentially high fire risk.
- Monitor ecosystems and assess biodiversity and wildlife populations.
- Evaluate the ability of drones to control or prevent the spread of infectious diseases affecting both wildlife and domestic animals.

Test site: Scots pine forest and surrounding mixed forest areas, Lithuania | **Key Partners:** ART21 & AFL

Rural Logistics Use Case

- Design and develop an innovative fleet management system for drone deliveries.
- Automate drone navigation operations by integrating state-of-the-art technologies.
- Assess three drone types in terms of size/weight and distance of packages to be delivered.

- Implement the principles of the DaaS model.

Test site: Vevchani, N. Macedonia | **Key Partners:** GS & AGFT

1.2 Abbreviations

AI	Artificial Intelligence	ML	Machine Learning
API	Application Programming Interface	Mr-M	Max ratio Multiple-drones
ASF	African Swine Fever	Mr-S	Max ratio Single-drone
BVLOS	Beyond Visual Line Of Sight	MSI	Moisture Stress Index
CAD	Computer-Aided Design	NAA	National Aeronautic Association
DaaS	Drone as a Service	NBR	Normalized Burn Ratio
DD-FMS	Drone-Delivery Fleet Management System	NDVI	Normalised Deference Vegetation Index
DEM	Digital Elevation Model	NMEA	National Marine Electronics Association
DSS	Decision Support System	POI	Points Of Interest
ESA	European Space Agency	PPPs	Plant Protection Products
EU	European Union	PWA	Progressive Web Apps
FBR	Fire Behaviour Prediction	RGB	Red Green Blue
GhG	Greenhouse Gas	RF	Radio Frequency
GNSS	Global Navigation Satellite System	SUD	Sustainable Use of pesticides Directive
GPS	Global Positioning System	TIFF	Tag Image File Format
GSM	Global System for Mobile communications	TSP	Traveling Salesman Problem
ICAO	International Civil Aviation Organization	UASS	Unmanned Aerial System Services
IoT	Internet of Things	UAV	Unmanned Aerial Vehicle
IR	InfraRed	UC	Use Case
ISO	International Organization for Standardization	UML	Unified Modelling Language
JPEG (JPG)	Joint Photographic Experts Group	VLOS	Visual Line of Sight
JSON	JavaScript Object Notation	VRP	Vehicle Routing Problem
KPI	Key Performance Indicator	VTOL	Vertical Take Off and Landing
LiDAR	Light Detection and Ranging	WP	Work Package
Mc-M	Max clique Multiple-drones	WSPs	Water-Sensitive Papers
MDSP	Multiple-drone Delivery Scheduling Problem		

2. Individual Use Case Plans

Each Use Case Leader, with the support of their respective Use Case Partner (Crop Monitoring Use Case: NMN & EI; Drone Spraying Use Case: AUA & HCPA; Livestock Monitoring Use Case: IDELE; Forestry and Biodiversity Use Case: ART21 & AFL; Rural Logistics Use Case: GS & AGFT), used the ICAERUS Use Case Planning template to explain how their Use Case will be developed and deployed according to the needs identified in “T1.1 Understanding the Drone Market”. Starting with the importance of the Use Case, the methodology and key activities, the UCs selected the drone platforms and technological components to be used during their deployment, utilising the findings from “T1.2 Stock-taking of Drone Technologies” and the models and algorithms for drone data analytics from “T2.1 Identify Existing Drone Data Analytics Models”.

Each of these Use Case Plans is divided into four sections: the introduction and its specific objectives, key activities, the technical requirements and the expected outcomes. The introduction describes the importance of the UCs proposed and contains information to clearly identify the reason the UC is being conducted and what is intended to accomplish, along with any assumptions being made. The introduction includes challenges and key questions, objectives, potential barriers, and Use Case scenarios. The key activities section includes a description of the key activities and their workflow, as well as a timeline for their completion. The technical requirements section provides information on the technical guidelines the site description where the UCs will take place, the equipment and methods used, along with a detailed description of all resources necessary to fully conduct the trials, and the expected timeline are included. Information is included on the drone platforms and mounted technological components to be used, measurements and data to be collected, and drone data analytics models. Piloting plans were mainly developed based on methods and instruments found in the scientific literature. Finally, the expected results section outlines the expected outcomes of the pilot trials, their potential impact, and the replicability of the results.

The following chapters present the five Individual Use Case Plans in great detail.

2.1 Use Case 1: Crop Monitoring

2.1.1 Introduction

Agricultural resources are witnessing tremendous supply side stresses as a result of rapidly increasing population, sub-optimal farming practices, increased pest damage occurrences due to climate change, and loss of productive land by other human activities such as urbanisation (Ortiz et al. 2008, Bebber et al. 2014, d'Amour et al. 2017). Several initiatives have been created with the goal of improving our ability to produce and share relevant, timely and accurate trends and forecasts of crop productivity globally (Jia et al. 2019). Robotic farm surveillance, automatic process control, and automated advisory for any event in the farms are becoming extremely important to increase quality of food production all over the world (Bhatt et al. 2019).

The overall scope of UC1 is to create a set of transversal solutions to manage, monitor, and interact within vineyards with the objective of detecting diseases and monitoring canopy health. UAVs and ground sensors will be implemented to identify causes and provide treatments at individual plant levels, minimising the effort to keep crops in good health and hence, maximise crop production and revenues. In order to accomplish these objectives, the solutions will be based on the adoption of UAV for image analytics processing, and sharing the data with a crop management dashboard to monitor and assess field data and operational field strategies.

The UAV platform will be equipped with multispectral cameras and suitable sensors to achieve our objectives of detecting diseases and monitor canopy health.

In collaboration with the ROMI (Robotics for Microfarms, <https://romi-project.eu/>) project team both NOUMENA (NMN) and Ecological Interaction (EI) partners have already conducted studies at the Mas Martinet Organic Viticulture farm in the Priorat region (Spain).

2.1.1.1 Challenges & Key Questions

Several challenges are expected to be encountered during the implementation process of the main targets within the UC1 plan of the ICAERUS Project. The most important of them (targets and challenges) are briefly described in the following:

A. Drone operability

✓ **Main Targets**

- 1) Set and define protocols for programming and executing on-field flights, providing 1 to 1 session with farmers and drone pilots operators for technology transfer over drone manipulation.
- 2) Ensure flight capabilities in adverse environmental conditions, setting an intelligent flight scheduling plan adaptable to weather conditions.

➤ **Challenges**

Ensure that the data extraction process can efficiently operate in different weather and lighting conditions.

B. Model preparation

✓ **Main Targets**

- 1) Define primary goals for detecting diseases. Identify the type of local grape vines (for instance, Macabeo, Parrellada, Garnacha Blanca, Masuela and Tempranillo, etc.). Consequently, analyse Tarragona vineyards plant disease based on the grape type.
- 2) Perform appropriate training to develop and assess ML algorithms for their usage in the operational field of this UC.

➤ **Challenges**

Provide a thorough and meticulous training process, associated with the different field conditions in which crop images will be collected and analysed during this UC.

C. Model estimation accuracy

✓ **Main Targets**

- 1) Set comparative studies to adopt optimized ML models for the identified tasks and organising ground data for IoT calculations.
- 2) Perform tests and simulations to validate models based on detection capacity.

➤ **Challenges**

Setup the optimal practices and methodologies of data acquisition and processing in order to avoid training processes with invalid data.

D. Data privacy

✓ **Main Targets**

- 1) Build a reliable data system architecture.
- 2) Periodic assessments, tests and updates of security protocols and software deployed to the system.

➤ **Challenges**

Avoid data leaks, and decrease or expose potential vulnerabilities.

E. Technology adoption

✓ **Main Targets**

- 1) Community consultation strategy aligned with local stakeholders.
- 2) Clear and robust explanations of benefits and outcomes.

➤ **Challenges**

Successful integration of information and technology transfer to all parties involved, fulfilling their goals and needs.

2.1.1.2 Objectives

The main objectives of the UC1 plan are summarized as follows:

- Integrate automated solutions to detect diseases appearing over crop canopies to monitor health of the plants and potentially reduce the usage of chemical PPPs.
- Reduce the amount of time and effort for farmers in crop inspection and management.
- Locate weeds and other diseases in the field through image analytics.

2.1.1.3 Potential Barriers

There are several potential barriers to the implementation of UC1 plan, as presented in **Table 1**. Regarding the regulations, safety measures have to be taken into account at all times. In addition, some technical barriers may arise. For example, harsh meteorological conditions typically impose significant difficulties to the deployment of UAVs, as well as the limited connectivity could cause inadequate bandwidth for saving the collected images and failing to execute the algorithms for their processing. Finally, a socio-economic potential barrier is related with the lack of knowledge or awareness in the agricultural industry about the new technologies, leading to a resistance in changing the usual routine in farming techniques.

2.1.1.4 Use Case Scenarios

The UC1 will be divided in two separate scenarios. In the first UC1 scenario, data will be collected for a single row of the Mas Martinet vineyard. Specifically, a UAV (drone) will perform two different flights, one equipped with an RGB and a thermal camera and a second one equipped with a multispectral camera, for

which the collected images will be combined with data from ground sensors. This procedure will be applied periodically (in collaboration with the farmers in order to decide the optimal timing for drone deployment). Subsequently, the retrieved data will be exploited to test the ML algorithms for the orthomosaic reconstruction, the segmentation and the disease detection.

In the second UC1 scenario, the overall process of the UC1 will be repeated, with the expansion of the area of interest, covering the whole region of the vineyard of Mas Martinet.

Table 1: Examples of potential barriers for the UC1 implementation.

Potential Barrier	Description
Regulations	1. Safety measures that aim to safeguard public health should be strictly followed at all times. 2. Compliance with local regulatory framework regarding the use of air-space by drones.
Technical	1. Difficulty to align in planning to changing farming schedules. 2. Low bandwidth given by lack of good connectivity in the vineyards. 3. Difficulty to effectively secure sufficient crop monitoring activities by lack of incentives for farmers. 4. Creation of credible datasets for the AI applications. 5. Combination of different sensors on the UAVs.
Socio-economic	1. Lack of awareness about the time/effort reduction from the farmers. 2. Resistance from the agricultural industry to adapt new technologies. 3. High cost of drone and camera technologies.

2.1.2 Key Activities

In this section, the key activities, the workflow and the implementation timeline of the UC1 are described, providing a main overview of the progress status and planning.

2.1.2.1 Description Of Key Activities

The key activities of the UC1 covers a variety of aspects from field trials to socio-economic impact. The description of the main key activities in UC1 is summarized in **Table 2**.

2.1.2.2 Key Activities' Workflow

The workflow plan of the key activities in UC1 includes five (5) discrete parts, namely the plant disease detection, the drone flights in farms, the image processing and data visualization and the evaluation of the outcome, defining the provided benefits, as well as the KPI. The workflow plan of the UC1 is illustrated in **Figure 2**.

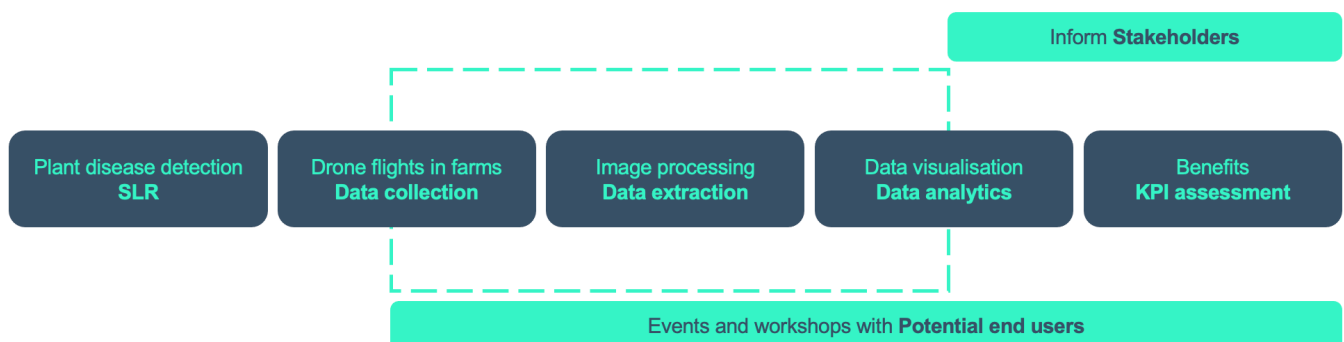


Figure 2: Illustration of the workflow plan of the key activities in UC1

2.1.2.3 Timeline

The implementation timeline of the key activities in UC1 is presented in **Figure 3** and covers the time span from the year 2022 until the end of 2025.

Table 2: Key activities of UC1

	Activity	Description
1	Current State Analysis	Detection of common diseases for grapevine, monitor canopy health, calibrate algorithms for object identification from data collected at a site, evaluation of effectiveness and accuracy.
2	Field Trials	Set on-field data collection protocols, correlating methodologies for data extraction through aerial and ground data to assess the accurate detection of diseases at each plant.
3	Documentation & Capacity Building	Determine a scalable and repeatable approach, validate data collection, data processing and data visualization through the generation of an easily accessible online platform to support farmers in field management and decision-making.
4	Socio-economic Study	Compare the implementation and management costs of the system architecture, compare existing farmer protocols of crop management with the proposed digital and automated procedure, according to estimated benefits and key performance indicators.
5	Dissemination	Share the project's outcomes with all relevant parties and educate them on the importance and necessity of crop monitoring.
6	Demonstration	Plan workshops and demonstrations with prospective end-user groups.

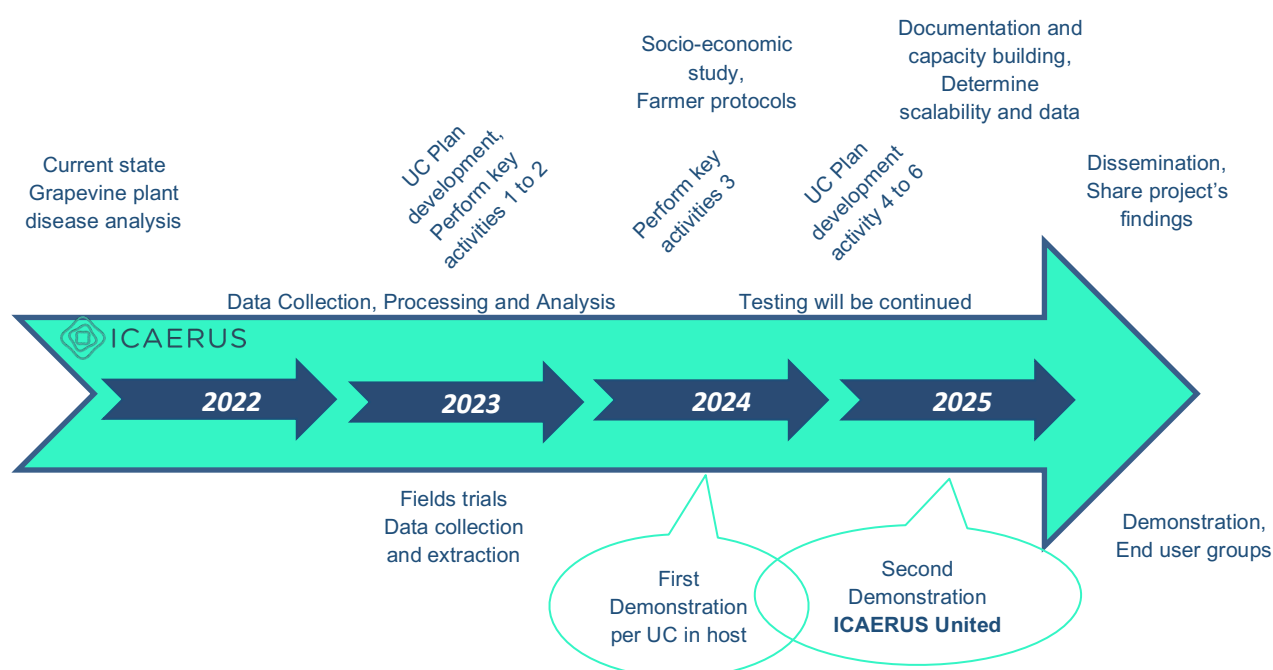


Figure 3: Timeline of the key activities in UC1

2.1.3 Technical Requirements

2.1.3.1 Technical Guidelines

Site description

The pilot area of the UC1 implementation is located at the vineyard Mas Martinet in Tarragona, Spain (φ^0 : 41.17500N, λ^0 : 0.79193E). The farm (**Figure 4**), consists of 120ha of viticulture production for different vine varieties (an example of the viticulture analytics is presented in **Figure 5**).



Figure 4: Map of Mas Martinet vineyard in Tarragona (Catalonia, Spain)

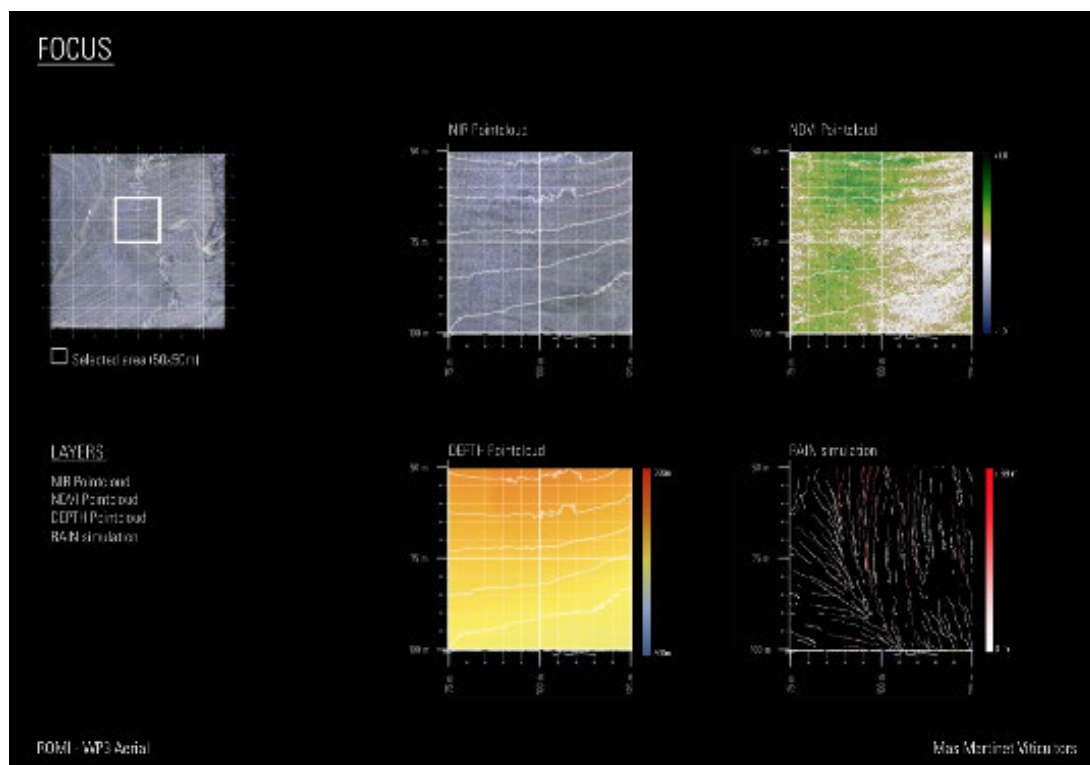


Figure 5: Mas Martinet vineyard viticulture analytics

Methodology

Information about the methodologies and implementations of the UC1 are briefly described in the following:

A. Data system architecture

For the architecture of the data system, a suitable network will be developed in order to share the retrieved images (not in real-time) from the deployed drone to the processing hardware. After the image processing with ML algorithms, the output data will be uploaded to a cloud service.

B. Data Storage

For the data storage, the MongoDB database (NoSQL structure) will be used, while all the available data will be converted to a standard text-based format, such as JSON, for hardware communication.

C. Data acquisition (drone technology)

Aerial data acquisition will be performed with the deployment of UAVs (for instance, with similar characteristics as the DJI Mavic 3 enterprise, <https://www.dji.com/gr/mavic-3-enterprise>) with RGB, thermal and multispectral cameras, providing the corresponding images of the crop.

D. Orthomosaic reconstruction

The orthomosaic reconstruction of the collected images will be based to a Scale Invariant Feature Transform algorithm, which transforms the image content (features) into local coordinates.

E. Custom training

The custom training will involve the creation of manual labels and masks for each image of the crop's segmentation, usage of emerging tools for labelling, etc., in order to provide sufficient skills for object detection and crop monitoring.

F. Object Detection

The orthomosaic reconstruction results will be exploited for the identification of the grapevines in the study area. The segmentation of the farm will be performed using a deep learning architecture, such as Mask-RCNN or U-Net.

G. Individual plants catalogue

In order to create an individual plant catalogue, each crop will be associated with a suitable health status. The health of the plants will be estimated from the processing of aerial and ground data (RGB, thermal and multispectral images) with the developed ML algorithms. An example of a plant growth monitoring is displayed in **Figure 6**.

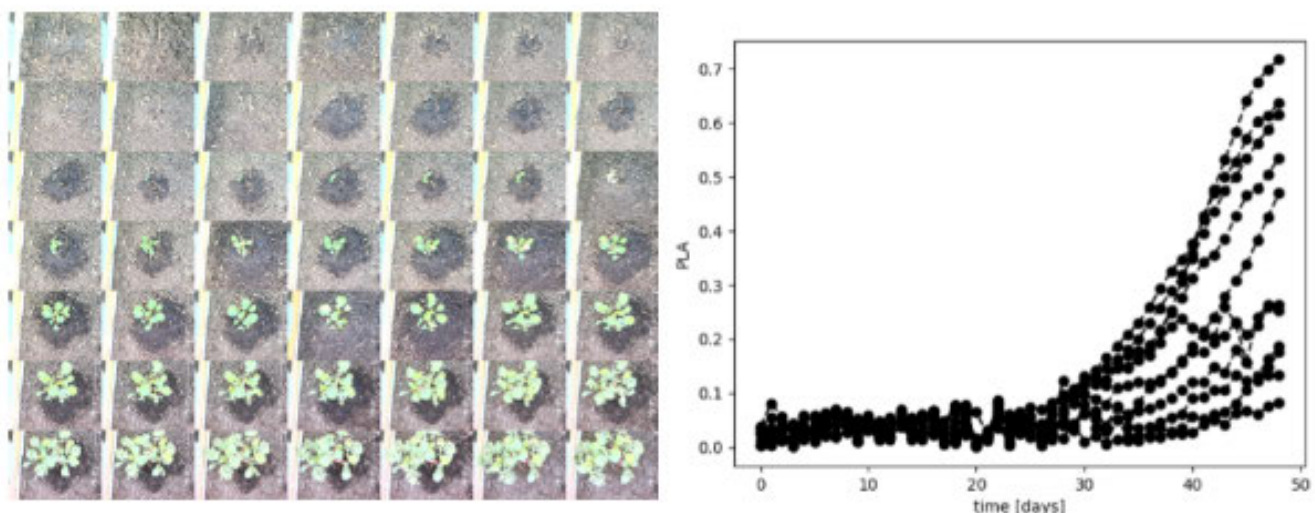


Figure 6: Example of a plant growth curve

2.1.3.2 Platforms & Mounted Technological Components

The required platforms and mounted technological components for the realization of the UC1 are described in the following:

- A drone equipped with high zoom and wide-angle cameras, a M2ED or MAPIR Survey3 thermal camera for the estimation of NDVI values, battery autonomy of ~30min of flight and a payload of ~0.7kg, specifications similar to the DJI Mavic 3 Enterprise (see Figure 7).
- Weather stations with temperature, humidity, CO2, GPS, soil, wind and rain sensors, for additional data extraction.
- Protocols of communication and data transfer (e.g., images), such as MQTT, HTTP, SCP.
- Computer vision and Deep Learning algorithms.
- 3D models.

Figure 7 shows a 3D reconstructed image (left part of the figure), the DJI Mavic 3 Enterprise drone (middle part of the figure) which will be deployed for the data acquisition and an example of a leaf with the corresponding NDVI value (right part of the figure).

2.1.3.3 Measurements – Data & Datasets

Data related queries

What is UC1 testing for?

UC1 is testing for the development of integrated automatic solutions to detect common disease appearing over leaves, the monitoring of plants and canopy health and reduce the usage of chemical pesticides.

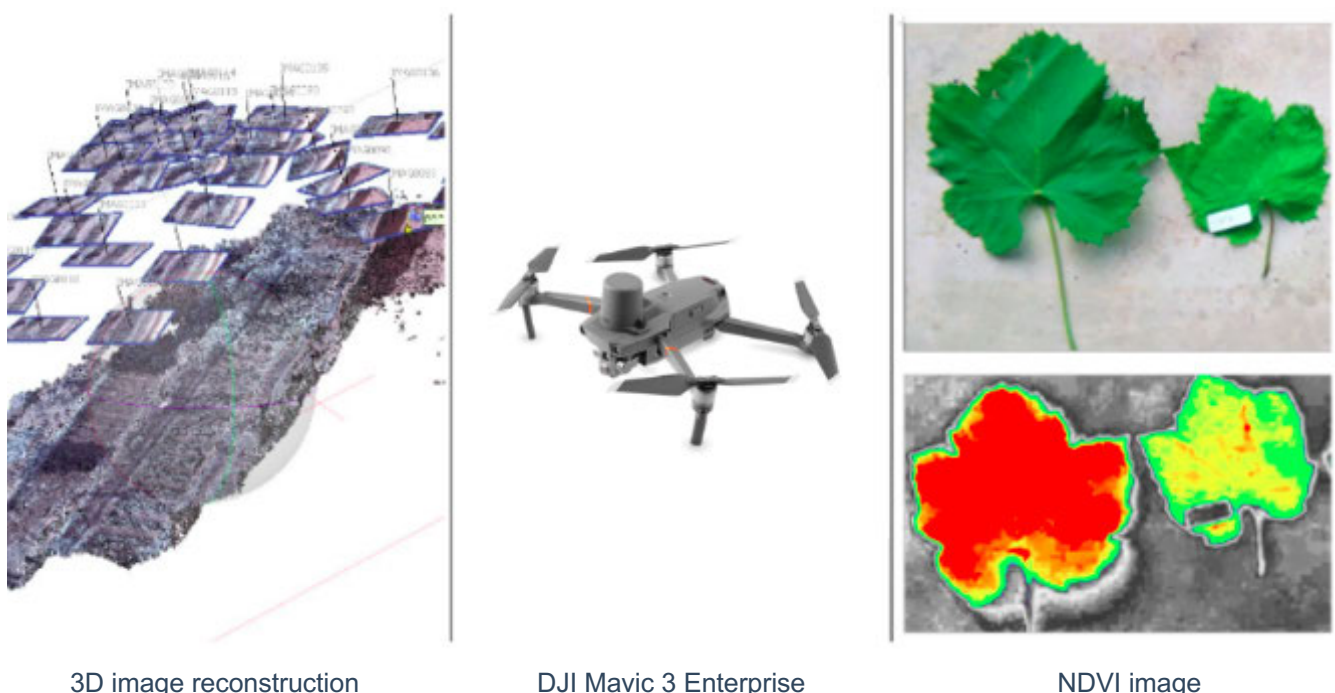


Figure 7: Example of the platforms and mounted technological components required for the UC1

Is there already existing data? Open/public data?

There exist several studies and datasets focusing on crop monitoring using UAVs (e.g., [Khan et al. 2021](#)). Nonetheless, a primary goal of the UC1 is the creation of a custom database in order to optimise the training process and the object (plants) detection.

How will data be acquired? When? How many times? What are the environmental conditions?

Data will be acquired with two different approaches. In the first approach, UAVs will be deployed to collect

aerial data (images), using RGB, Thermal, as well as Multispectral cameras. In the second approach, the aerial data will be combined with data collected from ground sensors to enhance the results. Data acquisition will be aligned with the farming cycles, ensuring that crop monitoring operations will be intensively applied during the optimum time period.

How will the collected data and datasets be used to operate in favour of the ICAERUS project?

The UC1 will provide a set of applications and services for the improvement of crop management, specifically the identification of plant disease, useful for prompt interfering and effective restore plant health, introducing individual plant management and pesticide optimization.

Data categories

Input data:

- Georeferenced images captured by UAVs.
- RGB images.
- Multispectral images (Thermal, NDVI) captured by UAVs.
- Metadata from sensors.

Expected output data:

- Cartographic representation of different information about crop monitoring.
- Quantitative parameters associated with the health of the plants.

2.1.3.4 Drone Data Analytics Models

The image analysis will consist of an Object Detection and Semantic Segmentation. The object detection and the semantic segmentation will be performed with the usage of deep learning models (such as, RetinaNet, Yolov5, U-Net or Mask-RCNN), incorporating manually created bounded boxes.

2.1.4 Expected Results

2.1.4.1 Expected Outcomes

The main expected outcome of the UC1 concerns the development of an image analysis software, providing insights to crops and farms.

2.1.4.2 Impact

Socio-economic

The socio-economic impact of UC1 is summarized in the following:

- Optimization in the resources administration.
- A local self-sufficiency.
- Increasing job opportunities in data-science, robotics, etc. within the context of farming and agriculture.
- Internal estimation of investments/costs made for the activation of automated systems in comparison with traditional and existing workflows of cultivation, including human resources.

Environmental

The environmental impact of UC1 is mainly related with the following:

- Quality / yield per plant.
- Disease detection over plants will guarantee healthier status for a larger number of plants, therefore increasing the productivity of the crop.
- Efficient management of fertiliser usage per output.

The technology proposed implementing optical sensors and adopting computer vision and machine

learning algorithms will detect individual plants and allow targeting bio fertiliser applications. Thus, this will decrease the amount of chemical fertilisers used.

2.1.5 Replicability

The proposed methodology and application process in the UC1 can be considered as replicable. Images of the crop with the RGB, Thermal and Multispectral cameras allow the integration with other applications in vineyards with similar types of plant disease in order to reduce pesticides, improve and contribute to the organic wine market. In addition, the proposed methodology could be implemented in other farms dealing with plants with similar properties in order to save financial resources and improve their harvesting. Each step will be developed with available hardware and open-source tools. The deployment of a standard workflow and the development of a custom dataset for crop monitoring and plant diseases contribute to the replicability of the procedure.

The outcomes of UC1 mainly concern vineyard owners and generally farmers dealing with plant diseases. It is worth mentioning that in most cases there is a lack of aerial images and data for the health of plants in diverse climate and soil conditions. Thus, there is a potential opportunity to scale-up and improve the methodology proposed in UC1 by collecting additional aerial images from different farms and vineyards. This data collection process can be used as inputs for the update of ML models, leading to efficient crop monitoring and plant disease detection at an early stage.

2.2 Use Case 2: Drone Spraying

2.2.1 Introduction

PPPs are used in farming to protect crops against pests, weeds and diseases, and help ensure European agriculture remains productive, profitable and sustainable. Plant protection applications, and more specifically spraying, is a core aspect of the agricultural production of all open-field crops, including vegetables, orchards and vineyards, and arable crops. Spraying drone refers to any UAV, operated manually or automatically, that is capable of applying agrochemicals at a desired rate close to the canopy (typically < 5m). The scope of the UC2 is to test and assess spraying configurations for optimal drone spraying applications in field conditions. To this end, the experimental design focuses on both the evaluation of spraying quality (i.e., deposition, canopy penetration and spray drift) achieved through various operational configurations (i.e., spraying altitude, speed, nozzle flow and liquid deposition rates) for spraying drones, as well as their comparison with existing conventional spraying machinery, such as conventional terrestrial boom and mist sprayers. Finally, the UC2 aims to identify inherent risks of drone spraying and address them through the development of novel mitigation strategies, enabling safe and eco-friendly drone-based plant protection applications.

2.2.1.1 Challenges & Key Questions

Several challenges are expected to be encountered during the implementation process of the main targets within the UC2 plan of the ICAERUS Project. The most important of them (targets and challenges) are briefly described in the following:

A. Limited knowledge about sub-optimal operation of spraying systems

✓ **Main Targets**

- 1) Raise awareness on the importance of operational planning and optimal agrochemical usage.
- 2) Explore how drone spraying can be optimised and how the environmental impact of spraying can be minimised.

➤ **Challenges**

Spraying applications do not receive the required attention from farmers, most of whom make reckless use of PPPs under the misconception that "more is better". This, in combination with sub-optimal operation of the spraying systems, such as the use of improper type or worn nozzles, non-optimised system configuration settings, and high operating pressure, have a major environmental impact, contributing to soil, water and air pollution, and affecting biodiversity.

B. Environmental impact from spraying settings, quality of application and respective spray drift levels

✓ **Main Targets**

- 1) Study the correlation of spraying configurations and how they affect spraying efficiency and quality.
- 2) Calculate the environmental impact of spraying drones through numerous field trials.

➤ **Challenges**

Spray drift significantly affects other neighbouring non-target plants, insects, and animals, even at great distances from the application area, while exposing nearby populations and agri-food consumers to quantities of PPPs that far exceed regulatory thresholds set to protect public health. Misplacement of fungicides, herbicides, and pesticides beyond the target is undesirable as it represents wastage of product and exposure to sensitive, non-target areas. Spraying application is complex and there is currently no way of receiving immediate feedback to indicate if spray set up and operation is correct. Spray drift and movement of PPPs is currently a global issue.

C. Outdated framework that renders most drone spraying applications illegal

✓ **Main Targets**

- 1) Provide field-based evidence that spraying drones can be a highly precise and safe application tool for plant protection.
- 2) Promote the efficient deployment of spraying drones and develop best-practice guidelines and risk mitigation strategies for UAV spraying.

➤ **Challenges**

As drone regulations vary across the EU, drone spraying is outright banned in several countries, as there is no clear regulatory distinction between low altitude (less than 5m above ground level) and traditional air spraying (performed by manned aircrafts, at much higher altitudes, resulting in high spray drift rates). To this end, the necessity of an updated regulatory framework that promotes the sustainable use of pesticides applications through drones becomes obvious.

2.2.1.2 Objectives

Agriculture stakeholders are calling for the update of the SUD and allow the use of drones for aerial spraying of pesticides. This can help farmers reduce the use of pesticides in line with the ambitions of the EU's flagship policy, the Farm to Fork strategy, that stipulates an EU-wide target of a 50% reduction in the use and risk of all chemical pesticides by 2030. The Farm to Fork strategy, which resides at the core of the Green Deal, and the biodiversity strategy, place agriculture at the epicentre of the European Commission's concerted efforts to tackle climate and environmental related challenges, and place European society and economy on a more sustainable track, in its attempt to realise the United Nations 2030 agenda for sustainable development. One promising solution includes the use of drones for the targeted application of PPPs. Spraying drones offer an environmentally friendly and sustainable alternative to conventional spraying methods, greatly reducing the use and negative effects of pesticides and other agrochemicals.

The main objectives of the UC2 are the following:

- Assess the drone spraying settings/operation.
- Identify optimal spraying parameters and create methodological guide for optimal drone spraying applications.
- Test and assess the application approaches.
- Examine socio-economic/environmental impact.
- Develop business and governance models.
- Identify risks and develop mitigation strategies.

2.2.1.3 Potential Barriers

Several barriers can potentially hinder the deployment of spraying drones, both on a regulatory and technical level (**Table 3**). First of all, in most EU countries, the operation of spraying drones is classified as aerial spraying similar to applications carried out by manned aircrafts, and is thus considered illegal unless special permissions (i.e., proof of inaccessibility for the field of interest, special permits for insecticides/infestation control etc.) are provided. Moreover, drone spraying operations are performed in VLOS conditions (the operator must maintain visual contact with the aircraft throughout the flight), while adequate distance should be maintained and safety measures should always be considered, to ensure the protection of public health (both operators and nearby civilians). The latter is a parameter of utmost importance that is often neglected and despite legislations have been established and strict guidelines exist, they are difficult to properly enforce. Internet coverage is another critical aspect for drone spraying, as network connectivity is often required to achieve high precision and accuracy of applications. Finally, spraying drones must comply with aviation standards and procedures defined by the ICAO, and any potential aircraft/components modifications should be done according to these standards. In all cases,

proper testing of the modified aircraft should follow, to validate its flight capability and ensure its safe operation.

Table 3: Examples of potential barriers for the UC2 implementation.

Potential Barrier	Description
Regulations	1. Spraying operations performed by drones are considered aerial sprayings, and no regulatory framework distinguishes them from applications by manned aircrafts, despite their inherent major differences. 2. Safety measures that aim to safeguard public health should be strictly followed at all times.
Technical	1. Modifications in spraying drones should be applied in a way that does not alternate the aviation standards of the aircraft and does not interfere with its flight capabilities. 2. Internet connectivity is often required for certain applications for receiving positioning corrections, while some remote areas (which are often the ones benefiting the most from UAV spraying) have poor connectivity.
Socio-economic	1. Lack of knowledge/awareness in the agricultural sector of the multiple ways spraying drones can be utilised. 2. Resistance to change from existing agricultural practices and aversion of adoption of new technologies. 3. High upfront costs of drone spraying technologies. 4. Lack of cost-benefit understanding from the farmers.

2.2.1.4 Use Case Scenarios

During the use case we will explore the following scenarios:

1. Assess drone spraying efficiency (canopy penetration, deposition) across different phenological stages of crops of interest. The parameters that are examined in different combinations among them are the following:
 - Spraying altitude (from ground level): 2 and 2.5 m AGL.
 - Deposition rate - different flow rates per nozzle: 1.4 and 1.8 L/min per active nozzle.
 - Cruising speed: 4 and 6 km/h.
 - Spraying positioning: Inter or intra row.
2. Evaluate spraying drone potential in reducing spraying drift, by comparing it with terrestrial sprayers and standard spraying practices.

2.2.2 Key Activities

In this section, the key activities, the workflow and the implementation timeline of the UC2 are described, providing a main overview of the progress status and planning.

2.2.2.1 Description Of Key Activities

The key activities of the UC2 covers a variety of aspects from field trials to socio-economic impact. The description of the main key activities in UC2 is summarized in **Table 4**.

Table 4: Key activities of UC2.

	Activity	Description
1	Analysis of Current Spraying Practices	Analyse existing conventional and drone spraying practices in crops of interest and evaluate their respective effectiveness. The advantages and disadvantages of different practices will be assessed.
2	Field Trials	Investigation through rigorous experimental field trials of the optimal configuration settings and spraying parameters for drone spraying, as well as investigation of their impact on the environment, biodiversity and human health.
3	Documentation & Capacity Building	Create a methodological guide and capacity building materials for the proper use of spraying drones in order to reduce spray drift while optimizing spraying parameters, such as pesticide coverage and canopy penetration in the proposed crops. Finally, risks associated with drone spraying will also be documented and categorized, and mitigation strategies will be proposed.
4	Socio-economic Study	Assessment of the socio-economic and environmental effects of the use of drone sprayers. Demonstrate different business and governance models.
5	Dissemination	Disseminate the results of the project and inform stakeholders on the benefits and importance of sustainable spraying, with emphasis on public attendance at demonstration events.
6	Demonstration	Organize demonstration events and workshops with various potential end-user groups, including but not limited to agrochemical manufacturers and distributors, agricultural cooperatives and advisors, policy makers, academia and individual farmers.

2.2.2.2 Key Activities' Workflow

The workflow plan of the key activities in UC2 cover two fundamental spraying parameters, namely the spraying quality (spraying performance of UAVs) and the efficiency (possible uncovered areas through each spraying application). Each evaluation pipeline is described in detail in the following section. whereas the overall workflow plan of the UC2 is illustrated in **Figure 8**.

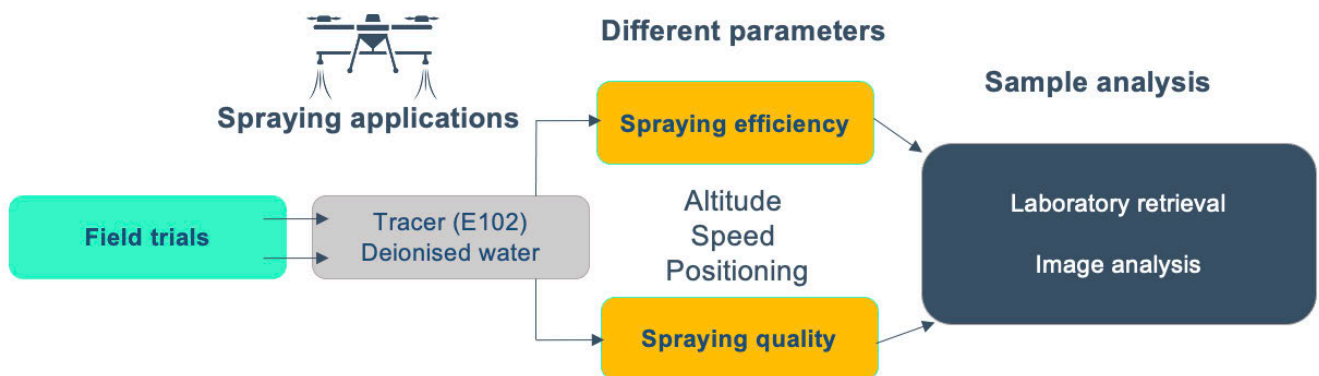


Figure 8: Illustration of the workflow plan of the key activities in UC2

2.2.2.3 Timeline

The implementation timeline of the key activities in UC2 is presented in **Figure 9** and covers the time span from the year 2022 until the end of 2025.

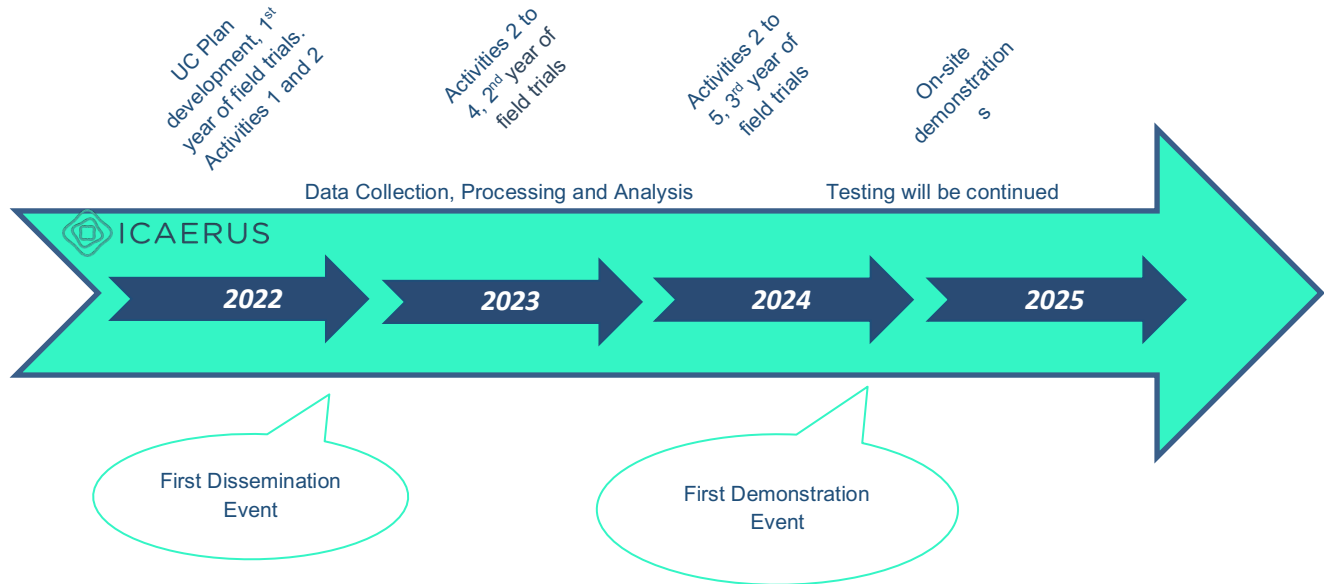


Figure 9: Timeline of the key activities in UC2

2.2.3 Technical Requirements

2.2.3.1 Technical Guidelines

Site description

The pilot area is the organic vineyard of the Agricultural University of Athens farm in Spata, Greece (37°59'06" N, 23°54'21" E) (**Figure 10**). The vineyard has 2.0 m row spacing with 1.6 m spacing of vines along the row to result in a density of 3125 vines per ha. The average vine height is about 1.3 m, with the leaves and grapes occupying the zone above ground between 0.3 and 1.4 m.

Flight testing prior to the field trials took place in both the field segments of the pilot area (for the optimisation of spraying route planning), while equipment testing and configuration setup took place on the campus of AUA, in a strictly controlled environment and fully isolated location. The laboratory analysis as well as image analysis of all collected samples has been conducted in dedicated, fully equipped laboratories within AUA.

Methodology

The methodology followed by UC2 aims to evaluate two things:

- Drone spraying quality.
- Drone spraying drift.



Figure 10: The pilot area of UC2 in Spata, Greece

To this end, two types of measurements will take place in extensive field trials, to estimate these parameters and how different spraying/flight configurations interact between them and affect the spraying:

A. Drone Spraying Quality

The drone's performance will be evaluated in two different application methods, namely by flying over the inter-row and by spraying over a single row (**Figure 11**).

The collectors used for the sampling of spraying droplets are WSPs of 0.76 mm x 26 mm that intercept the spray droplets and instantly change colour upon contact with liquid. Three canopy WSPs will be placed inside each row at three heights stabilised to the trellis (**Figure 12**): 0.3 m, 0.6 m, and 1 m in order to evaluate the droplet distribution of the two systems. Moreover, ground WSPs placed on wooden dedicated supports are used to evaluate wasted agrochemicals that did not reach the vegetation but the soils. For this application, no tracer is required for data collection, and therefore spraying is conducted with filtered water. The WSPs sprayed by the UASS should be collected one minute after the distribution and stored in a specific designed box for preventing colour changes due to moisture, and in individual sampling bags to prevent contact between papers.

The samples are then analysed with an image processing software for chromatography to determine the D10, D50, and D90 by using the image processing system derived by the MATLAB script (Ghiani et al. 2019) (**Figure 13**). The numerical subscript after the D refers to the percentage of droplets that has a diameter (D) equal or lower of the one reported. Ex: D50=75 μ m means that half of the droplets have a diameter equal or smaller than 75 μ m. Dx is the arithmetic mean of the diameter of a spray pattern μ m.

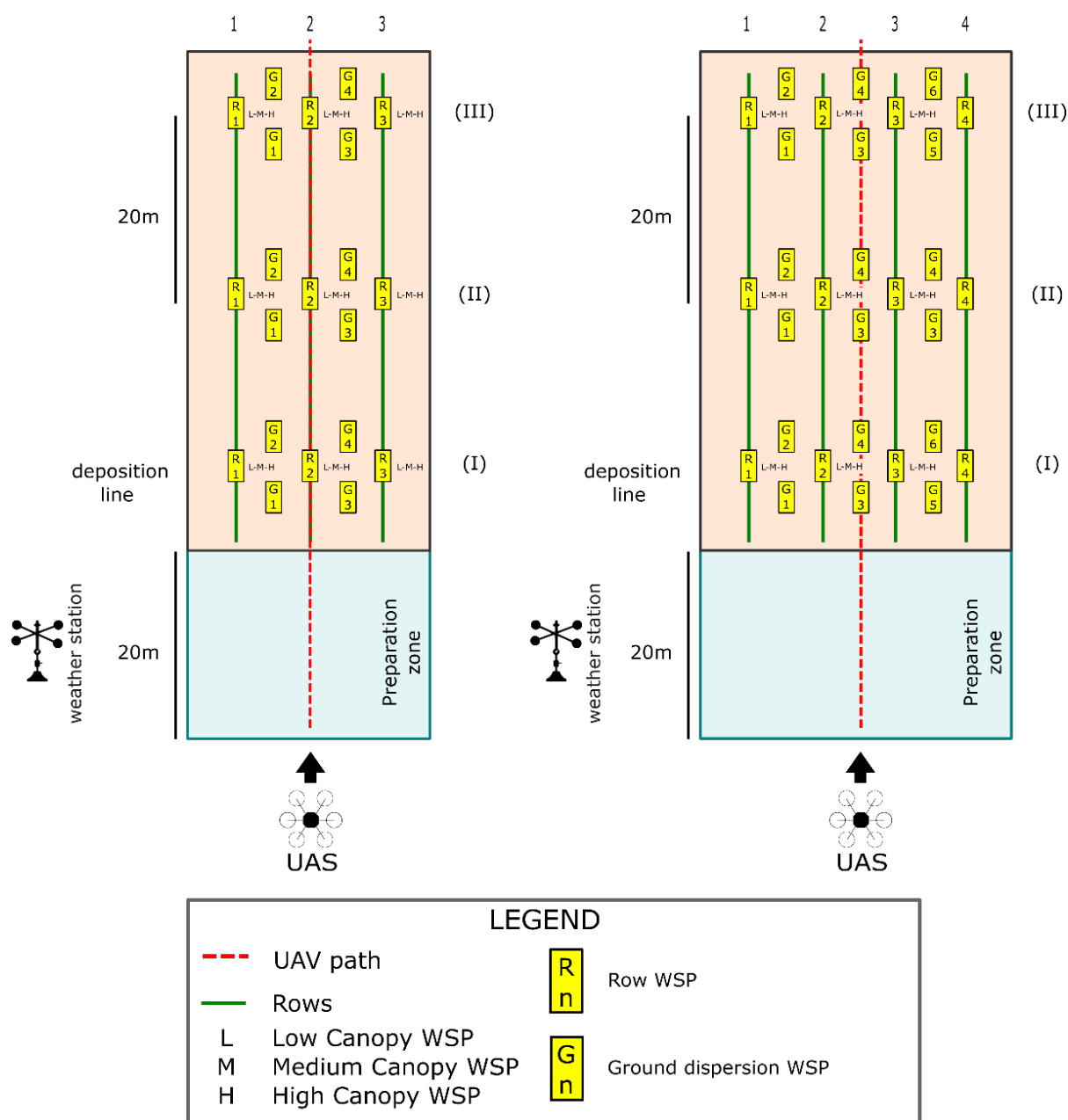


Figure 11: The experimental design of the spraying quality trials



Figure 12: The WSPs collectors deployed and collected in field trials

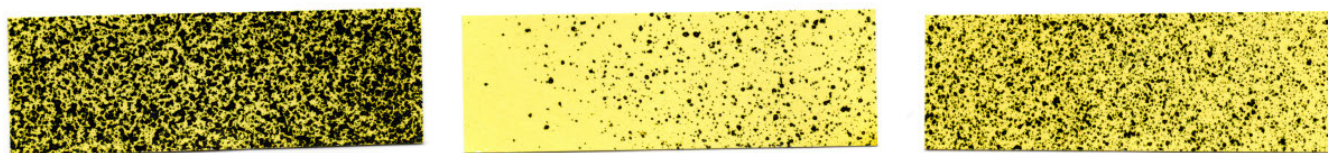


Figure 13: Example of WSPs used to sample spraying droplets

The droplet size is determined by averaging the spray width from three sets of test cards, and the number of droplets per cm² is also extracted by using the same image processing MATLAB script (Ghiani et al. 2019). The droplets number per cm² is determined by averaging the spray width from three sets of test cards.

The total number of experimental trials that constitute a measurement and all tested parameters are presented in **Table 5**. Each iteration is replicated three times, resulting in a total of 24 measurements per dataset.

Table 5: Total iterations for the experiment within UC2

Treatment	Factors	Factors Values
A	H1-S1-OR	2.5 (m) – 1 (m/s) – Over row
B	H1-S2-OR	2.5 (m) – 1.5 (m/s) – Over row
C	H2-S1-OR	2.0 (m) – 1 (m/s) – Over row
D	H2-S2-OR	2.0 (m) – 1.5 (m/s) – Over row
E	H1-S1-IR	2.5 (m) – 1 (m/s) – Inter row
F	H1-S2-IR	2.5 (m) – 1.5 (m/s) – Inter row
G	H2-S1-IR	2.0 (m) – 1 (m/s) – Inter row
H	H2-S2-IR	2.0 (m) – 1.5 (m/s) – Inter row

B. Drone Spraying Drift

The field experiments were carried out based on the ISO 22866:2005 standard, which set the criteria on the conditions for spray drift measurements. In accordance with this, the directly-sprayed area shall be at least 20 m wide upwind of the edge of the cropped area and the length of the spray track at least twice as the largest downwind sampling distance, and should be symmetrical to the axis of the sampling array. For these trials, filtered water is mixed with a coloured tracer (high purity tartrazine - E102) used to fill the spraying tank at a concentration of 4 g/L. Moreover, weather conditions must be measured during the entire test duration at a point near to the test site and 15 m off the flight path in the direction of the wind and height of 1.5 m every 1 second. Ambient dry temperature should be between 10 °C and 35 °C, relative humidity should not exceed 70% and the mean wind speed should be under 2.0 m/s. The test must be stopped if wind speed exceeds 3 m/s at any point during spraying.

In each drift trial, ground sediment droplets downwind to the directly-sprayed area are sampled. The ground collectors are placed at 12 different sampling distances in bare soil at 1, 2, 3, 4, 5, 7.5, 10, 12.5, 15, 20, 25, and 30 m from the end of the directly-sprayed area. These distances started from the parallel straight line in front of the last plant row spaced 1 m. At each sampling distance, three wooden laths were placed with an upper surface covered in filter paper, Whatman Grade-1, 46 x 8 cm (**Figure 14**).



Figure 14: The filter paper collectors used at the first 5 sampling distances (1 to 5 m from the last vine row)

After collecting the samples, they were transferred for analysis to the laboratory, where tartrazine concentration in soil collectors is measured using a spectrophotometer functioning at a wavelength of 426 nm, after the deposits of the tracer are extracted from the collectors using deionized water (**Figure 15**). To avoid high dilution rates and inability to trace tartrazine concentration, for the respective samples the following volumes of deionized water are applied: A total of 40 mL for filter paper from 1 to 5 m distance, 20 mL for filter paper from 7.5 to 30 m distance. Similarly, to the spraying quality experiment, different spraying configurations are examined, namely different altitude (2 and 2.5 AGL) and speed (1 and 1.5 m/s, which result in flow rates of 1.3 and 1.8 L/min per active nozzle).

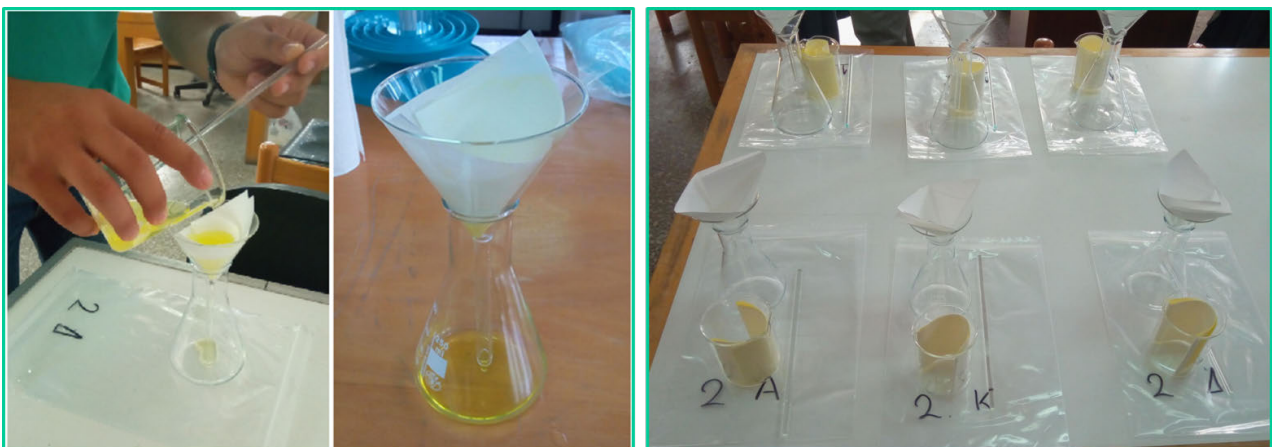


Figure 15: Retrieval of the tracer deposits in the laboratory

2.2.3.2 Platforms & Mounted Technological Components

The required platforms and mounted technological components for the realization of the UC2 are described in the following:

- Meteorological station to monitor environmental conditions during spraying applications (**Figure 16 left**).
- Spraying drone (DJI Agras T10 and T16, <https://www.dji.com/gr/t16>) (**Figure 16 centre**).
- Various nozzles to extend the field trial methodology in upcoming years.
- Spectrometer and spectroscopy analysis laboratory (**Figure 16 right**).



Figure 16: Example of the technological components deployed in UC2

2.2.3.3 Measurements – Data & Datasets

Data related queries

What is UC2 testing for?

UC2 is testing for drone spraying quality (penetration, canopy deposition) and drift (displaced off-target chemical rate).

Is there already existing data? Open/public data?

Several studies exist for terrestrial data, but very limited literature/research on drones, especially within EU and for row crops.

How will data be acquired? When? How many times? What are the environmental conditions?

Data are collected using two different types of collectors (explained in the Methodology paragraph). A total of 24 iterations per year for spraying quality and 8 iterations per year for drift (for drone data). All trials take place in field conditions according to standardised thresholds which are also monitored throughout the duration of each trial.

How will the collected data and datasets be used to operate in favour of the ICAERUS project?

The UC2 will provide newly acquired knowledge on spraying drones, and will aim to provide concrete evidence on their efficiency, thus trying to enable a potential update in the regulatory framework of EU countries.

Data categories

Input data:

- Canopy penetration and deposition data.
- Spraying drift data.

Expected output data:

- Penetration and deposition curves for crops of interest.
- Drift curves for spraying drones.

2.2.3.4 Drone Data Analytics Models

The image analysis part of UC2 is currently performed with a MATLAB script (described in the Methodology paragraph).

2.2.4 Expected Results**2.2.4.1 Expected Outcomes**

An outline of the main expected outcomes in UC2 is presented in the following:

- Promote drones as a sustainable and “green” alternative to conventional ground sprayers.
- Allow for low-input or less environmentally damaging plant protection practices, focusing on reduced PPPs use, through optimised drone spraying techniques, greatly reducing agrochemical inputs.
- Ensure the safety of consumers and public health, especially focusing on rural populations that are often directly exposed to major amounts of pesticides and other agrochemicals.
- Create a methodological guide and a capacity building material for the proper use of spraying drones in order to reduce spray drift while optimising spraying parameters, such as pesticide coverage and canopy penetration in the proposed crops.
- Contribute to the development of different business and governance models.
- Showcase the importance of sustainable spraying, with emphasis on public attendance at demonstration events.
- Contribute towards achieving the goals of the Farm to Fork and Biodiversity strategy.
- Reduce the risks related to the use of drones in the agricultural sector, especially in the context of spraying.

2.2.4.2 Impact***Socio-economic***

The socio-economic impact of UC2 is summarized in the following:

- Increase the efficiency and reduce the operational and input costs of pest control applications.
- Reduction of human labour and intensity of work for farmers.
- Safeguard human health by drastically reducing the exposure levels of farmers to agrochemicals, and also reducing chemical residue to the produce.
- Enable safe applications in distant or inaccessible locations that would be otherwise dangerous to approach with terrestrial machinery.

Environmental

The environmental impact of UC2 is mainly related with the following:

- Decrease contamination of groundwater and/or soil through the reduction of agrochemical application volume.
- Prevent biodiversity loss due to pesticide displacement.
- Reduce soil compaction by performing aerial applications instead of terrestrial machinery ones.
- Reduce carbon-based fuel consumption, as spraying drones mainly use electricity to operate, thus lowering the carbon impact of the sector.

2.2.5 Replicability

The entire methodology of UC2 is fully replicable, and can even be transferred to other crops or cropping systems by adjusting the data collection (water sensitive papers and filter papers) to the needs and geometric structure of the new crop of interest.

The technological components are commercial products, while the image analysis script is a free software. The outcomes of UC2 mainly concerns agricultural researchers and agrifood companies as well as innovative farmers/associations across the EU.

The experimental design of UC2 can be easily scale-up, both for applications in similar crops/cropping systems but in different geographic regions, but also in entirely new crops and cultivation systems.

2.3 Use Case 3: Livestock Monitoring

2.3.1 Introduction

The occurrence of livestock systems in grasslands offers several benefits to the environment and the surrounding areas, such as the carbon sequestration from the activities of the system's biodiversity, the low-cost production of forages for cattle and valorisation of areas that cannot be used for crops, etc. In addition, grazing animals in free-field conditions provide good nutrition resources for the food production industries. However, the monitoring of grazing animals from the farmers is a quite strenuous task. In fact, at lowland pastures animals are typically grazing far away from the farm settlement, hence outside the visual inspection abilities of the farmers. In most cases, farmers must cover a wide region in order to track the animals, which are usually scattered in different areas. Moreover, this procedure must be regularly repeated and depending on the livestock it might vary from 2-3 times per week up to several times per day. In woody rangelands and summer mountain rangelands, animals are shepherded continuously during the day, although visibility issues may arise due to the topography of the area and the dense vegetation. Thus, livestock monitoring is time-consuming, especially in large areas, and a significant burden to the workflow of the farmers.

The scope of this UC3 is to evaluate the risks and the advantages to exploit drones for cattle and sheep monitoring in grassland-based systems, leading to the improvement of the life quality of the farmers. Based on existing and recent UAVs technologies, they will be deployed in 2 pilot areas (farms) including 2 species and 3 types of grasslands. Specifically, the first pilot area concerns a beef cattle herd in pastures lowlands, whereas the second pilot area involves a sheep flock in a pastoral system within 3 types of grasslands (low-lands pastures, woody rangelands, summer mountain rangelands). The UAVs (drones) will be deployed as an "eye-in-the-sky" service, allowing farmers and shepherders to monitor their livestock with less effort. Furthermore, the available information obtained with the deployment of drones provide a significantly larger variety of parameters for the livestock, in comparison with the conventional ground inspections, such as the precise detection of the number and position of animals, their access to water and their health and welfare levels. The main target of UC3 is not the replacement of farmers with UAVs, but to facilitate the livestock monitoring, decreasing the required effort from the farmers and enhancing the efficiency of the overall livestock activity.

The UC3 will assess 3 main challenges regarding the use of drones in grassland-based livestock monitoring: a) the limited knowledge about the "appropriate" use of drones, b) the limited knowledge of the socio-economic impact of using drones, and, c) provide cost-effective solutions.

Two scenarios will be investigated to evaluate these challenges:

1. Monitoring of beef cattle in "bocage" grasslands.
2. Monitoring of sheep flocks in a pastoral system.

These scenarios will allow the risk evaluation of using drones in a variety of configurations (animals, landscapes, farming systems) and their social, economic, and environmental impacts on standard tasks employed by farmers. The demonstration and dissemination of the results will be exploited to overcome the lack of knowledge of the stakeholders, regarding both the impacts and regulations for the deployment of drones in livestock monitoring.

2.3.1.1 Challenges & Key Questions

Several challenges are expected to be encountered during the implementation process of the main targets within the UC3 plan of the ICAERUS Project. The most important of them (targets and challenges) are briefly described in the following:

A. Limited knowledge about the "appropriate" use of drones in grasslands for livestock monitoring

✓ *Main Targets*

- 1) Raise awareness about the drone regulations.
- 2) Promote adequate information about the regulations, the safety of people, animals and materials in cases of drone deployment.
- 3) Provide guidelines for legal and safe usage of drones.

➤ **Challenges**

Livestock monitoring applications began to spread in the farm systems. Currently, farmers purchase recent and technologically advanced drones, with insufficient attention to the flight regulations, which are valid even in remote regions. However, several risks may occur in rural areas, mainly associated with agricultural and/or military implementations, as well as the possibility to cause stress to the animals that usually affects their behaviour. Thus, guidelines should be provided for a legal and safe use of drones in grassland environments.

B. Limited knowledge about the socio-economic impact of using drones

✓ **Main Targets**

- 1) Evaluate the socio-economic impact of using drones for livestock monitoring in farms.
- 2) Promote a sustainable use of drones.

➤ **Challenges**

Recent studies have shown that the usage of livestock farming technologies are promising tools for labour relief and increase of the socio-economic performance of a farm. In particular, the general financial adverse situation in sheep and beef cattle farming systems, enhance the demand of the stakeholders for information and demonstrations of the impacts and applications of drones. Thus, a suitable approach is required, in order to assure the stakeholders for investing in drones' purchases and piloting training, emphasising to the advantages they offer, such as the significant decrease of time-consuming and strenuous walks in grasslands, the efficient tracking of livestock activities, etc.

C. Provide cost-effective solutions

✓ **Main Targets**

- 1) Provide detailed information about economically affordable use cases that can be implemented on livestock farming systems.
- 2) Examine governance models allowing cost-effective drone uses.

➤ **Challenges**

Cattle farms and sheep flocks have limited budgets to invest in new technologies. Cost-effective solutions should be investigated, minimising the required quantity of components and software for legal and safe usage of drone technology, while maximising the impact to the farm.

2.3.1.2 Objectives

Drones equipped with standard or thermal cameras allow the farmers to facilitate their livestock monitoring, providing a socio-economic and environmental impact on cattle farms and sheep flocks.

The main objectives of the UC3 are the following:

- Assess the drone and camera models adapted to different grassland-based cattle and sheep systems.
- Create an inventory of different routines and uses of drones according to the systems and technologies and provide appropriate guidelines.
- Assess the impact of using drones for livestock monitoring, such as time-saving, labour decrease, decision planning, etc.
- Assess other socio-economic and environmental impacts.

Table 6: Examples of potential barriers for the UC3 implementation

Potential Barrier	Description
Regulations	1. A significant part of the airspace over the grasslands is considered as a restricted area for flying drones (Géoportail, France). The deployment of drones requires a certification (for flight height, the time windows of operation, etc.) from the local authorities. In addition, grassland regions and remote areas are utilized by military services for training, avoiding the proximity with cities or airports. To overcome this barrier, the farm workforce should be trained and certified as drone pilots to master their manipulation, as well as the regional regulations. 2. Farmers consider drones as a tool for obtaining visual feedback of livestock and areas away from the base settlement. Although, in France the BVLOS flights are forbidden without a drone pilot certification, whereas for certified pilots the horizontal flight distance is not allowed to exceed 1 km. For this reason, the farm workforce should be trained and certified as drone pilots in order to operate BVLOS flights legally. Moreover, there will be an effort to quantify the certified pilots within the farm stakeholders and to inform the non-certified yet about the regulations.
Technical	1. The BVLOS flights in environments with heterogeneous vegetation are unpredictable and unsafe. The selection of the drone models will be based on their equipped systems for obstacle avoidance. Pilots will map the environment where BVLOS flight will occur to have a good knowledge of the presence of obstacles. 2. The weather conditions can strongly affect drone flights, although it is not possible to mitigate their effects with affordable drone technologies and solutions.
Socio-economic	1. Daily or regular drone flights for livestock monitoring can potentially pose public perception and annoyance. Thus, inhabitants in close proximity with the flight zone of the deployed drones should be noticed and consent to their implementation, while their privacy should be ensured. 2. To regulate the typically high-cost of the UAVs purchase, different configurations of drone types and equipment will be tested, suggesting the most affordable solutions for livestock monitoring in a variety of environments. 3. There will be an effort to mitigate the risk of harming or stressing the domestic or wild animals within the area of drone monitoring.

- Promote a legal and safe use of drones through dissemination and demonstration of the project outcomes.
- Present the use of drones to farmers and other livestock stakeholders and examine governance models, the drones' adoption and the leverage the offer to the farm operation.

2.3.1.3 Potential Barriers

Several barriers can potentially confine the deployment of drones for livestock monitoring at different levels, as presented in **Table 6**.

2.3.1.4 Use Case Scenarios

During the UC3 the following 2 scenarios will be explored, as well as some additional complementary scenarios:

- **Use Case Scenario 1: Monitoring beef cattle in “bocage” grasslands**

This scenario evaluates the risks and the advantages of using drones which are piloted by the farmer for monitoring a cattle herd, as well as the entire farming system in “bocage” grasslands.

The selected pilot farm is representative of beef cattle farming on grasslands. Totally, 150 beef cows and calves are reared at a pasture area of 200ha. The animals are classified in batches according to their age, physiological stage and sex, allowing the farmers to adjust their management to the specific needs of each batch. The number of batches varies in the pastures, depending on the season and the grass availability (for instance, there are up to 10 batches of animals in pastures during spring, when there is a lot of grass available to graze). Often, the animals stay in pastures for several months without returning to the barns at the main farm settlement. The pastures are scattered within the pilot farm, whereas they are divided in smaller units, namely the paddocks (**Figure 17**). Each batch of animals is placed in a paddock, although they might be relocated to another paddock according to the grass availability. This movement of batches of animals from one paddock to another is commonly known as “rotational grazing”. Furthermore, different batches of animals can share paddocks (in some cases even more than 20 paddocks) (**Figure 18**).

The conventional (from the ground) livestock monitoring is realized with routine visits from the farmers. Farmers visit every paddock with a batch of animals daily, to assess the grass availability and the optimal time to relocate the animals at the next paddock. In this daily monitoring routine, farmers visually check the number of animals, their health and welfare level and the availability of water and grass for each batch. Since the distances between each batch in a paddock or between different paddocks are generally long, the summed time of walking or driving can reach several hours per day.

A drone equipped with a camera will facilitate the farmers, providing them a view from the sky. In particular, both RGB (with a x56 zoom) and thermal cameras will be investigated for livestock monitoring. The drone images and footage can be exploited to retrieve similar information with the close visual inspection for every batch of animals (number, position of the herd, access to water, health and welfare levels), remotely, fast, without any time-consuming effort and BVLOS up to 1 Km away (according to the regulations of drone flight) (**Figure 19**). In UC3 the conventional daily visits at the paddocks and the flights with drones will be evaluated in order to obtain the optimal proportion of both implementations for livestock monitoring, without diminishing the human/animal relationship and the efficient monitoring performance. The UC3 will also produce an inventory of all tasks in livestock farms that can be feasibly supported by a drone.

- **Use Case Scenario 2: Monitoring sheep flocks in mountain rangelands**

This scenario evaluates the risks and the advantages of using drones which are piloted by the farmer for monitoring sheep flocks, as well as the entire farming system in mountain rangeland.

The selected pilot farm accommodates a flock of 650 ewes that is exploited for lamb delivery and meat production. The sheep flocks graze during the year in three different types of grasslands: a) lowland pastures, b) woody rangelands, and, c) summer mountain rangelands (**Figure 20**). In the lowland pastures, sheep are enclosed with temporary fencing. The proximity of the lowland pastures with the main settlement of the farm, allow the farmers to avoid shepherding. Instead, they visit the flocks at least once per day for visual inspection of their general condition. On the contrary, in woody rangelands and in summer mountain rangelands, sheep flocks are shepherded continuously during the day and they are constrained at night inside specific night enclosures to protect them from predation. Typically, every flock contains from few to hundreds of sheep.

According to the type of grasslands, the monitoring of the sheep flocks differs. As mentioned above, in lowland pastures farmers perform daily routine visits to the enclosed batches of sheep, checking their number, health and welfare level, as well as the availability of water and grass for each batch. With this information, they decide whether they will relocate the flock to another place. It is worth mentioning that

due to the large number of animals within the batches (may be hundreds), counting them is not usually a straightforward task. Moreover, the individual inspection of every sheep is not feasible, hence the farmers must check for abnormal behaviours or certain patterns (isolated animals, animals slower than the others in the flock) in the herd that might be an indication of health issues.



Figure 17: Map of the pilot area (Farm A, 70 ha), which is divided into 28 paddocks so that several lots can rotate grazing. In general, up to 5 batches of animals can graze in different paddocks at the same time



Figure 18: "Bocage" landscape (left) and a group of animals (cows and calves) in a paddock (right)

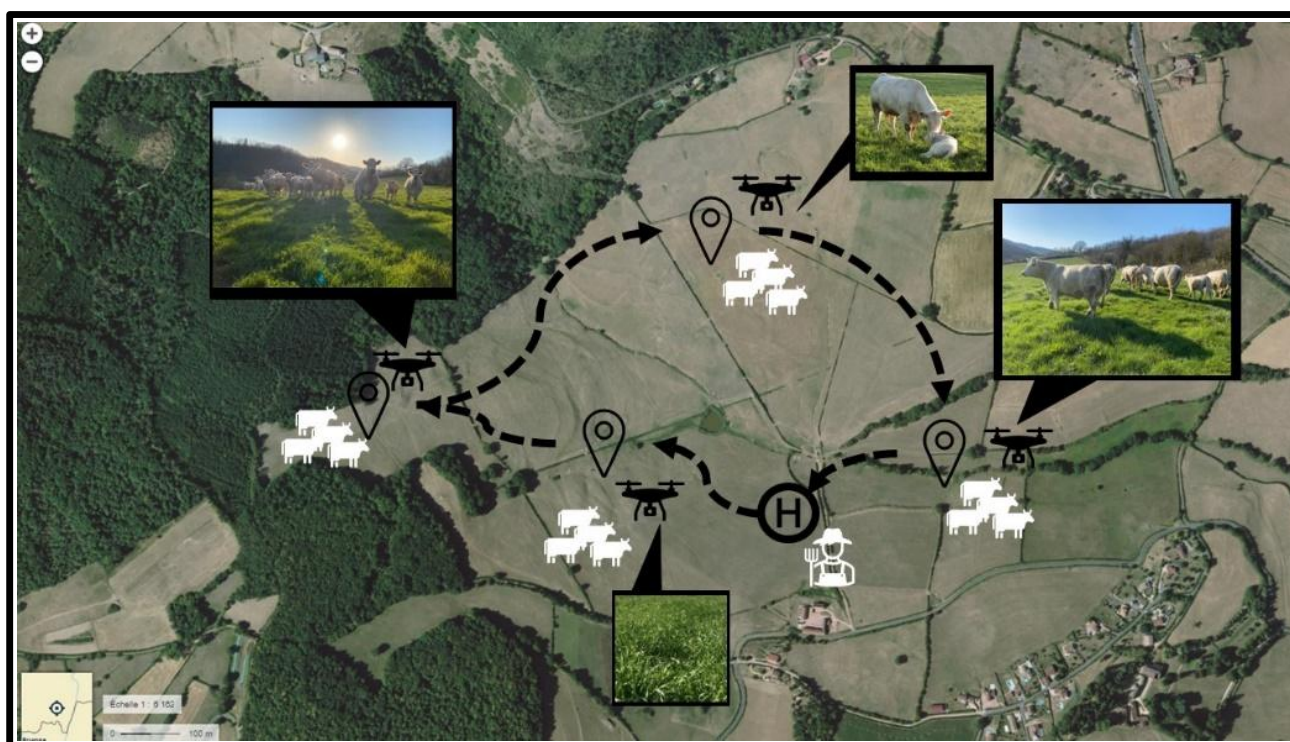
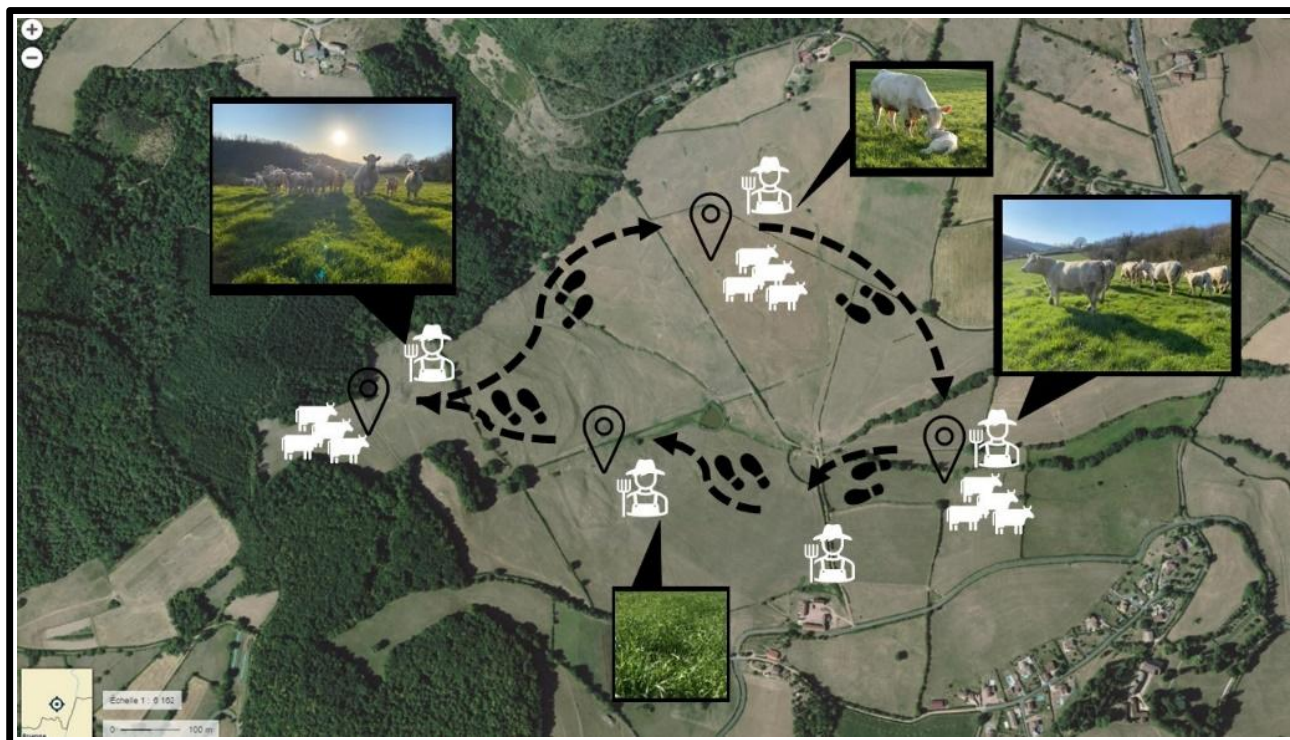


Figure 19: Illustration of how the use of drones can facilitate daily routine work in a grassland. The farmer has to check daily on foot the different batches of animals (white cows) scattered around the farm and assess the availability of the grass (top) or alternatively perform the same checks with the use of a drone from the main settlement of the farm (marked with the letter H) without much effort (bottom)



Figure 20: Lowland pastures (left), woody rangelands (centre) and summer mountain pastures (right)

On the other hand, in woody and summer mountain rangelands the sheep flocks require continuous shepherding during the day, with an effort to detect the necessary resources (grass and water) for a large number of animals inside quite complex ecosystems. For this reason, the shepherd follows a certain path, attending to minimize the scattering of the animals, especially in areas with low visibility (e.g., topography, dense vegetation), leading the flock to different areas for grazing, areas with sufficient shade and water, as well as to areas to keep them protected from predators. An additional difficulty in shepherding at summer mountain rangelands rises due to the fact that flocks from different farms interact and eventually mix together. Nevertheless, the vegetation in these higher altitude regions is generally lower and the main visual obstacle for livestock monitoring is related to the topography of the area.

A drone equipped with a camera will facilitate the farmers, providing them a view from the sky. In particular, both RGB (with a x56 zoom) and thermal cameras will be investigated for livestock monitoring in lowland pastures.

The drone images and footage can be exploited to retrieve similar information with the close visual inspection for every batch of animals (number, position of the herd, access to water, health and welfare levels), remotely, fast, without any time-consuming effort and beyond the visual line of sight (BVLOS) up to 1Km away (according to the regulations of drone flight). Thus, it will not be a necessity for the farmers to drive at the location of the pastures through rural roads (**Figure 21**), which are usually in bad condition or even inaccessible. In UC3 the conventional daily visits at the paddocks and the flights with drones will be evaluated in order to obtain the optimal proportion of both implementations for livestock monitoring, without diminishing the human/animal relationship and the efficient monitoring performance. The UC3 will also produce an inventory of all tasks in livestock farms that can be feasibly supported by a drone.

Drones can be similarly deployed in woody and mountain rangelands for the sheep flocks monitoring. In fact, drone images can provide valuable information about the quite complex and spatially extended environment, such as the topography and the vegetation of the area (**Figure 22**). Thus, the farmers are able to observe the flocks with accuracy and to avoid or prevent the scattering of the animals. Within the UC3 the optimal circumstances to maximize the benefits from drone deployment for livestock monitoring in such environments. The UC3 will also produce an inventory of all tasks in livestock farms that can be feasibly supported by a drone.

2.3.2 Key Activities

In this section, the key activities, the workflow and the implementation timeline of the UC3 are described, providing a main overview of the progress status and planning.

2.3.2.1 Description Of Key Activities

The key activities of the UC3 covers a variety of aspects from field trials to socio-economic impact. The description of the main key activities in UC3 is summarized in **Table 7**.

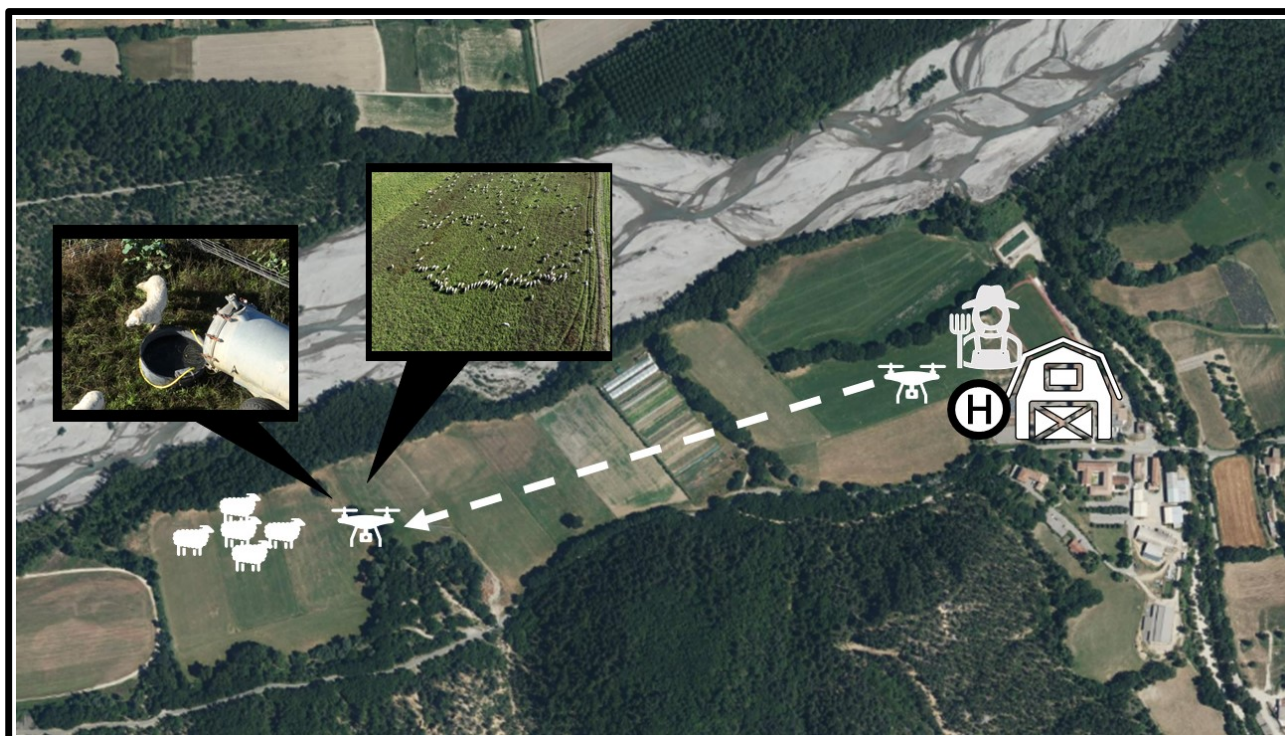
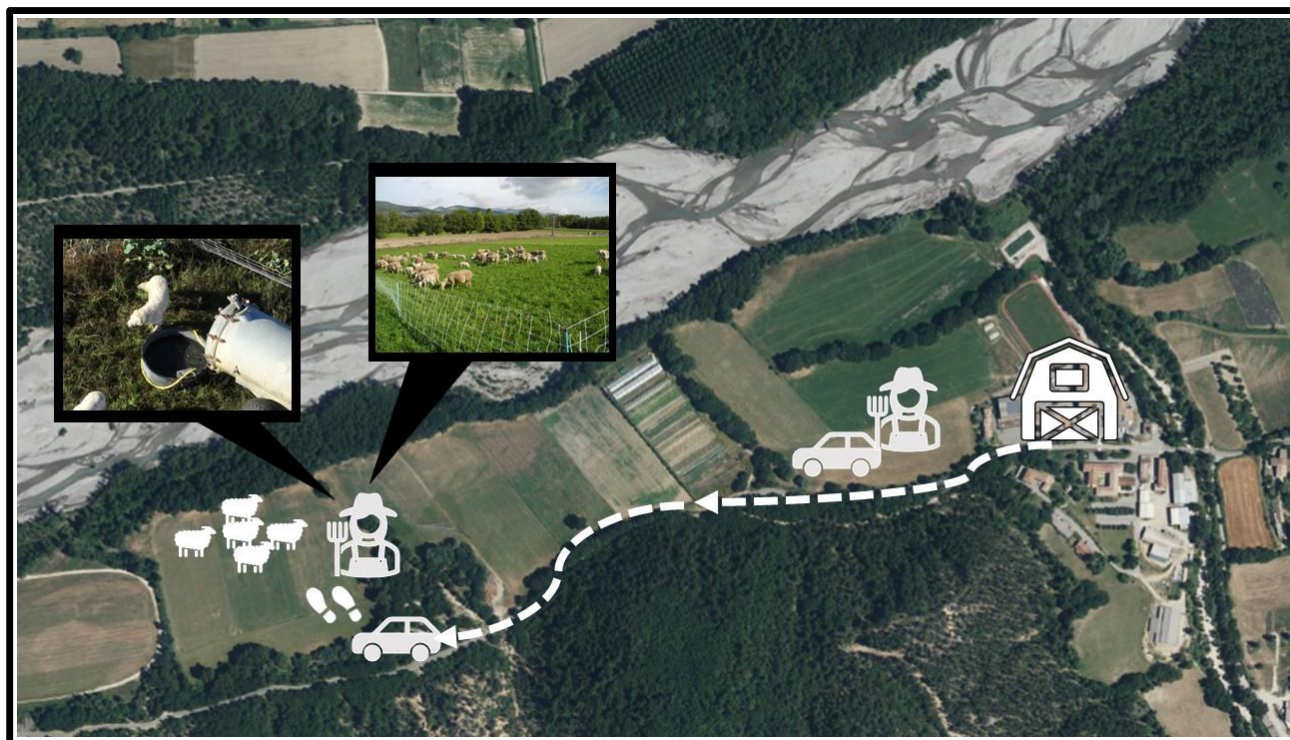


Figure 21: Illustration of how the use of drones can ease the daily routine work on a lowland pasture. Every day, the farmer has to use a car to check the various flocks of sheep scattered around the farm and assess the availability of grass (above). Alternatively, he can carry out the same checks with the use of a drone from the main settlement of the farm (marked with the letter H) without much effort (below)

Table 7: Key activities of UC3

	Activity	Description
1	Risk evaluation and recommendations for optimal practices performance	Evaluation of risks concerning the workforce of the farm, the livestock and the operation of drones. Tests will be performed to assess the appropriate height of drone flight for efficient livestock monitoring without disturbing the animals. Recommendations for optimal performance to the implementations of drone flights will be developed.
2	Assessment of drones' capabilities to facilitate the daily routine of livestock monitoring	The main target is to decrease the required visits of the farmer to the paddocks for livestock inspection by replacing them with the deployment of drones. Assess the possibility to monitor several paddocks remotely from a selected location.
3	Database of farmers' daily routine activities for livestock monitoring	A database will be created containing the majority of the daily routine activities from the farmers for livestock monitoring, combined with quantitative and qualitative parameters (time-consumption, labour, skill set, etc.) (implementation during spring of 2023).
4	Estimation of drones' performance for livestock monitoring	Based on the created database, the performance of drones in the daily routine activities will be evaluated, emphasizing their contribution to the labour improvement (implementation from fall of 2023 to summer of 2025).
5	Investigating the feasibility of livestock monitoring with drones	The deployment of drones is a well-established tool for video feedback, tested in a plethora of applications from a variety of users. However, it is not yet clear if the deployment of drones has the same efficiency for other tasks in farms, such as livestock management or grass growth detection. The feasibility of livestock monitoring with drones will be investigated via 2 selected tasks, according to the outcomes of the WP 1 of ICAERUS project. Some examples of these tasks are the following: ➤ Drone usage as a "herding dog" for navigating the herds within the farm area. ➤ Easy and fast livestock counting, with the incorporation of machine learning software. ➤ Grass growth monitoring in order to adjust the grazing calendar of the livestock (e.g., decision of the relocation of animals to another paddock).
6	Database of drones' capabilities to facilitate the labor in a farm, excepting the livestock monitoring	Drones can be deployed for numerous applications, other than the livestock monitoring, which are relevant with the farm operation and requirements. For instance, a drone can be implemented to inspect the barns, for land cartography, monitoring of crops or detect crop degradations due to drought/wild boars etc. Thus, farmers can provide information about these additional drone applications and how they facilitate their labor in the farm. Consequently, this database might influence the business models that will be investigated in WP 5 of ICAERUS project.

7

Demonstration and communication

Demonstrations of drones' deployment, mainly for livestock monitoring, are planned to be performed in farms, addressing to farmers, drone service providers and rural stakeholders. The selected languages for the demonstrations will be French (assisting the local community) and English including:

- Videos of best practices.
- Scientific lectures.
- Discussion on technical issues.
- Technical workshops.

The main outcome of the demonstrations will be a guidebook in French and English, including recommendations for optimal practices performance for livestock monitoring.



Figure 22: The drone is an eye-in-the-sky providing visual feedback in places where the shepherd has a low visibility on his flock

2.3.2.2 Key Activities' Workflow

The workflow plan of the key activities in UC3 includes 7 discrete parts, namely the risk evaluation, the assessment of drones' capabilities in livestock monitoring, the database of farmers' daily routine activities, the estimation of drones' performance to livestock monitoring, the investigation of the drones' feasibility for livestock monitoring, the database of other drones' applications (other than the livestock monitoring) to facilitate the labour in farms and the demonstrations of the outcomes. The workflow plan of the UC3 is illustrated in **Figure 23**.

2.3.2.3 Timeline

The implementation timeline of the key activities in UC2 is presented in **Figure 24** and covers the time span from the year 2022 until the end of 2025.



Figure 23: Illustration of the workflow plan of the key activities in UC3

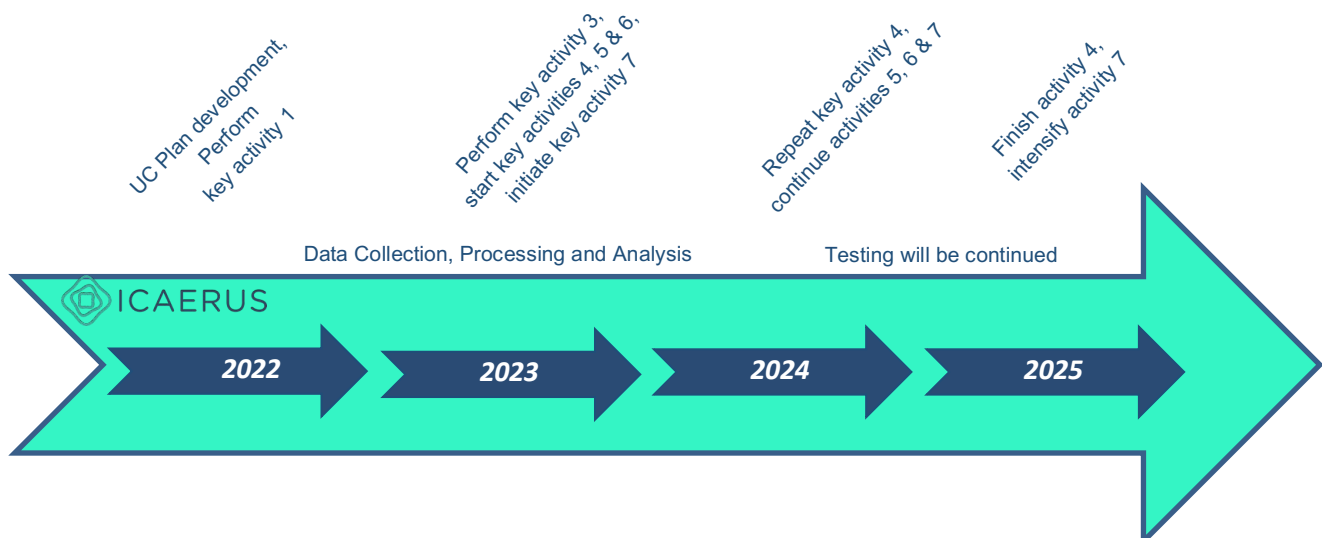


Figure 24: Timeline of the key activities in UC3

2.3.3 Technical Requirements

2.3.3.1 Technical Guidelines

Site description

The first pilot area (farm A), where beef cattle herds are raised, is located in the central-east part of France (46.40418° N, 4.65306° E) (**Figure 25**).

In general, three regions in farm A (denoted with green colour in **Figure 25**) exhibit interesting characteristics. In particular, drone flights can cover a relatively large area (from top to bottom: 70ha, 39ha, 39ha) compatible with the national BVLOS regulations (flight distance < 1Km). On the contrary, many other regions in farm A (denoted with blue colour in **Figure 25**) are not suitable for drone deployment due to several reasons, such as their usage for crop production, unsuitable for take-off procedure, nearby inhabitants, etc.

The second pilot area (farm B) is related to sheep flocks and located in southern France. The geographical coordinates of the main regions are:

- Farm main settlement: 44.03122°N, 6.13589°E.
- Summer mountain land 1: 44.20560°N, 6.47091°E.
- Summer mountain land 2: 44.36800°N, 6.39803°E.

The environment of farm B contains areas with varying characteristics that will have different uses during the year (typical pastoral sheep farm). Specifically, areas denoted with green colour in **Figure 26**, represent grasslands near the farm's main settlement, where sheep flocks can be monitored without violating the national BVLOS regulation. Thus, transportations with cars and walking through the farm will be avoided. On the other hand, areas denoted with red colour in **Figure 26**, cover a larger woody rangeland region, where the deployment of drones will facilitate livestock monitoring. Within these areas, ground monitoring of animals is not a straightforward task due to the low visibility from the dense vegetation. For this reason, drones equipped with RGB and thermal cameras will be implemented for livestock monitoring, while the results of each case will be compared and addressed. Finally, the highlighted areas in **Figure 27** are indicative of mountain grasslands with rapid altitude changes, where sheep flocks are grazing during the summer.

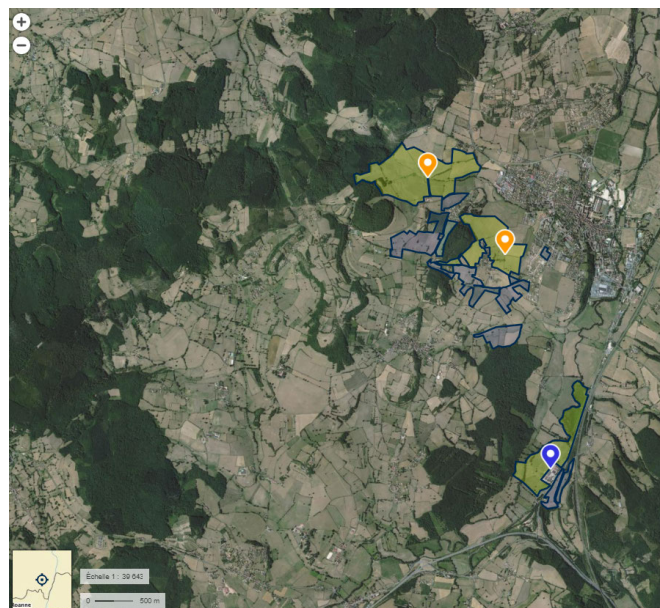


Figure 25: Map of the area of Farm A. The coloured polygons represent areas where a drone can perform a continuous flight. The green polygons denote 3 main regions for monitoring cattle with drone use. The blue polygons denote regions where drone use is less beneficial due to various constraints (roads, proximity to other facilities or residents). The orange markers represent potential launch sites suitable for efficient drone flight planning, covering the entire surrounding area (green polygons), while the blue markers indicate the main settlement of the farm

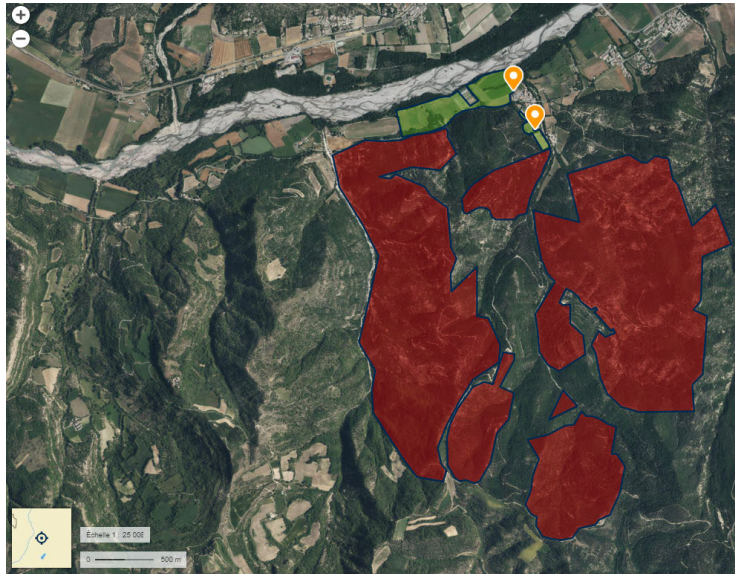


Figure 26: Map of the area of Farm B. The coloured polygons represent areas where a drone can perform a continuous flight. The green polygons indicate 2 main areas for monitoring cattle with drone use in winter. The red polygons indicate large forested grazing areas of more than 500 ha. The orange markers represent potential launch sites for drone flights within the green polygons. Both launch sites are located in the main settlement of the farm.

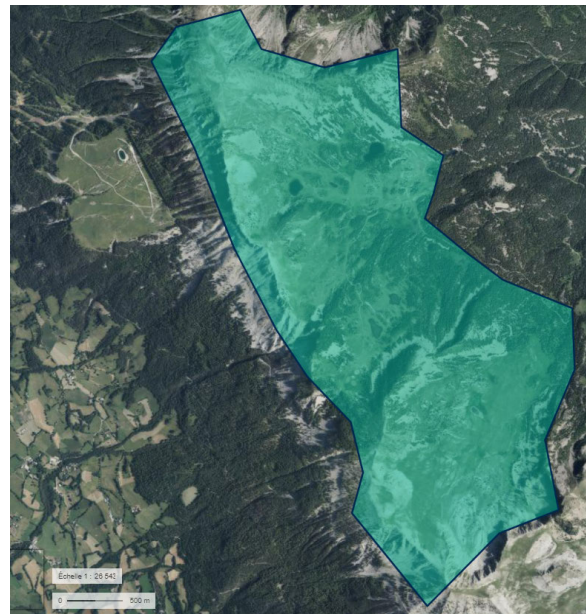
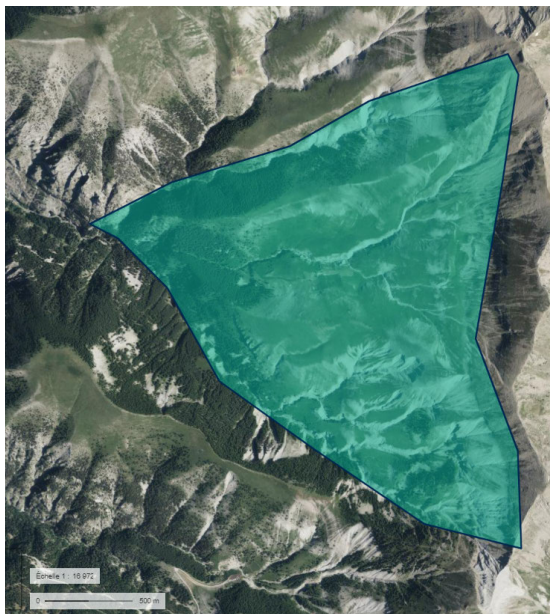


Figure 27: Map of the summer mountain lands of farm B. Highlighted polygons represent areas where a drone can perform continuous flight

Methodology

All methodologies involved in UC3 are mainly related to the evaluation of farmers' activities while monitoring the livestock in grasslands. Initially, a detailed record of farmers' tasks will be assessed, in order to extract necessary information about their specific requirements during the livestock monitoring. The outcomes of this procedure will be updated during the year, adjusting to each season, and used as a standard reference for the farmers' typical activities. Finally, drones will be deployed to perform these reference activities and the advantages of their usage for livestock monitoring will be evaluated.

2.3.3.2 Platforms & Mounted Technological Components

The required platforms and mounted technological components for the realization of the UC3 are described in the following:

- A drone equipped with RGB camera (x56 zoom), approved by national authority for flying BVLOS into a 1 km radius. The drone MAVIC 3 Enterprise from DJI (<https://www.dji.com/gr/mavic-3-enterprise>) has been purchased.
- A drone equipped with both RGB and thermal cameras (x56 zoom), approved by national authority for flying BVLOS into a 1 km radius. The drone MAVIC 3 Thermal from DJI has been ordered. Is it also equipped with a powerful zoom, a wide range camera, allowing a large inventory of services to be exploited from farmers.
- Speakers will be tested as an additional payload on the drones, in order to assess their implementation for relocating the animals using specific sounds (for instance, herding dog records).

It is worth mentioning that lighter (< 250g) and less expensive drone models might be tested at the later stages of ICAERUS project, in an attempt to provide more affordable solutions to the farmers for livestock monitoring.

2.3.3.3 Measurements – Data & Datasets

Data related queries

What is UC3 testing for?

UC3 is testing for the impact of using drones to support livestock monitoring and livestock farm tasks.

Is there already existing data? Open/public data?

Unfortunately, few data exist about the impact of using drones for livestock monitoring or the farming system.

How will data be acquired? When? How many times? What are the environmental conditions?

Data from drones' deployment will be acquired during the year, both in grasslands and mountain rangelands, and will be repeated at least one more time in later years of the project.

How will the collected data and datasets be used to operate in favour of the ICAERUS project?

The collected data and databases will assist to the improvement of the social and environmental impact of livestock monitoring on the farmers. Drone images recorded in a variety of contexts will support the optimization and the test of models identified in the WP 2 of ICAERUS project.

Data categories

Input Data:

- Map tiles of France from Geoportail (<https://www.geoportail.gouv.fr/>).
- Maps from the ICAO.
- Weather forecast data from open-source repositories.
- Actual weather conditions from installed weather monitoring stations.
- End-user data.
- Number of animals (as a reference for used or developed counting models).

Metadata (Georeferenced images - shapefile):

- Shapefile reporting obstacles, no-fly zones reported by farmers and the team project.

Expected Output Data:

- Drone performance logs.
- Flight mission plans to be registered in NAA and other involved agencies.
- End-user data to assess the farmers' labour.

2.3.3.4 Drone Data Analytics Models

Development of “livestock counting” models/software (open source).

2.3.4 Expected Results

2.3.4.1 Expected Outcomes

An outline of the main expected outcomes in UC3 is presented in the following:

- Assessment of the impacts of using drones for livestock monitoring.
- Provide guidelines for a legal and safe use of drones in grasslands.
- Promote the use of drones as multi-purpose vehicles in grasslands systems.

2.3.4.2 Impact

Socio-economic

The socio-economic impact of UC3 is summarized in the following:

- Decrease farmers' labour in livestock farming. Livestock farmers suffer from demanding working conditions. New generations of farmers claim for a decrease of work duration, physical workload, and improvement of work flexibility. As a fast eye-in-the-sky, drones have the potential to be a time saver technology for many tasks. On the other hand, drone technology will also impact the relation between “human-animal-(machine)” and the required skill set. An assessment of the global socio-economic impact will be performed.
- Improvement to the relationship and respective knowledge between drone service providers and livestock farmers.
- Integrated knowledge of drone regulations.

Environmental

The environmental impact of UC3 is mainly related with the following:

- Drones generate low CO2 emissions and extremely low noise levels, leading to a minimum footprint both in terms of environmental pollution, noise pollution and disturbance of fauna and flora. Nevertheless, in order for the drones to operate properly, energy from relatively high-capacity batteries is required. In UC3, a robust usage of drones will be tested, incorporating mainly images and less video footage.
- The deployment of drones in grassland-based livestock systems can contribute to the preservation and improvement of agriculture.

2.3.5 Replicability

In UC3, affordable drone technologies and open-source models (or providing open-source models) will be used to ensure the replicability of the outcomes. In fact, an effort will be made to provide guidelines and define a reference for livestock monitoring in grassland-based systems.

The results of UC3 mainly concern livestock farmers with grassland-based systems (typical environment in mountain areas), wetlands and rangelands, focusing in Europe.

The UC3 can be easily scaled-up by providing to the farmers all the necessary information (or guidelines) to adopt drone technology and utilize them as a powerful tool for livestock monitoring.

2.4 Use Case 4: Forestry and Biodiversity

2.4.1 Introduction

Lithuania's forests are currently in a good state of health. Still, threats remain, emerging from the impact of extreme natural phenomena on forests. Climate change is increasing in severity and frequency, such as winds, storms, droughts, torrential rains, heavy snowfall, heat waves, and sudden weather events changes in weather patterns. As the climate warms, the aggressiveness of harmful insects and diseases changes, and new ones appear or start to cause damage to native species that were not previously damaging to stands. Due to extreme events and other risks, there is an increasing need for risk mitigation - a shift from template-based to more adaptive forestry (*State Forest report*).

The main problems related with forestry and biodiversity are:

- In Lithuania's state forests, damage caused by insects, pathogens, animals and abiotic factors is recorded at 8.469 ha in 2021, or 27 % less than a year earlier (11.679 ha in 2020). In focus, measures to improve the health of stands were applied on 4,720 ha and 193,145 cubic metres of damaged trees were felled (State Forest report).
- Infectious diseases affected 1.197 ha of forest (mainly: aspen sponge on 588 ha, ash dieback on 432 ha, root-knot nematode on 151 ha). Forest sanitation measures were taken to remove diseased trees on 518 ha and to cut down 23.314 cubic metres of wood. By 2022, 666 ha of chronically diseased stands remain (State Forest report).
- Abiotic natural factors damaged 2,883 ha of trees and plantations (mainly: snow on 1.638 ha, wind on 1.140 ha, drought on 78 ha). Inanimate natural disturbances were eradicated on 2.295 ha, 47.425 cubic metres of damaged trees were felled (State Forest report).
- The primary objective is to evaluate the levels of the health status of individual trees affected by a combination of drought and pests. Also, drought identification could potentially contribute to the monitoring and assessment of forest fires risk (according to 2021 data, 6.4 ha damage) (State forests overview of sanitary conditions 2021).
- The spreading of wild boars' population is severely destroying large areas of fertile land. This does not only affect soil health and carbon emissions, but it also threatens biodiversity and food security that are crucial for sustainable development. The expansion of wild boars' population into areas with abundant soil carbon, will lead to the release of even greater amounts of greenhouse gas emissions in the future.
- ASF is a highly contagious viral disease in domestic and wild pigs, and wild boars. Outbreaks of this disease, frequent in European countries in recent years, cause significant economic losses. The most critical financial losses for the pig farming and meat processing industries are caused by the suspension of exports of pigs, pig meat, and other agricultural products. In Lithuania alone, the losses caused by ASF in the livestock sector are estimated at around €50 million. In Lithuania, cases of ASF are still recorded in the wild. According to the State food and veterinary services, the virus was detected in almost 400 wild boars in 2021 and four in January this year. There is still a risk of transmitting viruses from the forest to the pig-holding area (State food and veterinary services).
- GhG emissions and removals from forests and forest products will play a key role in achieving the Union's ambitious target of absorbing 310 million tonnes of carbon dioxide equivalents. Sustainable forest management plays the leading role in this process, which approaches are based on a recognised and internationally agreed dynamic approach to the sustainable forest management concept (EU forest strategy).

In consequence, two main needs have to be fulfilled:

- **Forestry monitoring.** We will need to reverse negative trends, monitor more effectively to gather more accurate information on the state of our forests and step up our efforts to protect and restore forest biodiversity to ensure forest resilience. A more precise, cost-efficient and straightforward

implementation of forest monitoring is needed.

- **Wildlife monitoring.** Estimating the size and geographical distribution of the wild boar population is of great importance for controlling the spread of the ASF, and knowledge of the geographical distribution and population size of susceptible animals is essential for understanding the risk of spreading the infection to different areas and countries.

Forestry and forest maintenance can be a tedious and tiring process that, in some sense, requires a lot of manpower, skills and relevant resources. The maintenance of forest lands is carried out to prevent dangers that pose a greater risk to nature - forest fires, illegal logging, etc. However, surveillance and monitoring of the forest status is the main current and future challenge of forestry due to their vast surface and lack of experienced personnel (forest managers, engineers and workers) based onsite. Therefore, it is very difficult to spot risks at early stages. However, it is of much importance, since in a lot of cases immediate action must be taken. In this regard, UAVs could play a significant role in detecting risks (Torresan et al. 2017).

Abstraction of the distribution of potentially beneficial use cases of crewed aircraft and different UAV types used for remote sensing in forestry (**Figure 28**): a) by scale and spatial resolution, b) by scale and costs per m². Within the overlap area in the top graph, UAVs often have a significant cost advantage over crewed aircraft and are faster and more frequently deployable. Multirotor drones are easier to handle compared to fixed-wing aircraft, but are only suitable for relatively small areas (Ecke et al. 2022).

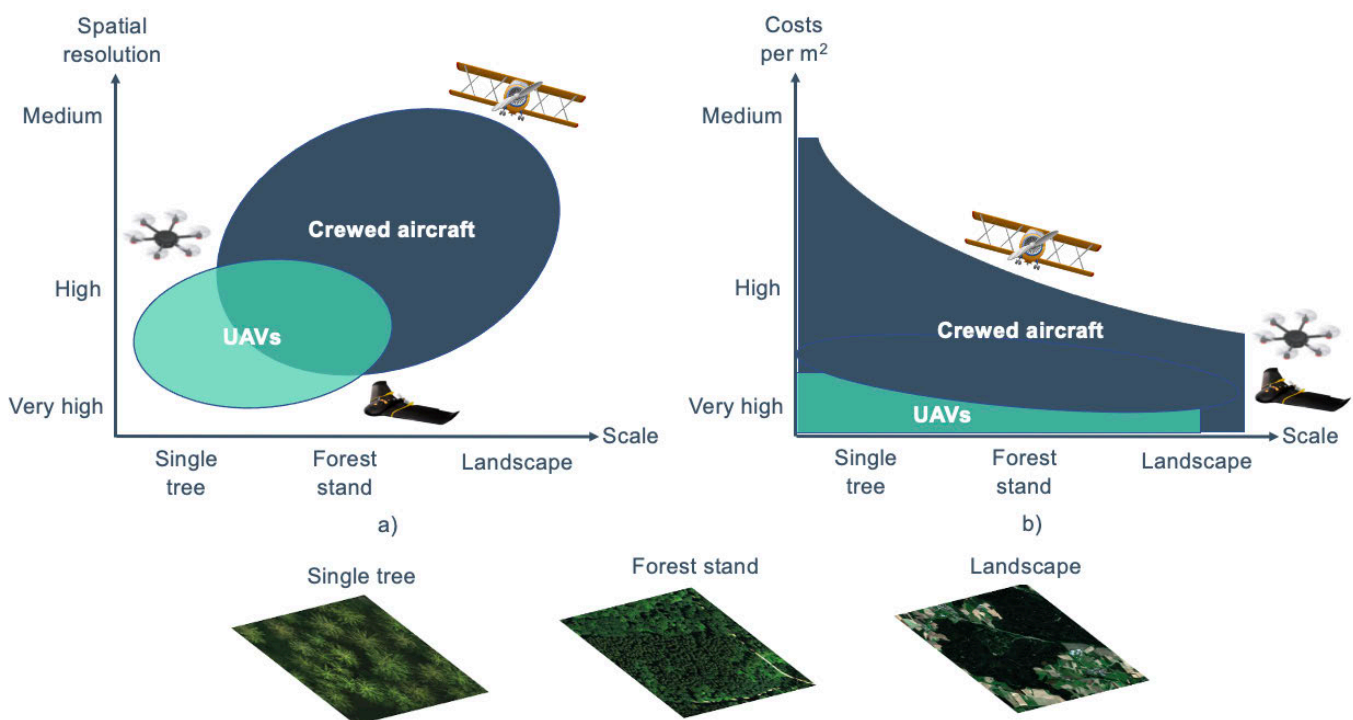


Figure 28: Distribution of potentially beneficial use cases of crewed aircraft and different UAV types for remote sensing in forestry

In UC4 the combination of different types of UAVs and cameras will be used to create optimised solutions for the specific scenarios: for tree health and fire risk monitoring - a multi-rotor drone, and for wildlife monitoring - a fixed-wing drone.

The satellite imaging data will be used to detect possible tree stress, meanwhile multi-rotor drones will be used for detailed (high-resolution) monitoring of specific forest areas (including tree health and fire risks), while fixed-wing drones are becoming an efficient tool in forestry research and will be used for wildlife monitoring due to their capacity to cover vast areas and provide fast monitoring data. Since they can cover large areas of interest within a limited time frame, the operational costs of implementing UAVs are significantly reduced in comparison to other monitoring means, such as manned aerial surveys.

All activities carried out in the U4C will fall under one of the three following main scenarios/missions:

- I. Forest Tree Health Assessment
- II. Wildfire Risk Monitoring
- III. Wild Boars Monitoring

The main goal of the UC4 is to develop and demonstrate multipurpose drone utilisation to monitor forest condition and wildlife. The successful implementation of the UC4 will create such outcomes:

- Methodology for UAV-based tree health monitoring and risk assessment.
- Methodology for UAV-based forest monitoring - fire risk assessment.
- Methodology for UAV-based wildlife (specifically wild boar) population assessment and monitoring to prevent the spread of potential African swine fever and management of its risks.
- Operational demonstration of multipurpose UAV (fixed-wing, multi-rotor drone) utilisation in forest biodiversity (tree health, wildlife) and forestry management (wildfire risk) monitoring.

2.4.1.1 Challenges & Key Questions

Several challenges are expected to be encountered during the implementation process of the main targets within the UC4 plan of the ICAERUS Project. The most important of them (targets and challenges) are briefly described in the following:

A. Regulatory

✓ **Main Targets**

Mission planning and control will comply with local governmental regulations. Carried out missions will not disturb the everyday air traffic and will not include flying over protected or restricted spaces so as not to create any precedents.

➤ **Challenges**

Mission planning will need to be done carefully so that it complies with all laws and regulations and the critical airspace would not be included in the flightpath. A two-way communication with governmental institutions has to be established.

B. Technological

✓ **Main Targets**

Hyperspectral imaging and thermal imaging cameras will be successfully paired with UAVs for an inflow of valuable specific information analysis which will give a clear picture and insight of the current forest health and wildlife behaviour.

➤ **Challenges**

Ensure optimal conditions (angle, vibration dampening, stability, etc.) for the hyperspectral and thermal data collection during the flight. Ensure sufficient flight time for the data collection and monitoring.

C. Socio-economic

✓ **Main Targets**

Development and implementation of a solution which would reduce the burden of monitoring large areas of forests on a periodic basis. Reducing the workload and the time needed to detect potential risk areas at the same time reducing the manpower needed at such tasks.

➤ **Challenges**

The acceptance of utilisation of drones and mathematical analysis systems for forest monitoring can be hindered by the view that new technologies cost too much and they will reduce job

opportunities in the field. The socio-economic benefits and improvements of such a system should be clearly addressed and messaged.

2.4.1.2 Objectives

The main objectives of multipurpose drone utilisation for the application in forestry are:

- Monitor forest tree health through the use of drones, satellites (Sentinel-2) and data science.
- Identify and inspect areas of potentially high fire risk and assess fire fuel types.
- Monitor ecosystems and assess biodiversity and wildlife populations.
- Evaluate the capacity of drones to manage or prevent the expansion of infectious diseases affecting both feral and domestic animals.

Other objectives related to the main activities are:

- Plan the use case (choose forest area of interest, conduct mission planning and data gathering, etc.).
- Conduct research of the spectral signatures used to evaluate stress and find the optimal set of signatures and analysis parameters.
- Create a set of spectral signatures for the precise forest health evaluation.
- Create a set of spectral signatures for the precise discrimination and evaluation of the various forest fire fuels.
- Create a methodology and a seamless workflow for combining the results of the satellite imagery data and the data gathered using UAVs resulting in the most efficient forest monitoring.
- Develop mathematical analysis algorithms for satellite and hyperspectral imaging data analysis.
- Create a methodology for precise wild boar monitoring.
- Develop mathematical analysis algorithms for wild boar identification, counting and monitoring.
- Conduct a socioeconomic impact analysis of the innovation.
- Design and implement the software architecture.
- Demonstrate the UAV-based solutions.

2.4.1.3 Potential Barriers

Several barriers can potentially hinder the objectives of UC4, described in (**Table 8**).

2.4.1.4 Use Case Scenarios

During the UC4 the following scenarios will be explored:

1. Scenario 1 - Forest Tree Health

Satellite images of the forest are analysed and a drone equipped with a hyperspectral camera is deployed to scout the identified possibly unhealthy forest areas and determine the symptoms of forest health deterioration.

2. Scenario 2 - Wildfire Risk Monitoring

A drone equipped with a hyperspectral camera is deployed to scout the forest area, identify forest fire fuel types, their availability and condition.

3. Scenario 3 - Wild boars monitoring

A drone equipped with a thermal imaging camera is deployed to scout the forest area, detect and count wild boars.

Table 8: Examples of potential barriers for the UC4 implementation

Potential Barrier	Description
Regulations	1.Regulations and restrictions that affect the widespread adoption of drones as a sustainable and environmentally friendly alternative in several EU countries. 2.Accountability for drone owners. 3.Drone's route (especially at the border). 4.Insurance obligations. 5.Pilot certification and training. 6.Crowding airspace for manned aircrafts. 7.Determination of liability.
Technical	1.Limited internet accessibility to improve precision monitoring application. 2.Complex equipment is inevitable. 3.Difficulties in calibration and setting of prototype/customized solutions.
Socio-economic	1.Lack of knowledge/awareness in the forest industry of the multiple ways how efficient UAVs can be utilised. 2.High upfront costs of UAVs technologies and monitoring equipment. 3.High operating costs. 4.Resistance to change from existing forest and biodiversity practices. 5.Lack of cost-benefit understanding. 6.Risk aversion of adoption of new technologies.
Environmental issues & Meteorological phenomena	1.Adverse weather and climate conditions affecting the planning of drone missions: Fog, Dazzling light, Clouds, Wind and turbulence, Rain, Solar storms, Temperature and humidity, Snow, Drizzle, Lightning, Hail, Storm.

2.4.2 Key Activities

In this section, the key activities, the workflow and the implementation timeline of the UC4 are described, providing a main overview of the progress status and planning.

2.4.2.1 Description Of Key Activities

The key activities of the UC4 covers a variety of aspects from field trials to socio-economic impact. The description of the main key activities in UC4 is summarized in **Table 9**.

Table 9: Key activities of UC4

	Activity	Description
1		Forest Tree Health
1.1	Satellite imagery data collection and pre-processing	Multispectral satellite data from various time periods will be collected to create a starting database of the analysed forest areas. The satellite imagery will be pre-processed in order to remove unusable image areas (cloudy, obstructed, etc.).
1.2	Development of the	Spectral signature and parameter research will be conducted in order to

	high-risk forest area identification component	find the optimal set of parameters for high-risk forest area identification. Mathematical algorithms for satellite data analysis will be developed (training, testing, validation).
1.3	In-depth high-risk forest area investigation	The drone flight missions will be planned in accordance with the data provided by the satellite imagery analysis. Drone and the hyperspectral analysis hardware will be assembled. Hyperspectral data acquisition missions will be carried out in the identified high-risk areas.
1.4	Development of the in-depth high-risk forest area analysis component	Spectral signature and parameter research will be conducted and a set of optimal spectral parameters will be described. Mathematical algorithms for hyperspectral data analysis will be developed (training, testing, validation).
1.5	Development of the forest health analysis software prototype	The final combined analysis system will be described, created and tested. Final optimisation of mathematical analysis algorithms will be performed.
2	Wildfire Risk Monitoring	
2.1	Description of the environmental background of the forest under investigation.	A background identification of the forests will be conducted. Regarding the state of the environmental parameter set, the highest wildfire risk forest and its areas will be determined.
2.2	Development of the potential wildfire risk forest area identification component	Spectral signature and parameter research will be conducted in order to find the optimal set of parameters for different forest fire fuel identification.
2.3	In-depth high wildfire risk forest area investigation	The drone flight missions will be planned in the highest forest fire risk areas. Drone and the hyperspectral analysis hardware will be assembled. Hyperspectral data acquisition missions will be carried out in the identified high wildfire risk areas.
2.4	Development of the forest health analysis software prototype	Hyperspectral data analysis will be carried out and results will be used to create a detailed map of the forest fire fuels in the scanned forest regions.
3	Wild Boars Monitoring	
3.1	Optimal parameters	Investigating, identifying and describing the optimal parameters for conducting aerial surveys;
3.2	Methodology for data processing	Developing a cartographic presentation methodology of the processed data – results.
3.3	Methodology for UAV wildlife monitoring	Improving a methodology for conducting wildlife monitoring using aero-distance methods.
3.4	Algorithms	Improving an algorithm for classification of aero-distance data (object recognition in images).
3.5	Model	Improving classifier model based on the developed algorithm.

3.6	Architecture description	Describing the architecture of the classifier model and its parameters.
3.7	Model testing	Testing and accuracy evaluation of the classifier model.
3.8	Data classification process	Identification and describing characteristics of the data classification process and of the data itself at different stages of processing, processing flow, formats.
3.9	Digital library	Creating the digital library of wild boar images (under different environmental and technical conditions for aerial surveys).
3.10	Identification of methods	Identification of methods for filtering and processing of primary aerial data.
3.10.1	Boars' identification and counting data collection component	• Task formulation (UAV preparation for autonomous flight). • Data acquisition (captures thermal and visible light image).
3.10.2	Preparation and processing of boars' identification and counting data component	• Data transfer to the computation system (Transferred data for further processing). • Data formatting (data prepared for analysis).
3.10.3	Classification for boars' identification and enumeration data component	Data analysis module training (boars detection classification and calculation algorithm).
3.10.4	Boars' identification and counting data classifier training and verification data sets	• The data processing module (low quality and high-quality data). • Data refinement module (refined data set for retraining).

2.4.2.2 Key Activities' Workflow

The UAV mission activities' workflow plan, as well as the general key activities workflow for the defined UC4 scenarios are illustrated in **Figure 29** and **Figure 30**, respectively.

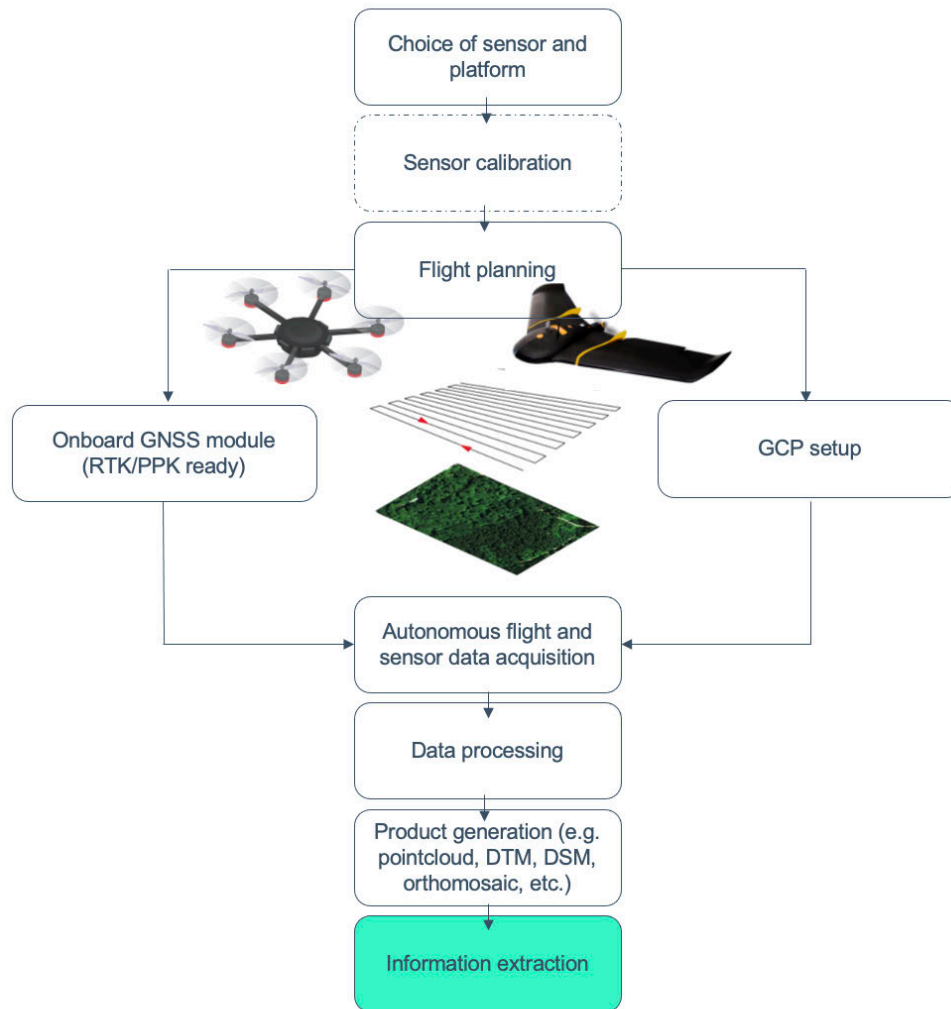


Figure 29: Illustration of the UAV mission activities' workflow plan for the UC4

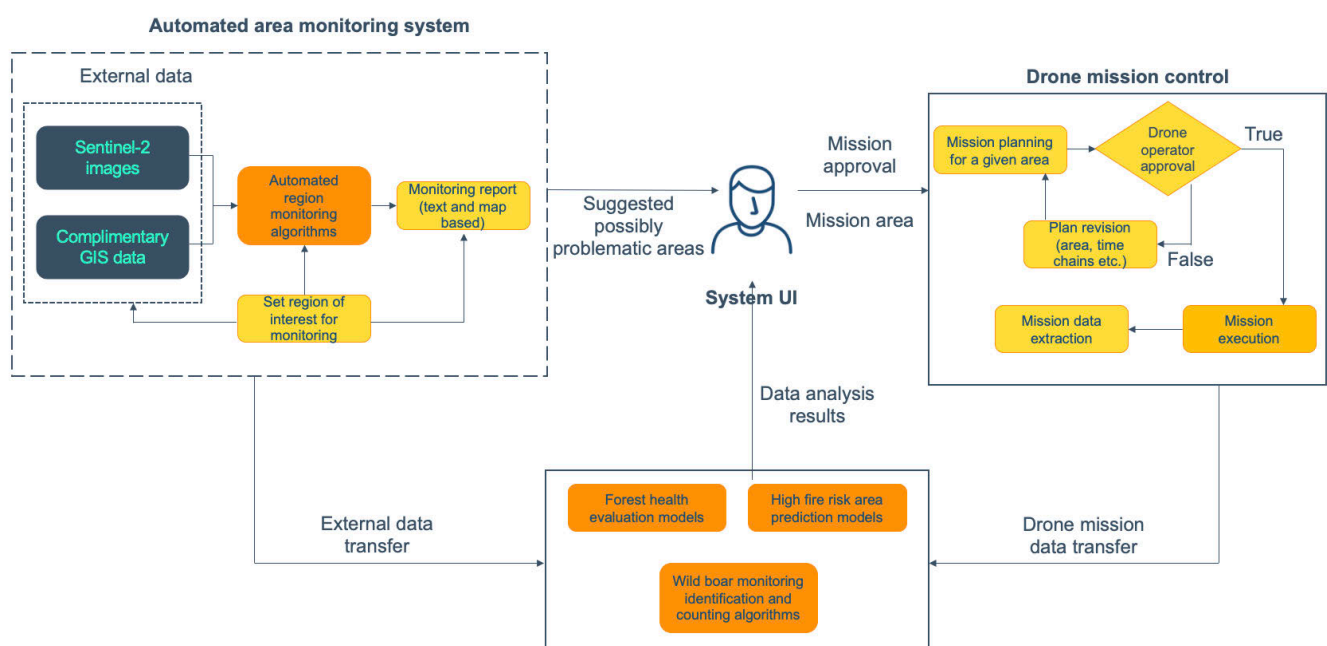


Figure 30: Illustration of the general workflow plan of the key activities in UC4

2.4.2.3 Timeline

The implementation timeline of the key activities in UC4 is presented in **Figure 31** and covers the time span from the year 2022 until the end of 2025.

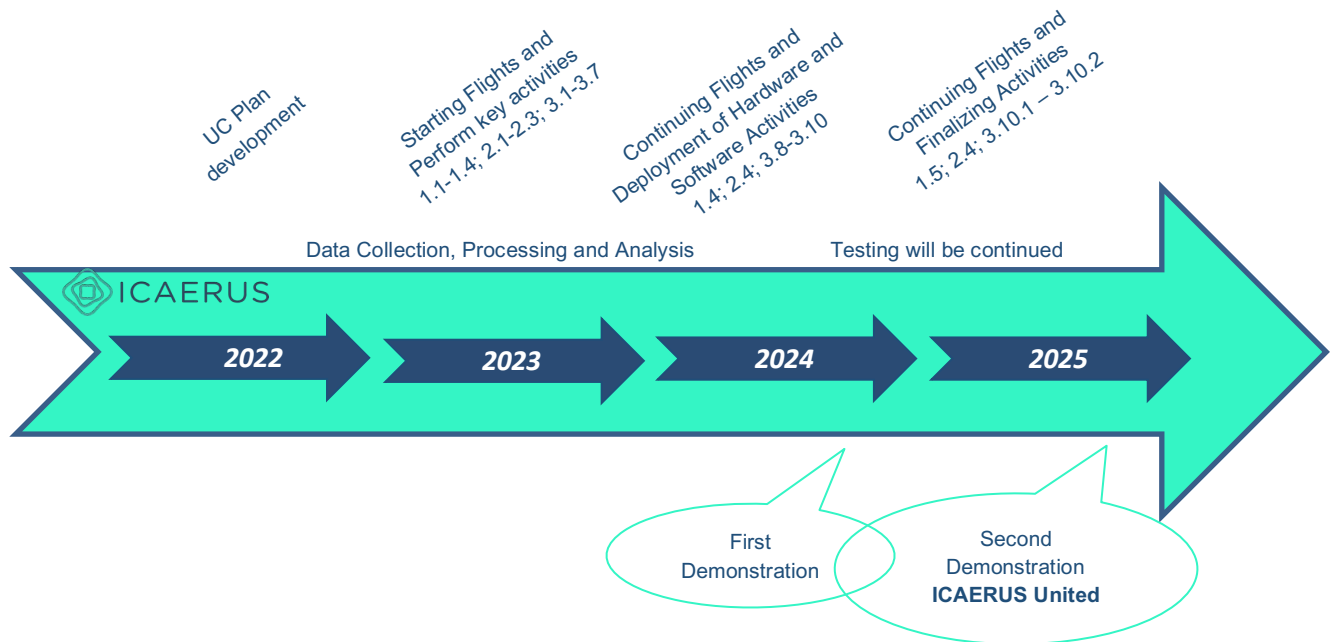


Figure 31: Timeline of the key activities in UC4

2.4.3 Technical Requirements

2.4.3.1 Technical Guidelines

Site description

Lithuanian forest areas will be selected to conduct the pilot testing based on (a) prevailing tree species, and, (b) the specific areas depending on environmental and other conditions.

Scenario 1 - Forest Tree Health

The testing area will be selected in one of the Scots Pine forests (**Figure 32**) located in the regions with high potential of Pine health risks.

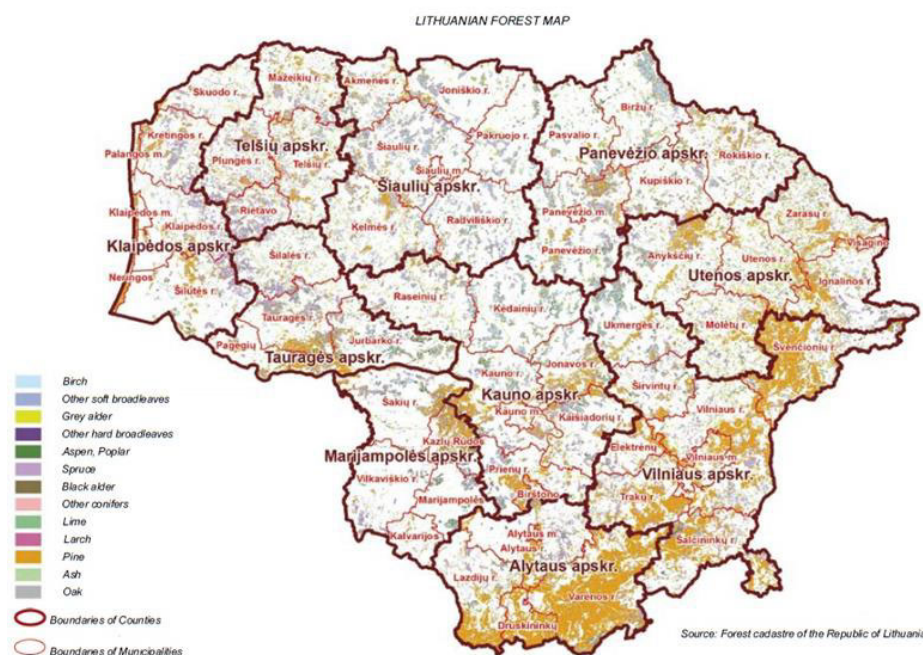


Figure 32: Test area for the scenario 1 of the UC4

Scenario 2 - Wildfire Risk Monitoring

The testing sites will be selected for Lithuanian forests according to natural fire potentiality classes (**Figure 33**, left part) and locations of forest fires in the last few years (**Figure 33**, right part) (*Lithuanian's national inventory report 2021*).

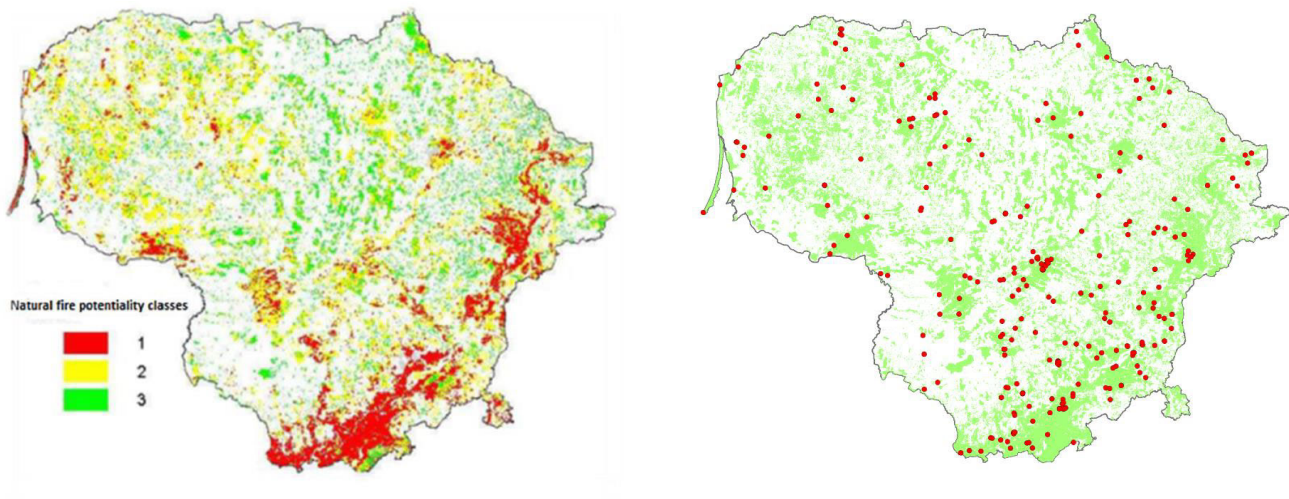


Figure 33: Test site for the scenario 2 of the UC4

Scenario 3 - Wild Boars Monitoring

ASF regionalization map (**Figure 34**) (State food and Veterinary services).

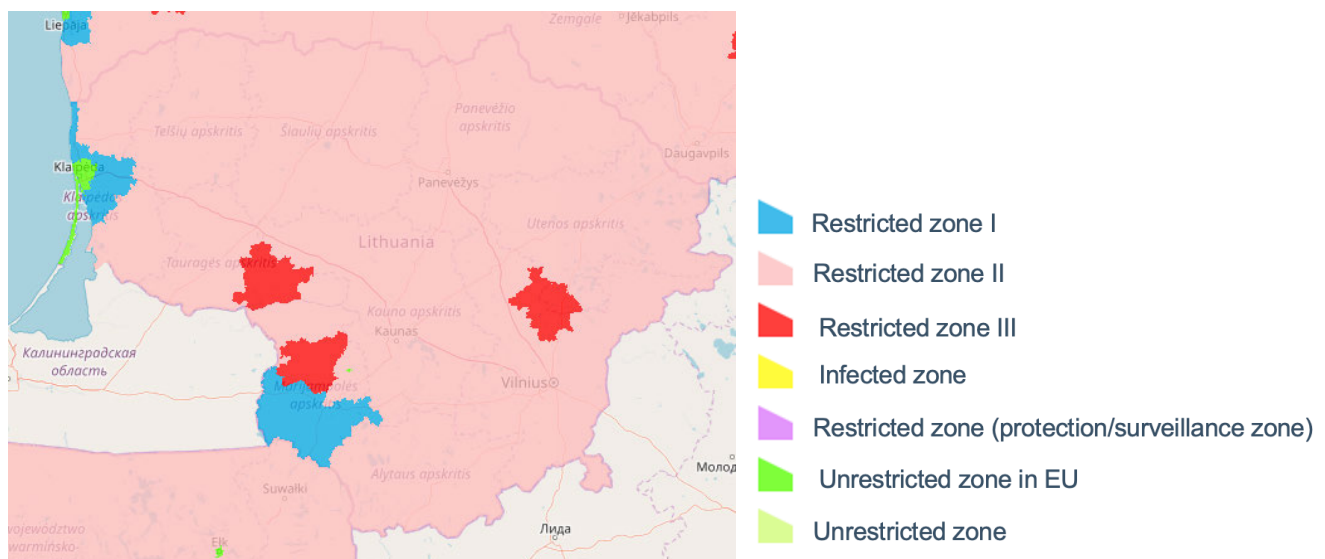


Figure 34: Map of the African swine fever spatial distribution

It is worth mentioning that sites with dense mixed forests will not be selected for the autumn - spring monitoring period.

Methodology

Scenario 1 - Forest Tree Health

The methodology of the forest tree health monitoring will be based on the combined usage of the multispectral satellite imagery (Sentinel-2 MSI) and the UAV system consisting of the multi-rotor drone and VNIR-range hyperspectral camera. Forest tree health monitoring will consist of several steps of execution:

- The primary assessment of forest tree health from satellite images.
- Drone mission planning and execution over the satellite-identified unhealthy forest areas.
- Processing of hyperspectral drone sensing data.
- Detailed assessment of forest tree health symptoms using hyperspectral imaging data.

A primary inspection of forest tree health will be performed using multispectral Sentinel-2 satellite images with a spatial resolution of 10 m. The forest state will be assessed using a time series of a set of broadband spectral indices sensitive to different forest health measures that are commonly used in forest health studies. Indices will be selected based on the frequency of their usage and their performance in predicting forest health. Probable broadband indices include NDVI, MSI, and NBR. These indices have been previously successfully used in studies seeking to identify forest tree defoliation (Hawryło et al. 2018, Pérez-Romero et al. 2019), forest decline (Grabska et al. 2020, Gupta and Pandey 2021, Mantas et al. 2022), disease damage (Pérez-Romero et al. 2019), or to construct forest health indicators (Meng et al. 2016), therefore, they are considered as good indicators for the discrimination of stressed forest areas. This set of spectral indices will be used to classify Sentinel-2 images into possibly healthy and unhealthy forest tree areas (Navarro et al. 2019, Neri et al. 2021).

Once satellite-detected unhealthy forest areas are predefined, hyperspectral drone sensing will be used for the detailed inspection and characterization of these areas. For this purpose, flights of a multi-rotor drone equipped with a hyperspectral VNIR (400-1000 nm) camera will be planned. Collected hyperspectral data will be pre-processed using specialised software to generate hyperspectral images with high spatial (< 1 m) and spectral resolution. Algorithms to delineate individual tree crowns will be implemented on hyperspectral data (e.g., Ferreira et al. 2014, Maschler et al. 2018). This will allow separating tree cover from different land cover types in the forest area, as well as the assessment of quantitative forest characteristics, including tree count, tree crown diameter, and tree area (Gallardo-Salazar and Pompa-García 2020).

Detailed forest tree health condition will be assessed through the absence and presence of a set of symptoms showing tree health decline or vitality loss that may be caused by diseases, pests, forest animals, or unfavourable meteorological conditions, similarly to previous composite forest health estimations based on hyperspectral data (Ahmad et al. 2020b, Brovkina et al. 2017). The identified differences in symptoms may indicate the deficiency of different nutritional elements, diseases, or other causes (Žiogas 2007).

The hyperspectral data that will be collected over the critical forest areas allows the determination of narrowband spectral indices that require specific wavelengths and are designed for the precise detection of different vegetation stress factors. Also, the tree condition may be detected with higher precision using narrowband hyperspectral data compared to broadband multispectral data (Lee et al. 2004, Schlerf et al. 2005). For these reasons, forest tree health status will be determined based on narrowband spectral indices identified from the hyperspectral images with delineated forest tree crowns. Six groups of narrowband spectral indices showing biochemical, structural and exterior tree health characteristics will be used, including spectral indices of: (1) leaf/needle pigments; (2) light use efficiency/pigment ratio; (3) water content; (4) chlorophyll content; (5) discoloration; or (6) general vitality. The preliminary list of the hyperspectral indices that we are planning to use is given in **Table 10**.

Table 10: Preliminary list of the hyperspectral indices used in UC4

Group	Spectral Index	Purpose	Reference
Leaf/Needle Pigments	Chlorophyll/Carotenoid Index (CCI)	Indicates stress through the changes in concentrations of carotenoids and carotenoids to chlorophyll ratio	Wong et al., 2020
	Anthocyanin Reflectance Index (ARI1)	Indicates stress through the changes in concentrations of anthocyanins	Gitelson et al., 2001

	Carotenoid reflectance Index (CRI1)	Indicates stress through the changes in concentrations of carotenoids	Gitelson et al., 2002
Light Use Efficiency/Pigment Ratio	Structure Intensive Pigment Index (SIPI)	Indicates photosynthetic efficiency, tree productivity, carotenoid to chlorophyll ratio	Wong et al., 2020
	Photochemical Reflectance Index (PRI)	Indicate photosynthetic efficiency and tree productivity	Ahmad et al., 2020b
Water Content	Water Band Index (WBI)	Indicates moisture stress	Ahmad et al., 2020b; Claudio et al., 2006
Chlorophyll Content	Vogelmann Red Edge Index (VRI)	Indicates chlorophyll content and canopy leaf area, color change	Ahmad et al., 2020b
	Pigment Specific Simple Ratio (PSSR)	Indicates chlorophyll content	Blackburn, 1998
	Red Edge Position Index (REP)	Indicates chlorophyll content and stress	Curran et al., 1995
Discoloration	Yellowness Index (YI)	Indicates chlorosis	Adams et al., 1999; Ahmad et al., 2020a
General Vitality	Green-Red Region Spectrum Angle Index (GRRSGI)	Separates dead and vital trees	Zang et al., 2021

Based on calculated indices, tree vitality status, chlorophyll content status, moisture stress status, leaf pigment change status, and tree discoloration status will be determined using previously defined thresholds and thresholding techniques (Ahmad et al. 2020a, Kayet et al. 2019, Otsu et al. 2019, Zang et al. 2021). As a result, the indicators of tree health status will be mapped in high resolution. The derived dataset with tree health indicators will enable the identification of different tree damage levels ranging from the dead trees to the vital trees with clear visual symptoms of health decline and the vital trees with no visual decline symptoms but clear stress signals in their spectral signature. A flowchart of the abovementioned methodological scheme is displayed in **Figure 35**.

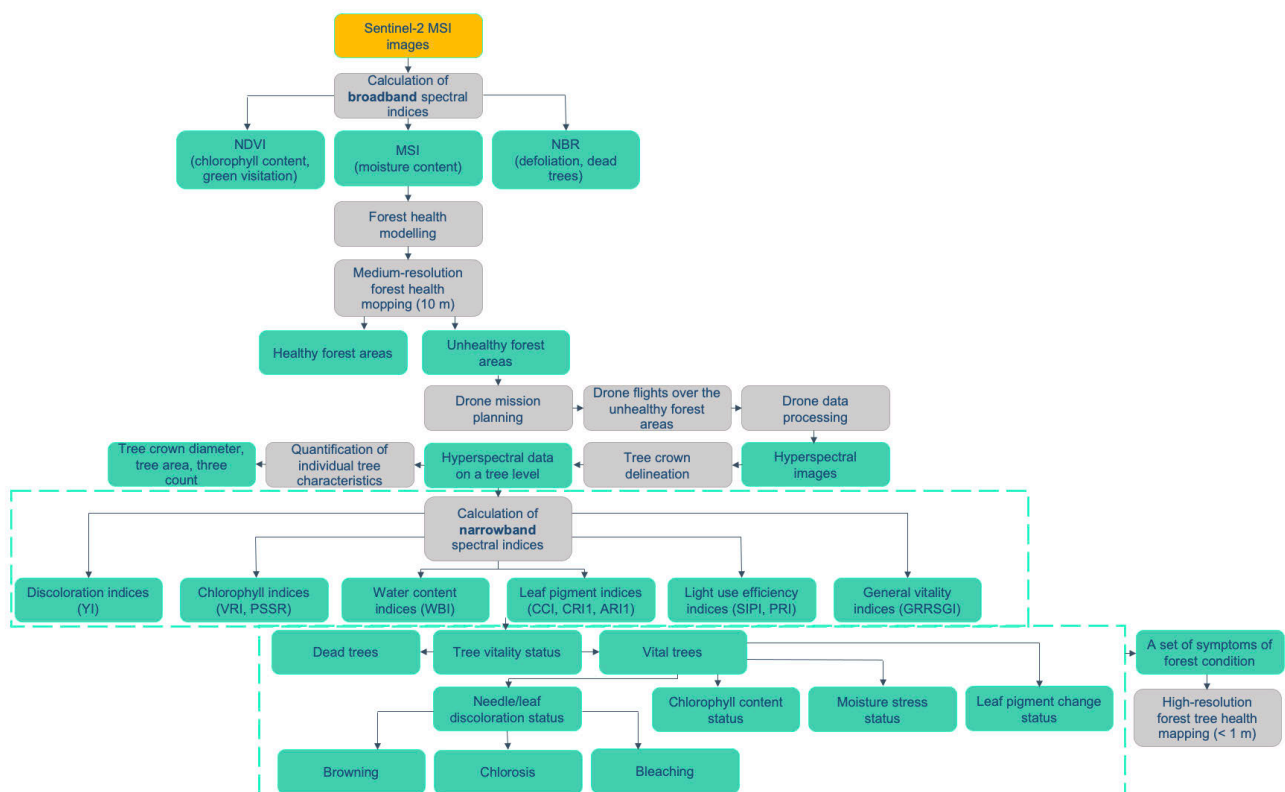


Figure 35: Flowchart of the employed methodology for the identification of the trees damage level

Scenario 2 - Wildfire Risk Monitoring

Forest structure and composition affect fuels available to burn, which in turn affect fire behaviour and emissions, as well as forest flammability (Stavros et al. 2018). Forest fire fuel maps can support fire mitigation management such as fuel treatments or fire behaviour and smoke prediction (Lanorte and Lasaponara 2008). Therefore, the Wildfire Risk Monitoring use case scenario will be based on forest fire fuel mapping as an important component of forest fire risk assessment.

First, forest fire fuel type represents an association of fuel elements that include vegetation species, form, and size that affects fire energy content that affects fire intensity (Keeley 2009). Second, it represents fuel condition that refers to moisture content and fuel vitality status (dead/live). These factors affect the flammability of forest fuels and fire spreading (Forkel et al. 2012). Previous studies have shown the potential of hyperspectral imaging in determining forest fire fuel types and their condition (Badola et al. 2021, Jia et al. 2003, Roberts et al. 2003, 2006, Romero Ramirez et al. 2018, Shaik et al. 2022, 2021, Smith et al. 2021). Lasaponara et al. (2006) determined an increase of around 20% of the overall accuracy when classifying forest fire fuels with hyperspectral data compared to multispectral data. For these reasons, hyperspectral imaging is selected for the forest fire fuel mapping.

The data acquisition system for forest fire fuel mapping will consist of a multi-rotor drone, hyperspectral VNIR-range camera, and flight mission planning software.

The use case scenario will be executed following the steps below:

- Drone mission planning over the forest test area.
- Drone flight execution and hyperspectral data collection over the forest area.
- Processing of UAV-collected hyperspectral data.
- Classification of forest fire fuel types in the hyperspectral image.
- Quantification and visualisation of forest fuel types and their availability in the forest test area.

One of the commonly used fuel type classification schemes such as the classifications from Albini (1976), Anderson (1982), Sandberg et al. (2001), or the Canadian FBP System (1996) will be used and applied to Lithuanian pine forest conditions if necessary.

Both forest fire fuel type and condition will be assessed. The condition of forest fuel types will include moisture content and tree vitality status (dead/alive). These metrics will be determined using the same methodology as in the Forest Tree Health use case scenario (Claudio et al. 2006, Zang et al. 2021).

A combination of national forest inventory data, national georeferential database, and publicly available CORINE land cover database will be utilised as reference data when classifying forest fire fuel types (similarly to Shaik et al. 2022). Hyperspectral images will be classified using machine learning classification algorithms (Lasaponara et al. 2006, Shaik et al. 2022, Smith et al. 2021). The classification results will be visualised and forest fuel types will be quantified. The database composed of forest fuel types and their attributes will be created. The resulting forest fuel types and their condition could be combined with LiDAR-derived Forest fuel load and forest fire risk could be modelled (Romero-Ramirez et al. 2018). A flowchart of the abovementioned methodological scheme is displayed in **Figure 36**.

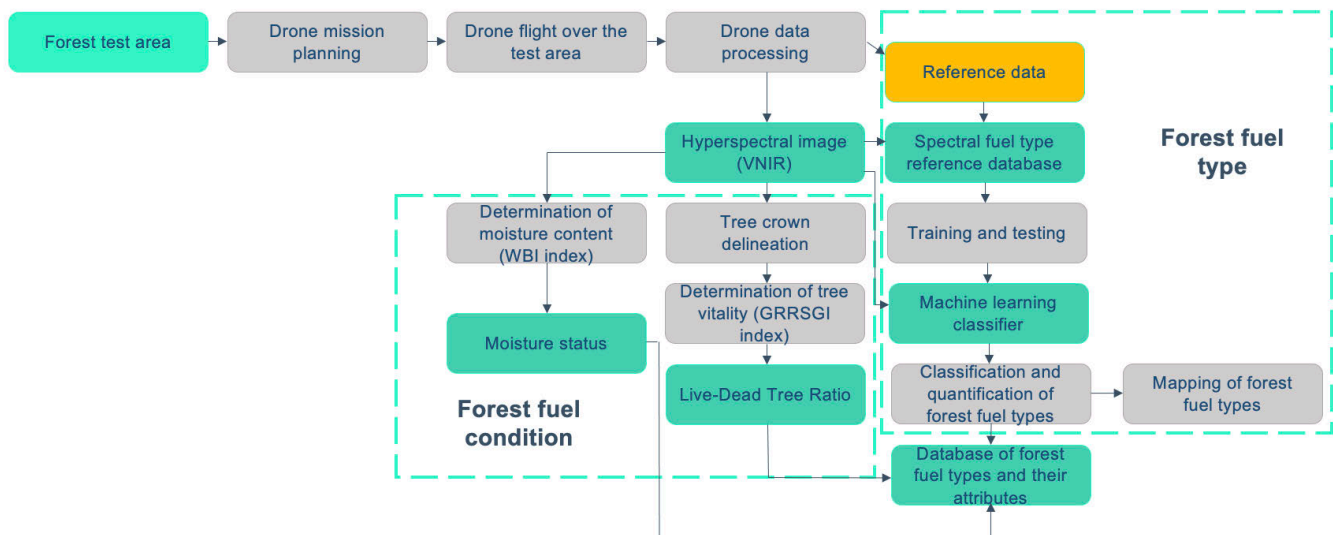


Figure 36: Flowchart of the employed methodology for the identification of the forest fuel types

Scenario 3 - Wild Boars Monitoring

The wild boars monitoring methodology is going to be developed as an improvement of the already piloted research and a prototype model in development by ART21 of an African swine fever control system that is based on remote aerial techniques and ML algorithms (TRL 5). The developed prototype model and algorithms are presented in **Figure 37** and their main characteristics are summarized in the following:

- Thermal data pre-processing and GPS data integration into thermal imagery and video data.
- Automatic wild boar detection in thermal images with AI models based on deep convolutional networks for object detection in images.
- Unique wild boar identification in different images and counting algorithms.



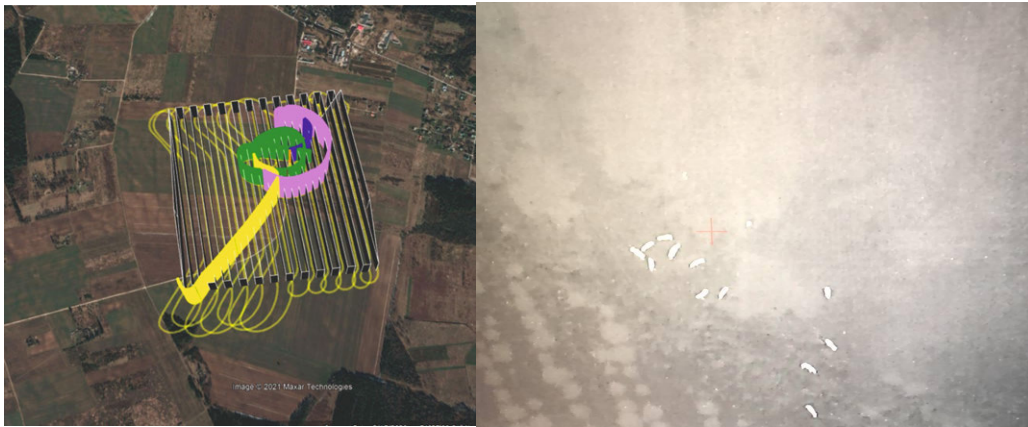


Figure 37: Example of the developed prototype models and algorithms for boars' detection

Data acquisition is provided by the first subsystem of the ACE system, which consists of components for flight operations and data acquisition. This subsystem and its components include:

- UAV (fixed-wing).
- Long Range Infrared Thermal Imaging Cameras.
- Flight planning and execution software.

The wild boars counting model is based on testing development principles (**Figure 38**).

System for boar counting

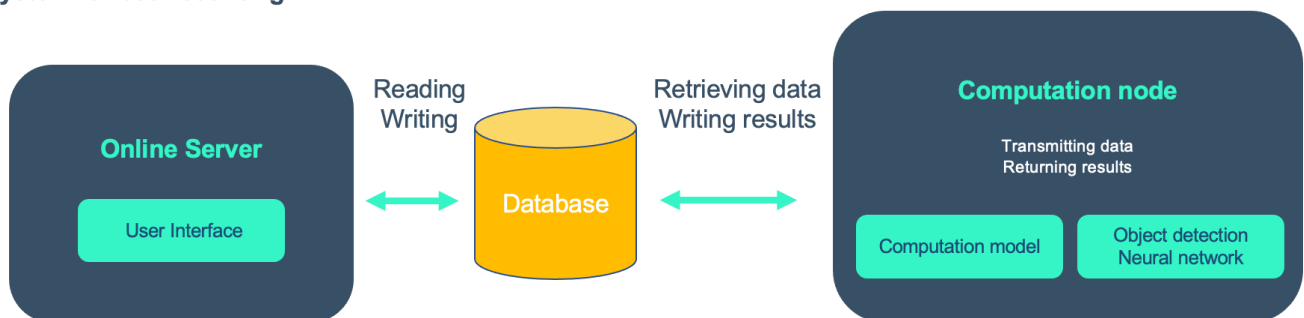


Figure 38: Illustration of the boars counting model

2.4.3.2 Platforms & Mounted Technological Components

To deploy UC4, a system of a fixed-wing and multi rotor drone, and high-end thermal imaging and hyperspectral cameras will be implemented:

- Fixed-wing drone (Volantex RC Ranger 2400 757-9 PNP) with a capacity to lift medium payload (up to 3 kg).
- Hardware control set for fixed-wing drone (Pixhawk 6C).
- Radio-wave transmitter (RadioMaster TX16S + TBS V2 crossfire).
- Multi-rotor drone.
- Hyperspectral camera (Specim), capable of high spectra and spatial resolution image collection in the wavelength range from 400 nm to 1000 nm.
- Gimbal stabilisation system for hyperspectral camera.
- Thermal imaging camera, with high sensitivity and capability of high-resolution thermal image collection (WIRIS).
- High-performance computing machine capable of processing large amounts of visual and spectral

data.

- Dedicated storage and computation server with at least 32 computation cores and 128 GB of system memory and 2 GPUs with at least 8 GB of video memory, and 40 TB of hard drive storage, and 1 Gb/s internet connection.
- Data processing and analysis software.
- Flight planning software UGCS or Ardupilot.

The listed UAVs and imaging devices are needed for a successful implementation of the use case. Depending on the use case scenario and the goals set in each one of them different setup (imaging, device, UAV, satellite data) will be used.

For the tree health monitoring Sentinel satellite data will be downloaded and analysed. The high amount of data will have to be processed therefore there is a need for a high-performance computing machine. The analysis of the satellite imagery will result in high-risk forest area identification. An in-depth analysis of the forest areas with elevated health-risk levels will be carried out using a multirotor drone equipped with a Specim AFX10 series hyperspectral camera. A stabilising gimbal Gremsy T7 will be used for stabilising the hyperspectral camera during the flight and ensuring the highest possible quality of the collected images. Hyperspectral camera is needed in order to conduct a precise analysis of the identified forest area and to evaluate the status of the said area with a tree level precision. Hyperspectral image analysis will allow us to evaluate the health of each observed tree and to provide much more information on the possible specific reason for the elevated health risk - such as drought, pest, disease, etc. This information will be passed down to the forest engineers and allow them to make precise decisions and planning of the preventive measures.

For the wildfire risk monitoring a multirotor drone equipped with a hyperspectral camera will be used. The wildfire risk of the investigated forest will be evaluated by producing a detailed forest fire fuel map. Such a map provides valuable information on the potential fire fuels and their percentage in the scanned forest area. These maps can be created by analysing the hyperspectral images and identifying the specific type of vegetation. Such analysis requires the use of sophisticated computation models for distinguishing different species of trees and plants and it also requires high computation power. The latter will be met using the high-performance computing machine.

The collected spectral data pre-processing will be performed using hyperspectral data manipulation and processing software - ENVI.

For the wild boar monitoring a fixed-wing drone equipped with a thermal imaging camera (WIRIS) will be used. The task of identifying a boar requires using a high precision and sensitivity thermal imaging device. Therefore, the thermal imaging camera from WIRIS will be used since it currently provides the highest temperature sensitivity (< 30 mK) and stability (± 2 °C) of the same technology level devices that are available on the market. Furthermore, the camera manufacturer provides a tool for enhancing the spatial resolution which is also a very important parameter for accurate discrimination and identification during thermal image analysis. As in the case of other scenarios the collected data will be processed and analysed using a high-performance computing machine designed for mass storage and fast image analysis using a local tiered storage system and a cluster of at least 2 GPUs for fast image analysis and machine learning model creation.

2.4.3.3 Measurements – Data & Datasets

Data related queries

What is UC2 testing for?

Scenario 1 - Forest Tree Health

A forest tree monitoring system composed of a combination of Sentinel-2 satellite imaging, targeted hyperspectral drone imaging, and image data processing algorithms is a powerful and suitable monitoring

tool to timely detect and provide high-resolution information about the symptoms of forest tree decline and vitality loss on a tree crown level.

Scenario 2 - Wildfire Risk Monitoring

High-accuracy and high-resolution forest fire fuel maps can be created using a combination of hyperspectral drone imaging and image classification algorithms for utilisation in forest fire risk modelling and risk assessment.

Scenario 3 - Wild Boars Monitoring

A wild boars monitoring (population counting) system which combines a drone assisted thermal imaging and a machine learning algorithm for visual data analysis can be developed for the efficient detection and behaviour monitoring of the wild boars. Information provided by such a system can be successfully used for the prevention of the spread of swine fever from wild animals to farm animals.

Is there already existing data? Open/public data?

Scenario 1 - Forest Tree Health

Freely available Sentinel-2 MSI data provided by the European Space Agency (ESA) for the primary assessment of the condition of forest tree health and identification of possibly critical forest areas. National forest inventory data may be used as supplementary/ground truth data in the development of forest health assessment algorithms.

Scenario 2 - Wildfire Risk Monitoring

Several public datasets as reference data in forest fire fuel type mapping: a national spatial georeferential database, national forest inventory data, CORINE land cover database provided by the Copernicus Land Monitoring Service.

Scenario 3 - Wild Boars Monitoring

Privately collected data from previous research, testing and piloting.

Open and public data from governmental institutions and African swine fever regionalization map.

How will data be acquired? When? How many times? What are the environmental conditions?

Drone flights will be started in 2023 and will be implemented continuously during the project finalization.

Scenario 1 - Forest Tree Health

Sentinel-2 images for the analysed forest area will be downloaded from a publicly available repository (AWS, Google Cloud, or directly from Copernicus Open Access Hub). Images acquired in spring-summer when trees are snow-free with low percentage of cloud cover will be selected. Sentinel-2 images will be gathered once in order to identify critical forest areas where drone flights will be planned.

Drone flights and hyperspectral imaging will be performed over satellite-detected critical forest areas. There will be a single drone flight per one critical forest area. However, flights might be performed on multiple days depending on the count of satellite-identified critical forest areas, their area coverage, and the distance between them.

Scenario 2 - Wildfire Risk Monitoring

Drone flights will be performed and hyperspectral images will be collected over the analysed Scots pine forest area. Drone images will be acquired once at the beginning of the forest fire season (spring-summer) to assess the availability of forest fire fuels and their types.

Scenario 3 - Wild Boars Monitoring

Multiple drone flights will be periodically performed over different areas harbouring wildlife. These will be secure enclosures and wild forests. Thermal images of wild boars will be gathered multiple times in order to create an extensive database for machine algorithm development and optimization. Flights will be performed in various environmental conditions that allow a safe drone flight.

A preliminary wildlife monitoring mission plan is presented in **Table 11**.

Table 11. Preliminary mission plan for wildlife monitoring in mixed forest areas (autumn-winter) within UC4

Month	Drone Flights			
	I	II	III	IV
October	Flights for calibration, testing and data collection – private wild animal farms	Flights for calibration, testing and data collection – agroforestry fields, crop fields, mixed forest	Flights for calibration, testing and data collection – mixed, not dense forest	Flights for calibration, testing and data collection – mixed, not dense forest
November				
December				

*The flight replicability for the Use Case and Demonstration Activities period depends on the model's developing difficulty and data needs.

How will the collected data and datasets be used to operate in favour of the ICAERUS project?

Scenario 1 - Forest Tree Health

Data collected with a drone equipped with a hyperspectral camera over the satellite-identified unhealthy forest areas will be used for the delineation of tree crowns and their health status assessment by identifying an absence or presence of a set of specific symptoms of tree health decline. The collected data will confirm or reject, as well as specify the status of unhealthy forest areas, detected using satellite images. The delineated tree crowns will be assigned with their quantitative characteristics and the status of each symptom.

Scenario 2 - Wildfire Risk Monitoring

Data collected with a drone equipped with a hyperspectral camera will be used to train the machine learning algorithms of forest fuel classification, discriminate different forest fire fuel types, detect their condition, quantify them and map the availability of different forest fuels. Derived information will be used in forest fire fuel mapping. It will increase the spatial resolution of any available forest fire fuel assessment. The outcome of the collected data will demonstrate the feasibility of hyperspectral drone sensing in high-resolution forest fire risk mapping.

Scenario 3 - Wild Boars Monitoring

Data collected using a drone equipped with a thermal imaging camera will be directly used to train, test and validate the machine learning algorithms dedicated for the wild boar detection and counting. Data will be used to train algorithms to distinguish wild boars from other heat sources, as well as count them.

Data categories

Scenario 1 - Forest Tree Health

Input data

- Sentinel-2 multispectral images.
- UAV-collected hyperspectral images.
- Basemaps.

Expected Output Data

- Medium-resolution dataset of satellite-detected healthy and unhealthy forest areas.
- High-resolution dataset of forest health attributes.
- Dataset of detected boundaries of forest tree crowns and their attributes.

Scenario 2 - Wildfire Risk Monitoring

Input data

- UAV-collected hyperspectral images.
- National forest inventory data.
- Publicly available land/vegetation cover datasets (e.g., CORINE land cover).
- Basemaps.
- Meteorological data for drone mission planning.

Expected Output Data

- High-resolution map of forest fire fuel types.
- Dataset of the forest fire fuel types and their attributes.

Scenario 3 - Wild boars monitoring**Input data**

- Thermal image datasets gathered using UAVs.
- Accurate drone GPS data logs.
- Drone flight mission data.

Expected Output Data

- Dataset of the detected wild boars in thermal images.
- Detected wild boar coordinates derived from drone GPS data.
- Shapefiles of points of detected wild boar positions and metadata.

2.4.3.4 Drone Data Analytics Models

Software that will be used:

- Pytorch machine learning framework.
- Numpy, Scipy, Scikit-learn and other mathematical and scientific calculation libraries for Python.
- QGIS and/or ArcGIS for GIS data calculations.
- ENVI and CaliGeoPro by Specim.
- Snap by ESA.

Algorithms/models:

- Sentinel-2 and meteorological data extraction, conversion and pre-processing algorithms.
- Automated region of interest monitoring machine learning models.
- Drone mission data pre-processing and format conversion automation algorithms.
- Forest health evaluation and prediction AI models.
- Models for forest fire fuel evaluation from hyperspectral imaging.
- Wild boar monitoring, identification and counting machine learning and computer vision models.

2.4.4 Expected Results**2.4.4.1 Expected Outcomes**

An outline of the main expected outcomes in UC4 is presented in the following:

- Methodology for satellite imaging combined with drone assisted imaging analysis for forest health evaluation and high-risk area identification and analysis.
- Accurate and up-to-date data sets of the forest under investigation. Reports on current and past forest health conditions and future perspectives.

- Methodology for drone assisted imaging analysis for forest fire fuel evaluation.
- Accurate and up-to-date data sets of and the fire fuel assessment report on the forest under investigation. Reports on wildfire risk in the forest and future perspectives.
- Methodology for the system, combined with drone (fixed-wing) assisted thermal imaging analysis using machine learning algorithms, employed for wild boar detection and monitoring.
- Data collection on wild boars' population in the forests as additional monitoring data for the prevention measures of possible African wild boar's fever migration by the stakeholders throughout the associated value chain.
- Accurate and insights that will contribute to risk assessment procedures (diseases' identification and mapping, fire risk assessment and prevention, etc).

2.4.4.2 Impact

Socio-economic

Forests and the forest-based sector provide multiple socio-economic functions and benefits, including additional jobs and growth opportunities in rural areas and recreational functions contributing to citizens' physical and mental health (*EU forest strategy 2030*).

Socio-economic impacts are directly related to forestry development plans accordingly to the long-term Lithuanian forestry policy goals (*National forestry accounting plan*):

- 1) ensuring multi-purpose and forest-friendly forest management by combining economic, social and ecological functions of forests.
- 2) increasing the forest area of the country.
- 3) preserving biodiversity in forests and enhancing the recreational potential of forests.
- 4) supply of wood to domestic industry and population.

General plan sets different forest cover increases for specific regions of the country: it is valuable to afforest the most infertile lands of the country, by increasing the forest cover by 10-15% in the Central Samogitia, East Aukštaitija and Dzūkija zones.

African swine fever is a particularly serious contagious viral disease in domestic and wild pigs and boars. Outbreaks of this disease, in recent years, often occurring in different European countries, have caused significant economic losses ([Niemi 2020](#)). The biggest financial losses for the pig breeding and meat processing industry are the suspended exports of pigs and pork and other agricultural products. The number of losses caused by African swine fever in the livestock sector is about 50 million Eur. It is expected that a more accurate identification of the boar population and their migration routes mapping could lead to a more successful control of it, which, as a result, could potentially prevent African swine fever spread and its effect on a financial level. Nevertheless, IR passive sensors are not yet available, especially in many developing countries, because of the high market prices of commercial packages. This deprives forest managers of a potential monitoring tool. Finally, UAVs can save time, manpower, and financial resources for practitioners, public authorities, and researchers.

Environmental

The Commission launched a new EU carbon farming initiative to promote carbon sequestration as a new green business model (*EU forest strategy 2030*). The 2030 climate target plan identified carbon farming as a tool to create direct incentives for farmers and forest managers to take climate action and thereby help achieve the EU's target to decrease GhG emissions by at least 55 % by 2030, compared to 1990 levels. The adaptation strategy also announced that the Commission will promote carbon farming for land-based carbon removals and create financial incentives to roll out nature-based solutions. Carbon farming incentives can cover a large range of activities, including activities that will contribute to achieving the forest strategy goals such as:

- Planting new forests.
- Restoring degraded forests.
- Improving the management of existing forests.
- Supplying biomass for the production of long-lasting bio-based products.
- Planting trees in agricultural land as part of sustainable agroforestry systems.

Carbon farming could thus help create the financial incentives needed, for example, to plant 3 billion additional trees in the EU by 2030. To make carbon farming an effective business model, however, it will be necessary to improve land managers' advisory services and build a monitoring, reporting and verification system using the latest digital (UAV, IoT, AI) and satellite technologies.

2.4.5 Replicability

If something is replicable, it means that the same conclusions or outcomes can be found using slightly different data or processes. From this use case parts of methodologies for forest health and wildfire risk area analysis and identification can be replicated. This is because these parts include publicly available data or the general knowledge of the methodologies for the evaluation of the health and fire risk. Hardware used in the UC is commercially available, therefore it can be replicated as well.

By conducting the similar research to analyse the available data, investigate the spectral signatures and other parameters and to create their optimal sets. Using the parameter sets to build the prognostic algorithms for predicting high-risk forest areas. Purchasing the hardware components and assembling the UAV and hyperspectral or thermal imaging camera into one system.

- The outcomes of UC1 mainly concerns agricultural researchers and agri-food companies as well as innovative farmers/associations across the EU. Governmental institutions, forest protection specialists.
- Academia, nature scientists.
- Monitoring services providers.
- Drone and imaging device manufacturers.

Scalability is inherent in this use case. The employment of satellite imagery allows the quick scaling up. The only limiting factor for scaling up can be related to the restrictions for drone flight. However, in most areas where UC can be used there are no strict regulations on drone usage.

Scale-up possibilities for UAV, IoT, AI and satellite data combination solution:

- Insect pests (different types of forest).
- Infectious diseases of trees (different type of forest).
- Soil CO₂ emission due the damage by wild boar depredation.
- Damage from abiotic factors (different types of forest), such as fires, drought, snow, frost, water logging and wind.
- Wood logging monitoring.
- The pathological condition measuring and assessment.
- Forest biomass and soil carbon measuring and GHG balance assessments.
- Other wild animals monitoring.
- Agroforestry monitoring.

2.5 Use Case 5: Rural Logistics

2.5.1 Introduction

The scope of the UC5 is to design, develop and deploy an innovative drone-delivery fleet management system that will act as an alternative fast response system for delivering small parcels of importance (e.g., medical supplies, documentation, etc.) in remote areas of European rural areas. Such a system in case of expansion across Europe would serve these areas and optimize people's lives providing security of important supplies provision on time (Scott & Scott 2017, Quintanilla Garcia et al. 2021).

The proposed system will consist of both software and hardware.

From the software side there will be a cloud-based management system accepting requests for delivery services. The software will:

- Accept and sort requests depending on various criteria.
- Decide on the service availability and the service time slots.
- Book suitable drones and time slots to cover the demand for service.
- Assign tasks and monitor the drones enroute.
- Keep a record of all actions.

From hardware side, at least three different drone systems will be deployed serving different size/weight cargo and travelling distance:

- A 4-rotor multirotor drone based on Pixhawk autopilot technology being able to carry small mass cargo, up to 2 Kg and a maximum distance up to 5 Km.
- A 6-rotor or 8-rotor system drone based on Pixhawk autopilot technology. This drone will be able to carry big mass cargo up to a maximum of 6 Kg. Depending on the number of rotors and the payload mass maximum distance up to 6 Km. Figures and exact architecture need to be defined after running our simulation algorithms.
- A hybrid VTOL fixed wing drone based on Pixhawk autopilot technology. This drone will be able to carry a cargo mass up to 3 Kg for a maximum distance of 60 Km.

Drones will follow predefined routes taking into consideration local regulations, airspace restrictions, terrain elevation, and obstacles in the pathway. As with the practices followed in civilian aviation, each route will have different flight levels so more than one drone can utilize it without risking colliding.

The UC5 will focus on delivering a cargo mass between 0.1 to 7 Kg and on a travelling distance up to 45 km, approximately. Extensive testing will be done in Greece and the system will be deployed in North Macedonia at the demonstrator areas of Ohrid and Kuklish (see following paragraph 6.3). Scope of the tests prior to demonstrator is to assess the performance of proposed drone systems under fundamental external factors that are expected to have significant impact on the drone's performance. Those factors are:

- Ambient temperature, humidity, elevation and atmospheric pressure that all together are defined as Density Altitude.
- Wind speed.
- Drone optimal efficiency in respect to the payload weight.

During the demonstration period, the system will connect the aforementioned demonstration settlements with a number of smaller settlements that fulfil bad connectivity and remoteness criteria. Candidate connections points are presented in **Table 12**.

Table 12: Preliminary connection points for the drone logistics testing within UC5

Points Of Interest (POI)	Altitude (m)	Population	Straight Line Distance from Base X (Km)
Scenario 1			
Ohrid (Base 1)	694	55.749	0
Liubanista	696	171	43
Trpejca	729	303	35
Elshani	871	590	20
Scenario 2			
Kuklish (Base 2)	247	2.532	0
Piperevo	233	1.401	14
Borievo	208	926	20
Smolari	358	659	43

The new selected demonstrator settlements have been chosen after our initial meeting with NAA officers. After a very productive meeting we ended up at these settlements because their location will apply minimum stress to airspace traffic and at the same time can fulfil the scope of UC5.

As for the connection points, we will need to finalize them at a later stage down on the UC5 pipeline as we will have the results of our initial tests in Greece and after visiting local authorities seeking cooperation and support.

2.5.1.1 Challenges & Key Questions

Several challenges are expected to be encountered during the implementation process of the main targets within the UC5 plan of the ICAERUS Project. The most important of them (targets and challenges) are briefly described in the following:

A. Socio-economic

✓ **Main Targets**

Improving logistics management and support in rural regions with poor infrastructure. Support the local population by bringing central administration closer and easier to interact. Increase the sense of safety and security especially with elderly people. Minimize the impact of isolation and provide better living conditions.

➤ **Challenges**

Since drone delivery can be treated as a service of high liability from citizens (especially elderly), the main social challenge possibly faced is the social acceptance of this UC, even in the level of testing. As for the economic level, the cost challenges regarding first investment into such systems should be presented to local authorities (primarily in North Macedonia, but also to many other EU areas), in order to show the positive impact on other logistics types already in use.

B. Fleet Management System

✓ **Main Targets**

Design and development of an innovative fleet management system with utilization and integration

of modern technologies (AI, IoT). Flight routing and altitude automatic selection based on other drones scheduled routes.

➤ **Challenges**

Integration of existing open-source algorithms or models that are either integrated into new software with no copyright agreements or optimized during this application.

C. Mapping

✓ **Main Targets**

Enhance existing digital background map content with real-time/near-real time 3D mapping for better situational awareness below the airways. Design efficient airways (routes) and at the same time avoid dangerous points/zones.

➤ **Challenges**

GEOSENSE has the technical capacity to cover this mapping procedure, so the main challenge would be to receive the necessary information and attention from the local authorities.

D. Regulatory Framework

✓ **Main Targets**

Comply with local airspace use regulations/restrictions. Avoid flying over critical infrastructures, military installations, and other protected areas. Increase situational awareness by mapping trajectories of manned aircraft in real-time for BVLOS.

➤ **Challenges**

As above, this is mainly an issue of smooth collaboration with local and national authorities in North Macedonia.

E. Drone Technology

✓ **Main Targets**

Mix different drone architectures like multi-rotors and hybrid VTOL fixed wings. Develop a unified command and control ground station to design and assign trajectories to drones. Enhance RF point to point telemetry with 4G and 5G networks to extend the range of communication. Develop an extra drone independent layer of trajectory tracking in near-real time.

➤ **Challenges**

identification of areas within the UC region of low connectivity to 4G or 5G networks.

F. Data Privacy

✓ **Main Targets**

- 1) Build a reliable system architecture.
- 2) Periodic assessments, tests and updates of security protocols and software deployed to the system.

➤ **Challenges**

Avoid data leaks and decrease or expose potential vulnerabilities.

G. Technology Adoption

✓ **Main Targets**

- 1) Community consultation strategy aligned with local stakeholders.
- 2) Clear and robust explanations of benefits and outcomes.

➤ **Challenges**

Successful integration of information and technology transfer based on all parties involved goals and needs.

2.5.1.2 Objectives

The main objective of Drone-based delivery services in inaccessible rural areas is the design and development of an innovative DD-FMS with utilization and integration of state-of-the-art technologies (AI, IoT) and DaaS model principles.

Other objectives related to the main objective:

- User requirements (user needs, authority).
- Use case planning (area of interest, number of settlements, population, type of population, road network).
- Functional, non-functional, infrastructure, hardware, software, and drones' payloads requirements and specifications.
- System architecture (subcomponents, subsystems).
- Software development (mission planner, drone swarm fleet management system, integrated client ordering and support system).
- Demonstration (design, testing and assessment of drone delivery and receipt process).
- User evaluation system.
- System/whole procedure cost-benefit and swot analysis.
- Socio-economic/environmental impact analysis.
- Identify risks and barriers and develop a risk management plan.

2.5.1.3 Potential Barriers

The actual deployment of drones faces several barriers ([Sah et al. 2020](#)) that need to be addressed, especially with respect to regulation and general awareness. In most countries, operation of drones is limited to VLOS conditions (i.e., the pilot must keep the drone in sight), and must be run in rural areas of controlled airspace to avoid creating a hazard to people or other aircrafts. A real drone is considered an aircraft under the definition of the ICAO. A drone must comply with aviation standards and procedures.

Another important barrier is the integration of drones into undivided airspace. Drone regulations in each country are mostly independent today, and the level of harmonization between countries is decreasing ([Quintanilla Garcia et al. 2021](#)).

According to [Sah et al. \(2020\)](#), the critical barriers to the use of drones in the field of Rural services/ Logistics domain are presented in **Table 13**, where the **highlighted** descriptions are considered as most relevant to the specific use case. It must be noted that the barriers mentioned below, do not necessarily have to be recognized as true and real.

2.5.1.4 Use Case Scenarios

During the UC5 we will explore the following scenarios:

1. Small cargo delivery (less than 0.3kg) in moderate distances (up to 5km).
2. Medium cargo delivery (less than 3kg) in relatively big distances (up to 25-30km).
3. Large cargo delivery (less than 8kg) in small distances (up to 2.5km).
4. Multiple drone delivery missions in crossed trajectories.
5. Multiple drone delivery missions in the same trajectory.

Table 13: Examples of potential barriers for the UC5 implementation

Potential Barrier	Description
-------------------	-------------

Regulations	1. Accountability for drone owners 2. Drone's route 3. Insurance obligations 4. Pilot certification and training 5. Crowding airspace for manned aircrafts 6. Determination of liability
Technical	1. Short flight range 2. Navigation 3. Obstacle avoidance and mid-air collisions 4. Bad weather conditions 5. Tracking of drones 6. Performance risk 7. Limited carrying capacity
Socio-economic	1. Uneven distribution of income 2. Higher Initial costs 3. Economy and employment 4. Disrupt trucking industry
Public Perception & Psychology	1. Higher perceived risk 2. Transparency 3. Societal anxiety about automation 4. Awareness about drone technology 5. Drones and theft 6. Public annoyance (e.g., full skies) 7. Private sector use of drones
Environmental	1. CO₂ emissions 2. Harming wildlife 3. Visual pollution and sound pollution 4. Debris creation
Privacy & Security	1. Unauthorized photography 2. Identification of non-authorized drones 3. Surveillance and privacy 4. Violating rights 5. Physical attacks, jamming and spoofing 6. Cyber-attacks, terrorism

2.5.2 Key Activities

In this section, the key activities, the workflow and the implementation timeline of the UC5 are described, providing a main overview of the progress status and planning.

2.5.2.1 Description of Key Activities

The key activities of the UC5 covers a variety of aspects from field trials to socio-economic impact. The description of the main key activities in UC5 is summarized in **Table 14**.

Table 14: Key activities of UC5

	Activity	Description
1	Identification of Risks & Barriers	Risks and barriers must be identified, considering the potential trade-offs and knowledge gaps, as well as other drone adoption limiting factors within environmental, socio-economic and regulatory framing conditions. The timely and to-the-point identification of risks and barriers, is one of the main and primary keys for the optimal, at all levels (scientific, environmental, social, technical, etc.), approach to the solution of the use scenario.
2	Identification of Requirements	Investigation and determination of functional, non-functional, infrastructure, hardware, software, and drones' payloads requirements and specifications. The goal is the valid selection of critical parameters of the overall system to implement a sustainable and feasible system in accordance with the rules of science and art.
3	Research of Sourcing	Knowing the basic metrics, research of sourcing will follow to define the available vendors that can source us with the requested pieces of hardware and electronics, their price and their lead time. At this point, most from then non drone hardware that is needed should also be part of the sourcing research.
4	Hardware Assembly	Drone assembly and electronics programming. At the end, all drones should be fully tested and ready to fly with their cargo containers.
5	Simulation	Using specialized simulation tools we will set the requests per drone regarding the endurance, the wind resistance, the payload mass, and the components mass. In return, the simulation will output basic metrics regarding the thrust of the propulsion system and the amount of the energy.
6	Drone Fleet Management & Customer services infrastructure System (DFMCS)	Design the core fleet management software and start coding.
7	Drone Implementation/Integration with the DFMCS	At this point, all the necessary connections needed for the drones to report back to fleet management software should be defined and coded.
8	In-situ Demonstration Site & Investigation (North Macedonia)	Visit the demonstrator places and investigate different candidate settlements for the system to be deployed. Discuss with local authorities that will be involved, communicate the expected outcomes, seek for basic support that may be needed. Fix the service points, visit them, assess the locations. Work on regulatory compliance, design the potential drone routes, map parts of the routes where the existing base map is not accurate enough and create more detailed 3D maps of the approaching trajectories, with either LiDAR or Photogrammetry or both.
9	1st Working Prototype	Implement all the relative findings from the visit in North Macedonia to the fleet management system. Preparation for the first demonstration.
10	1st Demonstration (North Macedonia)	Deploy the system and test the use case scenarios. Finetune, repeat testing and finally run the first demonstration.

11	Evaluation Procedure of End-Users (1st Stage)	The Use Case will be evaluated by the end-users, both qualitatively (a large-scale usability test and user satisfaction) and quantitatively against the Key Performance Indicators (KPIs) defined by the relevant evaluation protocols. This will allow overall functionality assessment of the Drone Data Analytics Models and optimise further according to the given feedback.
12	2nd Working Prototype	Implement all the relative findings and comments from the first demonstration and the first end-users' evaluation procedure to the integrated drone logistics system/platform (software and hardware).
13	2nd Demonstration (Greece, Porto Carras)	The second demonstration for all UCs will take place in a common event, the ICAERUS United Event, which will take place in a rural area in Greece (Porto Carras), that represents the typical complex European landscape, incorporating all 5 use cases domains in one location to demonstrate their multi-purpose.
14	Evaluation Procedure of End-Users (2nd Stage)	The Use Case will be evaluated by the end-users, both qualitatively (a large-scale usability test and user satisfaction) and quantitatively against the Key Performance Indicators (KPIs) defined by the relevant evaluation protocols. This will allow overall functionality assessment of the Drone Data Analytics Models and optimise further according to the given feedback.
15	Final Working Prototype	The final integrated ICAERUS drone logistics platform.

2.5.2.2 Key Activities' Workflow

The workflow plan of the key activities in UC5 includes 15 discrete parts and is illustrated in **Figure 39**.

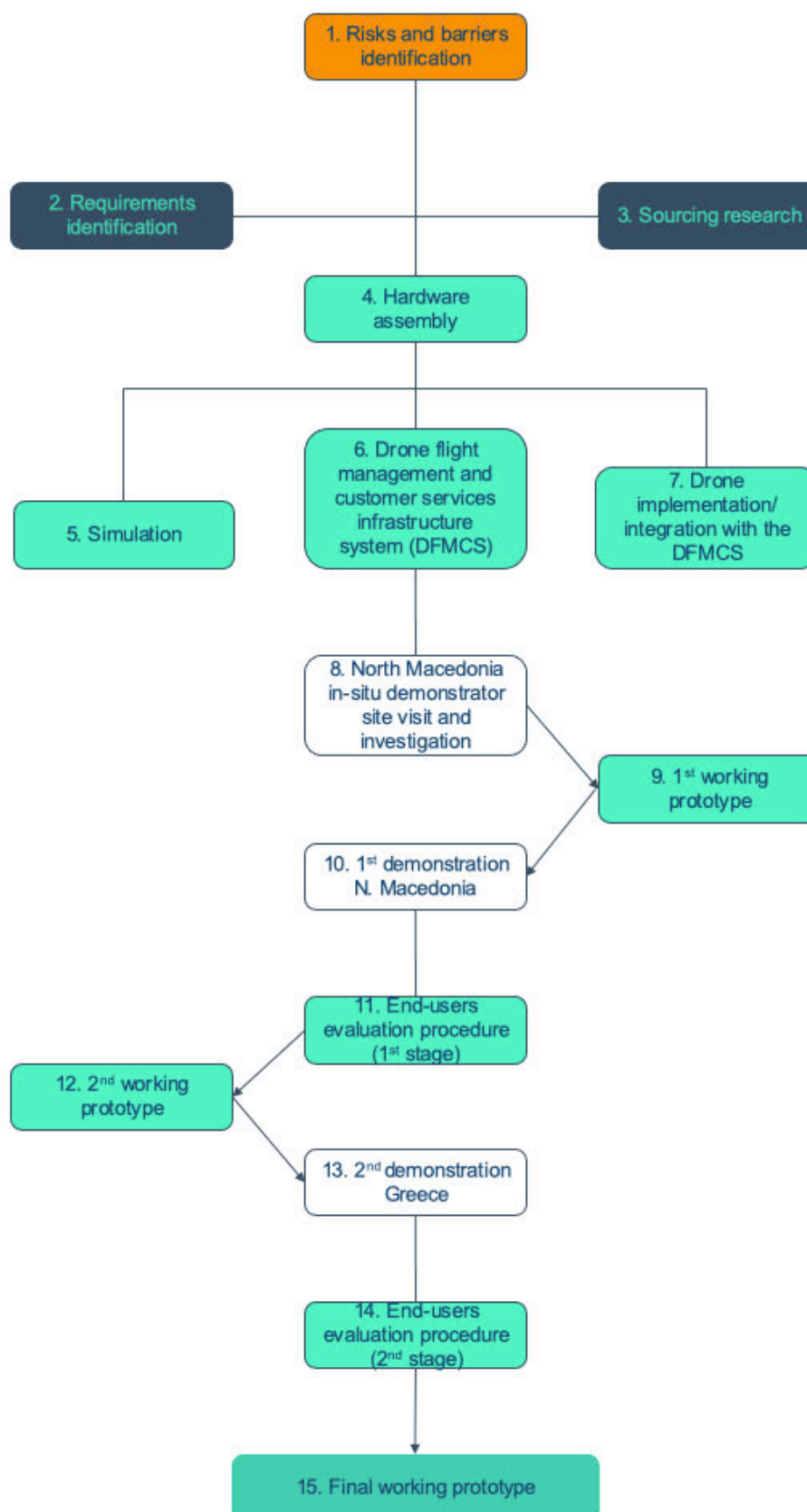


Figure 39: Illustration of the workflow plan of the key activities in UC5

2.5.2.3 Timeline

The implementation timeline of the key activities in UC5 is presented in **Figure 40** and covers the time span from the year 2022 until the end of 2025.

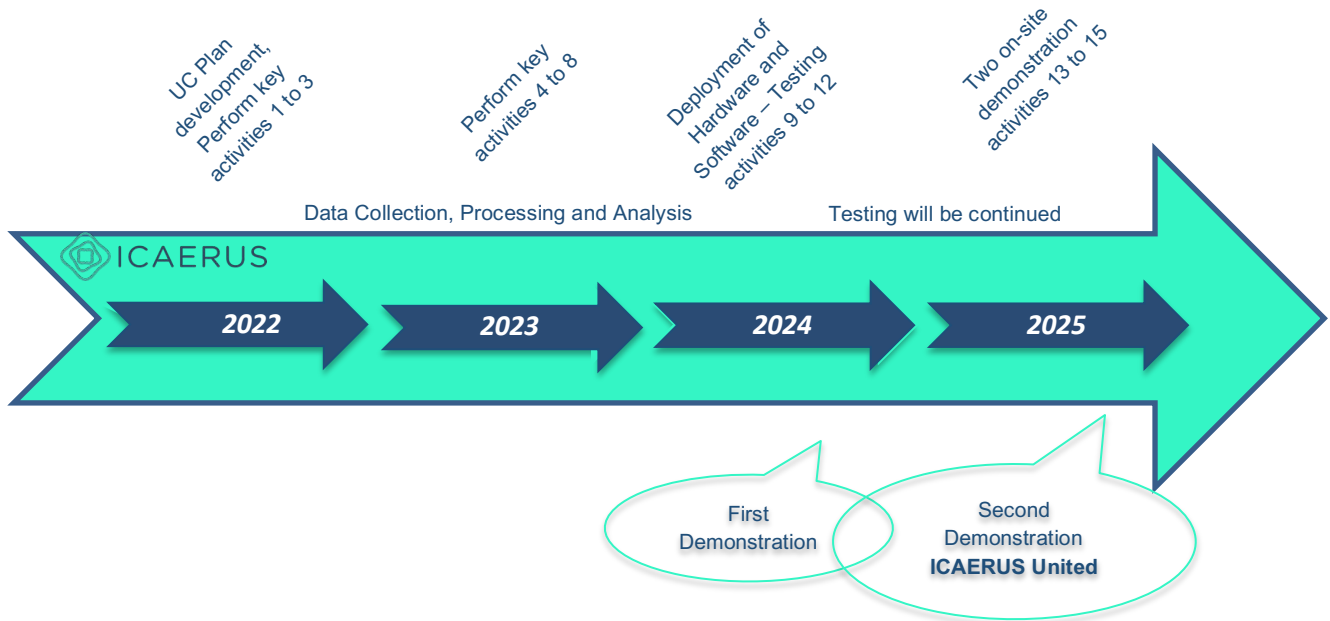


Figure 40: Timeline of the key activities in UC5

2.5.3 Technical Requirements

2.5.3.1 Technical Guidelines

Site description

The pilot area for scenario 1 & 2 will be in North Macedonia with the cities of Ohrid and Kuklish to be the centres of deployment.

Scenario 1 (**Figure 41**) is dealing with the problem of connecting remote and isolated settlements with a big service centre, Ohrid. Those settlements are serviced by a rough road network that especially during winter many days it is either blocked with snow or ice or very hard and dangerous to cross. Furthermore, considering the fact that most of the local citizens are elderly, the interaction with Ohrid (big service centre) more difficult. Items that can be delivered are mail, medicine, documents and blood samples to be examined in Ohrid hospital or other health infrastructure.

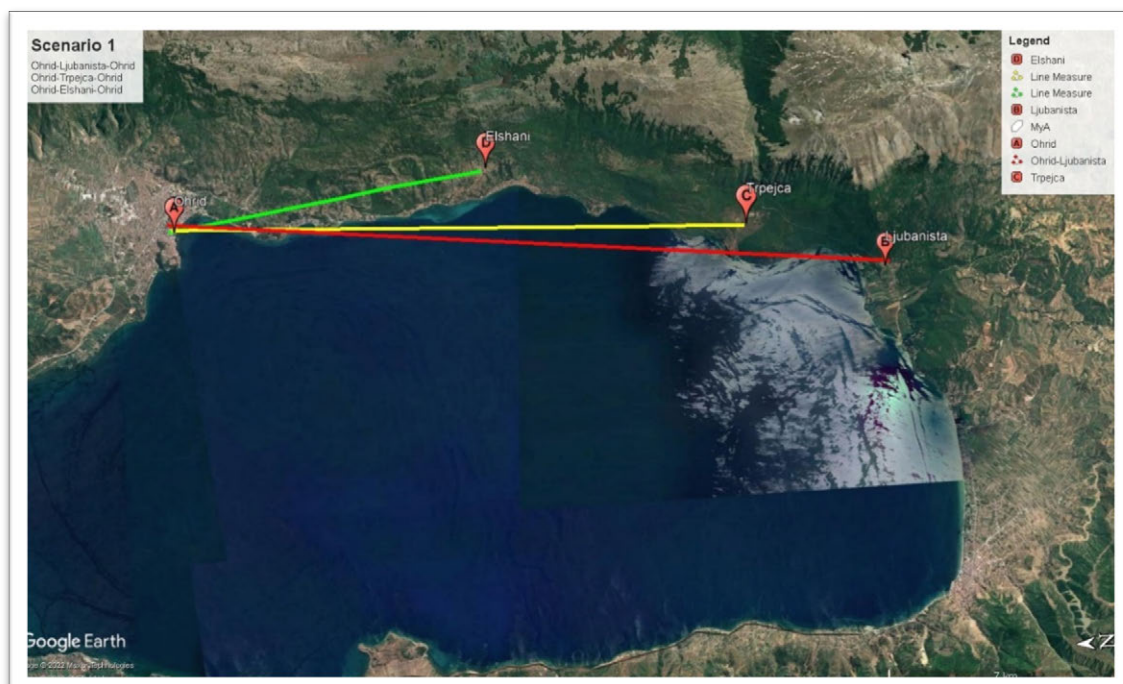


Figure 41: Map of the pilot area for the scenario 1 implementation within UC5 (Ohrid, North Macedonia)

Scenario 2 (**Figure 42**) is transferred to a completely different location of the country, where the terrain is much more even. That specific area is the agricultural heart of North Macedonia. The need we will serve is to establish a fast and cost-effective supply chain between a main service centre, Kuklish and 3 agricultural settlements providing seeds, pesticides and liquid chemicals needed in everyday business. As agriculture is a labour-intensive production, saving travelling time and fuel costs in a road network mostly paved with gravel is very critical.



Figure 42: Map of the pilot area for the scenario 2 implementation within UC5 (North Macedonia)

It is worth mentioning that prior to first deployment in North Macedonia, extended testing will be done in an area in the north-east of Thessaloniki, Greece (**Figure 43**, denoted with yellow color and red border line). That area has been selected as being close to our business installation and at the same time been free from airspace restrictions. It is an area that provides access to both even and uneven terrain so we can simulate as much as possible the topography of the demonstrator areas.

Methodology

The UML diagram presented in **Figure 44**, summarizes the system to be deployed. According to this diagram, extended testing will be performed to make sure that all the connections and designed functionality operate adequately.

2.5.4 Platforms & Mounted Technological Components

To deploy the UC5, we will design and assemble three different drones with different flight and payload characteristics:

✓ Drones

- A 4-rotor multirotor drone based on Pixhawk autopilot technology being able to carry small mass cargo, up to 2kg and a maximum distance up to 5km.

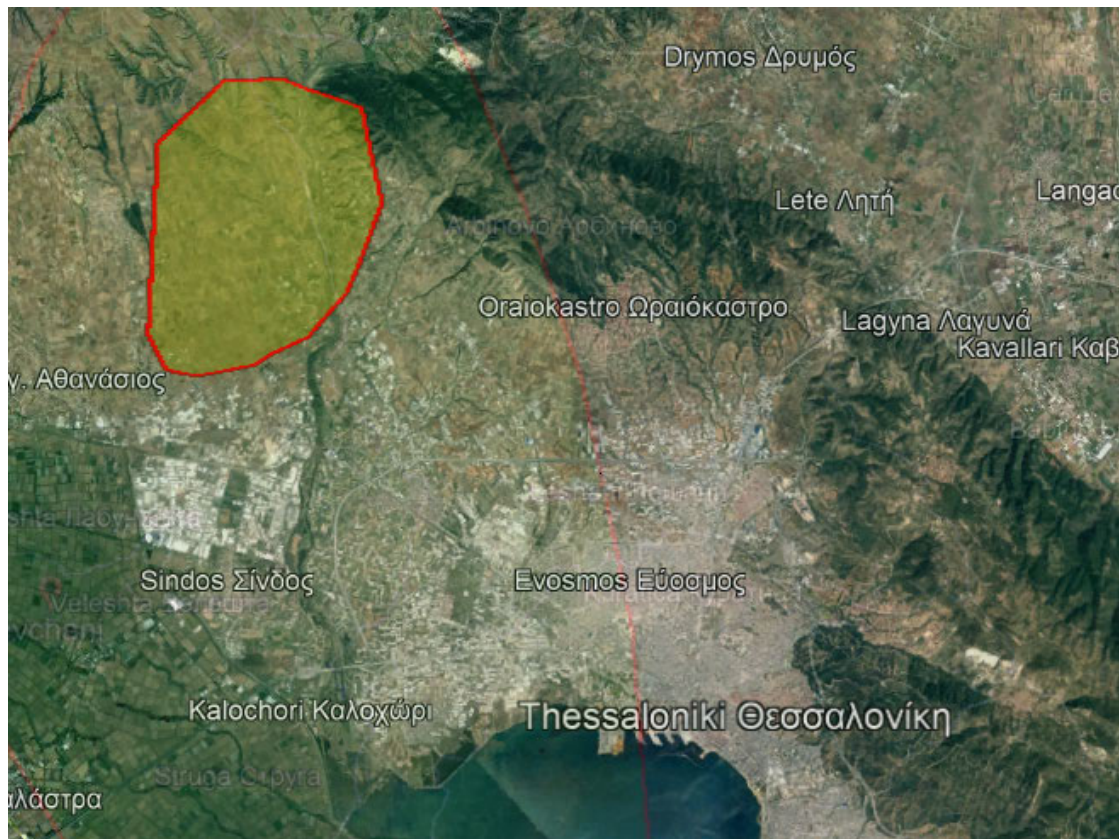


Figure 43: Example of a plant growth curve

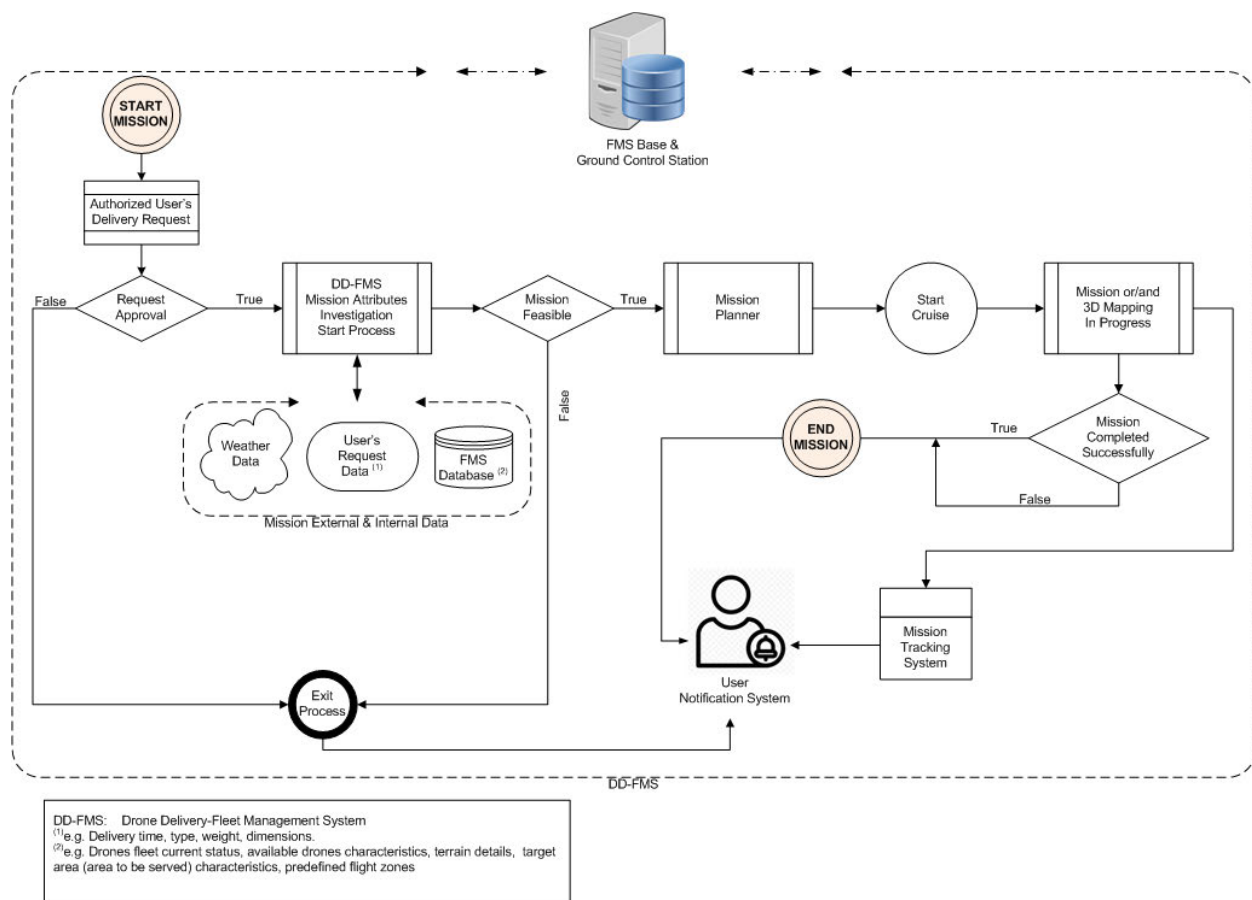


Figure 44: Illustration of the system's workflow that will be developed within UC5

- A 6-rotor or 8-rotor system drone based on Pixhawk autopilot technology. This drone will be able to

carry big mass cargo up to a maximum of 8kg. Depending on the number of rotors and the payload mass maximum distance will be not more than 3km. Figures and exact architecture need to be defined after running our simulation algorithms.

- A hybrid VTOL fixed wing drone based on Pixhawk autopilot technology. This drone will be able to carry a cargo mass up to 3kg for a maximum distance of 60km.

For each multirotor drone, a cargo bay will be designed in a CAD environment and will be 3D printed so as to be attached under the frame between the landing legs. For the hybrid VTOL fixed wing, special care will be taken so as not to disrupt the frame's aerodynamics. The best practice is to prepare a cargo bay inside the belly of the main frame.

All drones will be using an RF telemetry module to communicate with the base station. This connection is a bi-directional one. Subject to investigation and further research is to establish a second bi-directional communication channel over 4G/5G depending on the coverage and the performance of the network in the pilot area. Furthermore, for monitoring and tracking the drone's position during enroute especially when this is beyond the range of RF telemetry, an integrated GNSS/4G tracker will be installed in each system. This last one will only work as a one direction communication channel broadcasting to our server information about the position, the speed and the heading of the drone.

Furthermore, other required platforms and mounted technological components for the realization of the UC5 are described in the following:

- ✓ Fleet management system
 - Registration route requests (mentioning payload, delivery time, necessity) / service priority setting.
 - Request management (stock availability, service time).
 - Automatic flight planning based on current weather conditions, surface model, collision avoidance, restricted flight areas, national regulatory frame (confirmation from National Aviation Authority).
- ✓ 3D Mapping
- ✓ Mission Planner
- ✓ Web-based client application
- ✓ Operations Centre (Servers)
 - PHP, MySQL back-end server/database.
 - Node.js Server.
 - UDP Server.
 - TCP Server.

2.5.4.1 Measurements – Data & Datasets

Data related queries

What is UC5 testing for?

Drone-based delivery services in inaccessible rural areas is the design and development of an innovative DD-FMS with utilization and integration of state-of-the-art technologies (AI, IoT) and DaaS model principles.

Is there already existing data? Open/public data?

For the mission planning OpenStreetMap world map will be used and areas that need more details will be enriched with analytical 3D maps that will be acquired using Photogrammetry and LiDAR technologies.

For the terrain elevation the SRTM DEM 30m resolution will be utilized, implemented in OpenStreetMap and increase its resolution and accuracy when it is necessary, by using Photogrammetry and LiDAR technologies.

For the mission planning the Mission Planner ground station software will be implemented.

How will data be acquired? When? How many times? What are the environmental conditions?

3D detailed map data will be acquired during 2023 for the areas where the terrain is mountainous and below the scheduled drone trajectories. This process will be performed once and repeated only if there is a significant change in the topography that may intercept with drone trajectories.

How will the collected data and datasets be used to operate in favour of the ICAERUS project?

The UC5 will provide a set of applications and drone services for the development of rural logistics in remote areas, introducing an alternative, innovative and convenient method to deliver important and first aid products in inaccessible areas.

Data categories

Input data:

- Drone telemetry data in MavLink protocol.
- Drone position data in NMEA sentences.
- OpenStreetMap map tiles.
- Fusion of OpenStreetMap tiles and user acquired 3D maps using photogrammetry and/or LiDAR. Formats are TIFF georeferenced orthomosaics, DEM in TIFF, 3D point clouds.
- Weather forecast data from open-source repositories.
- Actual weather conditions from installed weather monitoring stations.
- End-user data.

Expected output data:

- Fleet management reports.
- Updated 3D base map.
- Drone performance logs.
- Flight mission plans to be registered with the National Aviation Authority and other involved agencies.

2.5.4.2 Drone Data Analytics Models

✓ 3rd party software

- Mission Planner.
- PIX4Dmapper pro.
- ZwCAD.
- OpenStreetMap APIs.
- ADS-B air traffic monitoring.
- Weather forecast API.

✓ Algorithms - Models

- TSP (Kiitjacharoenchai & Lee 2019, Sorbelli et al 2020, Jianxun et al. 2022, Tong et al. 2022).
- VRP (Roca-Riu & Menendez 2019, Kiitjacharoenchai & Lee 2019, Jianxun et al. 2022, Tong et al. 2022).
- Heuristic algorithm for MDSP with a single drone - Mr-S (Sorbelli et al 2020).
- Heuristic algorithms for MDSP, Mc-M and Mr-M (Sorbelli et al 2020).
- Dijkstra's algorithm (Deaconu et al. 2021).

✓ Development Methodologies

- Agile development methodologies (Nerur & Balijepally 2007).

2.5.5 Expected Results

2.5.5.1 Expected Outcomes

The main expected outcomes of the UC5 are mainly related with the following:

- Develop an integrated system for rural logistics using drones.
- Promote the use of drones as a cargo transporter to support isolated and hard to reach settlements.
- Introduce 3rd party wireless networks (GSM) into drone technology to transfer real-time / near real-time drone telemetry and test the integrity and applicability of those in drones remote piloting.
- Test and optimise several aspects of rural logistics and emergency deliveries.
- Test DaaS principles.
- Automate procedures and drone trajectories for delivery missions.
- Reduce the service time for emergency deliveries.

2.5.5.2 Impact

Socio-economic

The socio-economic impact of UC5 is summarized in the following:

- The delivery of medical drones was identified to have great potential for increasing system efficiency and saving more lives, enabling the provision of humanitarian aid in areas affected by natural disasters and emergencies with a more efficient response time, to reduce the delivery time of laboratory samples and products to remote health centres and hard-to-reach people (Quintanilla Garcia et al. 2021).
- Improve access to health services in difficult to reach areas.
- Improved clinical outcomes (e.g., survival following cardiac arrest and major traumatic injuries).
- Reduce of infection risks reducing personal contacts (e.g., Covid-19).
- Enhancing the sense of security of citizens and strengthening their trust in public administration.
- Reversal of population migration in difficult to reach areas due to inaccessibility of access to medicines and primary health services.
- Reduce manpower and reduce worker's fatigue and transport time and shift workforce to more profitable tasks.

Environmental

It is known that drones with zero emissions and extremely low noise levels, are "tools" with almost zero environmental footprint both in terms of environmental pollution, noise pollution and disturbance of fauna and flora.

2.5.6 Replicability

Most of the technological aspects of the UC5 is based on open source and public available repositories making it very easy to replicate and apply in any geographical region with any number and type of drones. For instance, OpenStreetMap data, ADS-B air traffic, Weather forecast data, Mission planner, Pixhawk autopilot, Mavlink protocol, open-source web-servers etc.

In particular, the main outcomes of UC5 can be replicable, acknowledging the following:

- Integrating all the above-mentioned software technologies.
- Developing hardware based on Pixhawk and Mavlink protocol.
- Using open data (weather, open street maps, etc.).
- Using common and replicable developing techniques as APIs', web services, widely used programming languages and interfaces for both front-end and back-end (PHP, JavaScript, Python, Ajax, MySQL, Node.js, PWA).

The outcomes of UC5 mainly concern private sector companies that wish to enter or expand their business in drone logistics, or even if already operate as a courier service provider, administrative authorities, drone manufacturers, academia, GSM service providers, citizens in remote areas and public health authorities.

Scalability is inherent in UC5. Apart from input resources and the regulatory framework regarding the use of airspace by drones, there is no limit to either spatial, aerial or number/type of drones to be used. Also, the same platforms, techniques, methodologies, developing tools and methods, can be leveraged and integrated into drone platforms, providing further innovative services in selected market segments such as infrastructure inspections, telecommunications, media, energy, architecture, engineering, agriculture, construction, focusing on the DaaS business model.

3. Summary

This deliverable **D3.1 Use Case Planning** describes the framework of the ICAERUS project in detail. In particular, the development and implementation of the ICAERUS project is based on five (5) different use cases aimed at investigating the effective and efficient use of UAVs in agricultural production, forestry and biodiversity, as well as in rural, remote and inaccessible areas. This report is therefore divided into 6 chapters to present the main and expected findings of each UC. It should be noted that this version roughly corresponds to the first six months of the project. Therefore, each UC focuses on the creation of an appropriate and feasible plan that will eventually lead to the successful completion of the project. Subsequently, the current version of the deliverable (A) will be updated with additional information, results and/or changes as the UCs' planning progresses (version B in the 16th month or version C in the 34th month of the project). Below is a summary of the chapters in this version (A) of the report:

The first chapter is **introductory** and highlights the main objectives of each UC.

The second chapter deals with the implementation of **crop monitoring** (UC1) and mainly with the use of drones to identify diseases and weeds in vineyards. Furthermore, aerial and ground images are combined to reconstruct the 3D canopies of the study area and to develop a user-friendly tool as a decision support tool.

In the third chapter, the implementation of **drone spraying** is tested (UC2), evaluating the optimal configurations for the most common applications under field conditions. Finally, a comparison of these UC results with conventional methods and practises will highlight the possibilities of drone use and highlight the advantages (or disadvantages), efficiency and environmental impact of using drones as an alternative technique for spraying in agriculture.

The fourth chapter illustrates the benefits of using drones for **livestock monitoring** (UC3), particularly cattle and sheep herds, and assesses the potential labour savings for stakeholders.

Forestry and biodiversity (UC4) are the main topics of the fifth chapter, which seeks to use drones as an inspection tool in forest areas with a dual purpose. On the one hand, it is about assessing the condition of trees and identifying areas of high fire risk in the forest; on the other hand, it is about monitoring ecosystems to investigate the extent to which drones can contribute to the management or prevention of the spread of infectious diseases in wild and domestic animals.

Finally, the sixth chapter discusses the design and development of an innovative drone-based system for operating a delivery fleet, to be used primarily in **rural logistics** (UC5) and remote areas. UC5 aims to automate and integrate state-of-the-art technologies for transporting vital (e.g. medicines) and important packages (e.g. government papers) to inaccessible regions, thus improving the quality of life of residents.

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