
ICAERUS

# D3.3: Performance Evaluation Report

## Version A

## WP3: Use Case and Demonstration Activities

Responsible Author: Marios Anthymidis (GS), Kostas Grigoriadis (GS), Vasilis Polychronos (GS)

Funded by
the European Union
Grant agreement N° 101060643

# Document Information

| | |
|---|---|
| **Grant Agreement No.** | 101060643 |
| **Project Acronym** | ICAERUS |
| **Project Title** | Innovation and Capacity building in Agricultural Environmental and Rural UAV Services |
| **Type of action** | RIA - Research & Innovation Action |
| **Horizon Europe Call Topic** | HORIZON-CL6-2021-GOVERNANCE-01-21: Potential of drones as multi-purpose vehicle – risks and added values |
| **Project Duration** | 01 July 2022 – 31 June 2026 \| 48 months |
| **Project Website** | icaerus.eu |
| **EU Project Advisor** | Alessandra Sasso |
| **Project Coordinator** | Spyros Fountas |
| **Address** | 75 Iera Odos, 11855 Athens, GR \| Agricultural University of Athens |
| **Reply to** | sfountas@aua.gr |

| | |
|---|---|
| **Work Package** | WP3: Use Cases and Demonstration Activities |
| **WP Lead Beneficiary** | GeoSense IKE (GS) |
| **Relevant Task(s)** | T3.2: UCs Testing, Monitoring and Evaluation |
| **Deliverable \| Version \| Status** | D3.3: Performance Evaluation Report \| V1.0 \| A - Final |
| **Deliverable Lead Beneficiary** | GeoSense IKE (GS) |
| **Responsible Author** | Marios Anthymidis (GS), Kostas Grigoriadis (GS), Vasilis Polychronos (GS) |
| **Reply to** | marios@geosense.gr, kgrigor@geosense.gr, vpoly@geosense.gr |
| **Deliverable type \| Dissemination level**[1] | R – Report \| PU - Public |
| **Due Date of Deliverable** | 30 June 2024 |
| **Actual Submission Date** | 30 June 2024 |
| **Version \| Status** | A \| Final |
| **Contributors** | Esther Vera (NMN), Vasilis Psiroukis (AUA), Aikaterini Kasimati (AUA), Adrien Lebreton (IDELE), Estelle Nicolas (IDELE), Kestutis Skridaila (ART), Mario Petkovski (AGFT), Bruno Barrionuevo (GS) |
| **Reviewer(s)** | Viara Bojkova (NSWR) |

[1] *Deliverable type R: Document, report; DEM: Demonstrator, pilot, prototype, plan designs; DEC: Websites, patents filing, press & media actions, videos, etc.; DATA: Data sets, microdata, etc; DMP: Data management plan; ETHICS: Deliverables related to ethics issues; SECURITY: Deliverables related to security issues; OTHER: Software, technical diagram, algorithms, models, etc. Dissemination level: PU – Public, fully open, e.g. web (Deliverables flagged as public will be automatically published in CORDIS project's page); SEN – Sensitive, limited under the conditions of the Grant Agreement; Classified R-UE/EU-R – EU RESTRICTED under the Commission Decision No2015/444; Classified C-UE/EU-C – EU CONFIDENTIAL under the Commission Decision No2015/444; Classified S-UE/EU-S – EU SECRET under the Commission Decision No2015/444*

## Document History

| Version | Changes | Date | Contributor(s) |
|---|---|---|---|
| 0.1 | Table of Contents and document structure | 18/04/2024 | Kostas Grigoriadis (GS), Marios Anthymidis (GS) |
| 0.3 | Performance and Evaluation Report Template | 30/05/2024 | Aikaterini Kasimati (AUA), Kostas Grigoriadis (GS), Marios Anthymidis (GS) |
| 0.7 | Input from each UC | 14/06/2024 | Esther Vera (NMN), Vasilis Psiroukis (AUA), Adrien Lebreton (IDELE), Estelle Nicolas (IDELE), Kestutis Skridaila (ART), Marios Anthymidis (GS), Bruno Barrionuevo (GS), Mario Petkovski (AGFT), |
| 0.8 | Compilation of information from each UC | 22/06/2024 | Marios Anthymidis (GS), Kostas Grigoriadis (GS) |
| 0.9 | Internal review | 27/06/2024 | Viara Bojkova (NSWR) |
| 1.0 | Final Version (A) | 01/07/2024 | Marios Anthymidis (GS), Kostas Grigoriadis (GS) |
| 1.0 | First Version \| **RP2 Revised** \| Final | 31/10/2025 | Kostas Grigoriadis (GS) |

| Participants | Contact |
| --- | --- |
| **Agricultural University of Athens** (AUA), Greece | **Spyros Fountas** sfountas@aual.gr |
| **Wageningen University** (WU), Netherlands | **João Valente** joao.valente@wur.nl |
| **Foodscale Hub** (FSH), Greece | **Grigoris Chatzikostas** gchatzikostas@gmail.com |
| **Noosware BV** (NSWR), Netherlands | **Efstratios Arampatzis** sa@noosware.com |
| **GeoSense IKE** (GS), Greece | **Dimitrios Ramnalis** ramnalis@geosense.gr |
| **Noumena Design Research Education SL** (NMN), Spain | **Aldo Sollazzo** aldo@noumena.io |
| **Institut De l'Elevage** (IDELE), France | **Jean-Marc Gautier** jean-marc.gautier@idele.fr |
| **ART21 UAB** (ART), Lithuania | **Laurynas Jukna** laurynas@art21.lt |
| **Ecological Interaction** (EI), Estonia | **Jonathan Minchin** jonathan@ecologicalinteraction.org |
| **Hellenic Crop Protection Association** (HCPA), Greece | **Francesca Ydraiou** fydraiou@esyf.gr |
| **Agrifood Lithuania DIH** (AFL), Lithuania | **Valdas Rapševičius** vrapsevicius@gmail.com |
| **AgFutura Technologies** (AGFT), North Macedonia | **Blagoja Mukanov** blagoja.mukanov@agfutura.com |
| **The Open University** (OU), United Kingdom | **Giacomo Carli** giacomo.carli@open.ac.uk |

## RP2 General Project Review – Revision

<table>
<tr><th>Expert opinion on deliverable/ Comment</th><th>Steps towards addressing it (Partner)</th></tr>
<tr><td>It is unclear what the results and the engagement of end-users are in the evaluation activities. This should be a core part of this deliverable.</td><td>We thank the reviewers for the helpful feedback and welcome the opportunity to clarify the intended scope and timing of Deliverable D3.3 Performance Evaluation Report (A) (M24) within the structure of WP3 and the Grant Agreement (GA).<br><br>As outlined in the deliverable, D3.3 focuses on the internal technical and operational evaluation of Use Case progress during M1-M24, following the Use Case Plan (D3.1) and the evaluation protocols defined in T3.2. Its purpose is to track implementation, document deviations, propose mitigation measures, and support project risk management. At this stage of the project, D3.3 does not include formal end-user validation, demonstration results, or stakeholder engagement outcomes, since these activities are assigned to Task 3.4.<br><br>This is consistent with the GA description of D3.3:<br><br>“Initial report (A, M24) and update (B, M46) describing the experiments performed, their parameters and results, and the methodology for evaluating results in accordance with the Use Case Plan and protocols defined in T3.2.”<br><br>End-user engagement, demonstration activities, and evaluation results are scheduled from M30 onwards, with outputs captured in:<br><br>• D3.8 Demonstration & End-user Evaluation (A) (M34), and<br>• D3.9 Demonstration & End-user Evaluation (B) (M46).<br><br>During the M1-M24 period, no pilot demonstrations with end-users had yet taken place; therefore, these elements were not yet available for inclusion in D3.3 and will be reported in the dedicated deliverables above. This resubmitted version includes explicit explanations of these timelines and WP3 responsibilities, ensuring that the scope and positioning of D3.3 are fully transparent.</td></tr>
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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 potential of drones in agricultural production, forestry and rural communities. The selected drone applications or Use Cases (UCs) 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 their potential 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 performed in two ways: a) an "eye in the sky" application 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 decarbonization, 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.

The main purpose of Deliverable "D3.3 - Performance Evaluation Report" is to provide a detailed overview of the UCs' progress that were carried out during the reporting periods of the ICAERUS project. The aim of this document is to internally evaluate the plan implementation (according to Deliverable "D3.1 – Use Case Plan A") and development of the five UCs. In particular, the UCs' evaluation process focuses on the detection of deviations from the initial plan, that typically emerge throughout the lifetime of a project and are able to potentially impact the expected outcomes. Thus, several mitigation strategies for the encountered challenges could be promptly suggested, ensuring the smooth progress and efficient implementation of the UCs, while simultaneously contributing to the risk management assessment of the project.

It is important to note that end-user engagement, stakeholder workshops, and validation activities are distinctly allocated to Task 3.4 Demonstration Activities & End-user Evaluation, with the inaugural demonstration events commencing from M30 onward [results to be integrated into D3.8 Demonstration & End-user Evaluation (A) at M34 and D3.9 Demonstration & End-user Evaluation (B) at M46].

The current deliverable structure 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, etc.). 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 deployed to multiple tasks or missions.

Each UC uses different methodologies and approaches for data acquisition and processing, depending on their specific objectives. For instance, UC1 exploits RGB and multispectral cameras to reconstruct orthomosaic maps of vineyards with photogrammetry methods, targeting to retrieve information about the health of the plants and the spread of diseases, whereas UC2 utilises drones for spraying applications in field conditions, measuring the deposition, the canopy penetration, the spray drift, through various

operational configurations (drone flight altitude and speed, nozzle flow, liquid deposition rates, etc.). Furthermore, UC3 and UC4 are dedicated to livestock, forestry and biodiversity monitoring, respectively, using ground images mainly from thermal cameras and incorporating ML (Machine Learning) algorithms to detect and recognise different livestock species and animal movements, as well as the health state of trees and areas prone to fire risk. Finally, in UC5 the delivery of important supplies (e.g. blood samples, documents, seeds, machinery parts) to remote, isolated and rural settlements is attempted, with the deployment of three types of drones (multi-rotors, VTOL and helicopter) according to the cargo properties (size, weight, destination, etc) and the development of an appropriate drone-delivery fleet management system that accepts, organises and executes the flight missions, depending on the end-users' requirements.

The key results of the UCs during the reporting period (M24) are briefly summarised in the following:

- Several datasets and analytic models for diverse drone applications (from all UCs) are uploaded to Zenodo and GitHub online platforms, respectively. This information is open-source and publicly accessible.
- Development of a decision-support utility for field management and crop monitoring (UC1).
- Implementation of drone spraying to three selected crop types (wheat, rice and corn), highlighting the efficiency of this application in comparison with conventional methods (UC2).
- Guidebook for drone utilisation in livestock monitoring (UC3).
- Identification of healthy tree areas, incorporating a qualitative damage categorisation (e.g., maximum, medium-large, minor and healthy), as well as of regions with high fire risk potential. Moreover, detection of wild boards in forests, combined with their movement tracking (UC4).
- Development of the core drone-delivery fleet management software for rural logistics, deployment of 3 different drone types (multi-rotors, VTOL and helicopter), integration of advanced security feature with the exploitation of the available 4G and 5G cell phone networks and reconstruction of custom-made cargo boxes tailored for specific drone-delivery missions (UC5).

In conclusion, the progress of the UCs is steady and consistent, whereas the development of each task is unfolding smoothly. This is supported from the data analysis of the evaluation reports, which each UC leader provided on a monthly basis. In cases where minor issues emerged, they were resolved effortlessly, either with internal communication with the project partners, or with rectification actions from the corresponding UC leader. It is worth mentioning that the information for each UC was directly provided by the corresponding UC leaders to ensure the smooth running of the activities. This deliverable will be updated periodically to reflect additional methodologies, measurements and data adopted during the lifetime of the project. This is the first version of Deliverable "D3.3 – Performance Evaluation Report". An updated version of this report, including refined plans for the five UCs, are scheduled for M46 of the project.

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# 1. Introduction

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 project 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 neighboring 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 "T3.2 UCs Testing, Monitoring and Evaluation", is to monitor the UC's progress and internally evaluate their results. Furthermore, the Drone Data Analytics Models optimised in T2.2 will be tested, with the determination of experimental and evaluation protocols. These protocols will be activated during the UC's deployment, whereas the outcomes of the UCs will be distributed to T5.1, in order to ensure a proper dissemination, and integrated in the ICAERUS platform (WP6).

The UCs of the ICAERUS project 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 practices 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 labor-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:** Ohrid Town and Kuklish Town, North Macedonia **| Key Partners:** GS & AGFT

# 2. Use Case 1: Crop Monitoring

## 2.1 Introduction

The overall scope of UC1 (Use Case 1) is to develop an integrated suite of solutions designed to manage, monitor, and interact within vineyards, with a primary focus on disease detection and canopy health monitoring. To achieve these goals, this suite will utilise UAVs (Unmanned Aerial Vehicles) for advanced image analytics and process visual data in combination with ground sensors, to identify potential issues and measure plant development. This targeted approach, aims to reduce the required effort of maintaining the crop's health and, as a result, to maximise crop yield and profitability.

Furthermore, in order to enhance agricultural efficiency and productivity, a comprehensive crop management dashboard will be implemented to track the growth and the overall status of crop plants. This system will evaluate plant health, pinpoint specific plant issues, and consequently reduce the need for chemical pesticides. By minimising the required time and effort for crop inspection and management, the system aims to assist farmers in optimising their agricultural practices.

### 2.1.1 Objectives

The main objectives of UC1 are:

- Study the growth and unique conditions for each analysed crop plant.
- Integrate automated solutions to detect diseases that appear over the leaves.
- Extract the geographical position of the plants to determine their accurate location and overview their environment.
- Development of a visualisation platform to access the overall condition of the crops, while facilitating the identification and localisation of plants' diseases within a comprehensive 3D model.

It is important to emphasise the interdisciplinary nature of UC1, which combines expertise from a variety of diverse fields, such as agronomy, GIS (Geographic Information Systems), computer vision and data visualisation. By leveraging advanced technologies and cross-disciplinary collaboration, UC1 aims to assist crop management practices, leading to increased efficiency and reduced environmental impact.

### 2.1.2 Use Case Scenarios

During the development of UC1, one (1) use case scenario will be implemented, namely the crop monitoring of a vineyard site. This activity encompasses all the necessary steps to study and integrate crop monitoring into a real-world scenario. Specifically, the vineyard's size and the scheduled data collection frequency is expected to provide sufficient data for analysing the health state of the plants within the investigated area.

Currently, the crop monitoring in this vineyard is manually performed. Farmers conduct weekly inspections, manually examining each plant and decide in-situ about the necessary treatments. However, they lack of historical images or other relevant data to support their decisions. This process is time-consuming and labour-intensive, requiring detailed inspection of every plant.

The integration of UAV technology will significantly expedite this inspection process. UAVs can capture both RGB and spectral images, providing valuable insights into the health status of the crops. These aerial images offer a comprehensive view of the vineyard, including detailed images of the plant leaves and a top-down perspective of the entire study area. Typically, this dataset is processed with photogrammetry methods, generating a global map of the vineyard.

In addition, weather sensors will be deployed around the vineyard to collect data on temperature, humidity, and solar radiation, complementing the visual information from the UAVs. This combined data will be used to train a ML (Machine Learning) model to automatically assess plant health status.

The acquired data will be integrated into a comprehensive dashboard, leading to a robust monitoring system. This platform will provide historical data, disease identification, growth measurements, and more, enabling the easy access and a consultancy tool to the farmers. Moreover, farmers will be able to visualise the development of the plants using a user-friendly service, facilitating the decision-making procedure and improving the management of the vineyard.

## 2.2 Progress Report

### 2.2.1 Evaluation Summary

#### 2.2.1.1 Specific Objectives

The specific objectives during the reporting period were to perform periodic data collection and processing to extract information, as well as to train ML models for analysing the plant's health of the vineyards. In particular, the following objectives have been achieved:

- Data collection in selected vineyards during 2023, whereas for 2024 the procedure is still in progress.
- Development of daily orthomosaic maps, 3D reconstruction of the vineyard and elevation model of the study area.
- Labelling of 2023 data for training a custom ML model.
- Training of an initial ML model for plant disease identification.
- Publication of the collected datasets and the developed models.
- Initiation of the data integration into the platform for easy visualisation.

#### 2.2.1.2 Achievements/Results

The achievements/results obtained for UC1 include the following:

- A complete data collection in the selected vineyard during 2023. This included scheduled UAV flights every one or two weeks (mainly according to weather conditions). The data acquisition followed top-view and row-vies flights, as well as the video recordings for dissemination purposes.
- Data processing for the generation of orthomosaic maps, point cloud images, DEMs (Digital Elevation Models) and NDVI (Normalised Difference Vegetation Index) analysis.
- Promotion of UC1 activities within ICAERUS project with various social media posts in LinkedIn and Instagram.
- Five (5) datasets published in Zenodo.
- Five (5) models available in GitHub that can be exploited for different UAV applications.
- A pilot platform that includes the processed data.

#### 2.2.1.3 Shortcomings/Obstacles

Key shortcomings/obstacles faced during the implementation of UC1:

- The chip crisis (or shortage) during the period of 2020-2023, affected the timely shipping of the main UAV platform (DJI Mavic 3M) for data collection, delaying the initiation of the process.
- Rainy weather conditions in the study area during August of 2023, contributed to a rapidly spread

mildew between the data collection periods, hindering the development of non-biased ML models.

- The localisation of individual plants into the orthomosaic maps was challenging for the extraction of precise data and analysis.

## 2.3 Deployment and UC Execution Status

### 2.3.1 UC Plan Progress

The conducted tasks of UC1 in the reporting period (described in §2.2.1.2) were a cumulative effort of the involved partners, starting from the ICAERUS project initiation (M1) till the current period (M24) – a total of 24 PM (Person Months). Particularly, Ei is the UC1 partner that collaborated with NMN, playing a key role in the development of the assigned tasks. In addition, Josep Raventós, the responsible agricultor of the selected vineyards, facilitated the data acquisition, as well as the retrieval of the necessary information.

The main goal of UC1 is to provide a methodology that efficiently integrates UAV technologies into the agriculture sector for crop monitoring, in order to assist any stakeholder through daily field practices. The proposed methodology involves data collection with specific techniques to evaluate the plants' growth and the spread detection of possible diseases.

The progress of activities within UC1 is unfolding as intended, with no or minor deviations according to the initial plan.

### 2.3.2 UC Activities

#### 2.3.2.1 Key Activities

The key activities of UC1 are summarised in **Table 1**.

*Table 1: Key activities of UC1.*

| id | Activity Name/Title | Description/Goal |
|---|---|---|
| 1 | Review state-of-the-art methodologies for crop monitoring applied to precision agriculture | Research of recent projects, that assess the implementation of crop monitoring, evaluating its limitations and possible improvements. In addition, identification of the hardware and software components that could potentially assist the UC1 applications. |
| | **Activity Progress**<br>The research was completed by classifying the available information into distinct documents and outlining the key points. | |
| 2 | Definition of methodology | Delineation of the critical steps to reach the main objective of UC1, considering the available resources and time constraints, in order to effectively establish the foundation for development over the closure of ICAERUS project. |

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|---|---|---|
| | **Activity Progress**<br>Several phases of data collection and processing were defined, as well as the prioritisation of the conducted tasks was determined. | |
| 3 | Data collection | A thorough investigation of data acquisition methods for crop monitoring, enabled to tailor this procedure into the specific objectives of UC1. Thus, the optimal UAV-based data collection methods were defined, ensuring the retrieval of high-quality and reliable information. |
| | **Activity Progress**<br>A variety of data acquisition methods was implemented during the summer seasons of 2023 and 2024. The UAV information incorporated ground images from both high and low altitudes, that were processed according to the specific requirements within UC1. | |
| 4 | Development of models and datasets | Development of models assisting the crop monitoring tasks and classification of open-source datasets for public sharing. |
| | **Activity Progress**<br>Several models have been developed to detect diseased plants with the usage of UAV imagery and to accurately determine their location. Additionally, NDVI analysis has been conducted to assess plant health. Totally, five datasets have been uploaded to Zenodo, providing open-source UAV information for vineyards. | |
| 5 | Implementation of the visualisation platform | Development of a dashboard that integrates key information for assisting farmers (or any stakeholder) to assess the health status of the crops and comprehend the benefits of crop monitoring using drones. This dashboard will provide both informative and predictive results, enabling more effective decision-making. |
| | **Activity Progress**<br>Initiation of the visualisation platform development, integrating processed data with a variety of models, aiming to present information in a user-friendly application environment. | |
| 6 | Demonstration activities and dissemination | Sharing the progress and results of UC1 through a variety of channels (e.g., social media) and demonstration activities planning to showcase the capabilities and applications of the conducted tasks in crop monitoring. |
| | **Activity Progress**<br>Communication through social media posts (e.g. LinkedIn, Instagram) and initiation of the demonstration activities' planning. | |

#### 2.3.2.2 Key activities' workflow

The key activities' workflow of UC1 are illustrated in **Figure 2**.

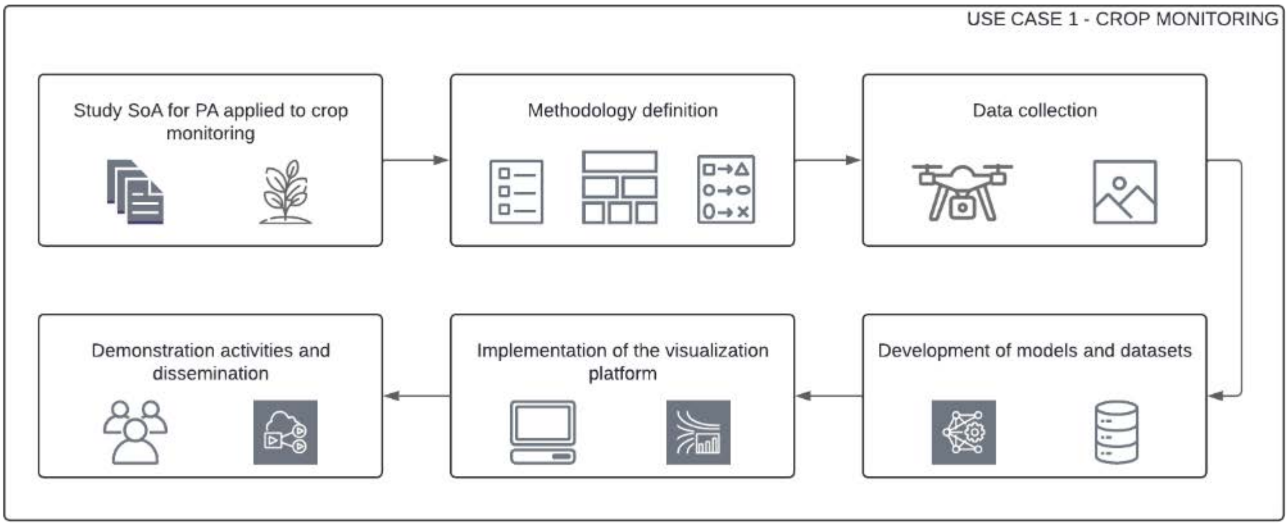



*Figure 2: Key activities' workflow for UC1 during the reporting period.*

#### 2.3.2.3 Timeline

The timeline of the key activities for UC1 is presented in **Figure 3**.

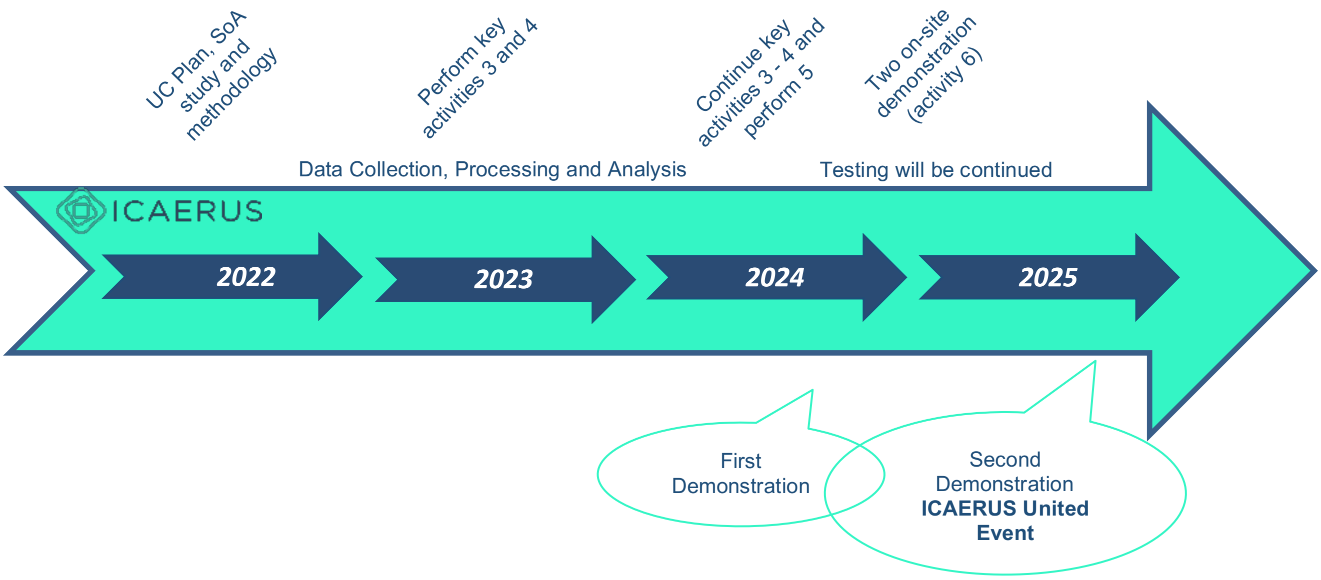



*Figure 3: Timeline of the key activities for UC1.*

### 2.3.3 Deployment Components

#### 2.3.3.1 Site description

The pilot area for the implementation of crop monitoring is located in Canyelles town, near Barcelona city, Spain (the geographical coordinates are 41.28865N and 1.71299E for latitude and longitude, respectively).

The spatial extent of the site is approximately 1.5 ha with an average altitude of 240 m, whereas the vineyard consists of 39 rows in total, with a row spacing of 1 m and crop height approaching 1 to 1.5 m. In **Figure 4** and **Figure 5**, a global and a top-left view of the whole vineyard area are presented, respectively.


*Figure 4: Global view of the vineyards area in Canyelles town (Barcelona, Spain), that was selected for the implementation of crop monitoring within UC1 of the ICAERUS project.*

*Figure 5: Top-left view of the vineyards area in Canyelles town (Barcelona, Spain), that was selected for the implementation of crop monitoring within UC1 of the ICAERUS project.*

Typically, two (2) different flights are performed:

- An automated flight (without the pilot intervention) to capture top-view images of the vineyards followed by the reconstruction of orthomosaic maps with the application of photogrammetry methods. These flights are performed at a predefined altitude with 80% image overlapping to obtain high resolution information for the study area. The data are collected with RGB and multispectral cameras. Particularly, the multispectral camera provides the ground image in R (Red), RE (Red Edge), NIR (Near Infrared) and G (Green) spectral bands. Examples of RGB and NIR images captured with UAV flights over the selected vineyard are shown in **Figure 6** and **Figure 7**, respectively.

*Figure 6: Top-view RGB image of the vineyards area, derived from UAV flight using an RGB camera.*

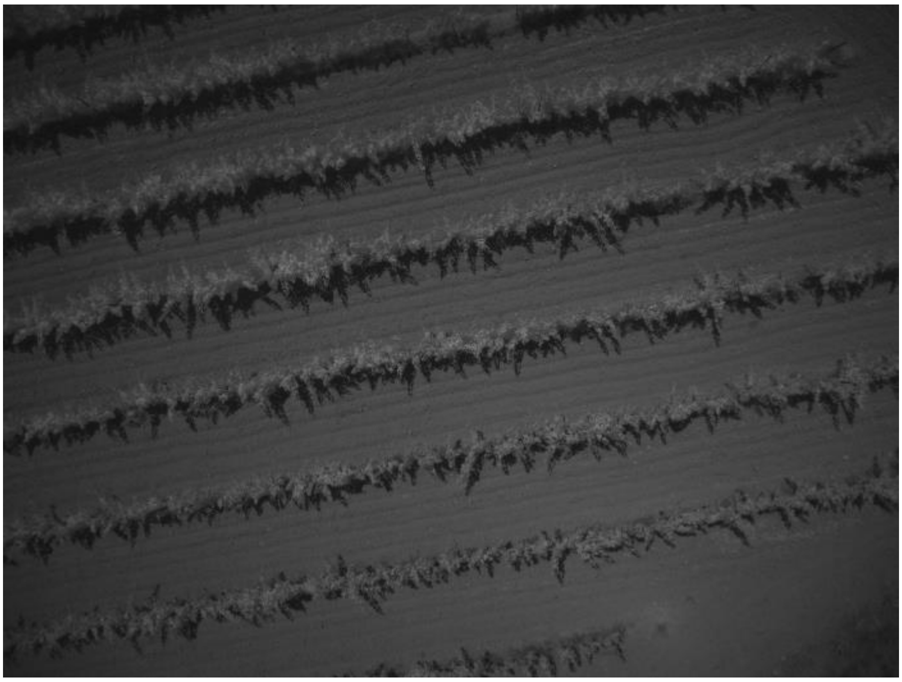


*Figure 7: Top-view NIR image of the vineyards area, derived from UAV flight using a multispectral camera.*

- A manual flight (the pilot has the continuous control of the UAV) to capture row-view images of the vineyards, in order to obtain information about the health status of the leaves and to identify diseased plants. Examples of magnified RGB and NIR images captured with manual UAV flights across the rows of the selected vineyard are shown in **Figure 8** and **Figure 9**, respectively.

*Figure 8: Row-view RGB image of the vineyards area, derived from UAV flight using an RGB camera.*

*Figure 9: Row-view NIR image of the vineyards area, derived from UAV flight using a multispectral camera.*

### 2.3.3.2 Platforms and mounted technological components

The platforms and technological components used in UC1 are referenced in the following:

- DJI Mavic 3M (UAV, presented in **Figure 10**).
- RTK (Real Time Kinematic) sensor (mounted on the UAV).
- RGB camera (mounted on the UAV).
- Multispectral camera (mounted on the UAV).
- Detection system (mounted on the UAV).
- Weather sensor (**Figure 11**).


*Figure 10: UAV platform (DJI Mavic 3M) used for crop monitoring implementation within UC1 of the ICAERUS project.*

*Figure 11: Weather sensor used for crop monitoring implementation within UC1 of the ICAERUS project.*

### 2.3.4 Gathered Data and Formats

#### 2.3.4.1 Data related queries

**What were you testing for? What was the gathered data for the UC?**

The gathered data during the reporting period had two (2) purposes:

- Obtain UAV images to generate an orthomosaic map of the area, determine the DEM, perform 3D reconstruction of the site, process multispectral data, and detect the rows of the vineyards. This information allows the complete recording of the vineyards and provide a variety of input data for the developed platform, offering significant insights. Additionally, the localisation of the individual plants is possible, assisting to the identification of the most affected areas.
- Analyse the health status of individual plants. The UAV flights capture images close to the plants, enabling the visualisation of diseases and other features that could potentially affect the plant growth. These images are used to train an ML model for plant disease identification, which can then be generalised to other cases.

**Were you using existing data? Open/public data?**

Existing data were not used, although the obtained dataset will be publicly shared.

**How was the data being acquired? When? How many times? What are the environmental conditions?**

The data for crop monitoring has been acquired using two UAVs, namely the DJI Mavic and DJI Mavic 3M. The first was mounted with an RGB camera, while the payload of the second model corresponded to multispectral camera that enabled the collection of multispectral images, leading to more precise results. Moreover, three weather sensors were installed in the study area during the current reporting period.

The data collection performed during April 2023 to August 2023, obtaining data for 8 different days. In addition, several datasets acquired in April 2024 till the current period. The data collection occurred every two weeks, while its frequency has been increased in 2024, reaching a weekly occurrence during May.

Usually, the UAV flights are performed during the morning hours and with sunny weather conditions, due to the encountered limitations in rainy or windy days.

**What was the associated data model/format? What was the data size in the reporting period?**

The associated data has been collected in TIFF (Tag Image File Format) and JPEG (Joint Photographic Experts Group) images. The point cloud data was saved as PCD format. Furthermore, some of the processed data for the NDVI calculation or for the determination of rows' location in the vineyards with the orthomosaic maps, were saved in JSON (JavaScript Object Notation) or CSV (Comma-Separated Values) files.

Totally, more than 900 Gb of data were collected during the reporting period, including videos, images from the UAV flights, as well as raw and processed data.

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

The collected data will be exploited to assist farmers as a decision-support utility for field management. By integrating this data into a comprehensive platform, farmers can monitor the evolution of their vines and determine if specific areas require targeted treatments. This dashboard will enable them to comprehend the growth stages of their vineyard over time, providing a valuable tool to streamline the crop monitoring process and enhance efficiency.

#### 2.3.4.2 Data categories

***Input data***

- UAV Canyelles Vineyard Dataset 2023-04-21: Crop monitoring dataset that contains RGB images, point cloud data, an orthomosaic image and the DEM. The data acquisition process involved manually flight of the UAV at an altitude of 10 m, with sufficient frontal and side overlap between the images. The data was collected in Canyelles, a region in Catalonia, Spain, on a cloudy day with an average temperature of 18 °C.
  - "UAV Images": This folder contains a set of 343 RGB images collected using the DJI Mavic 3 UAV. The images are encoded in the JPG format (.jpg). The image metadata includes location information, camera settings, and capture dates.
  - "Pointcloud": The "Pointcloud" folder consists of point cloud data generated from the RGB images using the Metashape program. The point cloud data is created with medium resolution and are saved in the PCD format (.pcd).
  - "ORTOMOSAIC_230421": This is the orthomosaic image resulting from the Metashape Agisoft program running with medium accuracy.
  - "DEM_230421": This is the DEM image resulting from the Metashape Agisoft program running with medium accuracy.
- UAV Canyelles Vineyard Dataset 2023-04-28: Crop monitoring dataset that contains RGB images, NIR images, point cloud data, RGB and NDVI orthomosaic images, DEM and the shape that defines the total vineyard terrain. The data collection procedure involved flights of the DJI Mavic 3 UAV over the vineyard in Canyelles a region in Catalonia, Spain. The flight of the UAV performed under sunny weather conditions with an average temperature of 26 °C.
  - “RGB.tar.gz”: A compilation of the top-view RGB images.
  - “SHAPE.tar.gz”: It contains the Agisoft shape that defines the vineyard area as *vineyard_shape*.
  - “POINTCLOUD.tar.gz”: Point clouds of the complete terrain and cropped vineyard area defined by *vineyard_shape*.
  - “ORTHOMOSAICS.tar.gz”: A folder containing the following RGB orthomosaic images of the complete terrain and the cropped vineyard area defined by *vineyard_shape*.
  - “DEM.tar.gz”: Represents the digital model of the surface that defines the ground topography.
- UAV Canyelles Vineyard Dataset 2023-05-05: Crop monitoring dataset that contains RGB images, point cloud data, an orthomosaic image and the DEM. The data collection procedure involved flights of the DJI Mavic 3 UAV over the vineyard in Canyelles a region in Catalonia, Spain. The flight of the UAV performed under sunny weather conditions with an average temperature of 26 °C.
  - “RGB.tar.gz”: A compilation of the top-view RGB images.
  - “SHAPE.tar.gz”: It contains the Agisoft shape that defines the vineyard area as *vineyard_shape*.
  - “POINTCLOUD.tar.gz”: Point clouds of the complete terrain and cropped vineyard area defined by *vineyard_shape*.
  - “ORTHOMOSAICS.tar.gz”: A folder containing the following RGB orthomosaic images of the complete terrain and the cropped vineyard area defined by *vineyard_shape*.

  - “DEM.tar.gz”: Represents the digital model of the surface that defines the ground topography of the complete and cropped vineyard area defined by *vineyard_shape*.

- UAV Canyelles Vineyard Dataset 2023-06-09: Crop monitoring dataset that contains RGB images, NIR images, point cloud data, RGB and NDVI orthomosaic images, DEM and the shape that defines the total vineyard terrain. The data collection procedure involved flights of the DJI Mavic 3M UAV over the vineyard in Canyelles a region in Catalonia, Spain. The flight of the UAV performed under sunny weather conditions with an average temperature of 26 °C.
  - “NIR.tar.gz”: A compilation of Near-Infrared (NIR) images of the flight.
  - “CROPPED_RGB.tar.gz”: A compilation of cropped RGB images from the original to match NIR size images.
  - “SHAPE.tar.gz”: It contains the Agisoft shape that defines the vineyard area as *vineyard_shape*.
  - “POINTCLOUD.tar.gz”: Point clouds of the complete terrain and cropped vineyard area defined by *vineyard_shape*.
  - “ORTHOMOSAICS.tar.gz”: A folder containing the following:
    - “ORTHOMOSAIC.tar.gz”: RGB orthomosaic images of the complete terrain and the cropped vineyard area defined by *vineyard_shape*.
    - “R_ORTHOMOSAIC.tar.gz”: Multispectral R orthomosaic images of the complete terrain and the cropped vineyard area defined by *vineyard_shape.*
    - “NIR_ORTHOMOSAIC.tar.gz”: NIR orthomosaic images of the complete terrain and the cropped vineyard area defined by *vineyard_shape*.
- UC1 DATA FOLDER GITHUB: This dataset contains the necessary data to execute the UC1_Crop_Monitoring codes in GitHub. It includes the following data:
  - "features": Saves some files with information about the row positions in the global vineyard orthomosaic, the plant positions, their health status and the parcels which divide the vineyards.
  - "images": Includes some orthomosaic images of the vineyard in different colour formats as well as the DEM and NDVI orthomosaics.
  - "images_row": It contains some images taken with the drone of the plants from a row point of view.
  - "images_saved": Images generated after executing some codes of the UC1 repository.

***Output Data***

- The image datasets have been used to reconstruct orthomosaic maps, point clouds and DEM.
- This data can be used to populate the comprehensive platform with historical information and analyse the variations of different days.

#### 2.3.4.3 Drone data analytics models

The drone data analytics models that were used during the implementation of UC1 are summarized in the following:

- Row-view disease detection model with YOLOv8: The model performs disease detection on row-view crops. A custom training has been performed on top of YOLOv8, to ensure the concrete characteristics and bias.
- Plant locator form row-view to global-view: This algorithm contains the complete workflow from detecting a plant in an image to the location of this plant in the global-view orthomosaic, visualising

its health status. It also locates the UAV position. The plant detection is made with YOLOv8 and then there several algorithms are applied, that map the row-view position of the plant to the global-view orthomosaic, using the position of the UAV and its pose.

- Create Grid: It obtains a grid that divides the vineyard rows between vegetation parcels.
- Calculate Vegetation Indexes: Calculates different vegetation indexes from the orthomosaic maps of the vineyard area. For example, using the NIR and the red spectral band orthomosaic maps, the NDVI values are obtained.
- NDVI Per Parcels: Using the previous NDVI image calculation and the grid information, the parcels are divided depending on the NDVI levels. As the NDVI is increasing, it is assumed to be more "greenery" in that part, hence the plant should be healthier. Additionally, other vegetation calculations can be used with this model.

## 2.4 Results and Sustainability Performance

### 2.4.1 Outcomes

The UC1 expected outcomes involve the following:

- Introduce the use of UAVs into the crop monitoring tasks.
- Provide a methodology to perform data collection and analysis in an automatic and concrete way.
- Offer a visualisation platform to retrieve information of different stages of the vineyard area, as well as key information about the health status of the plants.
- Enable predictive and decision-making tools for farmers.

### 2.4.2 Impact

#### 2.4.2.1 Socio-economic

- Reduce the amount of the required field-work for crop monitoring tasks by automatising this process.
- Assist the development of new methodologies, reducing the associated costs.
- Introduce a data collection flow into the agriculture market as a common approach.

#### 2.4.2.2 Environmental

- Reduce the use of pesticide by predicting and controlling potential plant diseases in advance.
- The use of UAVs is optimal for crop monitoring tasks due to their minimal impact on the environment and pollution, providing a promising alternative to farmers.
- Seamlessly integration of this technology into the agricultural sector to enhance crop performance through close and effective monitoring.

## 2.5 UC Modifications and Next Steps

**Please provide any deviations and UC corrective actions or the required plans for improvement.**

- The point clouds format will be changed from .pcd to .xyz, due to the observation of incorrect data in the former file format.
- The models will be improved with newer versions trained with additional data.

**Next Steps**

The next steps involve the optimisation of the processing methodology to acquire data for the platform more efficiently. Additionally, the data collection process will be continued and initiate new labelling to train more accurate models. Furthermore, growth analysis of the plants will be conducted using 3D information.

# 3. Use Case 2: Drone Spraying

## 3.1 Introduction

The scope of 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, 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.

### 3.1.1 Objectives

Agriculture stakeholders are calling for the update of the SUD (Sustainable Use of pesticides Directive) 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 environment-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 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.

### 3.1.2 Use Case Scenarios

The primary hypothesis of UC2 is that spaying UAVs have the potential to effectively and safely perform crop protection tasks on various crops, particularly vineyards (primary crop of interest), wheat, cotton, corn and rice, given appropriate environmental conditions and flight settings. To this end, during the use case we will explore the following scenarios:

1. Assess drone spraying efficiency (canopy penetration, deposition) across different spraying configurations in vineyards. 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. Examine the biological efficacy of various crop protection products in field conditions when applied by spraying UAVs, in the selected crops of interest.

3. Evaluate spraying drone potential in reducing spraying drift, by comparing it with terrestrial sprayers and standard spraying practices.

## 3.2 Progress Report

### 3.2.1 Evaluation Summary

#### 3.2.1.1 Specific Objectives

The main objective of UC2 during the reporting period of this manuscript was to conduct all experimental operations and complete all related data analysis pipelines for the cultivation seasons of Summer 2023 – Spring 2024. To this end, the primary objectives are as follows:

- Complete a full experimental set (24 iterations) of UAV spraying in vineyards to assess canopy deposition and in-field droplet distribution.
- Complete a full experimental set (24 iterations) of UAV spraying in vineyards to assess droplet drift (off-target disposition).
- Conduct a series of efficacy trials using actual crop protection products in wheat, corn and rice.

#### 3.2.1.2 Achievements/Results

Key achievements of the UC2 in this reporting period include:

- Successful implementation of all field trials and completion of all data acquisition operations.
- Complete the analysis of the vineyard coverage data, thus creating the complete “Vineyard Canopy Coverage” dataset that has been made openly available online through the project’s established pages.
- Collected field observations and laboratory analysis reports on the efficacy trials for all three (3) aforementioned crops of interest (wheat, rice and corn), obtaining very positive results on the effectiveness of spraying UAVs in the examined crop protection applications.

#### 3.2.1.3 Shortcomings/Obstacles

Key shortcomings/obstacles faced during the UC2:

- During the most recent summer period (2023), various experimental visits were either cancelled (called-off after setting up the equipment and positioning sample collectors on the field) due to high temperatures – short heatwaves of over 40°C were common during August in Athens.
- As all efficacy trials are conducted with agrochemicals, they require specific experimental permits from the Hellenic Civil Aviation Authority (HCAA), which created a form of delay due to internal administrative and logistic procedures.

## 3.3 Deployment and UC Execution Status

### 3.3.1 UC Plan Progress

- The aforementioned results were a cumulative effort of the UC2 partners for the reporting period of **summer 2023 to spring 2024** – a total of 9 PM**.**

- HCPA, the **UC2 partner** that works alongside AUA, played a vital role in connecting the UC with commercial crop protection companies, while also co-organising all efficacy trials.
- The primary **goal of UC2** is to collect and disseminate concrete results (based on extensive field trials) on the effectiveness of spraying UAVs in the examined crop protection applications**.**
- The **progress of activities within UC2** is going according to plan, as all targets set by the UC plan (as of writing this document) have been achieved.

### 3.3.2 UC Activities

#### 3.3.2.1 Key Activities

The key activities of UC2 are summarised in **Table 2**.

*Table 2: Key activities of UC2.*

| id | Activity Name/Title | Description/Goal |
|---|---|---|
| 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. |
| | **Activity Progress**<br>Successfully completed prior to the start of UC2's experimental operations. | |
| 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. |
| | **Activity Progress**<br>Successfully completed for the reporting period. Further experimental operations will continue in the following months. | |
| 3 | Methodological documentation and capacity building | Create a methodological guide and capacity building materials 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. Finally, risks associated with drone spraying will also be documented and categorised, and mitigation strategies will be proposed. |
| | **Activity Progress**<br>Successfully completed for the reporting period. AUA is currently working on a scientific publication showcasing the results of UC2 in vineyards, which can also support the creation of a short factsheet for optimal spraying configuration to ensure drift minimisation. | |

| | | |
|---|---|---|
| 4 | 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. |
| | **Activity Progress**<br>UC2 has created various informative audio-visual media posts and materials (shared through the project's social media pages as well as the UC2 partners' pages) regarding various activities that are conducted under UC2. | |
| 5 | Demonstration | Organise 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. |
| | **Activity Progress**<br>UC2 is currently organising the first demo event that will take place in Spata during July. | |

#### 3.3.2.2 Key activities' workflow

The methodology followed by UC2 aims to evaluate two things:

- Drone spraying quality.
- Drone spraying drift.

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. Both methodological pipelines followed by AUA have been described extensively in previous reports (namely D3.1 – Use Case Plan), and **Figure 12** acting as an overview of the data acquisition strategies and analysis is presented below.

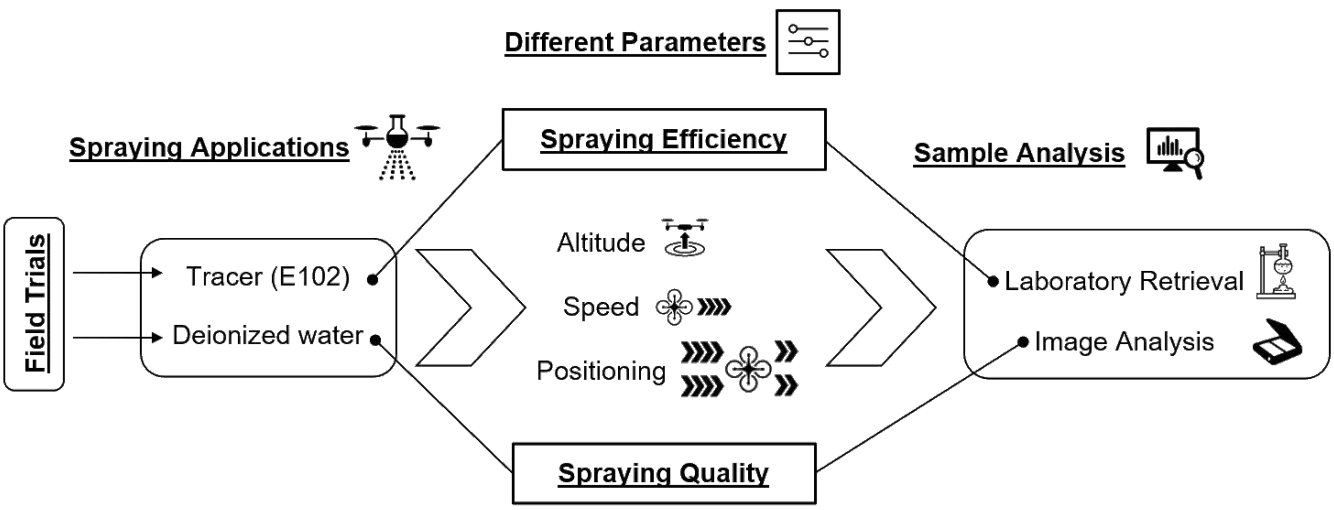



*Figure 12: Schematic overview of the data acquisition strategies and analysis within UC2 of the ICAERUS project.*

#### 3.3.2.3 Timeline

The timeline of the key activities for UC2 is presented in **Figure 13**.

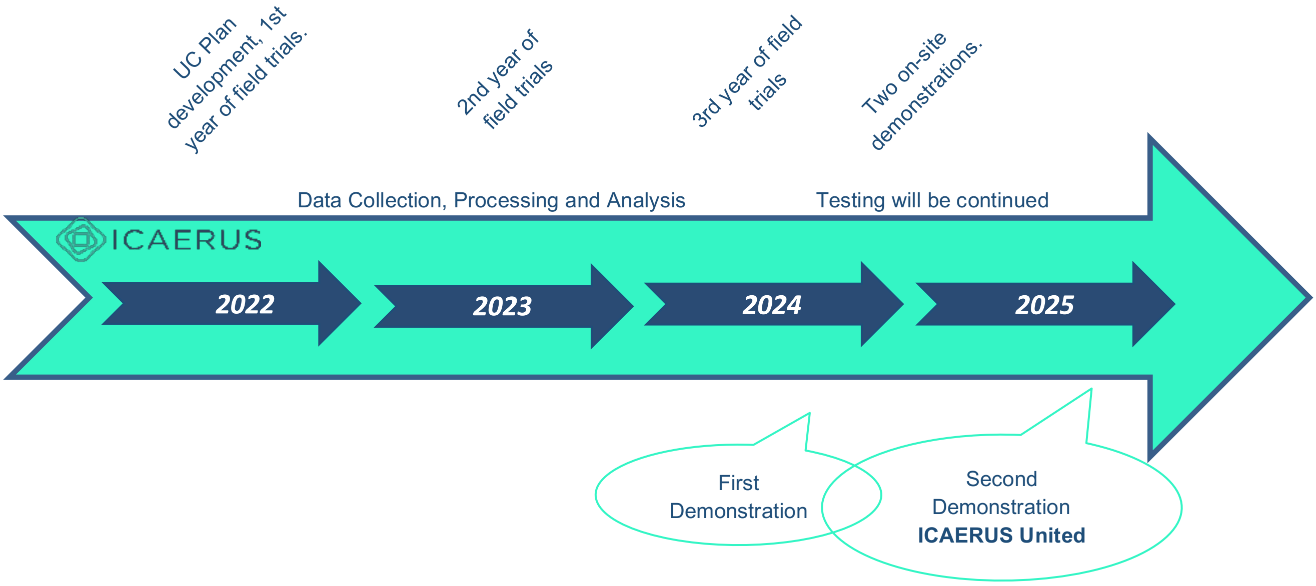



*Figure 13: Timeline of the key activities for UC2.*

### 3.3.3 Deployment Components

#### 3.3.3.1 Site description

***Pilot Area***

The experimental field is the organic vineyard of the Agricultural University of Athens farm in Spata, Greece (37°59'06" N, 23°54'21" E) (**Figure 14**). 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.


*Figure 14: The experimental area of UC2 in Spata, Greece.*

### *Testing Area*

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.

Moreover, efficacy trials are conducted upon obtaining the necessary experimental permits, in various fields across the country, prioritising fields within the premises of AUA whenever it is possible (see for example **Figure 15** and **Figure 16**).

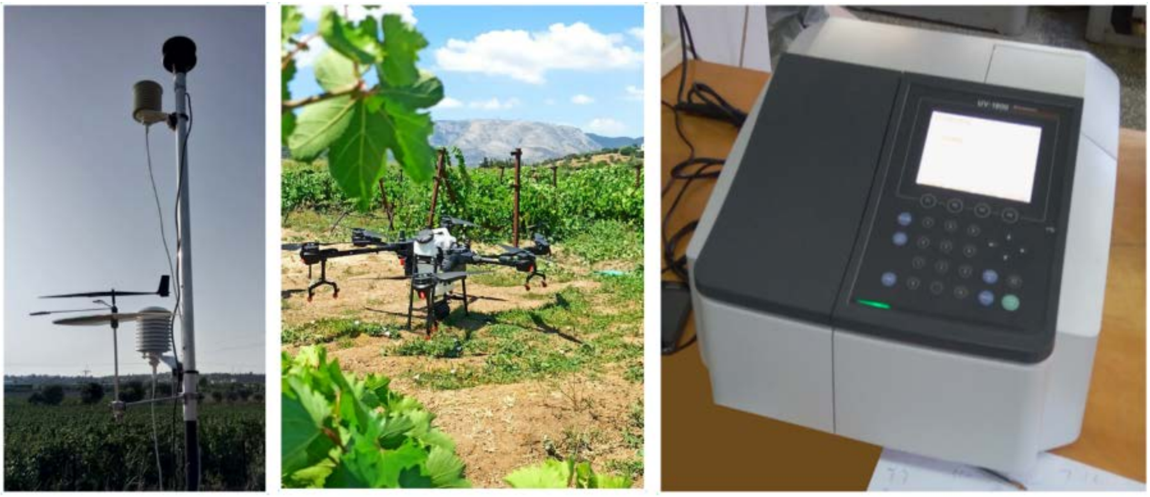
*Figure 15: Fungicide efficacy trial in rice field in Chalastra, Greece.*

*Figure 16: Herbicide efficacy trial in corn field in Aliartos, Greece.*

#### 3.3.3.2 Platforms and mounted technological components

The platforms and technological components used for the deployment of UC2 are the following:

- Meteorological station to monitor environmental conditions during spraying applications (**Figure 17a**).
- Spraying drone (we use DJI Agras T16 and T10) (**Figure 17b**).
- Various nozzles to extend the field trial methodology in upcoming years.
- Spectrometer and spectroscopy analysis laboratory (**Figure 17c**).



a b c

*Figure 17: The platforms and technological components deployed in UC2 of the ICAERUS project.*

### 3.3.4 Gathered Data and Formats

#### 3.3.4.1 Data related queries

**What were you testing for? What was the gathered data for the UC?**

Drone spraying quality (penetration, canopy deposition) and drift (displaced off-target chemical rate).

**Were you using existing data? Open/public data?**

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

**How was the data being acquired? When? How many times? What are the environmental conditions?**

Data are collected using two different types of collectors (explained in the Methodology segment). 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 were the collected data and datasets be used to operate in favour of the ICAERUS project?**

The UC 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.

#### 3.3.4.2 Data categories

*Input data*

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

*Output Data*

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

#### 3.3.4.3 Drone data analytics models

The image analysis part of UC2 is currently performed with the DepositScan software (developed by USDA). Other than that, the various regression models and equations that describe canopy coverage and droplet distribution for vineyards are currently extracted from the created dataset and will be uploaded on the project's repository in the following months.

## 3.4 Results and Sustainability Performance

### 3.4.1 Outcomes

- 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.

### 3.4.2 Impact

#### 3.4.2.1 Socio-economic

- 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.

#### 3.4.2.2 Environmental

- 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.

## 3.5 UC Modifications and Next Steps

**Please provide any deviations and UC corrective actions or the required plans for improvement.**

No deviations to report.

**Next Steps**

- Continue with an experimental year in vineyards, followed by the analysis of this year's samples.
- Finalise and share the results of efficacy trials for all crops of interest.
- Publish a scientific manuscript on the results of UC2 in a peer-review journal.

# 4. Use Case 3: Livestock Monitoring

## 4.1 Introduction

The scope of the UC3 is to evaluate the risks and the interests to use drones for monitoring cattle and sheep in grassland-based systems facilitating the monitoring work and improving the quality of life of farmers. Building on existing and “off-the-shelves” drones technologies, the UAVs will be evaluated in 2 complementary pilot farms representing 2 species and 3 types of grasslands: the first farm with a beef cattle herd in pastures low-lands, the second farm with a sheep flock in a pastoral system based on 3 types of grasslands (low-lands pastures, woody rangelands, summer mountain rangeland). Drones will be used as an “eye-in-the-sky” supporting farmers and sheepherders with visual information. Indeed, from the drones’ images, livestock farmers can collect a lot of information that they are currently obtaining through a close visual check of the herd (number of animals, position of the animals, access to water, health and welfare levels) when they are visiting them or shepherding them. The idea is not to replace farmers but to evaluate if a part of the farmers' visits can be facilitated by drones.

### 4.1.1 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 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.

### 4.1.2 Use Case 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. The conventional (from the ground) livestock monitoring is realised 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 to 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.

**2. 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 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.

## 4.2 Progress Report

### 4.2.1 Evaluation Summary

#### 4.2.1.1 Specific Objectives

During this reporting period, we implemented methodologies to address all our specific objectives. To promote the safe and efficient use of drones, we started by gathering feedback and experiences from one year of tests. This information was used to produce a guidebook that addresses the following questions:

- Which technologies are most appropriate for livestock farming?
- What is feasible on a livestock farm?
- What are the risks and best practices when using drones on grasslands?

The French version of the guidebook is complete and is currently being translated into English, with publication on the platform expected before month 28. Additionally, we conducted four preliminary on-farm demonstrations and participated in various technical and scientific events. These activities allowed us to define a demonstration methodology aimed at maximising impact during Year 3, when larger demonstrations are planned.

Regarding our impact assessment objectives, we specified methodologies and implemented trials on both our scenarios (beef cattle and sheep farming) and defined on each pilot farm a similar functional unit for data collection. Practically, we compared livestock monitoring activities in the traditional systems of monitoring (driving and walking in many pastures and paddocks) vs the drone monitoring (driving to large pastures and using the drone to monitor all the paddocks inside). We applied these protocols and collected data.

Finally, both our scenarios supported data collection for WP2 objectives. In practice, drones' images and videos were collected to train animal detection models and flock counting models.

#### 4.2.1.2 Achievements/Results

The main results/achievements of the livestock monitoring use case can be summarised in the following regarding our specific objectives:

- Two period (of 1 month) of data collection in the beef cattle farm.
- One period of data collection in the sheep farm.

The data collected in these methodologies, in both treatments, the traditional monitoring vs drone-facilitated monitoring are: time spent for every monitoring activity, energy consumption, feelings of farmers.

The second period of data collection ended in M24. Thus, data analysis is still on-going. A very preliminary result on the beef cattle scenario is that when the drone is usable it could decrease the time needed for animal monitoring by 20 to 30%. Weather conditions are limited regarding the year. On sheep farms, due to an increase in predation, in-person interventions have increased, limiting the potential of drones to significantly improve working conditions of the sheep farmers.

To promote a safe, legal and efficient use of drone we achieved:

- The publication of a free Guidebook for using drones in livestock monitoring.
- 4 demonstrations.
- Various interviews and communication in technical fairs.

Regarding the contributions to WP2, we achieved:

- 4 publications on the Zenodo platform of three (3) datasets or their updated versions.
- Publication of three (3) Models on Github.

#### 4.2.1.3 Shortcomings/Obstacles

Weather conditions in 2024 (record of rainy days), have complicated the trials by delaying the start of the grazing season and then significantly limiting the use of drones. However, the sunny weather in Fall 2023 allowed for the collection of diverse and representative data under various real-world conditions. Repeating the trials in Year 3 will further enrich the data, reducing its dependence on seasonal variations.

Surprisingly, drones seem less promising in the sheep farm scenario. Increased predation pressure has made in-person visits mandatory to feed guard dogs, which were not previously introduced to all batches of animals. Consequently, shepherds are also spending more time with the animals in person. However, while drones may be less effective for routine visits, they could significantly enhance counting activities using AI developed in WP2, thereby improving working conditions.

## 4.3 Deployment and UC Execution Status

### 4.3.1 UC Plan Progress

- The **Start month**, the **duration** and the **total PM.**
  - Start month: May 2023.
  - Duration: 12 months.
  - Total PM: 11.3.
- The **Partners involved** and the **third parties involved** (organisation names).
  - Jalogny Pilot farm (beef cattle) and Carmejane pilot farm (sheep).
- A **short description of the UC's goal.**

The UC3 goal is to evaluate the risks and the interests to use drones for monitoring cattle and sheep in grassland-based systems facilitating the monitoring work and improving the quality of life of farmers.

- The **progress of activities in detail.**
  - trial on impact assessment of monitoring animals with drones.
  - regular flights with feedbacks on a flight logbook.
  - User guide book for drone users.
  - Data collection for models in WP2, pushing datasets on Zenodo and codes on Github.

### 4.3.2 UC Activities

#### 4.3.2.1 Key Activities

The key activities of UC3 are summarised in **Table 3**.

*Table 3: Key activities of UC3.*

| id | Activity Name/Title | Description/Goal |
|---|---|---|
| 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. |
| | **Activity Progress**<br>The drones were tested in real-life conditions. A flight log was completed with a description of the flights and the difficulties encountered. | |
| 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. |
| | **Activity Progress**<br>We conducted trials on work impact assessment of monitoring animals with drones. | |
| 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). |

<table>
<tr><td></td><td colspan="2">Activity Progress<br>In progress.</td></tr>
<tr><td rowspan="2">4</td><td>Estimation of drones' performance for livestock monitoring</td><td>Based on the created database, the performance of drones in the daily routine activities will be evaluated, emphasising their contribution to the labour improvement (implementation from fall of 2023 to summer of 2025).</td></tr>
<tr><td colspan="2">Activity Progress<br>In progress.</td></tr>
<tr><td rowspan="2">5</td><td>Investigating the feasibility of livestock monitoring with drones</td><td>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 was investigated via 2 selected tasks, according to the outcomes of the WP 1 of ICAERUS project.<br>Some examples of these tasks are the following:<br>● Drone usage as a “herding dog” for navigating the herds within the farm area.<br>● Easy and fast livestock counting, with the incorporation of machine learning software.</td></tr>
<tr><td colspan="2">Activity Progress<br>We are developing an algorithm to automatically count animals and have referenced different semi manual ways of animal counting facilitated by the drones. A drone, acting as a herding dog, has been tested on a beef pilot farm. Other identified activities include:<br>● Monitoring forage crops from an aerial perspective.<br>● Manually identifying baby deer and other wildlife before mowing grass.<br>● Using drones as a communication tool to engage with the rural community, particularly for farms with direct sales.<br>● Inspecting photovoltaic panels, which are increasingly common on farm barns.</td></tr>
<tr><td>6</td><td>Database of drones' capabilities to facilitate the labor in a farm, excepting the livestock monitoring</td><td>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</td></tr>
</table>

| | | |
|---|---|---|
| | | 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. |
| | **Activity Progress**<br>In progress. | |
| 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 are French (assisting the local community) and English including:<br>• Videos of best practices.<br>• Scientific lectures.<br>• Discussion on technical issues.<br>• Technical workshops.<br>The main outcome of the demonstrations will be a guidebook in French and English, including recommendations for optimal practices performance for livestock monitoring. |
| | **Activity Progress**<br>We wrote and shared a drone practical guide and produced numerous other communications. | |

#### 4.3.2.2 Key activities' workflow

The key activities' workflow of UC3 are illustrated in **Figure 18**.

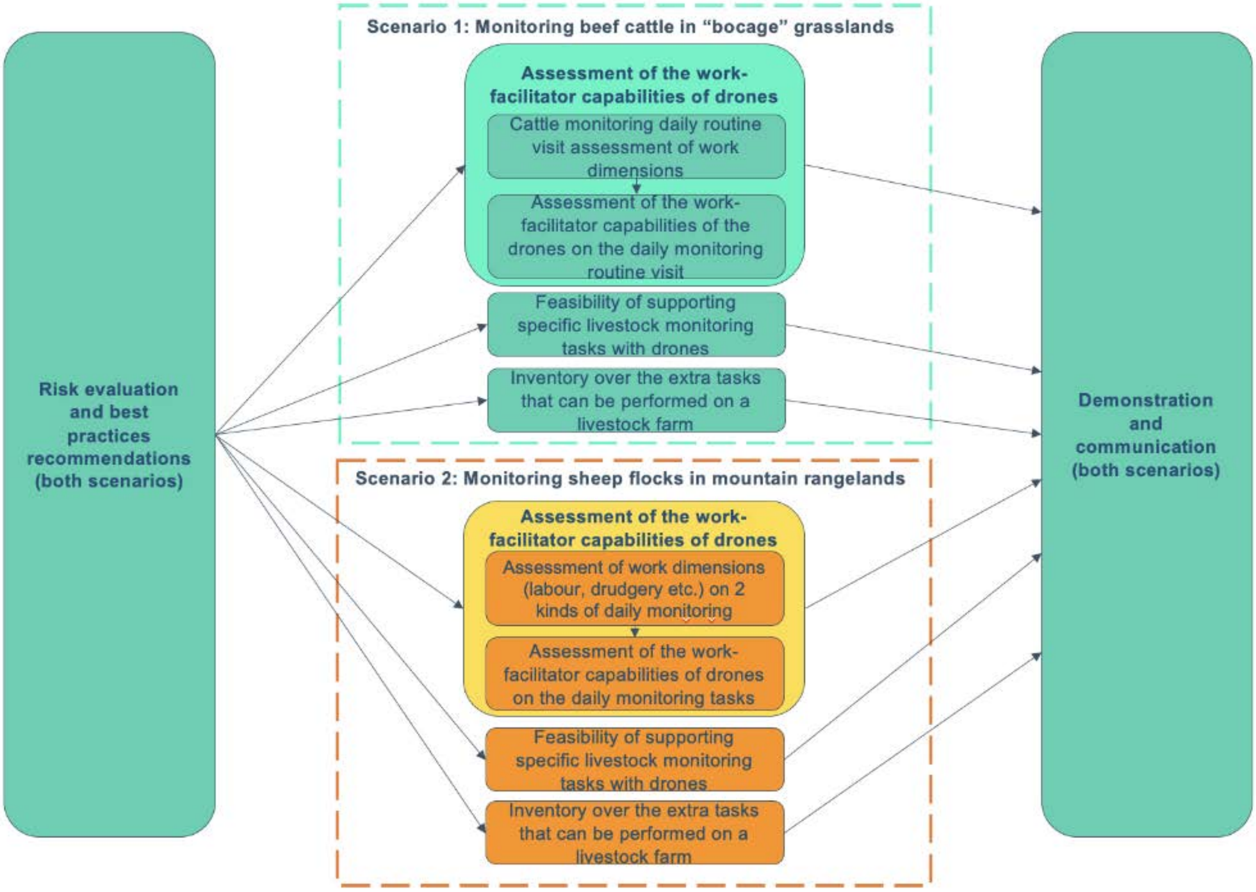



*Figure 18: Key activities' workflow for UC3 during the reporting period.*

### 4.3.2.3 Timeline

The timeline of the key activities for UC3 is presented in **Figure 19**.

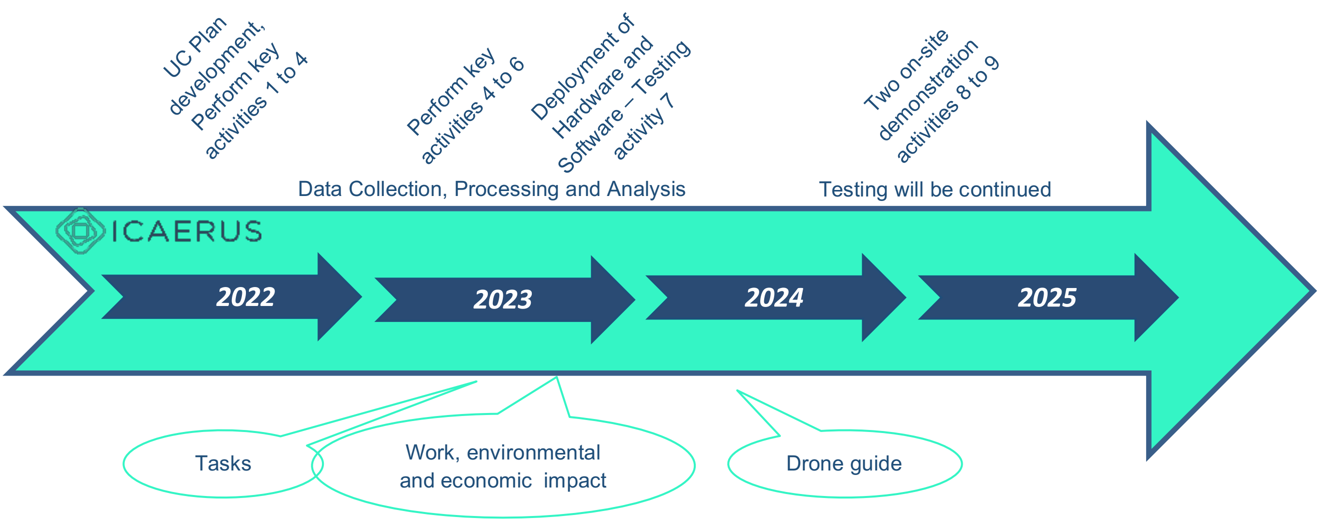



*Figure 19: Timeline of the key activities for UC3.*

### 4.3.3 Deployment Components

#### 4.3.3.1 Site description

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

In general, three regions in farm A (denoted with green colour in **Figure 20**) 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 < 1 Km). On the contrary, many other regions in farm A (denoted with blue colour in **Figure 20**) 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.

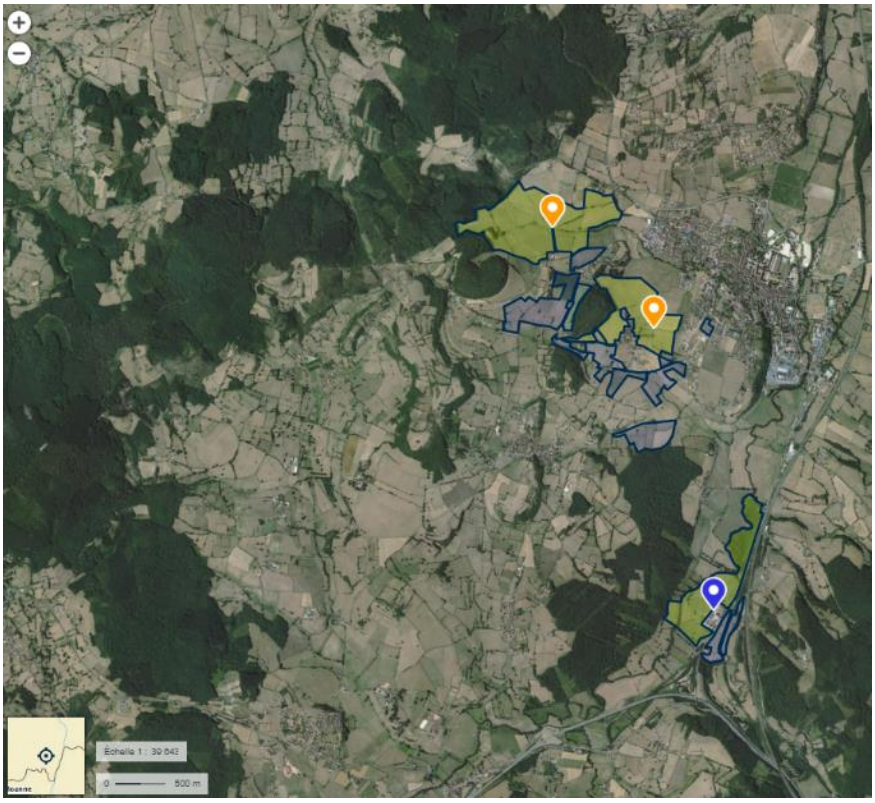


*Figure 20: Map of the area of Farm A. The coloured polygons represent areas where a drone can perform a continuous flight. The green polygons denote 3 main regions for monitoring cattle with drone use. The blue polygons denote regions where drone use is less beneficial due to various constraints (roads, 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.*

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: 44.03122ºN, 6.13589ºE.
- Summer mountain land 1: 44.20560ºN, 6.47091ºE.
- Summer mountain land 2: 44.36800ºN, 6.39803ºE.

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 20**, 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 21**, 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 22** are indicative of mountain grasslands with rapid altitude changes, where sheep flocks are grazing during the summer.

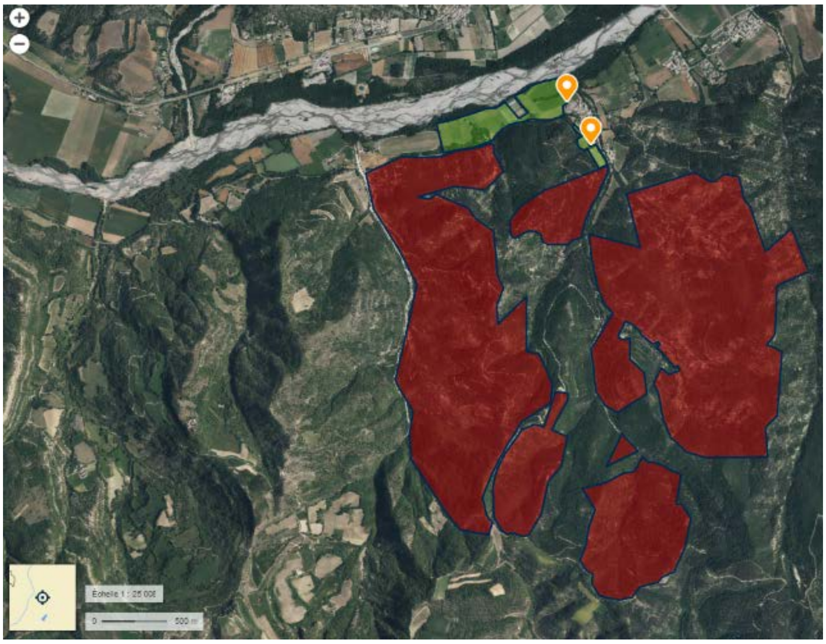


*Figure 21: Map of the area of Farm B. The coloured polygons represent areas where a drone can perform a continuous flight. The green polygons indicate 2 main areas for monitoring cattle with drone use in winter. The red polygons indicate large forested grazing areas of more than 500 ha. The orange markers represent potential launch sites for drone flights within the green polygons. Both launch sites are located in the main settlement of the farm.*

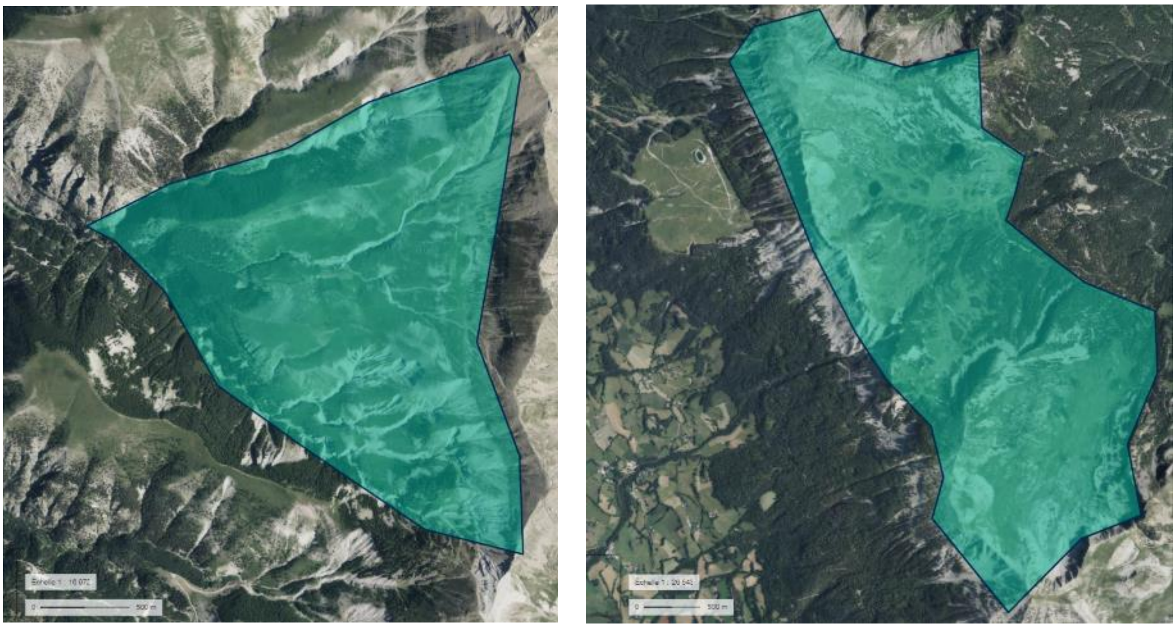


*Figure 22: Map of the summer mountain lands of farm B. Highlighted polygons represent areas where a drone can perform continuous flight.*

##### 4.3.3.2 Platforms and mounted technological components

The platforms and technological components used for the deployment of UC3 are 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 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. It is also equipped with a powerful zoom, a wide range camera, allowing a large inventory of services to be exploited by 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.

#### 4.3.4 Gathered Data and Formats

##### 4.3.4.1 Data related queries

**What were you testing for? What was the gathered data for the UC?**

UC3 is testing the ability of drones to improve the working conditions of farmers. Most of the gathered data are related to the time spent on the monitoring activities by the farmers. We are also producing datasets for the WP2 to develop animal counting models.

**Were you using existing data? Open/public data?**

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

**How was the data being acquired? When? How many times? What are the environmental conditions?**

Trials have been implemented to compare traditional way of monitoring vs the drone-facilitated way in Fall 2023 during a month and in May and June 2024. For datasets made for WP2, the idea was to take images all along the year and day to make variance in the images regarding light and colors of the background.

**What was the associated data model/format? What was the data size in the reporting period?**

The data on working conditions are a .csv file of <1 Mo.

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

The collected data and databases will assist in 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 of animal counting identified in the WP2.

##### 4.3.4.2 Data categories

***Input data***

- Drone sensing data.
    - Images and Videos are not used routinely but 3 data sets were produced for the WP2.
        - Drone images of cattle.
            - Lebreton, A. (2023). Drone raw images of cattle in french grazing areas (Version 1) [Data set]. Zenodo. https://doi.org/10.5281/zenodo.8234156

- ➢ Helary, L., & Lebreton, A. (2024). Drone images and their annotations of grazing cows (Version 2) [Data set]. Zenodo. https://doi.org/10.5281/zenodo.11048412
- ▪ Drone videos of passing sheep.
  - ➢ Lebreton, A., & Helary, L. (2023). Sheep videos taken from drone at low altitude (Version 1) [Data set]. Zenodo. https://doi.org/10.5281/zenodo.10400302
  - ➢ Helary, L., Nnenna OKOYE, K., KOLODZIEJCZYK, M., SCHEWE, J., Philip, L., Nicolas, E., & Lebreton, A. (2024). Drone videos and their annotations of passing sheep (for counting purpose) [Data set]. Zenodo. https://doi.org/10.5281/zenodo.12094356
- o Flight log is used internally to monitor the used of the drones in the pilot farms.

- Daily weather data are used to evaluate the usability of the drones along the year.

***Output Data***

- Time spent for monitoring activities regarding the traditional way vs the drone-facilitated way.

#### 4.3.4.3 Drone data analytics models

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

## 4.4 Results and Sustainability Performance

### 4.4.1 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.

### 4.4.2 Impact

#### 4.4.2.1 Socio-economic

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

- Degrease 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.

#### 4.4.2.2 Environmental

The environmental impact of UC3 primarily stems from replacing part of truck transportation during monitoring of the herd with drone flights. Drones produce low CO2 emissions and generate extremely low noise levels, resulting in minimal environmental and noise pollution, as well as minimal disruption to local wildlife. However, operating drones requires energy from relatively high-capacity batteries. Fortunately, over 80% of France's electricity comes from nuclear power, which ensures a very low carbon footprint for the energy needed to charge the drone batteries.

## 4.5 UC Modifications and Next Steps

**Please provide any deviations and UC corrective actions or the required plans for improvement.**

No deviations encountered during the reporting period.

**Next Steps**

The focus and next steps of the livestock monitoring use case can be summarised in the following:

- Finalising data analysis both on work and environmental dimensions.
- Planning other periods of data collection.
- Produce an English version of our Guidelines book.
- Data collection and analysis.
- Promote the project and engage with stakeholders.

# 5. Use Case 4: Forestry and Biodiversity

## 5.1 Introduction

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

Satellite imaging data are used to detect possible tree stress. Meanwhile, multi-rotor drones are deployed for detailed (high-resolution) monitoring of specific forest areas (including tree health and fire risks). Fixed-wing drones are becoming an efficient tool in forestry research and are utilised for wildlife monitoring due to their capacity to cover vast areas and provide fast monitoring data.

### 5.1.1 Objectives

The main objective of UC4 is to develop and demonstrate multipurpose drone utilisation to monitor forest conditions and wildlife.

Other objectives related to the main objective:

- 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 asses fire fuel types.
- Monitor ecosystems and assess biodiversity and wildlife (wild boars) populations.

### 5.1.2 Use Case Scenarios

During UC4, the following scenarios are explored:

- UC Scenario 1: Forest Tree Health Assessment.
- UC Scenario 2: Wildfire Risk Monitoring.
- UC Scenario 3: Wild Boars Monitoring.

## 5.2 Progress Report

### 5.2.1 Evaluation Summary

#### 5.2.1.1 Specific Objectives

The specific objectives of the UC4 that were served in the reporting period are summarised in the following:

- **Model development of Monitoring Forest tree health through drones, satellites (Sentinel-2) and data science.**

  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.

- **Model development of identifying and inspecting potentially high fire risk areas and assessing fire fuel types.**

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

- **Model development of Monitoring of ecosystems and assessment of the biodiversity and wildlife populations (Boars' identification and counting).**

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

#### 5.2.1.2 Achievements/Results

**UC Scenario 1: Forest Tree Health Assessment (using satellite data)**

Data and situation assessment through the three main perspectives: a) National, b) Regional, and c) Local.

**a) National**

The majority of damage caused by pine diseases and pests was recorded in the regional units of Ignalinos-Švenčionėlių, Druskininkai and Anykščiai (**Figure 23**). Thus, it is possible to identify more localised (regional) problematic areas.

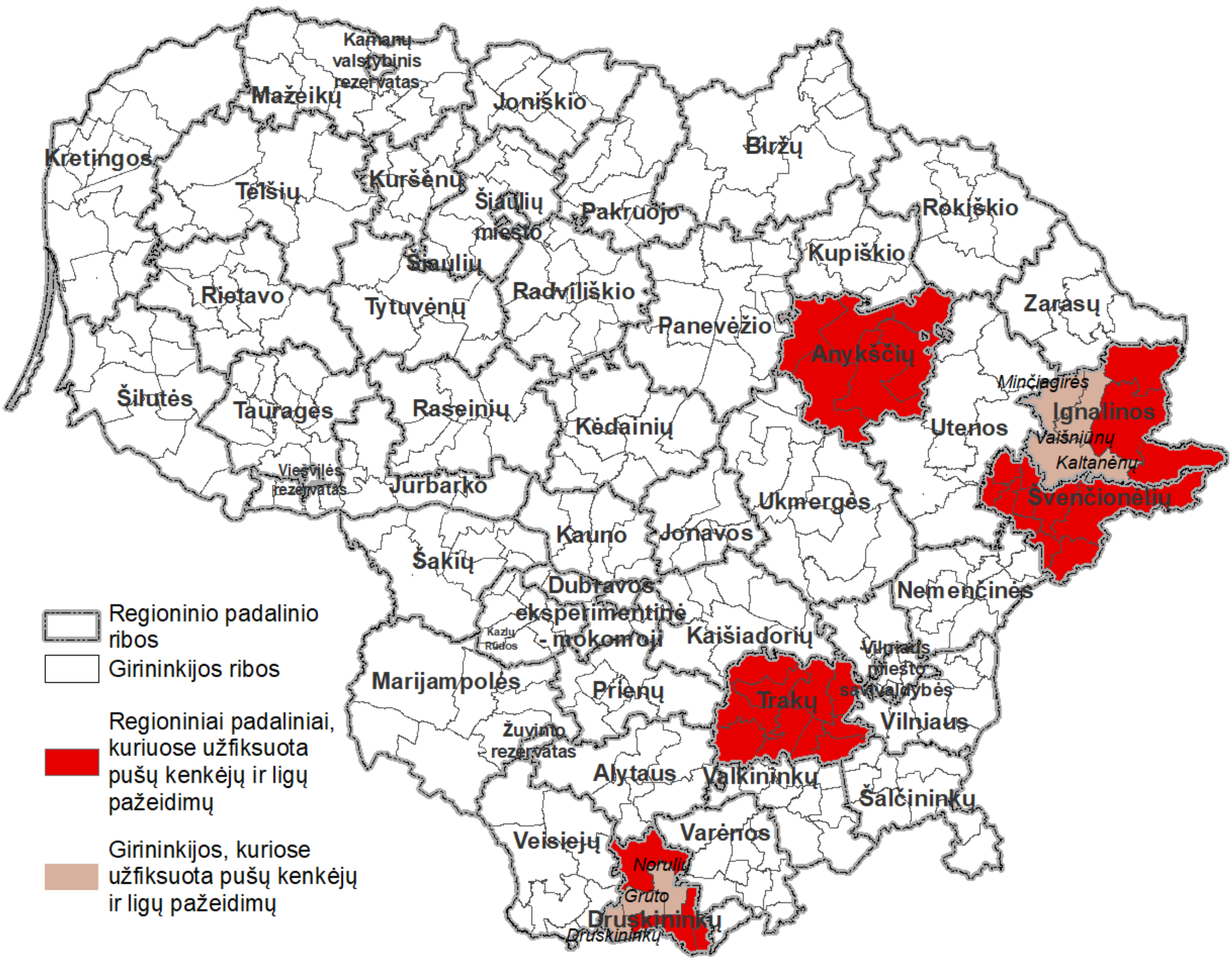



*Figure 23: Map of Lithuania. The majority of damage caused by pine diseases and pests was recorded in the regional units of Ignalinos-Švenčionėlių, Druskininkai and Anykščiai (denoted with red colour). Thus, it is possible to identify more localised (regional) problematic areas.*

**b) Regional**

In **Figures 24** to **28** the spatial distribution of the NDVI (Normalised Difference Vegetation Index) is presented, within the pine forests of the identified regions in Lithuania (see **Figure 23**).

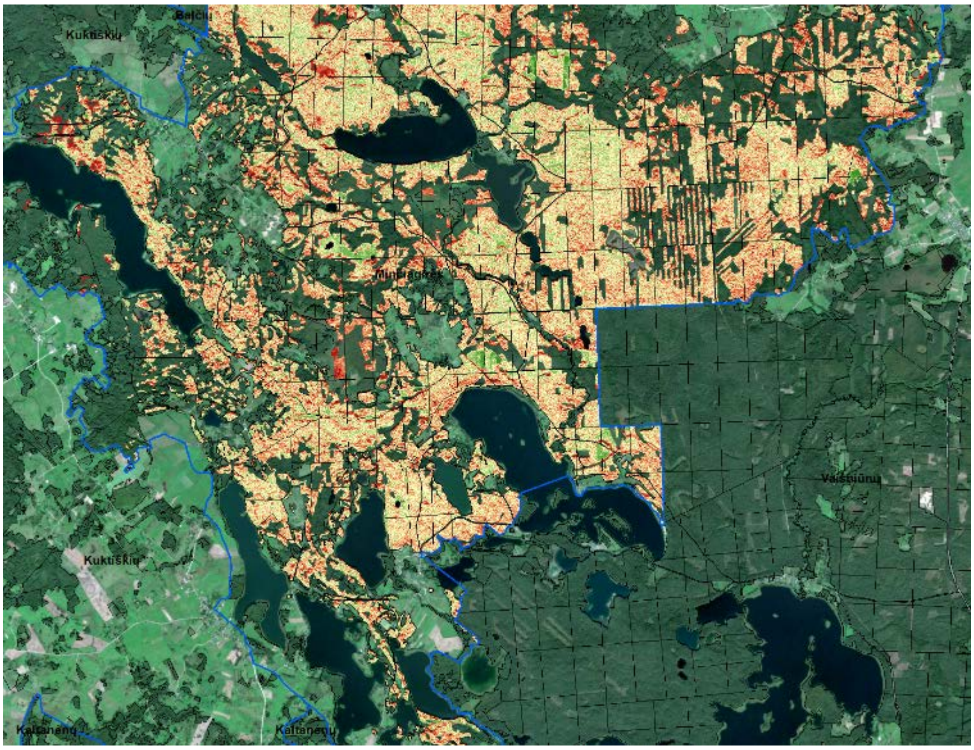



*Figure 24: Spatial distribution of the NDVI in the pine forests of Minčiagirė, within Ignalinos regional unit (East Lithuania) during 2021-2022. Large negative values (with dark red colours) are observed in scattered areas, indicating unhealthy parts of the forest.*

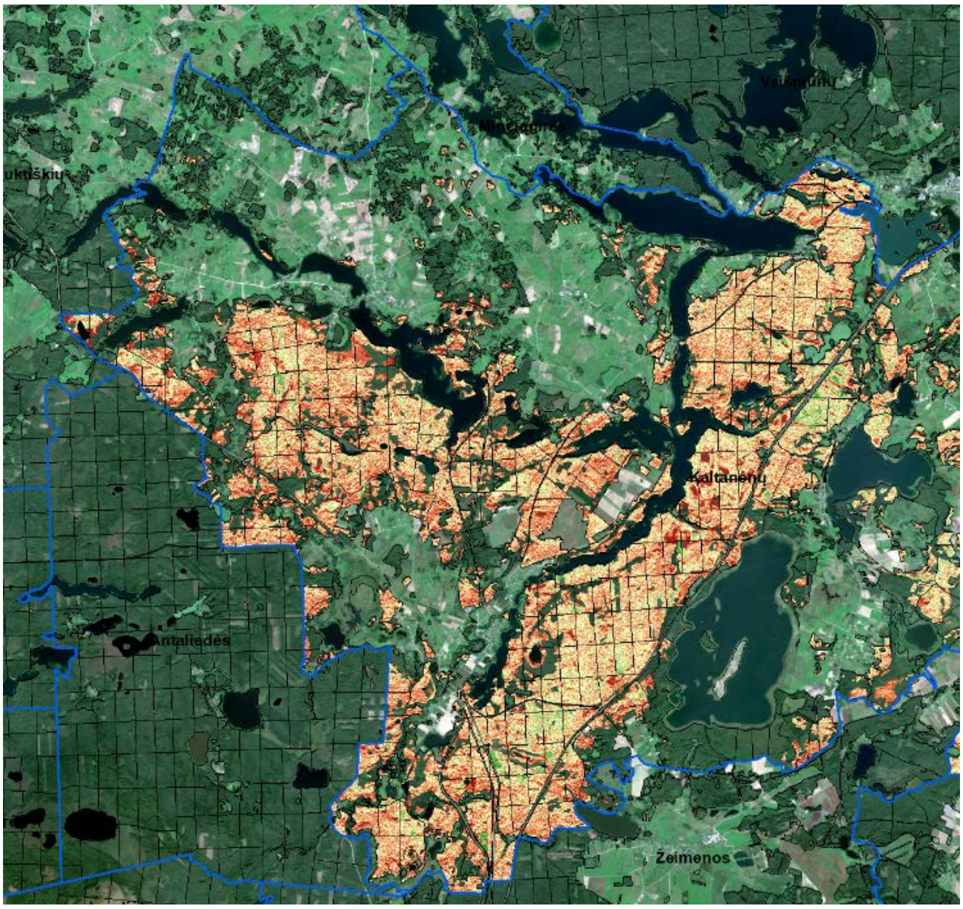



*Figure 25: Spatial distribution of the NDVI in the pine forests of Kaltanėnai (Tverečius) within Ignalinos regional unit (East Lithuania) during 2021-2022. Large negative values (with dark red colours) are observed in scattered areas, indicating unhealthy parts of the forest.*

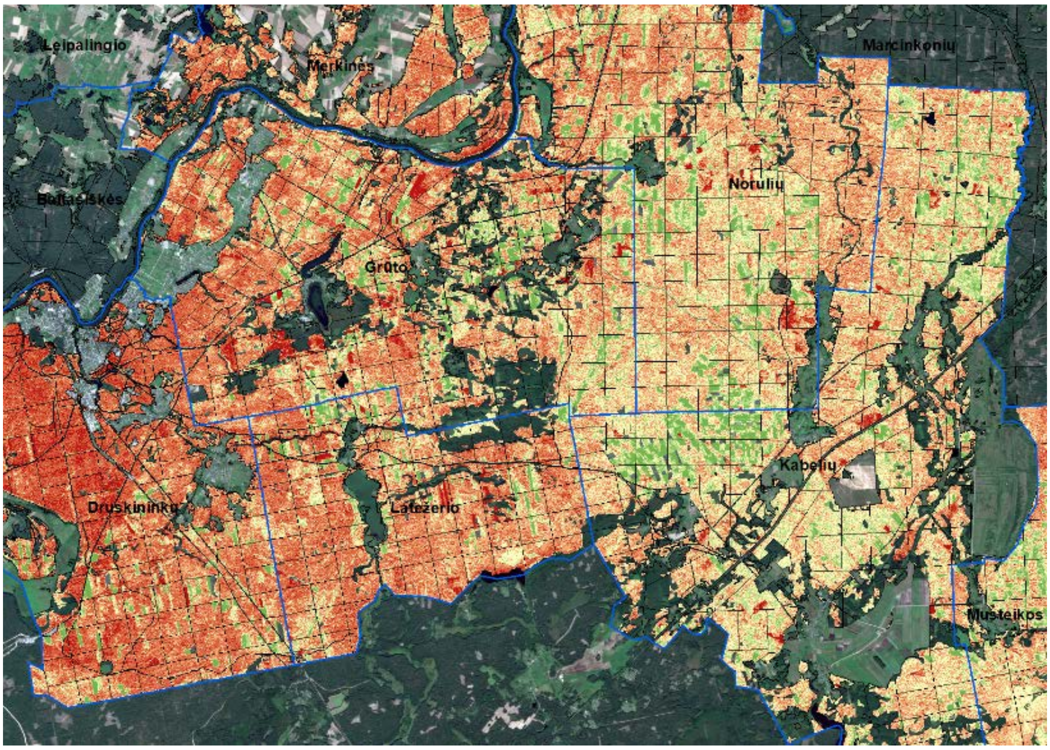



*Figure 26: Spatial distribution of the NDVI in the pine forests of Druskininkai regional unit (South Lithuania) during 2021-2022. Large negative values are observed in the west side of the region (with dark red colours), indicating unhealthy parts of the forest.*

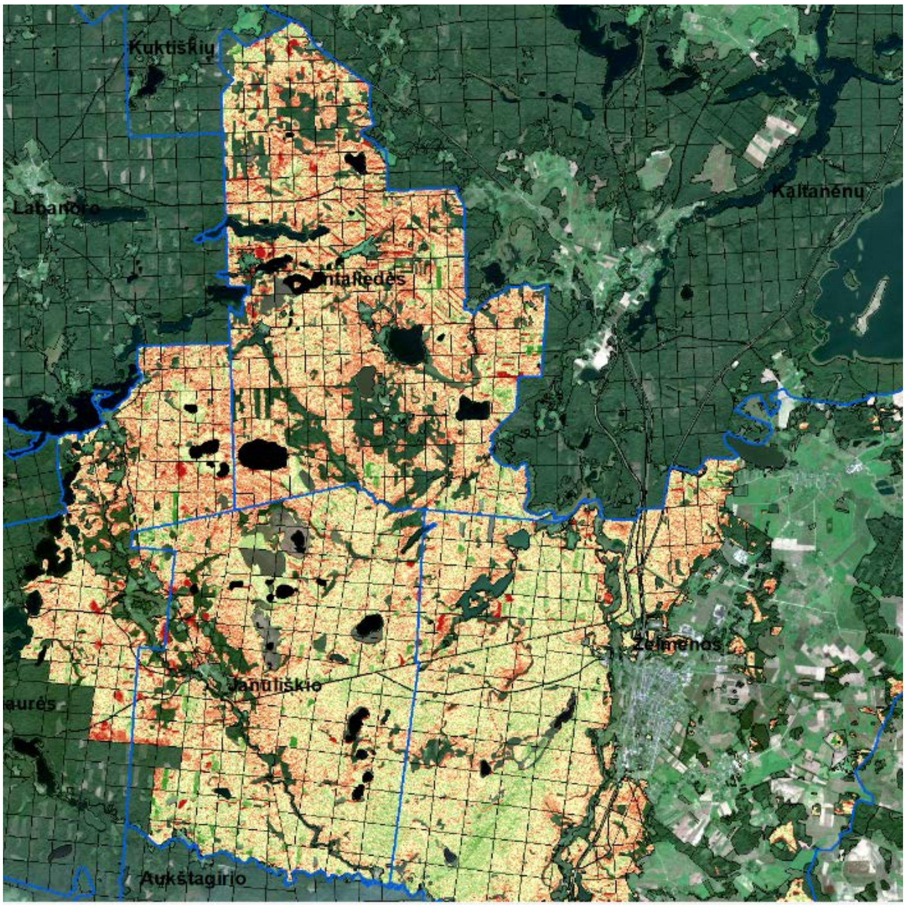



*Figure 27: Spatial distribution of the NDVI in the pine forests of Švenčionėliai regional unit (East Lithuania) during 2021-2022. Large negative values (with dark red colours) are observed in scattered areas, indicating unhealthy parts of the forest.*

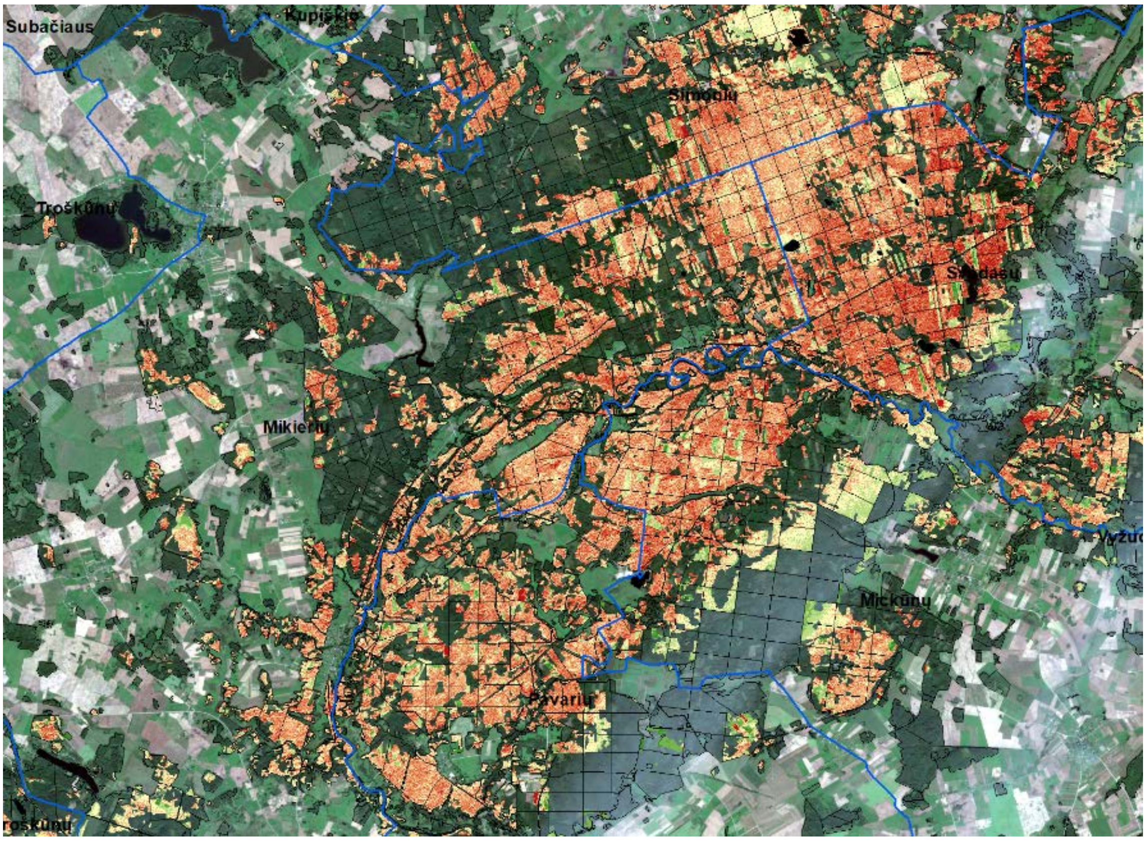



*Figure 28: Spatial distribution of the NDVI in the pine forests of the Anykščiai regional unit (North-East Lithuania) during 2021-2022. Large negative values (with dark red colours) are observed through the entire forest area, indicating the existence of unhealthy trees.*

### c) Local

The comparison of the NDVI values from regional scale satellite (Sentinel-2) images captured in October of 2021 and 2022, revealed that the main focus for forest tree health monitoring should be directed towards the Vaišniūnai forestry area, near Dringis lake (**Figure 29**). Several local blocks were outlined for further investigations and UAV missions (**Figure 30**). The UAV operations were performed during the time period from May (9-10$^{th}$) until the autumn season of 2023. The results of these UAV flights are presented in **Figure 31**. In particular, a categorisation of the tree health status was performed, in an attempt to qualify the forest damage and identify the healthy parts. Additional UAV flights are estimated to be initiated during the summer season of 2024.

The methodology of forest tree health monitoring is based on the combined usage of multispectral satellite imagery (Sentinel-2 MSI) and the UAV system consisting of a multi-rotor drone and a VNIR (Visible and Near-Infrared) hyperspectral camera (**Figure 32**). Forest tree health monitoring consist of several implementation steps:

- The primary assessment of forest tree health from satellite images.
- UAV mission planning and deployment over the satellite-identified unhealthy forest areas.
- Processing of hyperspectral sensing data, acquired from UAV flights.
- Detailed assessment of forest tree health symptoms using hyperspectral imaging data.

A primary inspection of forest tree health was performed using multispectral Sentinel-2 satellite images with a spatial resolution of 10 m. The forest health status was assessed using a time series set of broadband spectral indices, sensitive to different forest health measures that are commonly used in forest health studies. The indices selection was based on the frequency of their usage and their performance in predicting forest health.

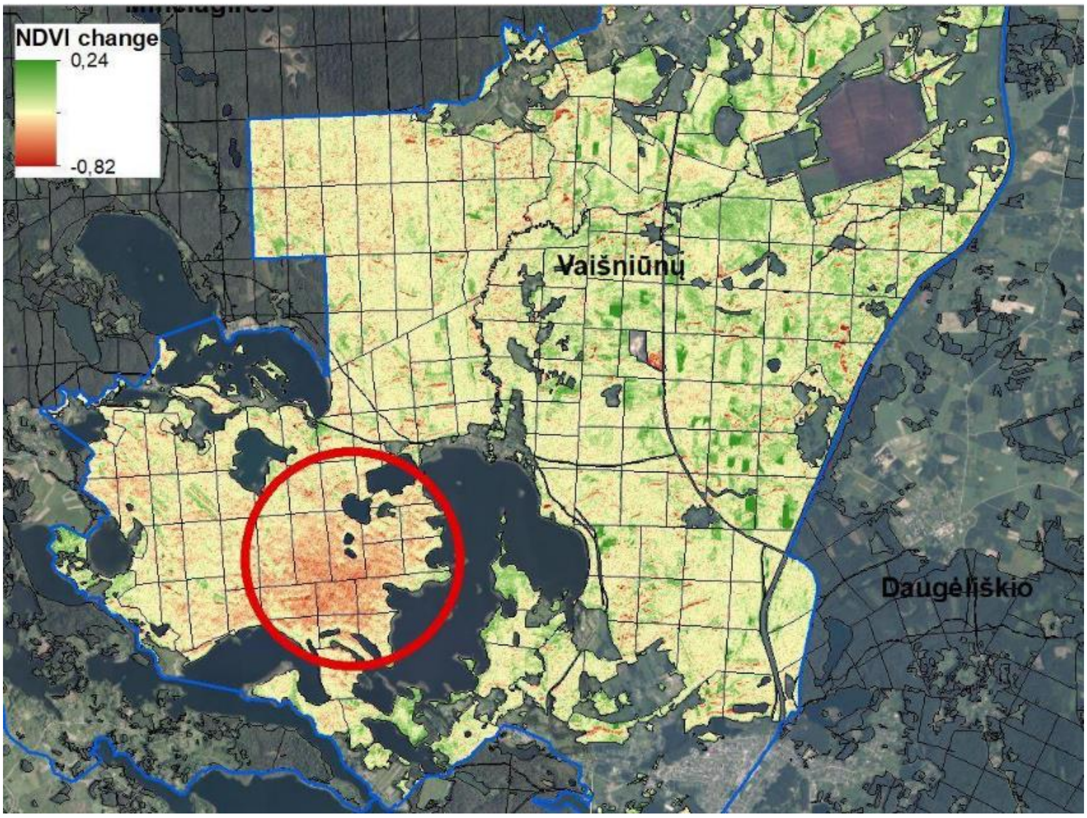



*Figure 29: Identification of local scale forest area (denoted with red circle), that requires further investigations for its health status. The area selection was based on the comparison of satellite (Sentinel-2) images captured in different time periods (during October of 2021 and 2022), whereas is characterised with large negative NVDI values (red colours).*

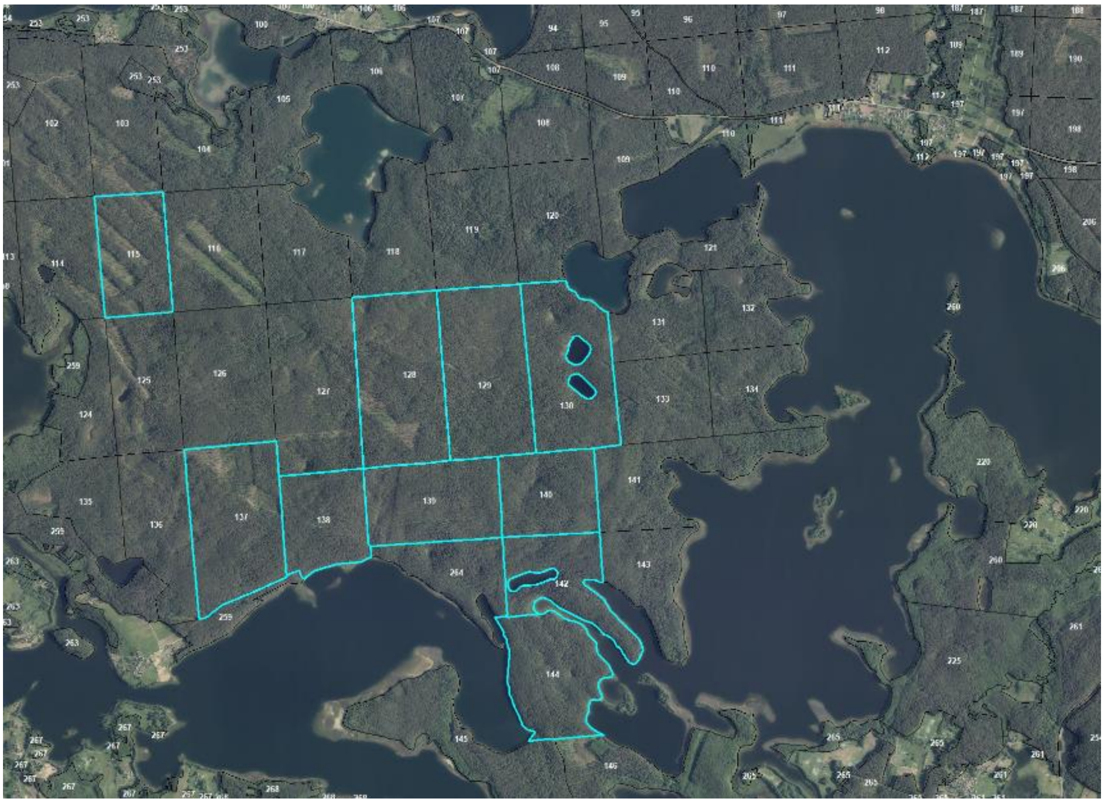


*Figure 30: Outlined blocks in the selected forest area (see Figure 29) for local scale tree health monitoring with the deployment of UAVs.*


*Figure 31: Results of tree health monitoring in the selected forest area (Figure 29). For every block (Figure 30), a qualitative categorisation was performed, indicating sites with maximum (red colour), medium to large (orange colour), minor (yellow colour) tree damage, as well as the healthy tree locations (green colour).*

*Figure 32: The UAV (multi-rotor) used for tree health inspections, mounted with a hyperspectral camera.*

The hyperspectral data was collected over the selected forest areas, allowing the determination of narrowband spectral indices of specific wavelengths that are designed for the precise detection of different vegetation stress factors. Moreover, this procedure provides a higher accuracy on defining the tree health condition than multispectral data. Particularly, the usage of hyperspectral images led to the delineation of the forest's tree crowns. Totally, six (6) groups of narrowband spectral indices were used, providing information about the biochemical, structural and exterior tree health characteristics, such as: 1) leaf/needle pigments, 2) light use efficiency/pigment ratio, 3) water content, 4) chlorophyll content, 5) discoloration, and 6) general vitality. Examples of hyperspectral images for the selected forest area are illustrated in **Figures 33** to **35**.

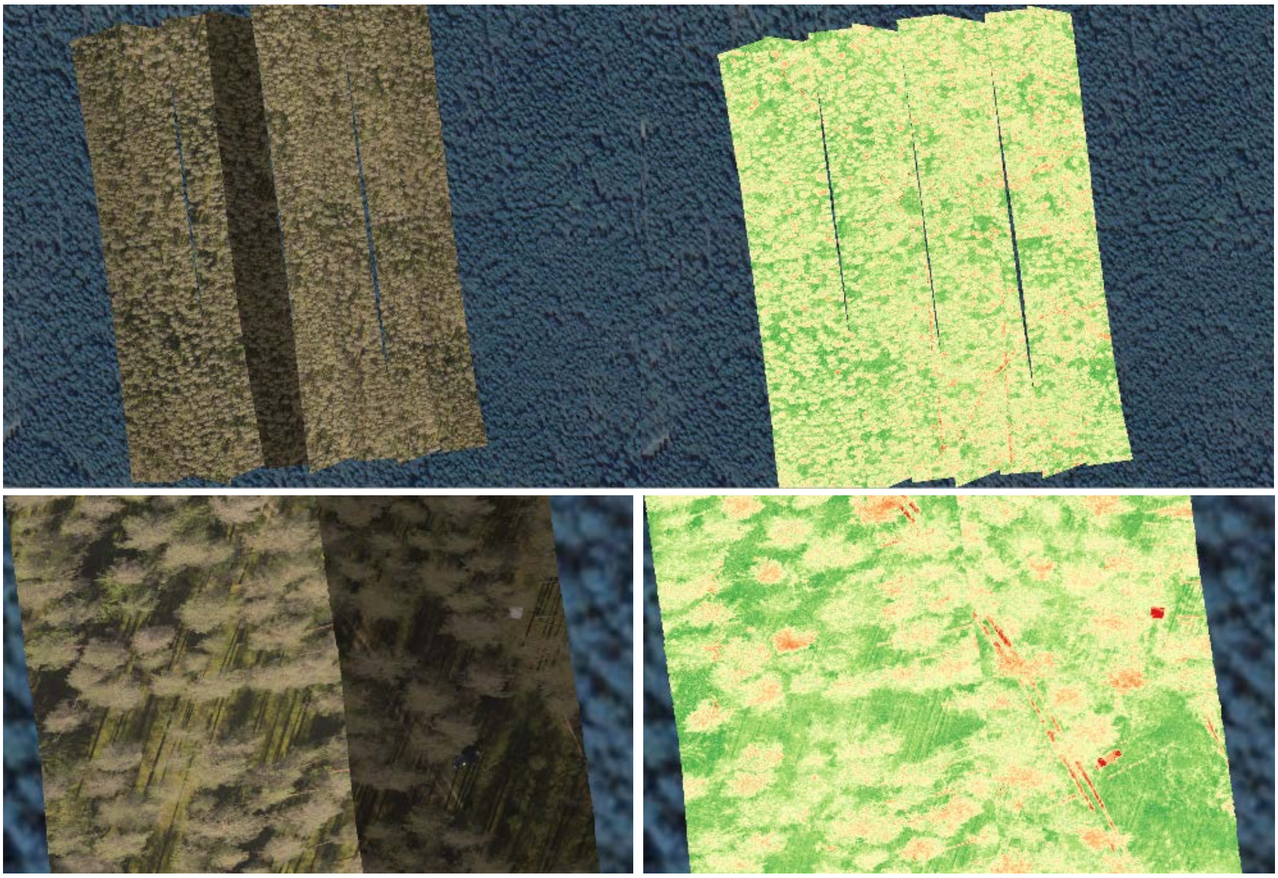


*Figure 33: Example of hyperspectral images retrieved from UAV flights over the selected forest area. Unhealthy trees, affected from pests (common pine sawfly - Diprion pini) are detected (denoted with light orange and red colours).*

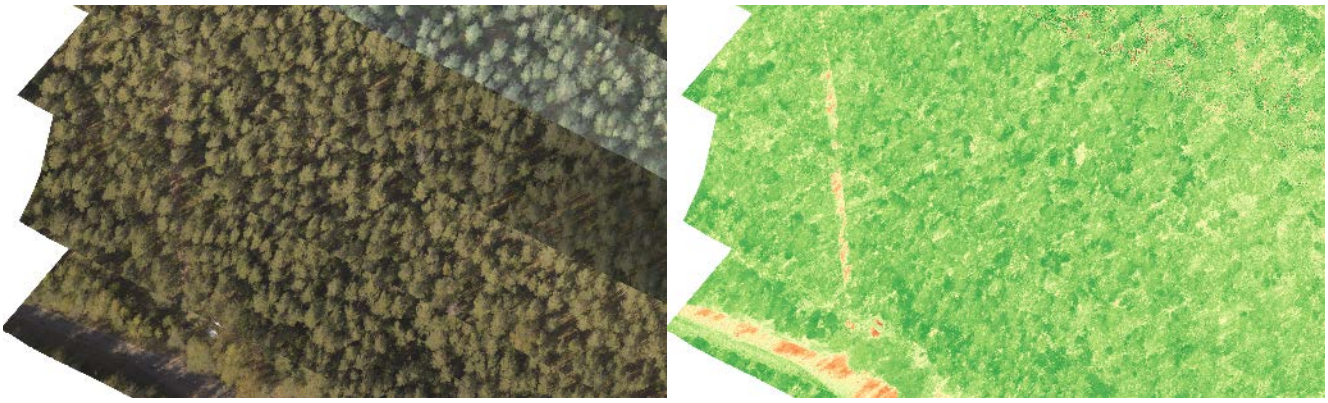


*Figure 34: Example of hyperspectral images retrieved from UAV flights over the selected forest area, indicating the spatial extent of healthy trees (denoted with green colours).*

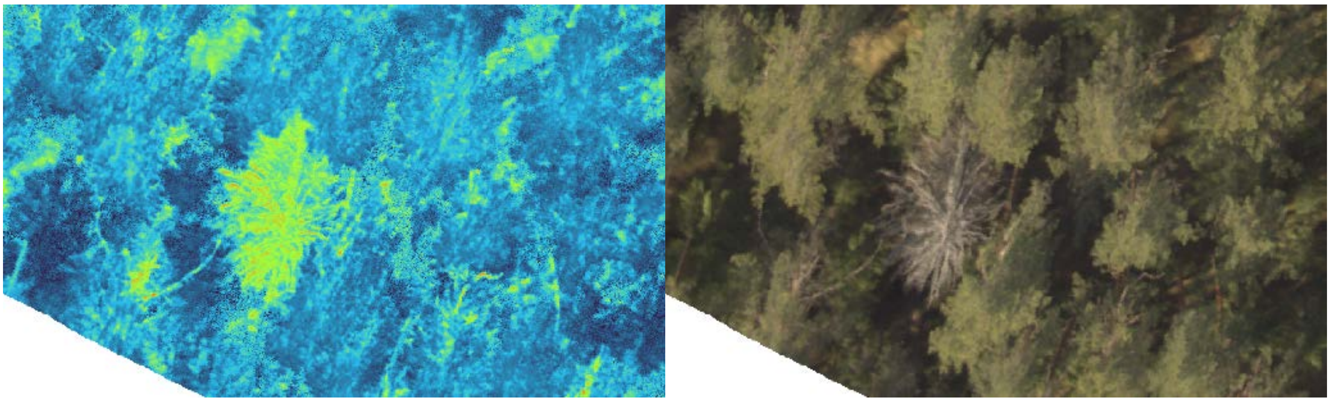


*Figure 35: Example of hyperspectral images retrieved from UAV flights over the selected forest area, indicating the location of healthy (denoted with bluish colours) and unhealthy (dead) trees (denoted with green colours).*

**UC Scenario 2: Wildfire Risk Monitoring**

The data acquisition system for forest fire fuel mapping consisted of a multi-rotor drone (**Figure 32**), a VNIR hyperspectral camera, and a mission planning software for the UAV flights.

The use case scenario 2 was implemented 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.

Whereas, the scheduled tasks involve:

- 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.

An example of an identified fire-prone site within the selected forest area (same as in UC scenario 1) is presented in **Figure 36**.

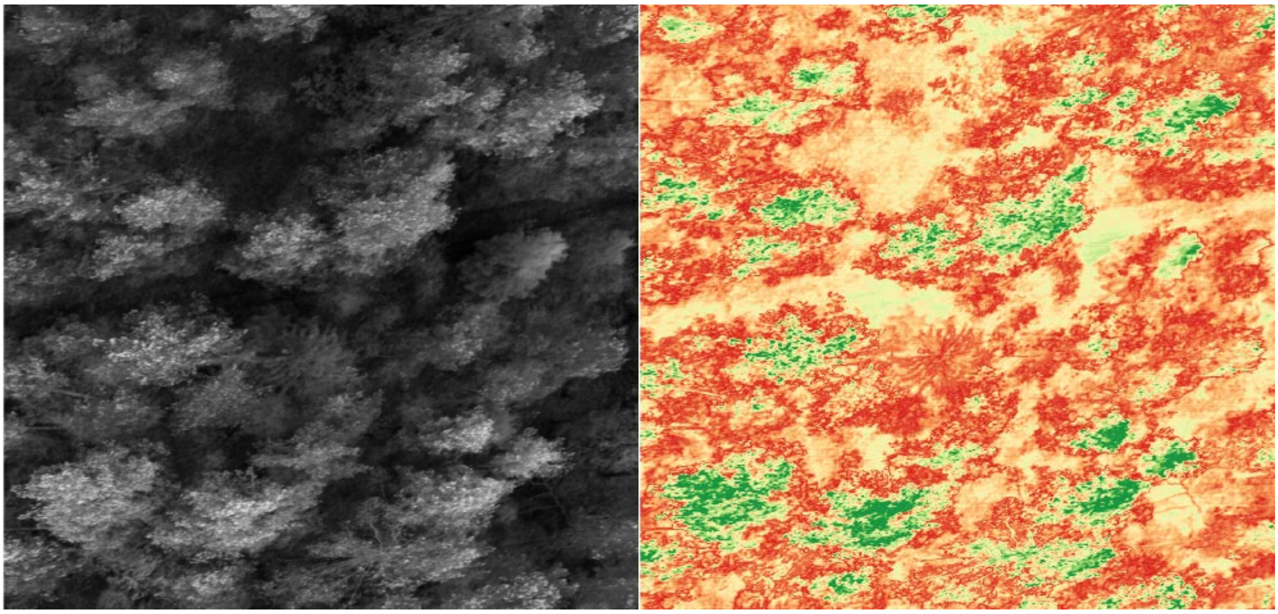


*Figure 36: Example of a hyperspectral image retrieved from UAV flights over the selected forest area. Green spots indicate healthy trees, whereas red spots are dead and dry trees, alerting for high fire risk.*

**UC Scenario 3: Wild Boars Monitoring**

The developed methodology for wild boars monitoring, functioned as an improvement of an existing research prototype model, operating as an African swine fever control system. This system is based on remote aerial techniques and ML algorithms (TRL 5), whereas ART21 was actively involved in the development.

The developed model and algorithms within UC4 of the ICAERUS project, include the following:

- Thermal data preprocessing and GPS data integration into thermal imagery and video data.
- Automatic wild boar detection in thermal images, using an ML model based on YOLOV5 framework.
- Identification of unique wild boars in multiple images and application of counting algorithms (**Figure 37**).

The data acquisition for wild boar monitoring performed with the deployment of the ACE system, which consists of several components for flight operations, such as:

- UAV (fixed-wing).
- Long range infrared thermal imaging cameras.
- Flight planning and execution software.

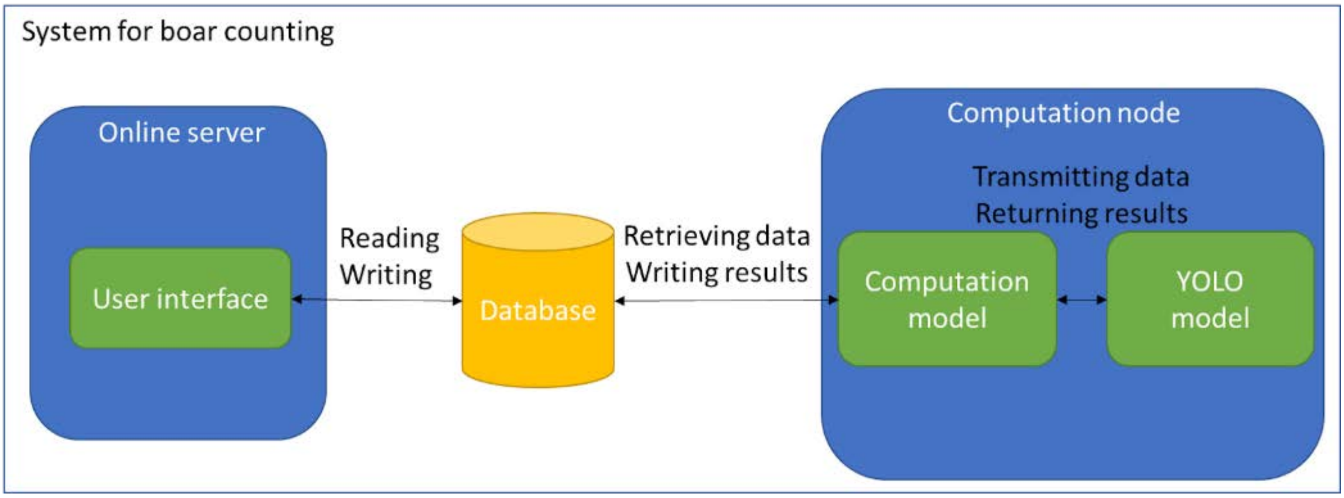



*Figure 37: Workflow of the implemented counting algorithm for wild boar counting.*

Examples of animal identification in hyperspectral images that were captured with UAV flights over the selected forest area are presented in **Figure 38**, while the detection of wild boars is shown in **Figure 39**. The location of the animals is clearly identified and, in some cases, it is possible to distinguish their form, as well as to track their path through the forest.

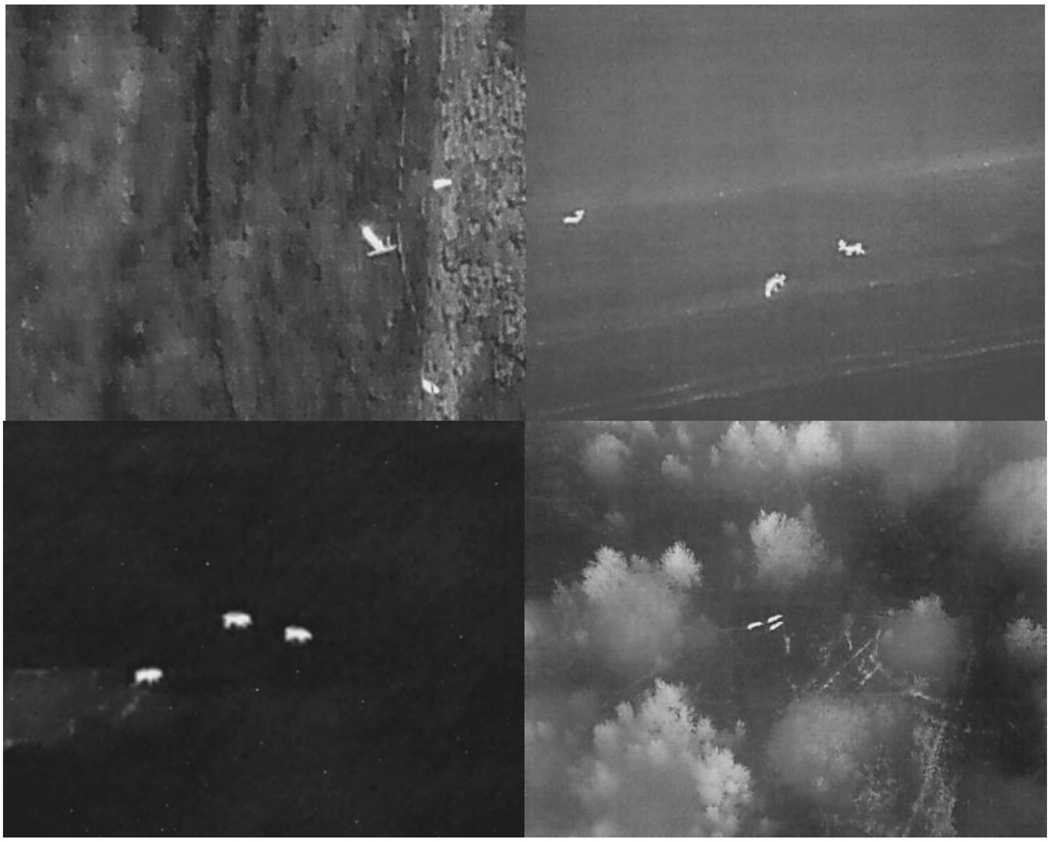


*Figure 38: Example of animal detection from hyperspectral images that were captured during UAV operations. Different types of animals can be distinguished from the images.*

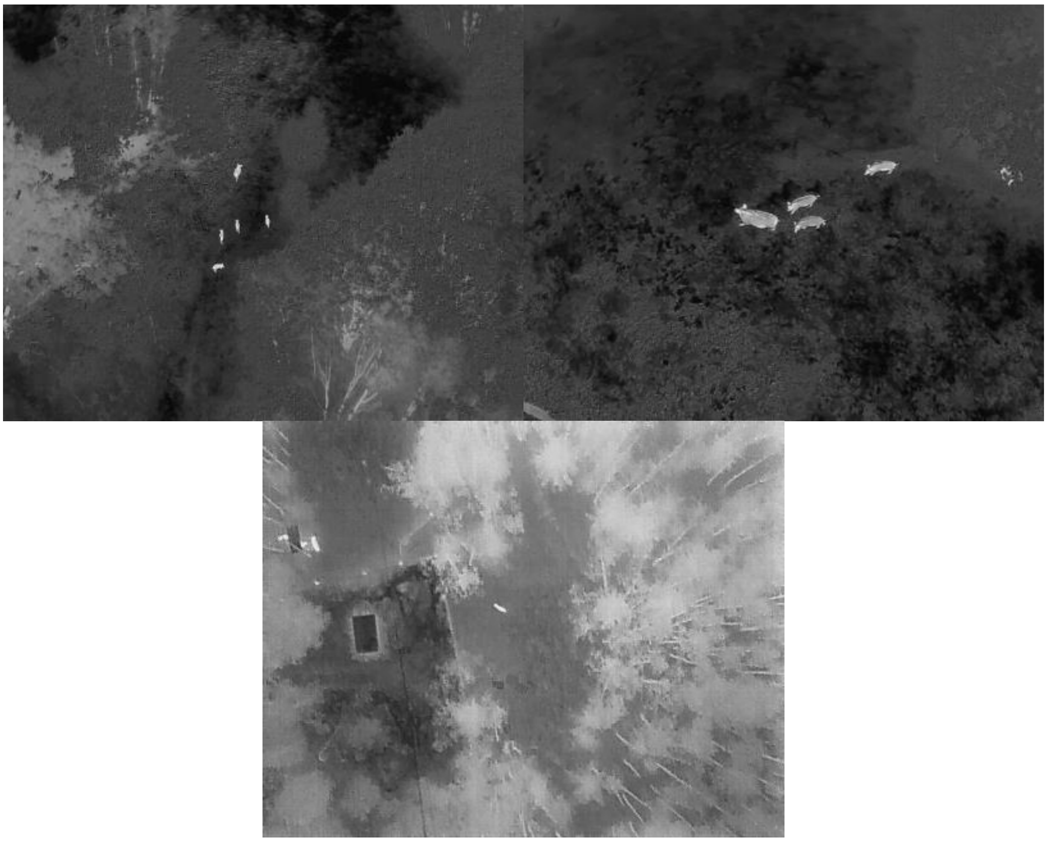


*Figure 39: Examples of wild boar identification from hyperspectral images that were captured during UAV operations. The path tracking of the wild boars through the forest is possible.*

#### 5.2.1.3 Shortcomings/Obstacles

Key shortcomings/obstacles faced during the UC4:

- Several shortcomings and obstacles are related to trials. The car approach to the selected drone launching sites was challenging. In some cases, alternative routes were designed.
- Adverse weather conditions. Alternations of atmospheric phenomena, such as rain, snow, low temperatures, etc.
- Locate the wild boars shelters and habitat places. This task typically requires the cooperation with hunters, or operate inside public wildlife parks.
- Technical issues, such as the manual control of the UAV in challenging environments, the fact that the images' metadata from the thermal cameras does not include geographical coordinates and the requirement of recalibration before each operation. The later technical issues were solved, after a request to the manufacturer.

## 5.3 Deployment and UC Execution Status

### 5.3.1 UC Plan Progress

- The **Start month**, the **duration** and the **total PM:**
  - The trials started on May 2023 and were initiated on a monthly basis for Scenario 1.
  - Scenario 2 - 2023 Summer.
  - Scenario 3 - 2023 Winter - 2024 Spring.
- The **Partners involved** and the **third parties involved** (organisation names):
  - ART21.
  - Agrifood Lithuania DIH.
  - Some trials were initiated in collaboration with Lithuania State Forest services.
- A **short description of the UC's goal:**

  The main goal of the UC4 is to develop and demonstrate multipurpose drone utilisation to monitor forest conditions 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.
- The **progress of activities in detail.**

  The forest tree health monitoring methodology 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 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.

- o Detailed assessment of forest tree health symptoms using hyperspectral imaging data.

The forest fire fuel mapping data acquisition system consists 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:

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

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 machine learning algorithms. Their main characteristics are summarised in the following:

- o Thermal data pre-processing and GPS data integration into thermal imagery and video data.
- o Automatic wild boar detection in thermal images AI models based on deep convolutional networks for object detection in images AI model based on YOLOV5 image detection model framework.
- o Unique wild boar identification in different images and counting algorithms.

### 5.3.2 UC Activities

#### 5.3.2.1 Key Activities

The key activities of UC4 are summarised in **Table 4**.

*Table 4: Key activities of UC4.*

| id | Activity Name/Title | Description/Goal |
|---|---|---|
| | **Forest Tree Health** | |
| 1 | Satellite imagery data collection and preprocessing | Multispectral satellite data from various time periods are collected to create a starting database of the analysed forest areas. The satellite imagery were pre-processed in order to remove unusable image areas (cloudy, obstructed, etc.). |
| | **Activity Progress**<br>The first model (Sentinel 2 Forest health NDVI and Sentinel 2 Tree health classification), algorithm (Sentinel 2 Forest health extended algorithms) and data set (Sentinel 2 Forest health NDVI) were developed. Continue working on models and data sets updates. | |
| 2 | Development of the high-risk forest area identification component | Spectral signature and parameter research are conducted in order to find the optimal set of parameters for high-risk forest area identification. Mathematical algorithms for satellite data analysis were developed (training, |

| | | |
|---|---|---|
| | | testing, validation). |
| | **Activity Progress**<br>In progress. | |
| 3 | In-depth high-risk forest area investigation | The drone flight missions were planned in accordance with the data provided by the satellite imagery analysis. Drone and the hyperspectral analysis hardware were assembled. Hyperspectral data acquisition missions were carried out in the identified high-risk areas. |
| | **Activity Progress**<br>In progress. | |
| 4 | Development of the in-depth high-risk forest area analysis component | Spectral signature and parameter research were conducted and a set of optimal spectral parameters were described. Mathematical algorithms for hyperspectral data analysis were developed (training, testing, validation). |
| | **Activity Progress**<br>In progress. | |
| 5 | Development of the forest health analysis software prototype | The final combined analysis system was described, created and tested. Final optimisation of mathematical analysis algorithms was performed. |
| | **Activity Progress**<br>In progress. | |

| **Wildfire Risk Monitoring** | | |
|---|---|---|
| 1 | Description of the environmental background of the forest under investigation. | The forests were background identified. Regarding the state of the environmental parameter set, the highest wildfire-risk forest and its areas were determined. |
| | **Activity Progress**<br>In progress. | |
| 2 | Development of the potential wildfire risk forest area identification component | Spectral signature and parameter research were conducted in order to find the optimal set of parameters for different forest fire fuel identification. |
| | **Activity Progress**<br>In progress. | |

| | | |
|---|---|---|
| 3 | In-depth high wildfire risk forest area investigation | The drone flight missions were planned in the areas with the highest forest fire risk. The drone and the hyperspectral analysis hardware will be assembled. Hyperspectral data acquisition missions occurred in the identified high wildfire-risk areas. |
| | **Activity Progress**<br>In progress. | |
| 4 | Development of the forest health analysis software prototype | Hyperspectral data analysis was carried out, and results were used to create a detailed map of the forest fire fuels in the scanned forest regions. |
| | **Activity Progress**<br>In progress. | |

| **Wild Boars Monitoring** | | |
|---|---|---|
| 1 | Boars' identification and counting data collection component | • Task formulation (UAV preparation for autonomous flight).<br>• Data acquisition (captures thermal and visible light images). |
| | **Activity Progress**<br>In progress. | |
| 2 | Preparation and processing of boars' identification and counting data component | • Data transfer to the computation system (Transferred data for further processing).<br>• Data formatting (data prepared for analysis). |
| | **Activity Progress**<br>In progress. | |
| 3 | Classification for boars' identification and enumeration data component | • Data analysis module training (boars detection classification and calculation algorithm). |
| | **Activity Progress**<br>In progress. | |
| 4 | Boars' identification and counting data classifier training and verification data sets | • The data processing module (low-quality and high-quality data).<br>• Data refinement module (refined data set for retraining). |
| | **Activity Progress**<br>In progress. | |

#### 5.3.2.2 Key activities’ workflow

The key activities’ workflow of UC4 are illustrated in **Figure 40**.

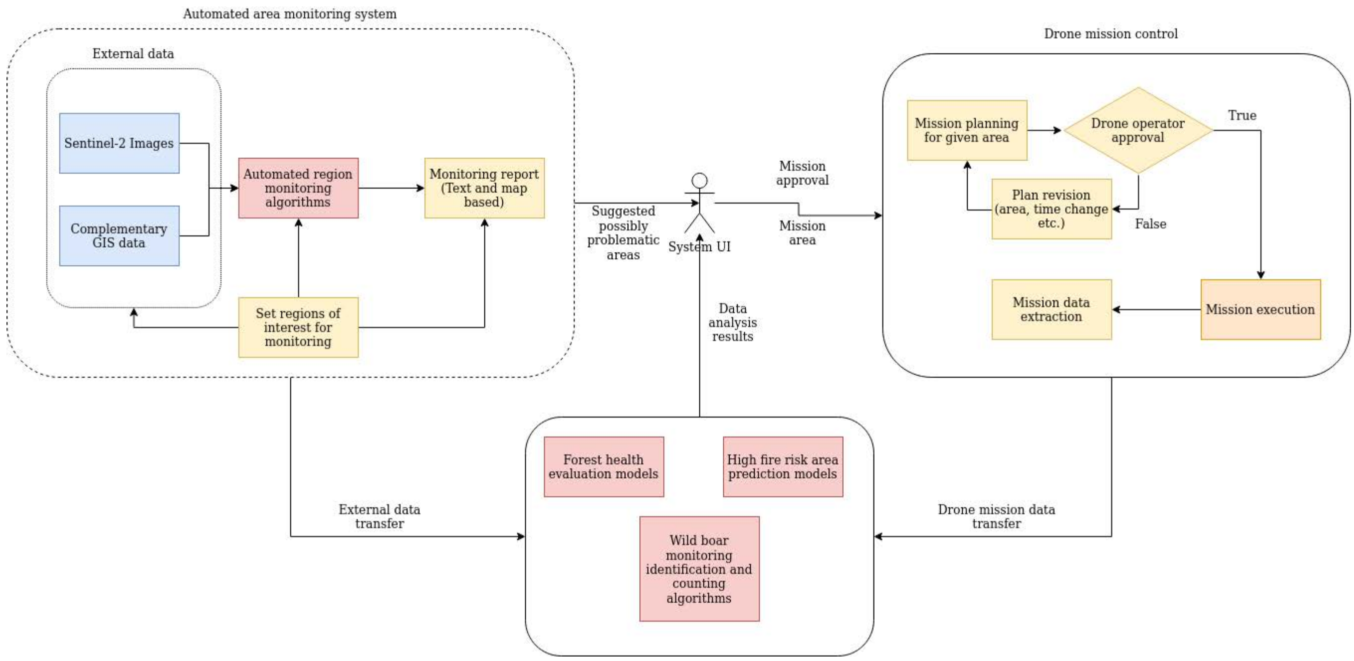



*Figure 40: Key activities’ workflow for UC4 during the reporting period.*

#### 5.3.2.3 Timeline

The timeline of the key activities for UC4 is presented in **Figure 41**.

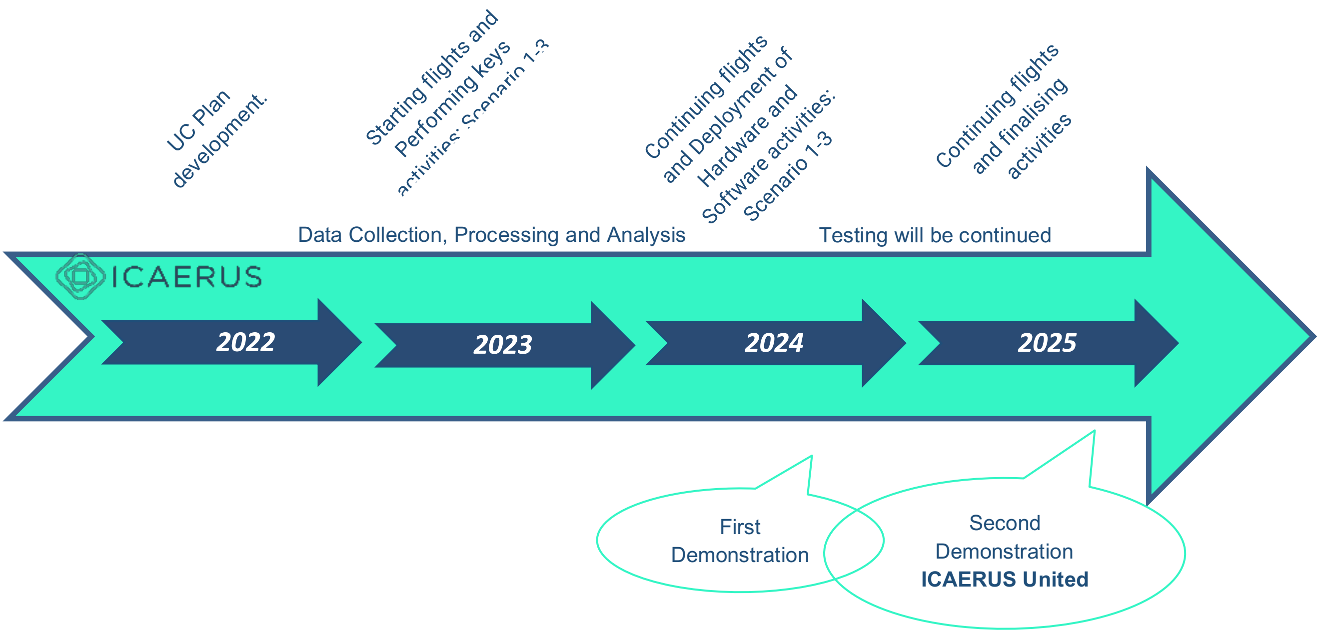



*Figure 41: Timeline of the key activities for UC4.*

### 5.3.3 Deployment Components

#### 5.3.3.1 Site description

***Pilot Area***

During the autumn of 2022, the SFE (State Forest Enterprise) reported that pine trees in the forests of Ignalina district had been damaged. Furthermore, it was announced that pine needles were massively gnawed by the common pine sawfly (Diprion Pini), as well as that an increase in the number of the pine woolly adelgid (Lymantria Monacha) was observed. At the outbreak site of the common pine sawfly, hazardous damage was recorded in Lithuania's' forests by the SFE, covering an area of 1063.60 ha (1192 ha in total, including private forests, according to reports from 2022), in which the larvae consumed 30% to 100% of the needles. For this reason, the Ignalina district (**Figure 23**) was selected for the tree health monitoring within UC4 of the ICAERUS project.

The test sites were selected according to natural fire potentiality classes (**Figure 42**) and locations of forest fires in last few years. Notice (from Figure 23 and Figure 42) that the selected Ignalina district is a high fire risk potential region, hence collected datasets from UC scenario 1 are re-used for UC scenario 2. In **Figure 43**, the broader implementation area for wild board monitoring is presented, together with local scale images.

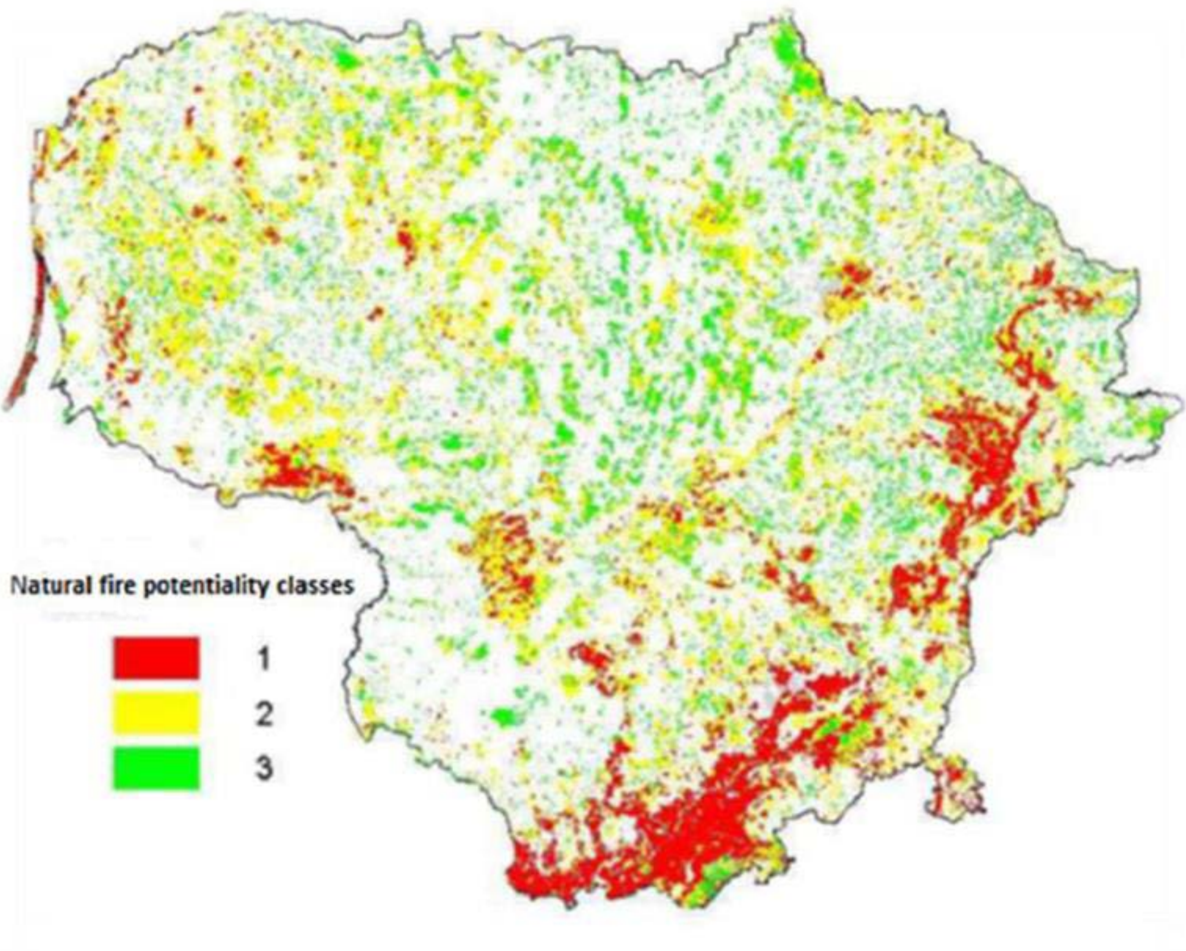



*Figure 42: Map of Lithuania, that presents the regions of natural fire risk potential. The selected test area for UC scenario 1 and 2 is located in a high fire risk site.*

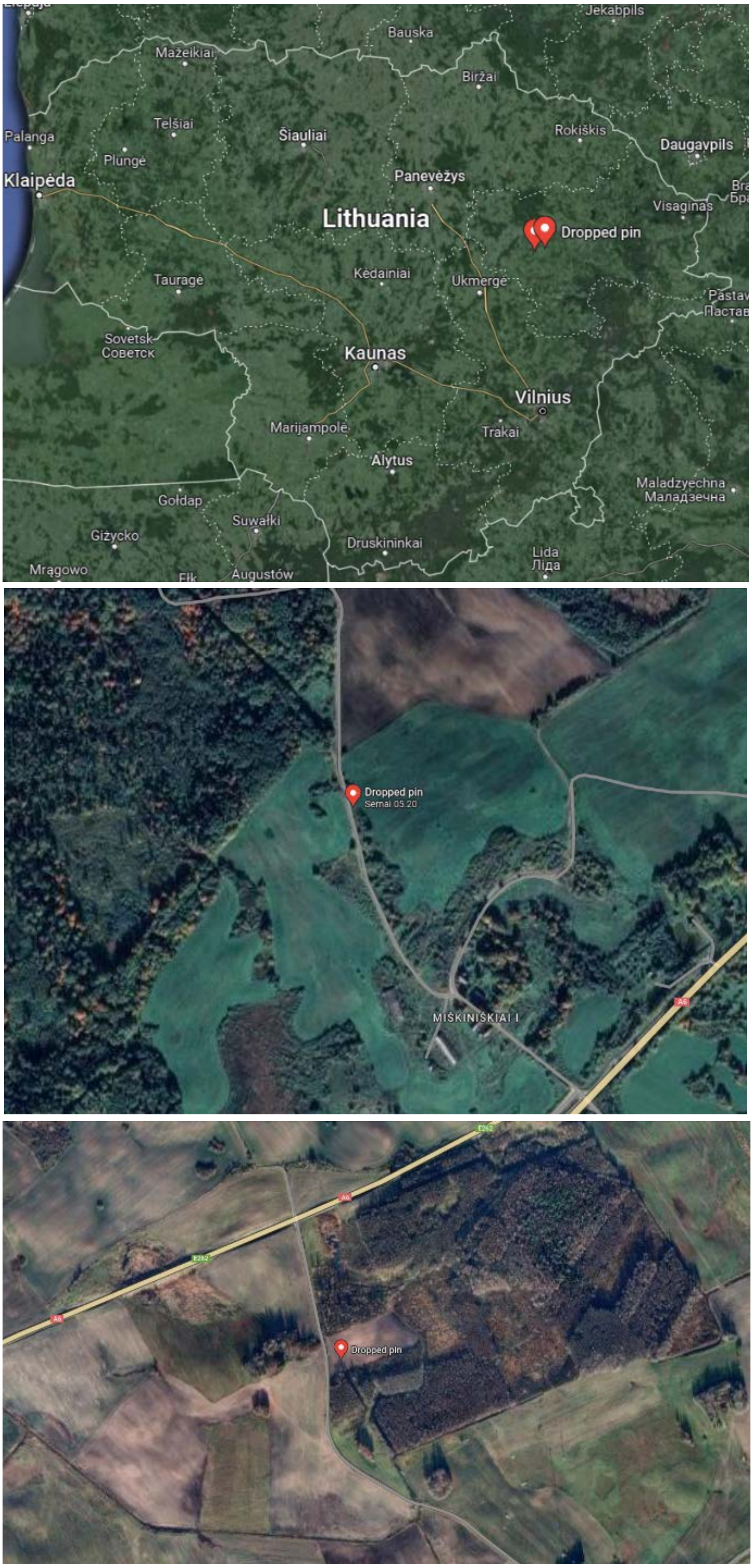



*Figure 43: Pilot area in Lithuania for Scenario 3.*

#### 5.3.3.2 Platforms and mounted technological components

The platforms and mounted technological components that were used within UC4 are listed below:

- Multi-rotor drones.
- Hyperspectral camera (Specim), capable of high spectra and spatial resolution image collection in the wavelength range from 400 nm to 1000 nm.
- Thermal imaging camera with high sensitivity and capability of high-resolution thermal image collection (WIRIS).

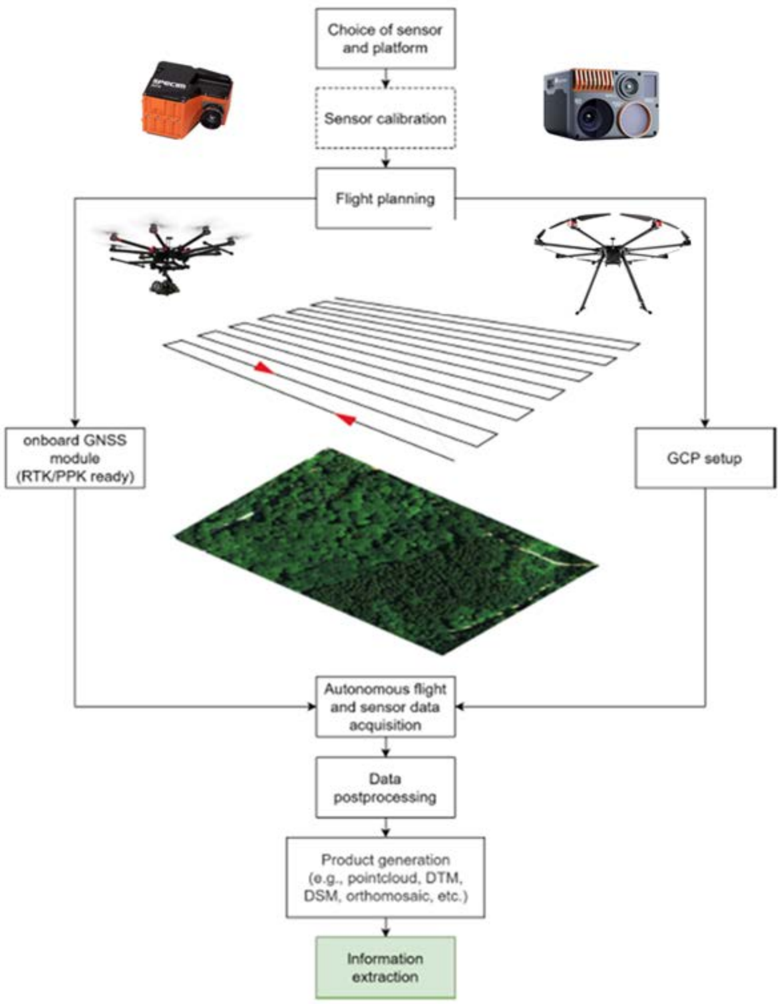



*Figure 44: Platforms and mounted technological components used in UC4.*

### 5.3.4 Gathered Data and Formats

#### 5.3.4.1 Data related queries

**What were you testing for? What was the gathered data for the UC?**

**Use Case 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 for timely detecting and providing high-resolution information about the symptoms of forest tree decline and vitality loss on a tree crown level.

**Use Case Scenario 2 - Wildfire Risk Monitoring**

A combination of hyperspectral drone imaging and image classification algorithms can create high-accuracy and high-resolution forest fire fuel maps that can be used in forest fire risk modelling and risk assessment.

**Use Case Scenario 3 - Wild Boars Monitoring**

A wild boar monitoring (population counting) system that combines drone-assisted thermal imaging and a machine learning algorithm for visual data analysis can be developed to detect and monitor wild boars' behaviour efficiently. 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.

**Gathered data:**

- Sentinel-2 multispectral images.
- UAV-collected hyperspectral images.
- Thermal image datasets were gathered using UAVs.
- Accurate drone GPS data logs.
- Drone flight mission data.

**Were you using existing data? Open/public data?**

- ***Use Case Scenario 1 - Forest Tree Health***

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

- ***Use Case Scenario 2 - Wildfire Risk Monitoring***

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

- ***Use Case Scenario 3 - Wild Boars Monitoring***

  Privately collected data from previous research, testing and piloting.

**How was the data being acquired? When? How many times? What are the environmental conditions?**

The data acquisition started in 2023 spring by analysing the Sttelite date for Scenario 1. The data collection using drones began in May 2023 and continues monthly until 2023 Autum. In the 2023 Winter - 2024 Spring, there were just 2-3 data collection sessions due to bad weather conditions.

**What was the associated data model/format? What was the data size in the reporting period?**

- .raw
- .tiff
- .wseq
- aprox. 1 TB

**How were the collected data and datasets used to operate in favour of the ICARUS project?**

Collected data was used to enhance the AI analysis models by retraining them in order to improve their accuracy and robustness. The data collected in various conditions also improved the applicability of analysis models for use in different scenarios and for error analysis.

#### 5.3.4.2 Data categories

***Use Case 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.

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***Use Case 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.

***3. Use Case Scenario 3 - Wild boars monitoring***

**Input data**

- Thermal image datasets were 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.

#### 5.3.4.3 Drone data analytics models

**Model(s) added:**

- Sentinel 2 Forest health NDVI.
- Sentinel 2 Forest health extended algorithms.
- Sentinel 2 Tree health classification.
- Thermal camera wild boar detection computer vision.
- Thermal camera wild boar automated counting and tracking.
- Hyperspectral forest fuel analysis.
- Automated region of interest monitoring.

**Model(s) updated:**

- Sentinel 2 Tree health classification.
- Thermal camera wild boar detection computer vision.
- Thermal camera wild boar detection.
- Hyperspectral forest fuel analysis.

**Dataset(s) added:**

- Sentinel 2 Forest areas labeled (healthy, affected).
- Wild boars.
- Processed and labeled Hyperspectral data.

**Dataset(s) updated:**

- Sentinel 2 Forest areas labeled (healthy, affected).
- Hyperspectral data.
- Wild boars.

The corresponding link for Zenodo: ***Forestry and Biodiversity monitoring in Lithuania with hyperspectral camera and UAV***

## 5.4 Results and Sustainability Performance

### 5.4.1 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 (in progress).
- Accurate and up-to-date data sets of the forest under investigation. Reports on current and past forest health conditions and future perspectives (in progress).
- Methodology for drone-assisted imaging analysis for forest fire fuel evaluation (in progress).
- Accurate and up-to-date data sets of the fire fuel assessment report on the forest under investigation. Reports on wildfire risk in the forest and future perspectives (in progress).

- Combined with drone-assisted thermal imaging analysis using machine learning algorithms, the system's methodology is employed for wild boar detection and monitoring (in progress).
- Data collection on wild boars' identification and migration (in progress).
- Accurate insights that will contribute to risk assessment procedures (diseases' identification and mapping, fire risk assessment and prevention, etc.) (in progress).

### 5.4.2 Impact

#### 5.4.2.1 Socio-economic

- **Environmental Conservation and Management**
    - Enhanced Monitoring and Data Collection: UAVs provide high-resolution imagery and real-time data, enabling more effective monitoring of forest health and biodiversity. This leads to better forest management practices, which are crucial for long-term environmental sustainability.
    - Cost-Effective: Compared to traditional methods (e.g., satellite imagery or ground surveys), UAVs are more cost-effective and can cover large areas quickly, making frequent monitoring feasible.
- **Economic Benefits**
    - Forest Resource Management: Improved monitoring helps in sustainable management of forest resources. This can increase the longevity and profitability of forest resources.
    - Tourism: Healthy and well-monitored forests attract ecotourism, providing an economic boost to local communities. UAVs can help in creating detailed maps and promotional materials to attract tourists.
- **Social Impact**
    - Community Involvement and Employment: Local communities can be trained to operate UAVs and analyse data, providing employment opportunities and involving them directly in conservation efforts.
    - Education and Awareness: UAVs can be used to create educational content and raise awareness about forest conservation among the general public, fostering a culture of environmental stewardship.

UAVs can save time, manpower, and financial resources for practitioners, public authorities, and researchers.

Economic factors are assessed during LCA and LCC.

#### 5.4.2.2 Environmental

Forest monitoring using UAV and remote sensing data may help ensure quality data and results and save labour's CO2 footprint.

Environmental factors are assessed during LCA and LCC.

## 5.5 UC Modifications and Next Steps

**Please provide any deviations and UC corrective actions or the required plans for improvement.**

A Fixed-wing aircraft is expected to be used when the developed models are demonstrated. Until then, we will use multi-rotor drones for more reliable data collection.

**Next Steps**

- Continue data collection trials for the 2024 period.

- Update datasets, and improve algorithms and models by deepening the R&D focus of use cases.
- Continue with LCA and LCC.
  - First results on the current situation (M30).
- Demo events in 2024 and 2025.

# 6. Use Case 5: Rural Logistics

## 6.1 Introduction

The scope of UC5 (Use Case 5) is to design, develop and deploy an innovative drone-delivery fleet management system that will act as an alternative fast response procedure for the transportation of small parcels of importance (e.g., medical products, documentation, machinery parts, seeds, pesticides, etc.) in European isolated, remote and rural areas.

Thus, UC5 is intended to explore the capability of UAVs (Unmanned Aerial Vehicles) to improve logistics and delivery schemes in rural areas, offering a rapid and efficient transport solution for critical supplies, while highlighting the role of UAVs in enhancing the accessibility to regions where the conventional transportation vehicles fail to operate adequately.

Such drone-delivery systems serve and optimise the citizens' life quality in rural areas, securing the continuation of the supply chain and the provision of merchandise or vital products on time (Scott & Scott 2017, Quintanilla Garcia et al. 2021).

### 6.1.1 Objectives

The main objective of UC5 is to design, develop and deploy an innovative drone-delivery fleet management system for rural logistics. In order to regulate the complex task of drone-delivery, the structure of this system is twofold, consisting of a software-oriented part, as well as of a hardware-oriented part.

For the software-oriented part of the drone-delivery management system, there are several specific objectives related to the main one, which are summarised in the following:

- Automate UAV operations with the integration of state-of-the-art technologies, such as Machine Learning (ML) and Internet of Things (IoT) algorithms.
- Integrate basic principles of the DAAS (Drone As A Service) model.
- Integrate elements from DSS (Decision Support Systems), incorporating a variety of auxiliary features, such as UAV telemetry information (e.g., heading, geographical position, altitude, state-of-health), terrain morphology, weather conditions and air traffic.

Similarly, for the hardware-oriented part of the drone-delivery management system, the specific objectives are focusing on:

- Determine the UAV type for rural logistics, according to the cargo size and weight, as well as the required transportation distance.
- Test flights at selected areas to assess the performance of the UAVs under fundamental external factors that significantly affect their operations (temperature, humidity, atmospheric pressure, wind speed, payloads, etc.).
- Integration of additional safety features on the UAVs, to exploit the available 4G or 5G cellular networks in cases of communication failure with the ground control station.
- Attachment of custom-made cargo boxes to the different UAV types, to fulfil the requirements of transportation.

Both of the abovementioned specific objectives, essentially lead to the final objective of UC5, which is the determination of the functional and non-functional components of the drone-delivery fleet management system. Consequently, the proposed architecture of the system will be optimised according to the users' requirements and the implementation area specifications.

### 6.1.2 Use Case Scenarios

During UC5 the following scenarios will be explored:

A) Use Case Scenario 1: “Connecting” isolated and remote areas with a service center.

B) Use Case Scenario 2: Establish a fast and cost-effective supply chain among a service center and agricultural or rural areas.

Both of these scenarios are aiming to optimise the rural services with the utilisation of UAVs technologies. Particularly, in Use Case Scenario 1 the delivery of small to medium weight cargo (< 3Kg) will be attempted, covering distances ranging from ~20-45Km, with the deployment of multi-rotor UAVs. The selected region for the implementation of Use Case Scenario 1 is located at the edges of Ohrid lake (North Macedonia), where medical supplies and documentation will be delivered from the main service center of the area (Ohrid town) to three (3) different villages (Elshani, Trpejca and Ljubanista, respectively) with varying distances. The common characteristic of these villages is the rural road network connection with Ohrid town, which in some cases could be inaccessible (e.g., during the winter period with snow and ice accumulation across the route).

On the other hand, Use Case Scenario 2 is mainly focused on the transportation of medium to heavy weight cargo (from 3 to 8Kg) at distances from ~15-45Km. For these operations, a VTOL (Vertical Take-Off and Landing), as well as a helicopter UAV will be deployed, which have the capacity to deliver relatively sizeable and heavy packages to large distances. The Use Case Scenario 2 will contribute to the continuity of the supply chain from a service center (Kuklish town, North Macedonia) to nearby agricultural areas (Piperevo, Borievo and Smolari), providing a time and cost-effective solution to stakeholders. For this reason, the cargo delivery of Use Case Scenario 2 corresponds to pesticides and fertilisers, as well as to small mechanical parts for agricultural machinery.

## 6.2 Progress Report

### 6.2.1 Evaluation Summary

#### 6.2.1.1 Specific Objectives

The specific objectives of the UC5 that were served in the reporting period are summarised in the following:

- Integration of DAAS model basic principles into the drone-delivery fleet management system to process users’ requests and enable stakeholders to leverage UAV technology, thus eliminating the complexities and costs associated with ownership and operation.
- Integration of various modules into the developed software system to provide diverse information, such as weather conditions, air traffic density, topography, etc., thereby exploiting the core components of a DSS.
- Selection of three (3) different UAV types (multi-rotors, VTOL and helicopter) to efficiently perform the operations for rural logistics and fulfil the users’ requirements for the cargo size, type and destination.
- Extensive test flights of the UAVs in selected areas, to evaluate their endurance in various scenarios and conditions.
- Integration of additional safety features on the UAVs to prevent devastating consequences in cases of communication loss with the ground control station.
- Manufacture of custom-made cargo boxes, equipped with proper drop-down mechanisms, that are easily attached to the UAVs, allowing the delivery of diverse supplies in rural areas.

#### 6.2.1.2 Achievements/Results

Key achievements/results of the UC5 include:

- Identification of key operational parameters, such as risks (e.g., environmental), barriers (e.g., regulatory frameworks) and payload requirements that significantly affecting UAV missions for rural logistics.
- Development and implementation of a comprehensive core fleet management software, designed to optimise the coordination and operation of the UAV fleet, emphasising to BVLOS (Beyond Visual Line Of Sight) flight conditions.
- Integration of an advanced security feature to the drone-delivery fleet management system, utilising an android smartphone to leverage 4G (or 5G when available) network connectivity, enhancing the reliability of BVLOS flights.
- Assembly and preparation of three (3) distinct UAV models (multi-rotors, VTOL and Helicopter) tailored for varied mission objectives.
- Successful UAV operations, highlighted by the use of a custom-made and designed cargo storage box with an innovative drop-down mechanism for precise delivery.
- Execution of simulations and practical test flights across designated locations in Thessaloniki, Greece, to evaluate the UAV functionalities under real-world conditions.
- Thorough inspection of the proposed demonstration sites in North Macedonia, culminating in securing the necessary permissions from the local aviation authorities for future UAV operations.

#### 6.2.1.3 Shortcomings/Obstacles

Key shortcomings/obstacles faced during the UC5:

The regulatory frameworks typically differ in countries of the EU, whereas in many cases are unclear or deficient. Thus, for the selected sites of demonstrations, permissions from the local aviation authorities were required. This procedure was time-consuming, due to the detailed information needed, the revision of various parameters for the UAV operations, the re-submission of the flight plan, and so on. Consequently, the project timelines and the implementation of the objectives were affected, although with minor deviations from the original UC plan.

## 6.3 Deployment and UC Execution Status

### 6.3.1 UC Plan Progress

- The conducted tasks of the UC in the reported period (described in §1.2.1.1) were a cumulative effort of the involved partners, starting from M6 of the ICAERUS project till the current period – a total of 18 PM.
- AGFT is the UC5 partner that collaborates with GS to optimise rural logistics with the implementation of UAVs. AGFT played a vital role in selecting the demonstration sites in North Macedonia, as well as to guarantee the necessary permissions from the local aviation authorities for the UAV operations.
- The primary goal of UC5 is to promote the implementation of UAVs as a useful and efficient tool for rural logistics and to demonstrate this fact with extensive test flights, as well as with practical application in remote and agricultural areas.
- The progress of activities within UC5 is unfolding as intended, with no deviations according to the initial plan.

### 6.3.2 UC Activities

#### 6.3.2.1 Key Activities

The key activities of UC5 are summarised in **Table 5**.

*Table 5: Key activities of UC5.*

<table>
<tr><th>id</th><th>Activity Name/Title</th><th>Description/Goal</th></tr>
<tr><td rowspan="2">1</td><td>Identification of risks & barriers</td><td>The identification of the risks and barriers is vital for UAV operations and incorporate diverse aspects, such as regulatory compliance, technical reliability, operational challenges, environmental impact and societal acceptance. Thus, the goal of this activity is to detect the main components that significantly affect the UAV missions in an area and adopt several mitigation strategies for each case.</td></tr>
<tr><td colspan="2">Activity Progress<br>A list of several risks and barriers that are commonly emerging during the overwhelming majority of UAV operations was derived, following the identified categories that mainly influence the safe and efficient deployment of UAVs. In particular, the regulatory frameworks for UAV operations typically differ in countries of the EU, requiring permissions from the local aviation authorities and submission of detailed information for the flight plan. For this reason, a communication channel established with the aviation authorities of North Macedonia, providing the necessary data for the deployment of UAVs (UAV types, safety measures, date and time of operations, location of take-off and landing sites, route, etc.), asking for license and for possible issues that might not been foreseen (e.g., restricted or private areas that were not detected in the initial flight plan). Regarding the technical reliability, the priority was concentrated in signal interference, since mechanical failures and software malfunction it is not straightforward to control. Specifically, an advanced security feature was integrated to the software and hardware of the deployed UAVs, incorporating a typical android smartphone and a Raspberry Pi 4 (Single-Board Computer – SBC) that will act as an alternative or back-up communication system in cases of UAV's telemetry is unresponsive. Additionally, this feature offers the possibility of voice interaction with civilians at the take-off or landing points of the UAV, as well as to announce warning messages during their maneuvers. Moreover, an air-traffic module was integrated to the fleet management system, that provides the position of each aircraft in real-time within the area of interest, allowing the prediction and avoidance of possible collisions. This module in combination with the retrieval of the local ground morphology information and the thorough inspection of the demonstration site, ensure the safety of the UAVs operations across the selected trajectories for the implementation of rural logistics.</td></tr>
<tr><td>2</td><td>Identification of requirements</td><td>Investigation and determination of functional and non-functional software and hardware components, as well as payload specifications and cargo demand for deliveries in rural settlements. The goal of this activity is the proper selection of critical parameters for the overall fleet management system, enhancing its</td></tr>
</table>

| | | |
|---|---|---|
| | | feasibility and sustainability for UAV operations. |
| | **Activity Progress**<br>Based on the defined UC5 scenarios (see §1.1.2) and the payload and cargo requirements for the rural logistics implementation, two critical parameters were set, namely the UAV types and the specifications of the custom-made cargo-boxes (material, size, drop-down mechanisms, etc.) for the delivery operations. In particular, two multi-rotor UAVs will be deployed, the first for light-weight (≤ 1.5Kg) cargo delivery to relatively small distances (< 20Km) and the second for medium-weight (≤ 3Kg) cargo for transportation to slightly larger distances (< 30Km). Furthermore, for medium-weight cargo (≤ 3Kg) transportation to large distances (≤ 45Km) a VTOL hybrid UAV system was selected, whereas for heavy-weight cargo deliveries to large distances (≤ 45Km) a helicopter will be exploited. It is worth mentioning that the abovementioned UAV selection derived from a multi-criteria analysis, taking into consideration a variety of factors, as described in Activity 1. For the current payload, cargo and distance requirements, two custom-made cargo-boxes were developed. The first one was specifically designed for the multi-rotor UAVs to facilitate its easy and quick attachment and detachment on the aircraft belly, while maintaining light-weight characteristics (~500gr) and small dimensions (20cm x 11.5cm x 7cm, for the length, width and height, respectively). This cargo-box will be utilised for light to medium-weight deliveries to rural areas, emphasising to agricultural supplies, such as seeds. In addition, an appropriate mechanism will allow the drop of the box from a few meters above the ground, obviating the necessity of UAV landing. The second custom-made cargo-box was configured to fit on the VTOL and helicopter UAVs, whereas its architecture was tailored to support medium to heavy-weight transportations at large distances. In detail, the box's shape is cylindrical with 65cm height and 33cm diameter, including suitable hatches for storing single or multiple supplies. The shape of this cargo-box is not disturbing the aerodynamics of the UAV, optimising the stability and the overall performance during the flight. | |
| 3 | Research of sourcing | Defining the available vendors for purchasing the requested equipment of the UAVs hardware, as well as the software components that will be utilised by the developed drone-delivery fleet management system. The goal of this activity is to properly schedule the assembly of the UAVs depending on the lead time of the necessary parts and to efficiently adjust the UC plan in cases of discontinuous or unavailable products. |
| | **Activity Progress**<br>The hardware components for the UAVs and cargo boxes have been purchased after a thorough market analysis to evaluate the optimal trade-off between price and lead time. Particularly, for the custom-made multi-rotor UAVs the main hardware parts included: a) Body frame (arms and landing gears from carbon fibre material, electric motors, propellers), b) Flight controller unit (Pixhawk PX4), c) ESC (Electronic Speed Controller) unit, d) Sensors (IMU – Inertial Measurement Unit and GNSS – Global Navigation Satellite System), e) Payloads (gimbal, RGB camera), f) Radio transmitter & receiver unit (antennas, remote controller), and, g) Power supply unit (Lithium Polymer type batteries). For the necessary software components of the flight controller and the ground control station, two open-source programs were installed and configured (Mission Planner and QGroundControl), providing fully customisable options and allowing the modification of the source code to the UC5 specific requirements. Additionally, | |

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| 4 | an integrated VTOL and a helicopter UAV were purchased, offering a complete hardware and software solution with minimal user intervention. | |
| | Hardware Assembly | Assembly of the multi-rotor UAVs' parts and programming of the flight controllers to manufacture mission-ready aircrafts for rural logistics. The goal of this activity is to extensively test the functionalities and capabilities of the selected UAV types (custom-made multi-rotors, VTOL and helicopter) for deliveries in rural areas, loaded with the associated cargo containers. |
| | **Activity Progress**<br>Several test flights of the UAVs were performed at selected sites, close to Thessaloniki city (Northern Greece). In particular, the site selection followed various criteria, aiming to approach the environmental conditions of rural areas (e.g., open space, vegetation, sparsely populated, etc.). For this reason, the multi-rotor UAVs performance was tested within a football field in Nea Mesimvria village (approximately 20Km North-West of Thessaloniki's city center), in order to evaluate the efficiency of the delivery process inside a secure and tightly supervised setting. A variety of scenarios were implemented, involving the transportation of seeds through routes with different trajectories and orientation, as well as with intermediate landings for cargo reloading. In addition, the applicability of the drop-down mechanism was successfully tested, providing the ability to deliver supplies without the necessity of the UAV landing. The flights of the VTOL and helicopter UAVs were performed in a rural environment at the fringes of Anatoliko village (approximately 20Km West of Thessaloniki's city center), allowing the testing of delivery operations at larger distances. Furthermore, the selected site offered the opportunity to safely deploy the UAVs for BVLOS (or near BVLOS) flights due to the excellent visibility in the area and the absence of obstacles. | |
| 5 | Simulations | Implementation of simulation tools to account for adverse environmental conditions (e.g., shear winds, low/high temperatures, etc.) during the flights of the UAVs. The goal of this activity is to assess the endurance of the aircrafts in such situations and to obtain information about the basic metrics (thrust of the propulsion system, flight time, battery life, payload capacity, stability and wind resistance, GPS accuracy, RTH (Return To Home) function, etc.). |
| | **Activity Progress**<br>Simulations performed for all the available UAV types (custom-made multi-rotors, VTOL and helicopter) assuming attached cargo boxes, testing the response and endurance of the aircrafts from normal to extreme environmental conditions. The simulations act as complementary information to the actual test flights of the UAVs (Activity 4), allowing to thoroughly inspect the performance of the overall systems. | |
| 6 | Drone-delivery fleet management system | Design of the core software algorithm, as well as of the auxiliary modules. |

| | | |
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| | **Activity Progress**<br>The basic architecture of the drone-delivery fleet management system consists of seven (7) main parts, whereas several software modules are utilised in each part. In detail, the main parts of the developed system are: a) User login and authentication, b) User request for UAV delivery (e.g., cargo weight, size and type, destination, date and time, etc.), c) Evaluation of the user's request (if the request is not feasible, the system redirects to part b), d) Evaluation of the mission feasibility, with the acquisition of weather information, air traffic condition, etc. (if the mission is not feasible, the system reports back to the user), e) Start of mission (initiate mission planning, optimal route calculation, UAV type, etc.), f) Real-time tracking of the UAV flight path, and, g) Stop of mission (completion of the delivery with notification to the user). It is worth mentioning that although the drone-delivery fleet management system is functional during the reporting period, several improvements, additions or modifications are expected to be performed to the later stages of the project, gathering feedback from the flight tests, recommendations from users, and the demonstration events. | |
| 7 | Integration of the system to the UAVs | Install a stable version of the drove-delivery fleet management system and establish reliable communication channels for data exchange from the ground control station to the UAV and vice versa. The goal of this activity is to ensure that the queries of the system is properly send to the UAVs, whereas the system is capable to receive responses and telemetry data from the flight controllers of the UAVs. |
| | **Activity Progress**<br>Extensive tests were performed to check the efficient integration of the developed software to the available hardware components. A stable and seamless communication was observed between the flight controller of the UAV and the ground control station, providing the required information and saving them in a standard format log file for easy sharing and compatibility. Conversely, the queries of the drone-delivery fleet management system were successfully transferred to the UAV, which was responding instantly to the commands, updating its status with no delays. | |
| 8 | In-situ investigation of the demonstration site (North Macedonia) | Inspection of the selected demonstration sites, as defined in the Use Case Scenarios (§1.1.2). The goal of this activity is to fix the UAV service points (take-off and landing spots), identify adjacent locations to serve as a contingency plan, communicate with the local aviation authorities to determine the no-fly zones and designate avoidance areas, meticulously design the UAV trajectories and retrieve the available terrain information (morphology, obstacles, etc.), especially for the service points. |
| | **Activity Progress**<br>The service points in the demonstration sites (North Macedonia) were fixed and alternative landing spots were defined. In addition, the necessary permissions from the local aviation | |

authorities were granted, with the submission of detailed information about the operations of the UAVs. Moreover, the restricted flight areas were set and the trajectories of the UAVs were adjusted accordingly. Finally, updated basemaps were produced for the take-off and landing sites, including DEMs (Digital Elevation Models), high resolution orthomosaic maps from the application of photogrammetry method, and point cloud images with LiDAR (Light Detection and Ranging) implementation. These surveys provided a detailed digital reconstruction around the areas of interest, allowing the identification of possible risks and obstacles that will potentially affect the UAV operations.

#### 6.3.2.2 Key activities' workflow

The key activities' workflow of UC5 are illustrated in **Figure 45**.


*Figure 45: Key activities' workflow for UC5 during the reporting period.*

#### 6.3.2.3 Timeline

The timeline of the key activities for UC5 is presented in **Figure 46**.

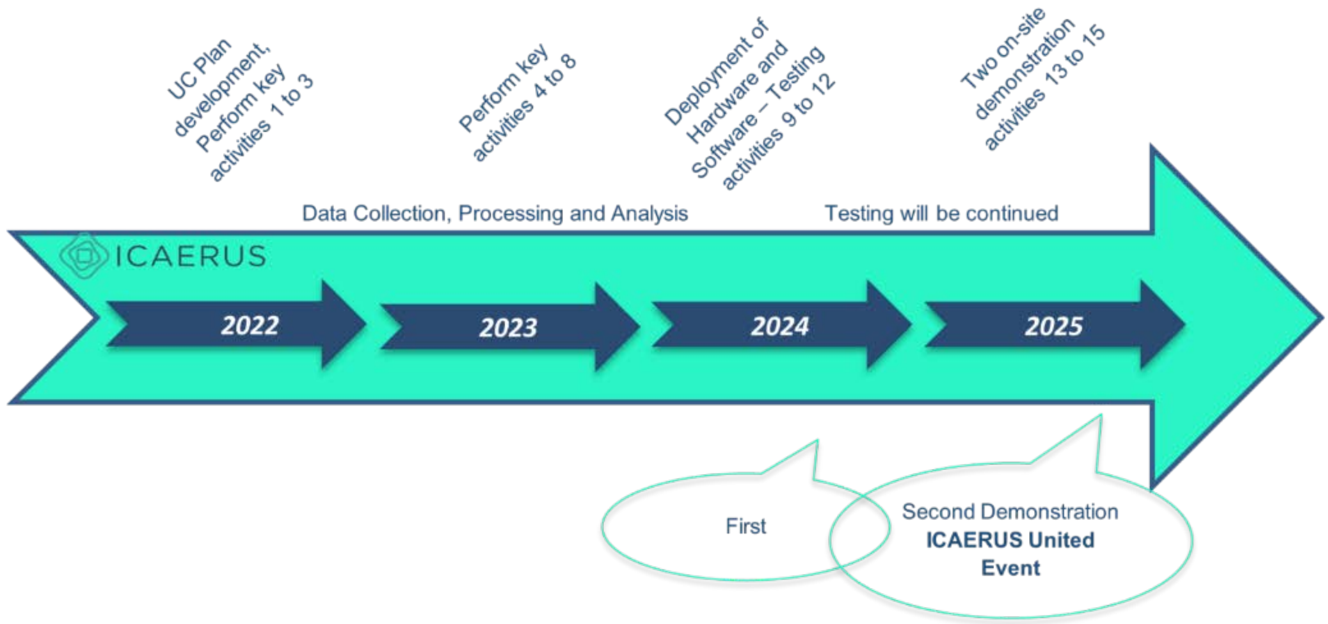


*Figure 46: Timeline of the key activities for UC5.*

### 6.3.3 Deployment Components

#### 6.3.3.1 Site description

The two (2) selected sites for the demonstration of the rural logistics scenarios are located in the W-SW and the E-SW part of North Macedonia, respectively (for more detail see §6.1.2). However, several test flights of the UAVs performed prior the demonstration, at pilot areas close to Thessaloniki city (Northern Greece). These pilot areas are settled NW-W from Thessaloniki's city center, at an approximate distance of 20Km (**Figure 47**). The environment of the pilot areas approaches the rural conditions, offering the possibility to perform test flights similar with the planned demonstrations, while simultaneously evaluate the UAVs' endurance and efficiency for cargo transportation (see also Activity 4 of §6.3.2.1).

#### 6.3.3.2 Platforms and mounted technological components

The UAV platforms and the technological components used for the implementation of UC5 are summarised in the following:

- Custom-made multi-rotor UAVs (**Figure 48**) for light to medium weight cargo (≤ 3Kg) deliveries at relatively small distances (< 30Km).
- A VTOL UAV (**Figure 48**) for medium weight cargo (≤ 3Kg) deliveries at large distances (≤ 45Km).
- A helicopter UAV (**Figure 48**) for medium to heavy weight cargo (≤ 8Kg) deliveries at large distances (≤ 45Km).
- Two custom-made cargo-boxes, designed to be easily attached and detached on the UAVs and equipped with an appropriate drop-down mechanism.
- A Pixhawk PX4 autopilot unit for the custom-made multi-rotor UAVs.
- RGB cameras.
- An android smartphone coupled with a Raspberry Pi 4, acting as an alternative security feature in cases of communication loss between the UAV and the ground control station with the exploitation of the available 4G networks.


*Figure 47: Pilot areas for test operations of the UAVs, close to Thessaloniki city (Northern Greece). The red circles denote the broader regions of the UAVs deployment, whereas the corresponding red rectangles illustrate a more localised view of the actual test sites (red polygons).*


*Figure 48: Three different UAV types for the implementation of rural logistics, depending on the type and size of the cargo, as well as to the distance of the delivery point.*

### 6.3.4 Gathered Data and Formats

#### 6.3.4.1 Data related queries

**What were you testing for? What was the gathered data for the UC?**

In UC5 of the ICAERUS project, the applicability of UAV-based delivery systems is tested, within the challenging and demanding environments of remote, isolated and rural areas. Moreover, the potential for multiple transportations of relatively small packages within the same area is explored, utilising both an advanced fleet management system and different types of UAVs. Thus, an alternative approach for delivering supplies in rural areas is proposed, offering a variety of benefits to the stakeholders in comparison with conventional transportation practices.

The gathered data for the UC5 mainly concern information about the required supplies (e.g., cargo type and size, date and time of delivery), the destination site (e.g., location, topography, construction density, distance from the service point), the weather conditions, the air traffic and restricted areas in the broader area of UAV operations.

**Were you using existing data? Open/public data?**

Several open-source data were utilised by the developed drone-delivery fleet management system to optimise the UAV operations for rural logistics. In particular, the mission planning and the navigation of the UAVs within the area of interest was based to existing basemaps (e.g., OpenStreetMap), whereas the digital elevation models of the broader flight region retrieved from the available SRTM (Shuttle Radar Topography Mission) data (resolution of 30m). Additionally, open-source repositories were used for the weather forecast and current condition, as well as for the air traffic information in real-time. However, in cases of inadequate or low-resolution data availability (for instance, at the take-off and landing points of the UAVs), complementary surveys were conducted, incorporating photogrammetry methods and LiDAR technology.

**How was the data being acquired? When? How many times? What are the environmental conditions?**

The necessary data for the implementation of rural logistics was acquired with several in-situ investigations to the selected take-off and landing points of the UAVs within the demonstration sites (North Macedonia). Furthermore, UAV operations performed at the same points, in order to increase the resolution of the terrain elevation model and to accurately detect possible obstacles, enhancing the security of the flights. These operations required frequent visits to the areas of interest, spanning from the winter of 2023 to the summer of 2024, approximately. Since the environmental, and especially the weather conditions, have a vital role to the efficient deployment of the UAVs, the data acquisition performed during windless and dry periods of the day.

**What was the associated data model/format? What was the data size in the reporting period?**

The collected data from the UAV operations in UC5, included high resolution images of the ground and detailed 3D point cloud reconstruction of the surface topography. The first dataset was processed with photogrammetry methods to produce a high quality orthomosaic of the investigated areas, allowing the accurate detection of various objects on the ground. The associated format of the collected images and of the corresponding orthomosaic maps was georeferenced TIFF (Tag Image File Format). The second dataset was acquired with the implementation of LiDAR technology and saved as LAS (LiDAR Aerial Survey) format, which is typically used for exporting such types of data and for maintaining the complexity and computational time at reasonable levels. Since the data from both surveys contained high resolution information, the size of the exported files was accordingly large, totally exceeding 60Gb during the reporting period.

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

The collected data and datasets of the UC5 will be used to optimise the implementation of UAVs in rural logistics at remote, isolated and inaccessible areas, introducing an innovative, alternative and convenient method for critical supplies delivery.

#### 6.3.4.2 Data categories

***Input data***

- UAV telemetry (heading, geographical position, altitude, state-of-health) via the MAVLink (Micro Air Vehicle Link) protocol.
- Mission planning for the flight paths of the UAVs, using open-source software (e.g., Mission Planner, QGroundControl).
- Basemaps, including basic geographical information, such as road networks, rivers, urban areas, rural environments, etc. from open-data resources (e.g., OpenStreetMap).
- DEMs for the broader area of UAV operations, retrieved from SRTM.
- Weather forecast (temperature, humidity, wind speed, wind gusts, etc.) from open-source repositories (e.g., OpenWeatherMap), as well as from available ground weather stations in the investigated area.
- Real-time air traffic conditions from open-source networks (e.g., OpenSky).
- Feedback from the End-users of the developed drone-delivery fleet management system.

***Output Data***

- Reports from the fleet management system.
- Log files containing the UAV performance during the delivery operation (Mission flow).
- Orthomosaic maps, obtained from the processing of high-resolution georeferenced ground images with photogrammetry methods.
- Updated and localised DEMs at selected sites with the implementation of LiDAR technology.

#### 6.3.4.3 Drone data analytics models

A variety of 3rd party software (both commercial and open-source) were used in UC5, namely:

- Mission Planner
- PIX4D Mapper
- ZWCAD
- OpenStreetMap APIs
- OpenWeatherMap APIs
- OpenSky APIs

Moreover, several algorithms (or models) were utilised to optimise the developed drone-delivery fleet management system, such as:

- The TSP (Travelling Salesman Problem) algorithm (Sorbelli et al. 2020, Tong et al. 2022) and its generalised version of VRP (Vehicle Routing Problem) procedure (Kiitjacharoenchai & Lee 2019, Jianxun et al. 2022) to determine the most efficient routes of the UAV fleet for cargo delivery to a set of different destinations.
- The Dijkstra's algorithm (Deaconu et al. 2021) to calculate the shortest path between two service points.

## 6.4 Results and Sustainability Performance

### 6.4.1 Outcomes

The main outcomes of the UC5 during the reporting period, are summarised in the following:

- Development of the main software core and modules for the drone-delivery fleet management system in rural areas.
- Introduction of an additional advanced security feature to UAV operations, incorporating the utilisation of an android smartphone to act as an alternative telemetry system in cases of communication loss with the ground control station.
- Development of a custom-made cargo box that increases the safety and efficiency of deliveries in rural areas.
- Extensive test flights with the UAVs in selected areas and determination of the functional and non-functional features for both software and hardware components.
- Automation of basic operations, such as the design of the UAVs trajectories and their flight paths for delivery missions.

### 6.4.2 Impact

#### 6.4.2.1 Socio-economic

- Provision of humanitarian aid in rural areas affected by natural disasters, significantly faster than conventional transportation methods.
- Improvement of the health services access, especially from remote or isolated areas.
- Contribution to the decrease of population migration from rural to urban areas and improving life standards of rural communities.
- Reduction of work fatigue in agricultural areas.

#### 6.4.2.2 Environmental

- Zero greenhouse gas emissions, in contrast with traditional delivery vehicles, which are typically powered by fossil fuels.
- Decrease traffic congestion by reducing the total number of the deployed conventional transportation vehicles, hence contributing to less harmful emissions to the atmosphere.
- Low noise levels during operations, limiting the overall noise pollution.

## 6.5 UC Modifications and Next Steps

**Please provide any deviations and UC corrective actions or the required plans for improvement.**

No deviations encountered during the reporting period.

**Next Steps**

GS and AGFT will continue their efforts in developing, improving and refining the drone-delivery fleet management software, as well as the first working prototype. Moreover, they will focus on the performance of the 1st project demonstration for selected sites in North Macedonia, with the deployment of different UAV types for rural logistics.

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# 7. Conclusions and Next Steps

The main purpose of this deliverable "D3.3 - Performance Evaluation Report" is to provide a detailed overview of the UCs' progress carried out during the reporting periods of the ICAERUS project. The aim of this document is to internally evaluate the plan implementation (according to Deliverable "D3.1 – Use Case Plan") and development of the five UCs. The UCs' evaluation process focuses on detecting deviations from the initial plan, addressing potential impacts on the expected outcomes, and suggesting mitigation strategies for encountered challenges. This ensures the smooth progress and efficient implementation of the UCs while simultaneously contributing to the project's risk management assessment. The structure of this deliverable is based on the individual plans of the UCs, which are strategically selected to cover multiple applications within the complex rural European landscape. This is the first version of Deliverable "D3.3 – Performance Evaluation Report," with an updated version scheduled for M46 of the project.

The ICAERUS project is effectively demonstrating the transformative potential of UAV technologies across five diverse use cases in rural European areas. Each use case has provided valuable insights into the multi-purpose applications of drones, emphasising their role in enhancing efficiency, sustainability, and accessibility. In crop monitoring, the integration of UAVs has significantly improved disease detection and canopy health assessment, reducing manual labour and increasing agricultural productivity. The development of a user-friendly dashboard has empowered farmers with actionable insights, leading to optimised crop management practices and reduced environmental impact. The successful testing of drone spraying configurations has highlighted the efficiency and environmental benefits of UAVs over conventional spraying methods. The findings support the reduction of chemical usage in agriculture, aligning with the EU's sustainable agricultural goals. UAV deployment in livestock monitoring has proven beneficial in reducing the time and labour required for herd management. The technology has enhanced monitoring accuracy and improved farmers' working conditions, despite challenges such as weather conditions and predation. The use of drones for forest health and wildfire risk monitoring, coupled with satellite data, has enabled precise detection of tree health issues and high-risk areas. Additionally, thermal imaging has facilitated effective wildlife monitoring, crucial for disease control and biodiversity conservation. The innovative drone-delivery fleet management system has shown that UAVs can significantly enhance logistics in remote areas. This system offers a rapid, cost-effective solution for delivering critical supplies, improving the quality of life in rural communities and ensuring the continuity of supply chains.

Building on the successful outcomes of each use case, the ICAERUS project will continue to enhance its impact and sustainability:

- In crop monitoring, the project will focus on optimising data collection and processing methodologies to enhance the accuracy and efficiency of crop health assessments. Expanding the deployment of UAV technologies across more agricultural regions will validate the models under diverse environmental conditions. Engagement with policymakers will promote the adoption of UAV technologies in agriculture.
- For drone spraying, further research will be conducted to refine spraying configurations and optimise pesticide application. The project will advocate for policy updates to allow broader use of drone spraying in agriculture and organise demonstration events to showcase the benefits to stakeholders.
- In livestock monitoring, machine learning models will be improved with additional data to enhance the accuracy of monitoring. Developing training programmes for farmers to effectively use UAV technologies and addressing challenges related to weather conditions and predation through targeted research and technological improvements will be a priority.

- In forestry and biodiversity monitoring, data collection trials will continue in 2024 to expand datasets and refine models for forest health and wildfire risk assessment. The integration of refined models into the ICAERUS platform and the conduction of demonstration events will showcase the capabilities to stakeholders. Engagement with regulatory authorities will streamline approval processes for UAV operations.
- For rural logistics, further development and improvement of the drone-delivery fleet management software will be undertaken. Preparations for project demonstrations in North Macedonia will involve finalising UAV types and ensuring regulatory compliance. Conducting simulations and test flights will validate the system under various conditions and scenarios.

Finally, the consortium has already taken into account the comments from the reviewers and is working towards following the expert monitors' suggestions. This includes ensuring that the use cases have a deep focus on R&D aspects, moving beyond off-the-shelf solutions and GitHub resources, and contributing more to the scientific community by providing cutting-edge investigations, comparisons, and evaluations. By addressing these next steps, the ICAERUS project can continue to lead the way in demonstrating the transformative potential of UAV technologies, ultimately contributing to the sustainability, efficiency, and resilience of rural European areas.

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