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Republic of Cyprus

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Executive Summary

This document reports on all the pilots implemented for the Green-HIT platform.

Section 2 presents the holistic pilot that covers most of the tools available through a series of scenarios done to imitate a real use case. The pilot is separated into three (3) scenarios, fire breakout, illegal hunting and illegal logging and it incorporates the 2-way verification protocol.

Section 3 presents pilot done to demonstrate tools that were not used in the holistic pilot such as illegal trespassing module and the reforestation/afforestation and deforestation modules. This section also details pilots of tools done for verification purposes such as UAV flights and the composite sensor evaluation criteria.

Section 4 passes through the evaluation metrics specified in deliverable D7.1 "Testing and Validation Methodology" to determine which metrics were passed and which were failed. Section 5 details all challenges faced during the project and any adaptations or changes made for future deployments based on those challenges.

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1. Introduction

This report details all pilots implemented for Green-HIT project to ensure each tool is properly tested and integrated into the platform. This report follows up on the methodology and evaluation metrics presented in deliverable D7.1 “Testing and Validation Methodology”.

Pilots were implemented in collaboration between partners and each pilot incorporated multiple tools available to the platform. The tools tested in the pilots were the:

- Composite Sensors
- UAVs
- LoRaWAN gateways
- LoRaWAN network server
- Cloud Platform
- Back-end system
- Web Dashboard
- Mobile Application
- Intelligence Modules

2. Holistic Platform Pilot

This pilot was performed with the purpose of incorporating as many of the tools available as possible in the same environment to validate the tools offered by the Green-HIT platform holistically. The pilot is based on the 2-way verification protocol and presents 3 scenarios, the first scenario involves a fire breakout, the second scenario involves illegal hunting, and the third scenario involves illegal logging. The 2-way verification protocol is triggered when a field sensor detects an incident, which will in turn alert the monitoring system to trigger a UAV to fly at the specific location for verification of the incident before manual human intervention.
The following tools were used in the pilot:

- Green-HIT Forest Management & Monitoring Web Dashboard
- Forest IoT Composite Sensors
- UAVs (VTOL and Quadcopter)
- Fire Prevention, Detection & Reaction Module
- Audio Recognition Module

2.1 Fire Breakout

In this scenario, a fire is broken out that is detected by the nearby smoke sensors. This done when the CO2 parameters sent by the sensor exceed the threshold set by the fire module.

Figure 1: Smoke rising to the CO2 sensor.

An alert is sent to the platform that notifies the user to dispatch a drone to inspect the area. The location of the device that triggered the alert is displayed on the map.

Figure 2: Fire detected, and alert sent.

Figure 3: UAV flies to the area to validate incident.

If a fire is detected, then the relevant authorities are involved to solve the issue.

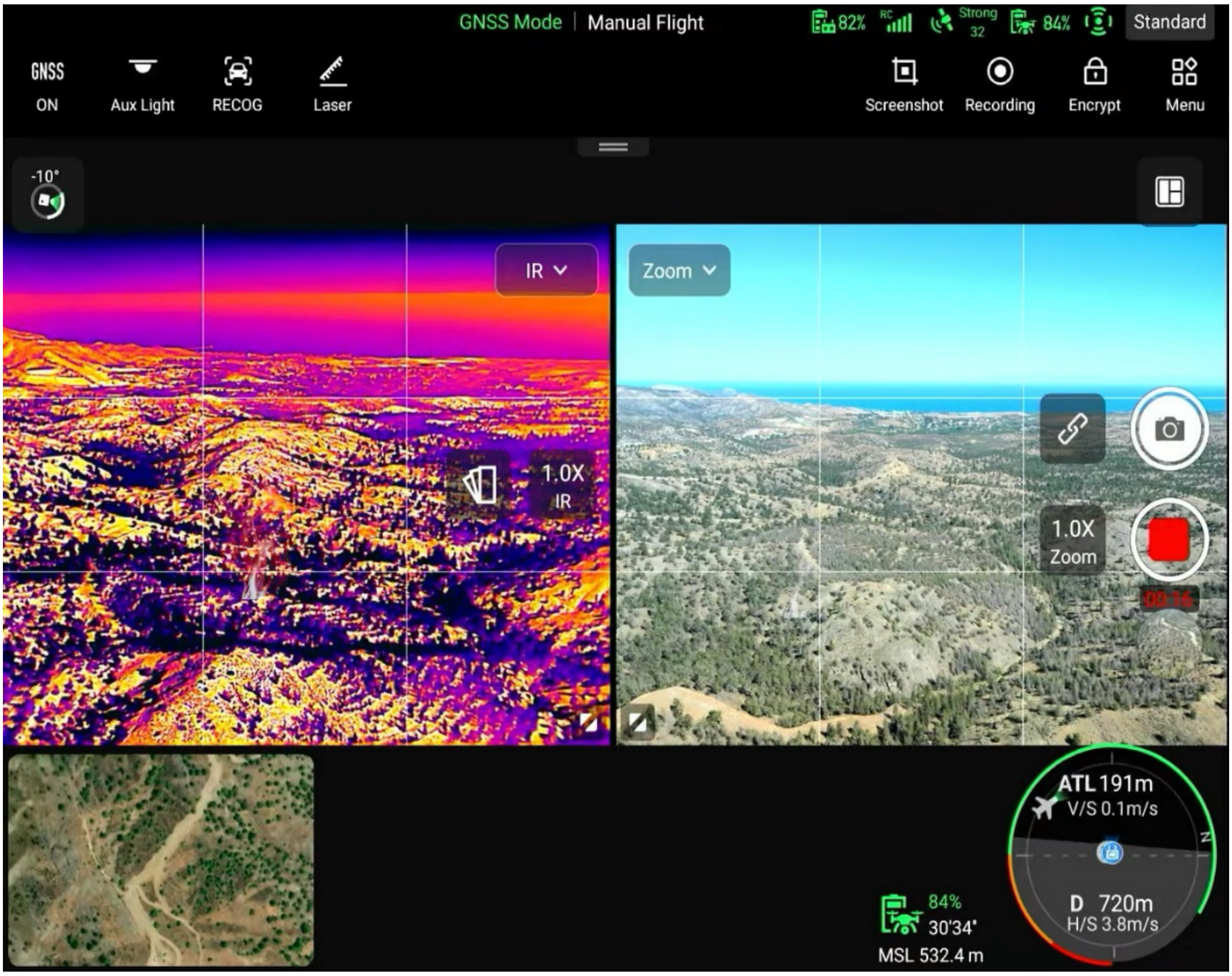

Figure 4: Smoke detected.

Figure 5: Human intervention.

2.2 Illegal Hunting

In this scenario, the audio recognition module detects a series of gunshot sounds.

Figure 6: Hunter firing gunshots.

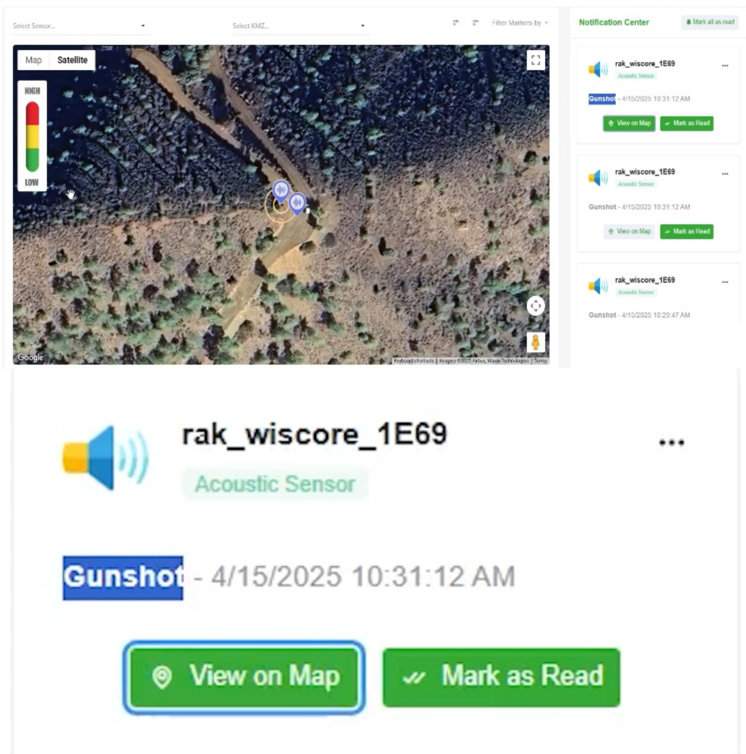

Figure 7: Gunshot sound and audio source detection and alert.

The platform is alerted by the gunshot notifications and the location of the device that detected the sound is displayed on the map, the user dispatches a drone to confirm whether a person is illegally hunting.

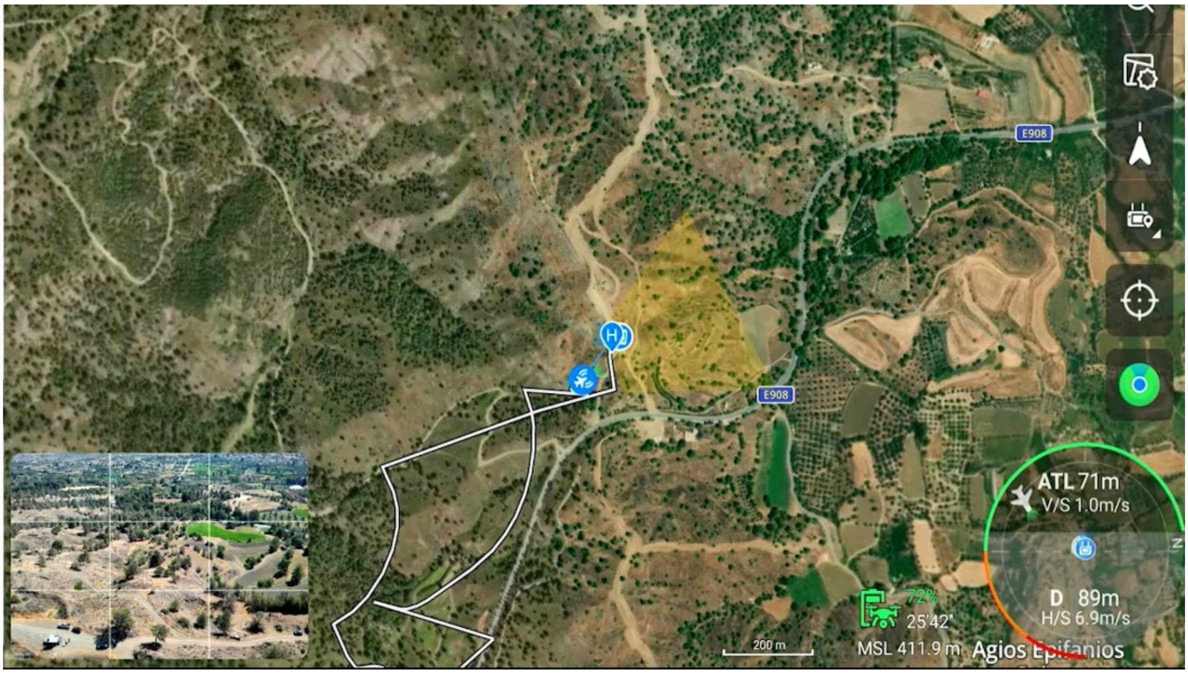

Figure 8: UAV flies to the area to verify.

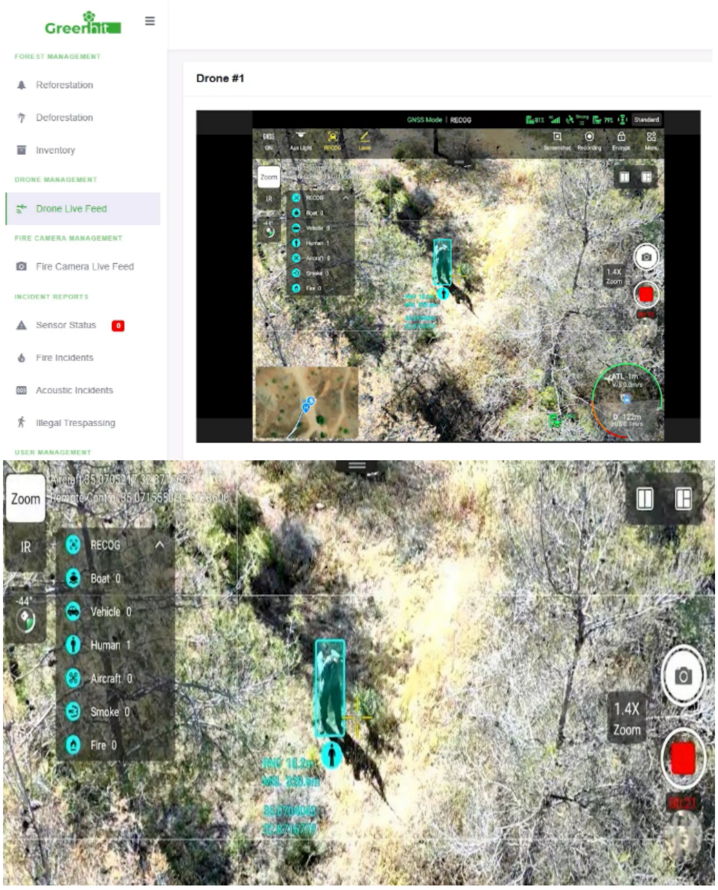

Figure 9: Hunter detected by the UAV.

When the person is detected by the drone, the relevant authorities are called to apprehend the hunter.

2.3 Illegal Logging

In the third scenario, the audio recognition module detects a series of chainsaw sounds.

Figure 10: Illegal logging.

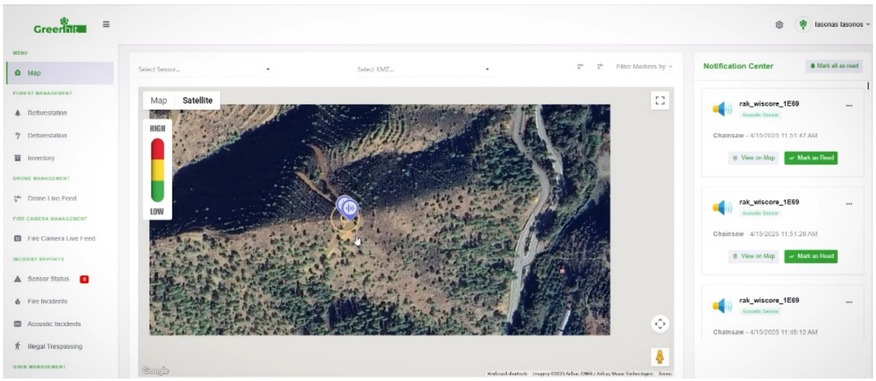

Figure 11: Chainsaw sound and audio source detection and alert.

The platform is alerted by the chainsaw notifications, the location of the audio source is also displayed on the map, the user then dispatches a drone to confirm whether a person is illegally logging.

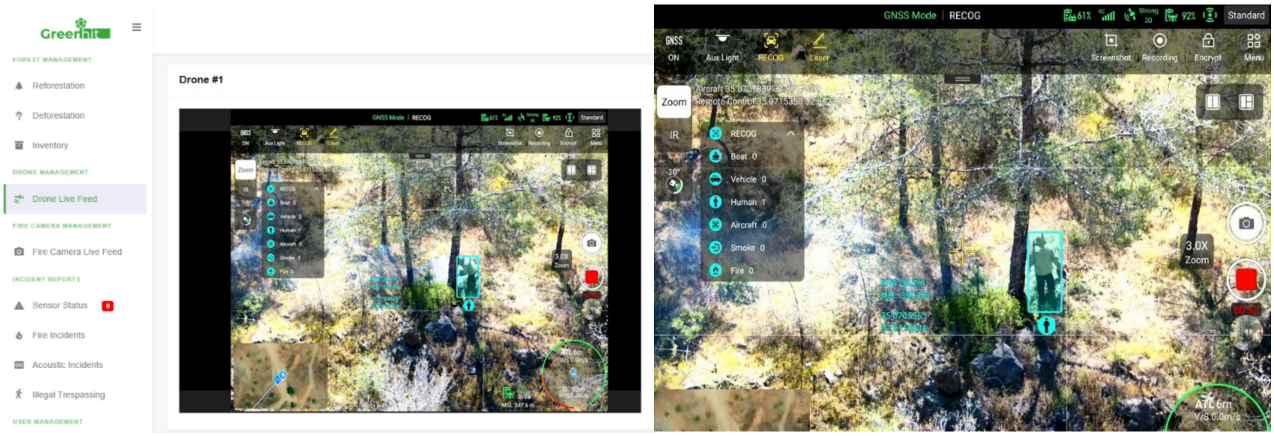

Figure 12: Logger detected by the UAV.

If a person is detected, then the relevant authorities are called to apprehend the logger.

3. Other Pilots and Tool Evaluations

3.1 UAV flights

Individual UAV flights were performed on areas designated in previous work, this was done both to test the routes themselves for network coverage and to confirm that they are covered within the 60-minute flight time. The following areas were tested:

- Koutrafas (18.85 km2)
- Chrysovrysi (1.4Km)
- Treis Elies (4.02km2)
- Milikouri (4.81km2)
- Omodos (1.89km2)

The Koutrafas Area was separated into 4 different sub areas from A to D due its large size (18.85km2). Koutrafas was used as the pilot site for flight tests using the VTOL UAV, the rest were used as pilot sites for the quadcopter UAV.

Figure 13: VTOL UAV preparing for take-off.

Figure 14: Koutrafas areas A-D left to right.

The areas separated have the following size:

- A: 4.03 km2
- B: 3.88 km2
- C: 5.14 km2

- D: 5.8 km2

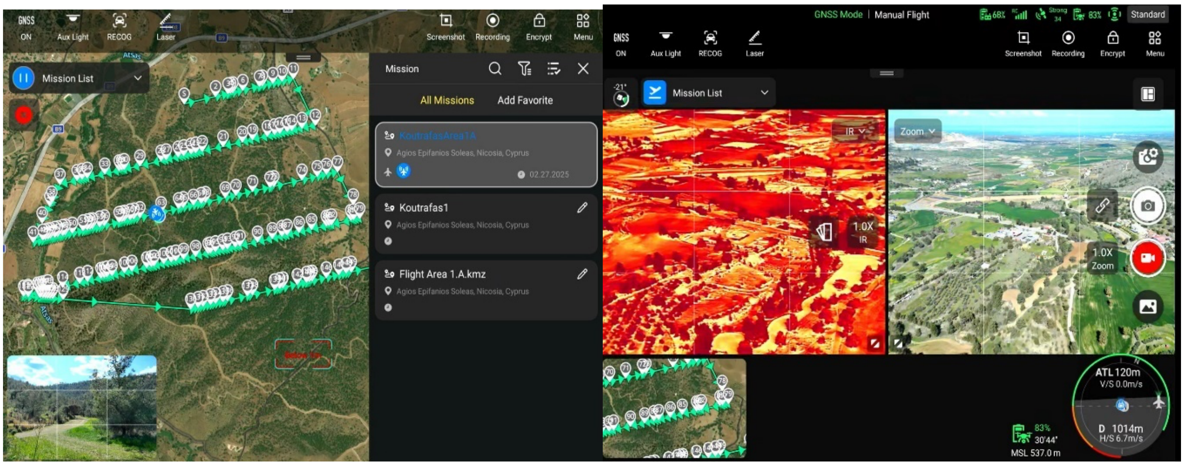

Figure 25: Koutrafas area A patrol path.

To operate under EU regulations the drones were allowed to flight in a maximum altitude allowed at 120m. Every area was mapped, and flight paths were created for patrolling.

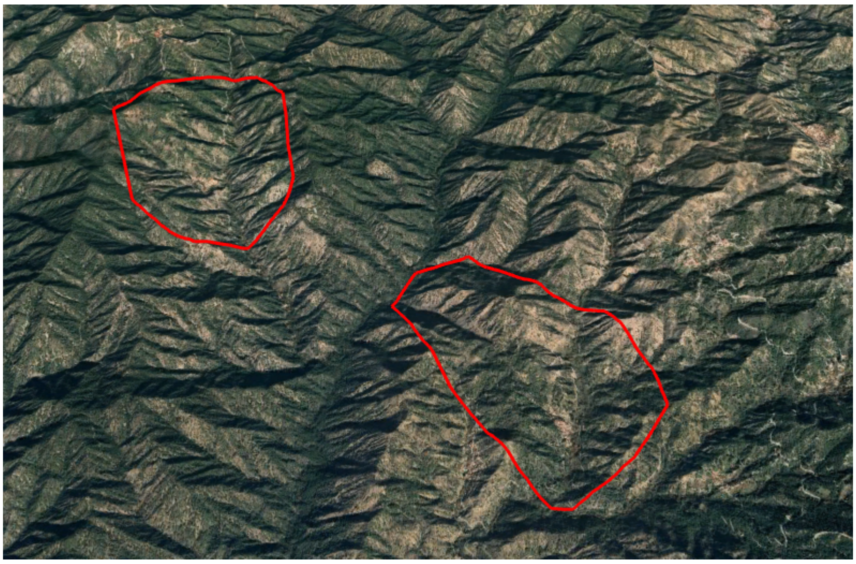

Figure 36: Milikouri (left) and Treis Elies (right).

Figure 47: Omodos.

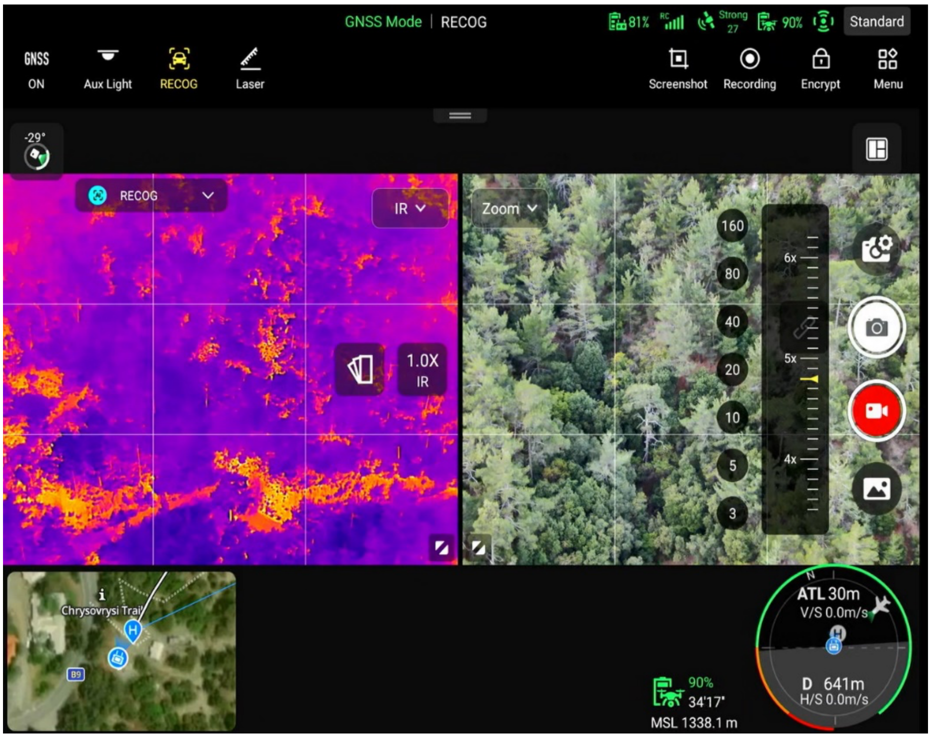

Figure 58: Chrysovrysi patrol.

Considering the quadcopter's 5 m/s average cruise speed and the VTOL's 20m/s average cruise speed, the areas required the following time to be navigated/patrolled:

- Koutrafas Area A: 7 minutes
- Koutrafas Area B: 6 minutes and 30 seconds
- Koutrafas Area C: 7 minutes and 30 seconds
- Koutrafas Area D: 8 minutes
- Chrysovrysi: 10 minutes
- Treis Elies: 24 minutes
- Milikouri: 26 minutes and 30 seconds
- Omodos: 17 minutes

Considering the above time required to navigate each location, each location be covered within a single UAV flight as the UAVs have a 60-minute flight endurance.

3.2 Illegal Trespassing

The illegal trespassing pilot presents a scenario where a vehicle illegally trespasses through a hiking trail that is only intended for hikers. The camera located at the entrance of the trail detects the vehicle when it drives towards it.

Figure 69: Illegal trespassing by vehicle.

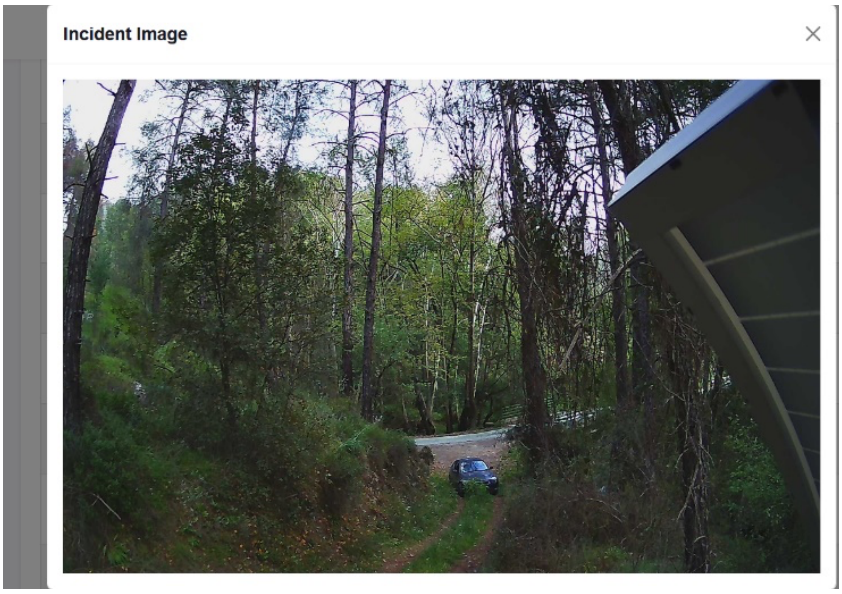

Figure 20: Incident detected by camera installed at the entrance.

The vehicle keeps driving deeper inside the trail and approaches the audio recognition model.

Figure 21: Audio module installed deeper in the trail.

The audio module then detects the engine sound and sends an alarm to the platform, the device is also visible on the map to help the user identify the location of the vehicle.

3.3 Forest IoT Sensors

The forest IoT sensors evaluation was not done based on pilot metrics but instead the evaluation was based on continuous observation of the devices to confirm that they maintained their functionality throughout the course of the project. The devices were installed for 12 months on the areas and have continuously gathered data.

Devices were evaluated on the following criteria:

- Measurement Accuracy
- Packet Loss and Signal Strength
- Long Term Functionality

Measurement accuracy: All devices were monitored for potential drift of parameters measured, in case any measurement was transmitted at unordinary values during nominal atmospheric parameters they were recalibrated, if any of those devices still transmitted faulty data, they would be replaced. During this 12-month period, no devices on either area had to be recalled for this reason.

Packet Loss and Signal Strength: All devices were monitored both during installation and during the 12-month period to ensure device payloads were transmitted with appropriate signal strength and with minimal packet loss. Any device with worse than -110dBi received signal strength indication (RSSI) or above 10% packet loss were relocated to improve signal quality.

Long Term Functionality: Devices were configured to be low power so that their battery lifespan can last for years; to confirm this all devices were monitored during the 12-month period for any battery outage. The expected battery lifespan for the devices installed following the configurations detailed in deliverable D4.2 "Green-HIT Hardware Components" is the following:

- Milesight EM500 CO2: 10 years
- Seeed S2103 CO2: 5 years
- Seeed S2120 Weather Station: 2 years
- Audio Recognition Module: 5 years (Rechargeable batteries that are replaced due to worsening capacity from accumulative charging and discharging)
- Milesight X5 Camera: 3 years (Rechargeable batteries that are replaced due to worsening capacity from accumulative charging and discharging)

During the 12-month period, no battery replacement was required.

4. In-the-Field Evaluation

The below table outline the evaluations carried out in the field after testing pertinent components of the Green-HIT platform.

Table 1: In-the-Field Evaluation Experiments.

	Testing Component	Type of Test	Test Environment	Other Components	Pass/Fail
1	Sensing end-nodes	Measurement accuracy	Development/Staging	LoRaWAN gateways/ LoRaWAN NS/ Cloud platform/ Back-end system/ Web dashboard	Pass
2	Sensing end-nodes	Power consumption	Staging	LoRaWAN gateways/ LoRaWAN NS	Pass
3	Sensing end-nodes	Bidirectional communication	Development/Staging	LoRaWAN gateways/ LoRaWAN NS/ Cloud platform/ Back-end system/ Web dashboard	Pass
4	Sensing end-nodes	Signal reception	Staging	LoRaWAN gateways/ LoRaWAN NS	Pass
5	LoRaWAN gateways	Range coverage	Staging	Sensing EN/ LoRaWAN NS	Pass
6	LoRaWAN gateways	Reliability	Staging	Sensing EN/ LoRaWAN NS/ Cloud platform/ Back-end system	Pass
7	LoRaWAN gateways	Interference resistance	Staging	None	Pass
8	LoRaWAN gateways	Throughput	Development/Staging	Sensing EN/ LoRaWAN NS	Pass
9	LoRaWAN gateways	Scalability	Staging	Sensing EN/ LoRaWAN NS	Pass
10	LoRaWAN gateways	Security	Staging	Sensing EN/ LoRaWAN NS/ Cloud platform/ Back-end system	Pass

11	LoRaWAN network server	Reliability	Development/Staging	Sensing EN/ LoRaWAN gateways/ Cloud platform/ Back-end system	Pass
12	LoRaWAN network server	Latency	Staging	Sensing EN/ LoRaWAN gateways/ Cloud platform/ Back-end system	Pass
13	LoRaWAN network server	Security	Staging	Sensing EN/ LoRaWAN gateways/ Cloud platform/ Back-end system	Pass
14	LoRaWAN network server	Scalability	Staging	Sensing EN/ LoRaWAN gateways	Pass
15	LoRaWAN network server	Integration	Development/Staging	Cloud platform/ Back-end system	Pass
16	LoRaWAN network server	Monitoring & management	Staging	None	Pass
17	UAVs	Flight ability	Development/Staging	None	Pass
18	UAVs	Power supply	Development/Staging	None	Pass
19	UAVs	Environmental protection	Staging	None	Pass
20	UAVs	Camera footage streaming	Staging	Cloud platform/ Back-end system/ Web dashboard/	Pass
21	Full-fledged Web platform	System Testing/ Acceptance Testing	Staging/ Production	Sensing EN/ LoRaWAN gateways/ LoRaWAN NS/ Back-end system/ Web dashboard/ Intelligence modules	Pass
22	Smartphone application	System Testing/ Acceptance Testing	Staging/Production	Sensing EN/ Web platform/ Intelligence modules	Pass

5. Challenges Faced & Best Practices for Further Deployment

Challenges were presented throughout multiple tools during the project.

5.1 Composite Sensors

The following challenges were identified for the composite sensors:

- **Theft**: Due to the installation areas, the sensors were installed in a way to be relatively hidden from public eye, but it is impossible to completely conceal their presence, due to this 2 of the composite sensors (1 in each area) were stolen during the 12-month evaluation period.
- **Concealing Devices with Solar Panels**: Due to the need for direct solar exposure, the devices that required solar power were much harder to conceal, this was mitigated by installing the devices in hard-to-reach location with hard to remove material. Despite this, 1 audio recognition module was stolen during the evaluation period.

Considering the above challenges, on further deployments, higher priority needs to be placed either on concealment of the devices or to make removal of those devices more difficult. A reserve of unused devices needs to also be available to quickly replace any lost or stolen devices.

5.2 UAVs

The following challenges were identified for the UAVs:

- **Low cellular coverage areas**: Some of the areas designated for UAV support have insufficient cellular coverage. This created latency issues both for flights and for the video streaming from the UAV camera feed, increasing risk of a crash and lowering effectiveness. To deal with this issue, the UAV command centre was outfitted with Starlink technology that functions agnostic of location.
- **Cloudy Weather Vulnerability**: The Starlink technology introduced a new problem not previously existing with cellular technology, as Starlink relies on satellite technology, cloudy weather significantly reduced its effectiveness, making the areas that don't have good cellular signal coverage vulnerable under cloudy weather.

Considering the above challenges, there are several approaches to the issue, but none offer a clear solution. One approach is to create a signal boosting station on area with low cellular coverage, depending on the location this approach could be costly and require maintenance, it is also subject to outside factors that could erode it such as human intervention. Another approach would be separate those areas into smaller sub-areas and categorize them by signal coverage, if an incident is triggered and the weather is cloudy, then instead of the 2-way verification protocol, human intervention would immediately be called upon for those areas.

5.3 Back-End

No significant challenges were encountered during the development of the Green-HIT back-end component.

5.4 Web Dashboard

During the development of the Green-HIT Web platform, two (2) key technical challenges emerged:

- Camera Integration for Real-Time Monitoring: Integrating the fire detection camera and drone camera feeds into the platform in real time proved to be one of the more complex tasks. The core difficulty stemmed from the need for reliable, low-latency video streaming across varying network conditions. To address this, a custom server leveraging the Real-Time Streaming Protocol (RTSP) was deployed. This solution enabled stable transmission of live video feeds, allowing users to monitor remote areas effectively through the platform interface.
- Google Earth Engine Integration for Reforestation Module: The afforestation/reforestation functionality of the platform required seamless integration with custom Google Earth Engine scripts. The challenge here was ensuring compatibility between external script execution and the platform's backend services. Significant effort was needed to synchronize data flows and handle the nuances of Earth Engine's asynchronous processing. With careful debugging and API management, full integration was eventually achieved, enabling dynamic visualization and interaction with geospatial analysis outputs.

These challenges highlighted the need for robust streaming infrastructure and flexible handling of third-party tools, both of which were successfully overcome through targeted technical adaptations.

5.5 Smartphone Application

No significant challenges were encountered during the development of the Green-HIT smartphone application.

5.6 Incident Detection Modules

The following challenges were identified for the illegal hunting & logging audio recognition module:

- **Disparate Audio Recognition Range**: The illegal hunting & logging module incorporated both gunshot and chainsaw audio for detection. For illegal hunting, one audio module is enough to cover a large area as the gunshot sound is detected from far away. For illegal logging, to properly cover a large area, multiple modules would need to be placed instead but if these modules also detect gunshot sounds, if a gunshot is fired, multiple modules would trigger.
- **Landscape Limitations**: During the pilots performed, a recurring issue with chainsaw detection was audio muffling. Any large obstruction between the audio source and the audio recognition module such as hill would result in a sound that was undetectable by the module. This meant the module had to be placed in locations that had clear view of the logging area which required higher elevation.

Considering the above challenges, the audio module for illegal hunting & logging can either be separated into 2 models or the chainsaw sound detection needs to be amplified to increase its effective coverage, this could lower the accuracy of the model, if budget allows the first option would yield better results at a higher cost and higher risk of theft as more devices are introduced into the same area. The chainsaw model would also be required to adapt to muffling effect, this would require the creation of an additional dataset that contains this audio sounds that they are detected by the model.

5.7 Fire Prevention, Detection & Reaction Module

The primary challenge was the limited data from weather stations in Cyprus. There are 53 weather stations all over Cyprus, but data was only available from five stations. This limited data coverage posed significant challenges. Those five AWSs are located close to urban areas rather than forested areas, which are generally more prone to wildfires. Consequently, the model's predictions are biased towards conditions that are common in urban settings. The absence of data from forested regions sets a limit to the model's accuracy when predicting fire occurrences in high-risk regions.

Critical issue confronted was the inadequate quantity of features available for the model training. Key factors such as rainfall precipitation, and fuel content (DFMC and LFMC) unfortunately weren't available. These variables are fundamental for an accurate fire prediction as they straightforwardly impact the likelihood of a fire. The absence of these decisive variables limited the model's ability to capture environmental and meteorological conditions in which fire is about to burst. Overall, this resulted in a less comprehensive model.

Finally, an extra challenge was the occurrence of deliberate, human-caused fires. It is intrinsically difficult to predict deliberate fires – mostly caused by arson, based solely on meteorological and environmental data. These incidents are not driven by natural factors; therefore, they cannot be measured, neither forecasted. If we knew which fires were intentional, our model would be better at predicting naturally caused fires, however it would still not be able to predict arsons. These challenges highlight the complexities involved in developing a solid, accurate and precise fire prediction model. My belief is that if these difficulties are constrained, then the performance will be enhanced.

In the Fire detection module, we faced the issue that the threshold value in the literature was much lower than the value that we measured in our sensors leading to a lot of false alerts. We had to readjust the threshold value to accommodate for Cyprus and we need to keep monitoring the values to make sure that they correspond to the absence or presence of fire.

5.8 Platform Integration

No significant challenges were encountered during the integration of the distinct Green-HIT modules. This smooth integration process was the result of careful planning and ongoing collaboration between the responsible partners. From early development stages, each module was designed with interoperability in mind, following shared interface standards and clear communication protocols. The close coordination between hardware and software teams ensured that all components, ranging from sensor inputs and AI detection modules to the Web platform and smartphone application, were seamlessly connected, enabling a unified and reliable operational environment.

6. Conclusions

In conclusion, as the project is coming to an end, it is extremely crucial to verify the integration and functionality of all the tools offered in the Green-HIT platform. Through collaborative efforts between the partners, multiple pilots were performed to properly evaluate and validate the various components of the system.

A holistic pilot was performed where the functionality of the majority of tools was evaluated and validated as the platform was tested as a fully functioning system by following the 2-way verification protocol for multiple scenarios. All challenges faced during design, development, testing, integration and validation of the tools were outlined along with suggestions and practices to further improve the system in future deployments.