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Green-HIT: A Holistic IoT System for Forest Monitoring and Management

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Abstract. Forests play a critical role in climate regulation, biodiversity preservation, and ecosystem sustainability, making their protection and effective management a strategic priority under the European Green Deal. Green-HIT is a holistic IoT system designed to transform forest management and monitoring through the integration of advanced technologies, namely, edge computing, AI-driven analytics, cutting-edge Unmanned Aerial Vehicle (UAV) technologies, and an interoperable data infrastructure. It addresses key challenges faced by forest authorities and environmental stakeholders by enabling real-time monitoring, intelligent decision-making, and automated response mechanisms. Green-HIT incorporates a range of modules to support prevention, early detection and reaction to forest fires, deforestation detection and reforestation planning, illegal activity detection, and forest mapping, using field and remote sensing data. This paper demonstrates the effectiveness and efficiency of the system through a series of controlled pilot deployments in selected forest areas in Cyprus.

1. Introduction

Forests play a pivotal role in regulating the Earth's climate, preserving biodiversity, and sustaining ecosystems. They serve as vital carbon sinks, protect water resources, and support countless species and communities. Considering the escalating threats posed by climate change and human encroachment, the *European Green Deal* underscores the strategic importance of protecting and managing forest resources more effectively and sustainably. Yet, despite growing awareness and policy support, forest authorities across Europe continue to face significant challenges in monitoring vast and often inaccessible forested areas. These challenges include delayed detection of forest fires, illegal logging and hunting, inefficient reforestation planning, and fragmented data collection methods. The increasing frequency and intensity of climate-related events only exacerbate the need for real-time, intelligent, and scalable forest management systems.

In response to these pressing challenges, this paper presents **Green-HIT**, an end-to-end Green Holistic IoT system designed to revolutionize forest monitoring and management. Green-HIT integrates a suite of advanced ICT, including edge computing, AI-driven analytics, UAV-based data collection, and interoperable data infrastructures. The system enables real-time situational awareness, early detection of threats, automated response mechanisms, and evidence-based planning for reforestation efforts. This work makes the following key contributions:

- It introduces a modular, scalable IoT-based architecture tailored for forest environments.
- It details the integration of heterogeneous data sources, including field sensors, UAVs, and satellite imagery, to enable comprehensive monitoring and analysis.
- It discusses controlled pilot deployments across selected forest areas in Cyprus, evaluating the system's effectiveness in real-world conditions.

The remainder of this paper is organized as follows: Sec. 2 discusses related work. Sec. 3 outlines the Green-HIT architecture. Sec. 4 and 5 elaborate on the technological components and key functionalities. Sec. 6 presents the pilot deployments and Sec. 7 concludes the paper.

2. Related Work

Green-HIT builds upon prior work in IoT-based environmental monitoring, forest management systems, and climate resilience technologies. Several general-purpose IoT platforms such as *ThingWorx* [1], *IBM Watson IoT* [2], *Google Cloud IoT* [3], *IoTango* [4], and *Cuttlefish* [17] provide robust infrastructures for device connectivity and data visualization. However, these platforms are typically domain-agnostic and are not optimized for the heterogeneous, high-resolution sensing and responsive decision-making required in forest ecosystems.

Forest monitoring systems like the *European Forest Fire Information System (EFFIS)* [5] and *EOS Forest Monitoring* [6] provide satellite-based early warnings, fire mapping, and vegetation analytics, but they primarily rely on remote sensing data, limiting their effectiveness for near real-time responses or granular event detection. Moreover, they lack integration with on-the-ground sensors, UAV verification protocols, and AI-based predictive analytics.

Recent EU-funded projects have demonstrated the value of domain-specific monitoring frameworks. The *FUTMON* project [7] established a pan-European forest monitoring network. *CLIMAFORCEELIFE* [8] focused on transitioning to climate-smart forestry in Eastern and Central Europe. *ONEforest* [9] introduced a multi-criteria decision-support system for harmonizing stakeholder interests in forest management. *HoliSoils* [10] provided methodologies for harmonized soil monitoring and modeling. While impactful, these initiatives do not fully exploit integrated sensor networks, UAV-based remote verification, and intelligent response modules.

In terms of scientific literature, Constantinou et al. [11] and Albreem et al. [12] underline the potential of IoT-enabled systems to mitigate environmental challenges by creating real-time, intelligent data networks. Buonocore et al. [13] propose the concept of a "Forest Digital Twin", highlighting the benefits of integrating heterogeneous data sources for forest analytics. However, their proposed frameworks remain largely theoretical or are in early experimental phases.

The Green-HIT platform advances the field by delivering an end-to-end, modular IoT architecture that combines composite sensors, UAVs, satellite imagery, and AI modules to enable forest fire prevention, biodiversity monitoring, and ecosystem inventory. With accuracy targets of over 85% in incident detection and a robust three-way verification protocol, Green-HIT moves beyond static data collection towards proactive, intelligent forest management.

3. Green-HIT System Architecture

As illustrated in Fig. 1, Green-HIT adopts a modular, layered system architecture designed to enable robust forest monitoring, intelligent incident detection, and informed decision-making across diverse natural environments. The architecture integrates a distributed sensing infrastructure, resilient communication protocols, intelligent data processing, and user-centric interfaces into a cohesive technological ecosystem.

At the core of the system lies a heterogeneous network of environmental and surveillance sensors (***perception layer***) deployed across forests in Cyprus. The sensors capture biophysical and environmental parameters, including wind speed and direction, atmospheric CO_2 levels, temperature, humidity, barometric pressure, soil moisture, and conductivity. The *SenseCAP S200* and *Milesight EM500* devices provide environmental monitoring, while acoustic sensors (*RAKwireless*) and thermal imaging cameras (*SN-TPT4233LPZ-M*) facilitate real-time detection of acoustic signatures and heat sources indicative of illegal activities or wildfires. To ensure coverage of hard-to-reach areas, Green-HIT incorporates custom multi-sensor hubs equipped with dual terrestrial and satellite communication capabilities. These are based on *EchoStar Mobile's LoRa-enabled S-band* modules, ensuring reliable data transmission in zones lacking conventional connectivity infrastructure.

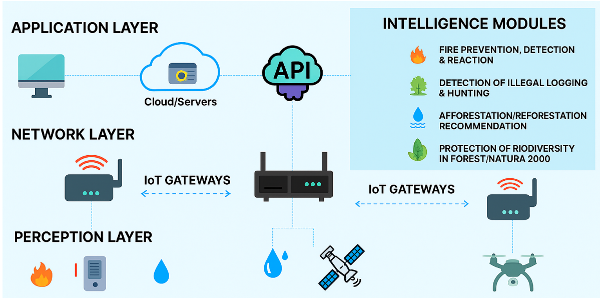

Figure 1. The Green-HIT architecture.

Data acquisition at the edge is complemented by a hybrid ***network communication layer***. This includes a terrestrial LoRaWAN network managed through *Kerlink iStation* gateways and the *Actility ThingPark Network Server*, as well as a satellite IoT link that extends coverage into blind-spot regions. Sensor data is buffered and transmitted using the SenseCAP S2100 LoRaWAN data logger, supporting asynchronous communication and improving resilience against transient network disruptions. The backend is hosted within a private cloud infrastructure, comprising a scalable NoSQL database system managing multimodal datasets, including sensor telemetry, UAV imagery, and user reports. A Content Management System facilitates data manipulation, while a RESTful API layer ensures seamless interaction between backend and front-end applications.

At the ***application layer***, Green-HIT integrates AI-driven modules tailored to the demands of forest ecosystems. The modules perform predictive analytics for wildfire risk assessment, real-time fire detection, and dynamic simulation of fire spread to support emergency response planning. Additional models focus on illegal activity detection by analyzing acoustic and visual data, while a suite of recommendation systems offers spatially explicit insights for reforestation and deforestation activities. These outputs are generated through the fusion of data from satellite imagery, UAV-acquired footage, and ground-based sensors, processed using Machine Learning (ML) and multi-criteria decision analysis techniques. User interaction is enabled through a Web-based dashboard and a smartphone application. The dashboard provides access to real-time incident maps, drone telemetry, sensor status, and interactive decision support tools. The smartphone application offers field operatives streamlined access to essential features, including incident reporting, inventory logging, and live system alerts.

4. Green-HIT Core System Modules

4.1 Fire Prevention, Detection, and Reaction

This module is designed as an end-to-end, data-driven sub-system for mitigating the growing threat of wildfires in Mediterranean forest environments [14]. It integrates predictive modelling, sensor-based early detection, and fire propagation estimation to facilitate both proactive forest management and rapid emergency response.

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Fire risk prediction. At the core of the prevention capability lies a Machine Learning (ML) model that estimates the daily probability of fire occurrence. The model was trained on meteorological data from five weather stations across Cyprus, covering the period from 2010 to 2018. Input variables included temperature, relative humidity, and temporal features derived from date fields. After pre-processing, including Min-Max scaling and encoding cyclical time-based features, the data was used to train and evaluate several classifiers. Among the tested models, *Extreme Gradient Boosting (XGBoost)* demonstrated the highest predictive performance, achieving an accuracy of *83.03%*. Feature importance analysis revealed that temperature and seasonal variables were the most influential predictors (Fig. 2). Notably, the model dynamically adjusts CO_2 alert thresholds based on predicted fire risk level: lower thresholds trigger alarms under high-risk conditions, thereby improving sensitivity during vulnerable periods.

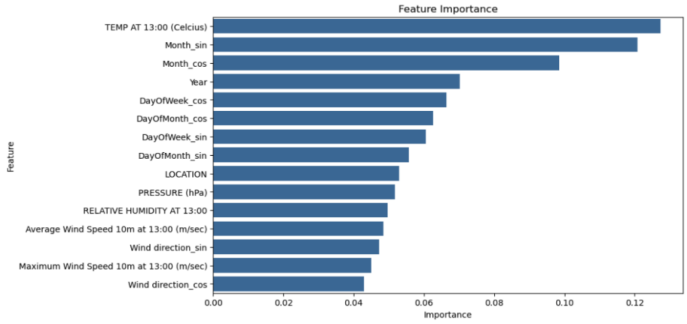

Figure 2. Feature importance.

Sensor-based fire detection. For real-time detection, the module relies on a distributed sensor network consisting of: (i) CO_2 Sensors (*Milesight EM500* and *Seeed SenseCAP S2103*), which monitor atmospheric gas concentrations indicative of combustion; and (ii) Weather Stations (*Seeed SenseCAP S2120*), which track wind speed, direction, temperature, pressure, UV index, and rainfall. Sensor installation was conducted in two high-risk regions in Cyprus, Troodos and Ayios Nikolaos, specifically targeting blind spots from fire lookout stations. Sensors operate on a 10-minute duty cycle and transmit data via LoRaWAN to field gateways (*Kerlink iStation* and *Milesight SG50*), ensuring wide-area coverage with minimal power consumption. Sensors are configured in *LoRaWAN Class A*, optimized for battery longevity, and transmit unconfirmed messages to further reduce energy usage. Examples of the deployed infrastructure are shown in Fig. 3. The sensors are installed in clusters to maximize coverage and detect CO_2 anomalies before visual signs of fire emerge.


Figure 3. Installations (Weather Station, EM500, SenseCAP S2103).

Fire propagation modelling and rate of spread estimation. Upon confirmed fire detection, the system employs a lightweight geospatial simulation module to estimate the fire's probable propagation trajectory. Using the initial sensor coordinates as the ignition point, a *Haversine-based algorithm* identifies the nearest weather station. It then fetches wind speed and direction to compute the directional bearing of fire movement. The slope angle between terrain points is calculated using data from the *OpenTopodata* API and *SRTM* elevation models.

The Rate of Spread (ROS) is estimated using a multiplicative model that combines a flat value with empirically derived wind and slope factors: $\mathrm{ROS}_{adjusted} = \mathrm{ROS}_{flat} \times f_{wind} \times f_{slope}$. Slope factors are computed using *Van Wagner's* model, which accounts for both positive (uphill) and negative

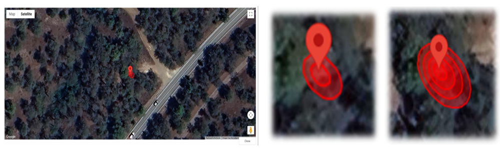
Figure 4. Fire propagation modelling output.

(downhill) gradients. Wind factors are derived via exponential scaling relative to wind velocity. This allows emergency services to anticipate spread patterns and prioritize responses (Fig. 4).

4.2 Detection of Illegal Activity: Illegal Logging, Illegal Hunting, and Trespassing

Illegal logging, hunting, and unauthorized access (off-road driving, littering, and overgrazing) often occur in remote, unmonitored terrain, making them difficult to detect using traditional methods. Green-HIT addresses this using a dual-sensor approach, camera-based and acoustic-based detection, integrated within the broader environmental surveillance framework. The acoustic-based detection module combines embedded edge- and cloud-based AI analytics to identify acoustic signatures associated with illicit activities, specifically, chainsaw operation, gunshots, and engine activity in remote trails.

Edge-based acoustic detection. The edge-based, in-situ detection component is designed for low-power, autonomous operation in forest environments. It consists of an embedded microcontroller-based audio recognition system built around the *Nordic nRF52840* platform, selected for its low power consumption and integrated DSP capabilities. Audio input is processed using *Mel-filterbank Energy (MFE)* extraction, which is optimized for environmental (non-speech) audio. The audio signal is divided into short frames (0.02s) with overlapping strides (0.01s), transformed using a 512-point FFT, and filtered across 40 Mel bands. This produces a spectrogram-like time-frequency representation of the signal, suitable for ML inference. The classification model is a *1D Convolutional Neural Network (CNN)* trained using *Edge Impulse*. It includes two convolutional layers with dropout regularization and outputs four classes: *Chainsaw*, *Gunshot*, *Engine*, and *Other*. The final model occupies just 51.8 KB of flash and 20.8 KB of RAM, and executes inference in 7ms, making it ideal for battery- or solar-powered field devices.

During testing, the model achieved 98.1%, 91.2%, and 100% accuracy for chainsaw, gunshot, and engine detection, respectively. To avoid false positives and ensure rapid response, an alert is triggered when classification confidence exceeds 99.5%. The module was validated with real-life audio events, confirming robustness under varying terrain and acoustic conditions. Gunshot detection proved effective even at long ranges, while chainsaw detection accuracy decreased with distance and line-of-sight obstructions (e.g., hills or dense forest). For engine sounds, an 8% false positive rate was observed. Field tests showed that the system was particularly effective in detecting continuous engine activity, such as motorcycles and 4x4 vehicles, even when not directly visible. Installation strategy was critical. Elevated mounting and unobstructed acoustic lines of sight enhanced performance, while rugged terrain with high reverberation or vegetation sometimes introduced audio dampening.

Cloud-based acoustic analytics. To complement in-situ detection, Green-HIT integrates a cloud-based audio classification pipeline built around *YAMNet*, a pre-trained deep neural network developed by Google. YAMNet is based on the lightweight *MobileNetV1* architecture and trained on *AudioSet*, covering over 500 environmental sound classes. The pipeline processes uploaded audio clips using: 16 kHz mono resampling; framing into 0.96-second windows; Short-Time Fourier Transform (STFT); and 64-band log Mel spectrograms. Each frame generates both class scores across 521 categories and 1024-dimensional embeddings, representing high-level semantic features of the sound. These embeddings are aggregated (e.g., via mean pooling) and fed into a lightweight Logistic Regression classifier trained on domain-specific data (e.g., gunshots, chainsaws, forest ambiance). The approach achieved 98.75% accuracy when evaluated on the ESC-10 dataset (a standard environmental sound benchmark), with minimal misclassification.

The cloud-based module allows for retrospective analysis of field recordings, training of updated models using collected acoustic data, and cross-validation with in-situ events. Its modularity enables flexible deployment in edge–cloud hybrid scenarios. For instance, the same audio samples that triggered LoRaWAN alerts in the field can be uploaded and reclassified by the cloud model for verification, retraining, or deeper pattern analysis.

Camera-based detection of trespassing. Camera-based detection provides a visual first layer of incident capture, optimized for fixed-location monitoring at forest access points. In the pilot deployment at Platy Valley, a high-value biodiversity area, a *Milesight X5* camera was installed eight meters inside the entrance of a restricted hiking trail to monitor for unauthorized vehicle entries. The camera operates either in continuous recording mode or in motion-triggered mode, with an effective detection range of six meters. When a vehicle is detected, the system captures an image and automatically logs the event on the Green-HIT Web platform, generating a real-time alert. The location and angle of installation were selected to minimize false positives from nearby legal roads, while still ensuring effective monitoring of entry paths. Captured images are uploaded to the cloud platform and presented through a live dashboard, providing immediate situational awareness for authorities. The camera's embedded analytics also reduce the need for continuous streaming, allowing it to function in low-power, bandwidth-constrained environments.

4.3 Deforestation Detection & Reforestation Recommendations

The Deforestation and Reforestation Module [15, 16] addresses the post-fire recovery challenge through a geospatial decision support system that prioritizes ecological restoration actions. It integrates remote sensing, multi-criteria analysis, and stakeholder input to identify, classify, and rank forested areas based on their need for intervention. The tool is designed to support national forestry authorities in strategic planning and to contribute to long-term biodiversity conservation and climate mitigation goals.

Deforestation detection via change analysis. The first component identifies zones of forest degradation using a change detection methodology applied to Sentinel-2 imagery. Specifically, the system computes Euclidean spectral distances between image composites captured before and after fire events, using a combination of raw bands and spectral indices such as NDVI, NBR, BAI, and NDWI to enhance vegetation and burn sensitivity. The detection algorithm incorporates a cloud-filtering process and spectral normalization to reduce variability due to atmospheric or seasonal effects. Once difference maps are computed, Otsu's thresholding method is applied to classify each pixel into change/no-change classes. This allows for an unsupervised, scalable approach to identifying deforested areas, without requiring extensive labelled data.

To improve semantic interpretation, detected changes are further classified using *CORINE Land Cover* data and cross-referenced with *MODIS Burned Area Products* to distinguish between urban, agricultural, and forest-based disturbances. The model achieved an overall accuracy of 78.6% in identifying deforested zones, as validated against 1,000 ground truth points derived from the *Hansen Global Forest Change* dataset and *EFFIS* fire records. The final output is a georeferenced raster (GeoTIFF) highlighting areas of significant spectral change, used as input for the restoration prioritization process.

Restoration prioritization using spatial multi-criteria analysis. To recommend reforestation strategies, a *Spatial Multi-Criteria Analysis (SMCA)* framework is applied using the *Analytic Hierarchy Process (AHP)*. This approach enables the integration of diverse ecological, climatic, and anthropogenic parameters into a single weighted decision index, the *GRESTO Index* representing the degree of restoration urgency. The decision model incorporates the following criteria: topography (elevation, slope, and aspect (SRTM); land use (CORINE land cover classes); fire impact (burn severity (dNBR) and fire frequency (EFFIS)); vegetation health (tree canopy density (Copernicus)); and climate (average temperature (MODIS LST) and precipitation (CHIRPS)). The criteria were selected through expert consultation with the *Cyprus Department of Forests* and weighted using pairwise comparisons in the AHP framework. For example, fire severity received the highest weight (29.4%), followed by tree density (22.4%) and land cover (16.9%), reflecting their direct influence on restoration viability and urgency.

Each raster criterion was standardized to a common 0–5 scale and the final GRESTO Index was computed as a weighted linear combination. The result is a continuous suitability map, which is reclassified into three categories: Low, Medium, and High restoration priority. High-priority zones correspond to areas requiring artificial interventions (e.g., planting, sowing), while low-priority zones are expected to regenerate naturally.

The system was deployed and validated on two major fire events in Cyprus, Solea (2016) and Argaka (2016), covering over 100 km^2. In both cases, restoration recommendations generated by the model were compared to official post-fire management plans implemented by the *Cyprus Department of Forests*. The accuracy of the prioritization model was evaluated using confusion matrices and F1-scores. For Solea, the overall accuracy reached 80.9%, with precision and recall metrics exceeding 85% for medium-priority areas. The Argaka validation yielded 72.3% accuracy, with some underperformance in distinguishing low-priority zones due to overlapping land cover classes and smaller unburned buffer zones. To evaluate model robustness, a One-At-a-Time (OAT) sensitivity analysis was conducted by perturbing each criterion's weight by ±20% and observing the resulting area changes in each priority class. Results showed that land cover, fire frequency, and burn severity were the most sensitive parameters, significantly influencing the size of high-priority zones. Less sensitive criteria included elevation, aspect, and precipitation, whose weight variation had minimal impact on final rankings.

4.4 Three-way Verification Protocol

All Green-HIT alerts, whether acoustic or visual, are routed through the *Green-HIT three-way verification protocol* to ensure accurate detection, rapid validation, and effective response to incidents. Upon detection of a fire or any illegal activity, the alert is logged and geo-referenced on the platform, relayed to the UAV ground station, and verified through live drone feed and optionally, on-site human confirmation.

Fig. 5 illustrates this process in action. Upon detection, the Web platform automatically highlights the event on its map interface and issues a notification in the designated alert area. These notifications are directly linked to the precise location of the triggered sensor. The location data is relayed to the drone operator's controller. This allows for seamless coordination between ground detection systems and aerial verification. Once activated, the drone navigates to the incident site and initiates a real-time video stream. This feed enables immediate situational awareness, helping stakeholders distinguish between false positives and actual threats, thereby enhancing the system's reliability. The three-way verification protocol serves as a layer of redundancy and trust in Green-HIT, ensuring that all alerts are verified swiftly and accurately before action is taken.

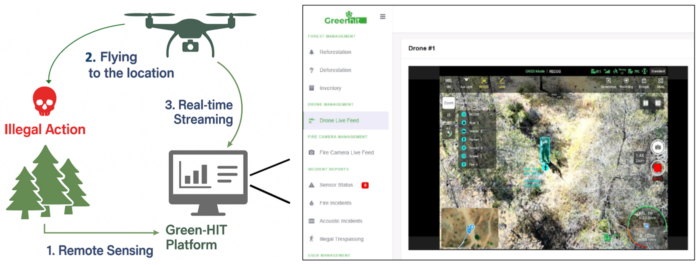

Figure 5. Green-HIT three-way verification protocol.

5. Green-HIT User Portals

5.1 Web-Based Monitoring and Management

The Green-HIT Web Dashboard is a central component designed to provide stakeholders with a comprehensive interface for forest monitoring, incident management, and environmental data analysis. Developed as a secure, user-authenticated system, it consolidates inputs from a wide array of sensors and subsystems into an intuitive and highly interactive Web environment.

At the core is the *Map Page* (Fig. 6), an interactive geospatial interface that visualizes real-time data from sensors, weather stations, and surveillance cameras. Each sensor type is represented with a unique icon and can be filtered by category. Users are alerted to events via the *Notification Center*, which provides actionable alerts such as illegal activity and fires, and supports immediate responses such as drone dispatch for live feed verification.

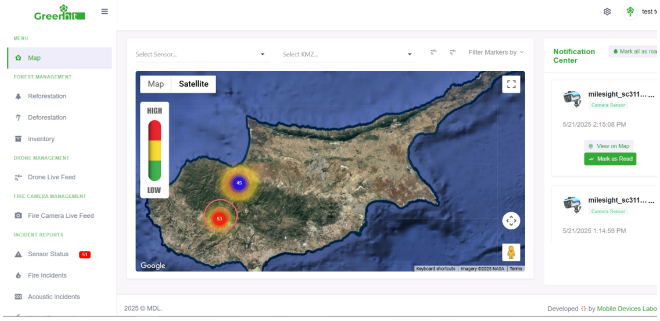

Figure 6. Green-HIT Web dashboard – *Menu* (left), *Map Interface* (centre), *Notification Centre* (right).

A key innovation lies in the dynamic fire probability visualization, where a color-coded map is overlaid based on algorithmically computed fire risk from live sensor data. In the case of a fire event, users can engage the fire reaction module, which simulates the fire's likely spread and direction, enabling faster and more informed response planning. Beyond fire detection, the platform supports reforestation and deforestation tracking, offering tools for both historical analysis and on-demand environmental assessments using satellite imagery and advanced image processing. Additional features include: (i) in-field data collection; (ii) a *Sensor Status Dashboard* that identifies offline or malfunctioning sensors; (iii) *Incident History Logs* for fire, acoustic, and illegal activity events; and (iv) interfaces for managing users and sensor deployments. Collectively, the platform functions as a multi-layered command center, blending situational awareness with historical insight and operational control to support data-driven management.

5.2 Smartphone Application for Field Data Collection and Awareness

The Green-HIT platform is complemented by a dedicated smartphone application that empowers field personnel with direct, on-the-ground interaction capabilities. Designed to operate as a lightweight and intuitive extension of the Web dashboard, the application facilitates both real-time situational awareness and crowdsourced environmental reporting. Upon login, users are presented with a map interface (Fig. 7, left) that displays active alerts and sensor data. Each map marker corresponds to a specific sensor event, and tapping the marker reveals contextual information, including timestamps and sensor metadata.

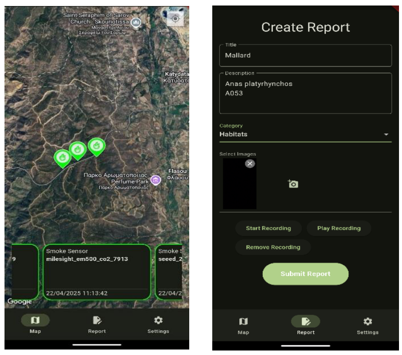

Figure 7. Smartphone app – *Map Interface* (left), *Report Submission* (right).

A core feature of the application is the *Field Reports* module, which allows users to browse past submissions and access historical reports directly from the field. These entries are visualized as a list or on the map, and each report includes metadata such as its description, time of submission, GPS coordinates, and attached media files.

The *Report Submission* interface (Fig. 7, right) allows users to quickly generate environmental reports. It includes fields for entering a title and description, a category selection

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dropdown for incident classification, image capture or upload functionality, audio recording tools, and an option for direct upload.

6. Pilot Deployments and Evaluation

To validate the full operational capacity of Green-HIT, an extensive series of pilot studies were conducted. The pilots tested the system in realistic conditions to ensure the effective integration of its hardware and software components. The primary pilot effort simulated a comprehensive deployment scenario using the three-way verification protocol, which combines automated sensor alerts with drone-assisted visual validation. Three real-world scenarios were tested: (i) *Fire breakout*, triggered by elevated CO_2 readings from composite sensors. (ii) *Illegal hunting*, detected via the audio recognition module identifying gunshots. The system localized the source and UAV footage confirmed the presence of a hunter (Fig. 8). (iii) *Illegal logging*: chainsaw activity was detected acoustically and verified via UAV flyover, which led to identification and virtual flagging of the perpetrator. Each scenario demonstrated the system's ability to transition smoothly from sensing to analysis to decision-making.

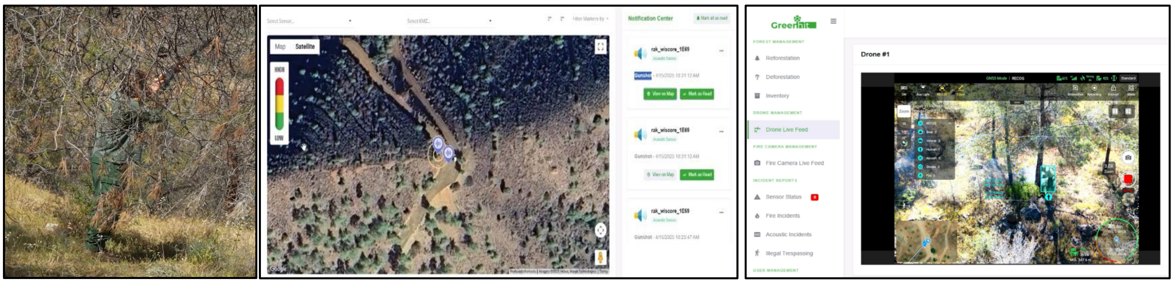

Figure 8. Illegal hunting pilot scenario – in-field hunter (left), Green-HIT Web dashboard alert (centre), three-way verification protocol live drone feed (right).

Complementary evaluations targeted specific additional functionalities, namely: (i) UAV flights: routes were mapped across multiple forested areas in Cyprus, testing both quadcopters and VTOL UAVs under constraints such as 60-minute endurance and 120m flight ceilings; (ii) Trespassing: camera and audio modules were deployed to detect unauthorized vehicle access along a hiking trail; and (iii) IoT sensor reliability: sensors were installed for a 12-month period and evaluated on accuracy, communication quality, and battery lifespan.

A field-testing matrix confirmed successful performance across all core elements. Composite sensors passed all tests including power consumption, bidirectional communication, and accuracy. LoRaWAN infrastructure demonstrated full reliability, scalability, and secure data transmission. UAV systems successfully passed tests on flight stability, environmental resilience, and video streaming. Finally, the Web and smartphone applications met acceptance criteria with seamless integration into the data ecosystem. Nevertheless, several implementation challenges were identified. Some devices were stolen despite efforts to conceal or harden installations. Areas with poor cellular coverage introduced latency in UAV control and video transmission. Starlink was deployed as a solution, but proved sensitive to weather conditions. Chainsaw detection required elevated placement for effective coverage, and sound muffling by terrain posed additional constraints. Finally, limited access to forest-area weather data and missing meteorological features (e.g., fuel moisture content) reduced the predictive power of fire modeling. Despite these limitations, all modules were successfully integrated and tested in the field, validating the system's end-to-end functionality.

7. Conclusions

This paper presented Green-HIT, a holistic IoT-based system for forest management and environmental monitoring through the seamless integration of remote sensing, edge-based detection, drone-assisted verification, and centralized data analytics. The system is composed of a rich set of interoperable components, including a dynamic Web dashboard, a smartphone field application, a network of heterogeneous sensors, and AI-enhanced incident detection modules. Real-world pilot deployments validated the system's operational robustness, responsiveness, and usability under varied environmental conditions. The three-way verification protocol demonstrated particular value in minimizing false positives and enabling timely interventions.

Evaluation results confirmed the system's effectiveness across all technical domains, from communication reliability and sensing accuracy to UAV performance and UI integration. Lessons learned from in-field testing highlighted areas for further improvement, particularly in regard to data coverage, connectivity limitations in remote terrain, and audio recognition under complex landscape conditions. Green-HIT lays the foundation for a scalable and modular smart environmental surveillance infrastructure. It offers a strong basis for national-level rollouts and future R&D activities, particularly in integrating satellite-based analytics, predictive fire modeling, and deeper community engagement in forest conservation efforts.

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