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Executive Summary

Deliverable D5.3 outlines the testing and verification activities conducted as part of the Green-HIT's technical development. It presents the methodology, tools, and results of unit testing procedures applied to ensure each individual software component functions correctly and according to the specifications. The document provides detailed insight into how different modules were verified independently, highlighting the final validation status. The goal of this deliverable is to demonstrate the technical robustness, functional reliability, and readiness of the developed components for integration and deployment within the Green-HIT ecosystem.

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1. Introduction

This deliverable presents the Unit Testing and Verification Plan and its corresponding results for the Green-HIT platform. Unit testing serves as a foundational step in the software validation lifecycle, ensuring that discrete software modules perform as expected in isolation. This report covers both the planning and execution phases, including the test environment setup, definition of testing objectives, and the verification methodologies employed. By adhering to systematic testing procedures, this deliverable aims to mitigate risks associated with faulty module behavior, thereby reinforcing the overall integrity of the system.

The remainder of this deliverable is structured as follows:

- Section 2 presents the unit tests for Green-HIT's afforestation/reforestation intelligence modules.
- Section 3 presents the unit tests for Green-HIT's fire-related intelligence modules (i.e., prevention, detection, and reaction to forest fires).
- Section 4 presents the unit tests for Green-HIT's intelligence modules related to detection of illegal activities (i.e., illegal logging, hunting, and trespassing).
- Section 5 presents the unit tests for Green-HIT's hardware components developed by the project.
- Section 6 presents the unit tests for Green-HIT's Web application.
- Section 7 presents the unit tests for Green-HIT's smartphone application.
- Section 8 concludes the deliverable.

2. Green-HIT Intelligence: Afforestation/Reforestation & Deforestation Modules

Module Name	Unit Test ID	Description	Input	Expected Output	Result (Pass/Fail)	Remarks
Afforestation/ Reforestation Module	ARF-01	Sentinel-2 (S2) ingestion and preprocessing: data availability & cloud masking.	Raw S2 imagery	Cloud-masked imagery.	Pass	-
Afforestation/ Reforestation Module	ARF-02	Spectral index calculation: NBR/dNBR indices calculation and thresholding.	Bands B8, B12.	NBR, dNBR.	Pass	-
Afforestation/ Reforestation Module	ARF-03	Burn severity classification: threshold-based reclassification.	dNBR index.	Burn severity map.	Pass	-
Afforestation/ Reforestation Module	ARF-04	CORINE land cover reclassification: land cover remapping.	COPERNICUS-CORINE dataset.	Remapped land cover.	Pass	-
Afforestation/ Reforestation Module	ARF-05	MODIS LST: reclassify LST data.	MODIS/061/ MOD11A1 imagery.	Reclassified LST.	Pass	-
Afforestation/ Reforestation Module	ARF-06	CHIRPS precipitation reclassification.	UCSB-CHG/CHIRPS/ DAILY imagery.	Reclassified precipitation.	Pass	-
Afforestation/ Reforestation Module	ARF-07	Topographic features: reclassify features.	USGS/SRTM GL1_003 data.	Topographic layer.	Pass	-
Afforestation/ Reforestation Module	ARF-08	Tree density: reclassify tree density data.	Tree density datasets (D_2012, TD_2015, TD_2018 assets).	Reclassified TD.	Pass	-
Afforestation/ Reforestation Module	ARF-09	Fire history integration: temporal difference & proximity.	Fire history layers and Euclidean distances.	Weighted fire impact.	Pass	-
Afforestation/ Reforestation Module	ARF-10	Weighted overlay scoring: using multi-criteria expression calculation.	Reclassified layers.	Suitability score.	Pass	-
Afforestation/ Reforestation Module	ARF-11	Priority reclassification: rule-based raster classification.	Weighted overlay scores.	Priority zones.	Pass	-

Afforestation/ Reforestation Module	ARF-12	Patch smoothing: pixel filtering.	ConnectedPixelCount, focal_mode.	Smoothed patches.	Pass	-
Afforestation/ Reforestation Module	ARF-13	Visualization: render final output.	GEE and geemap.	Display in UI.	Pass	-
Afforestation/ Reforestation Module	ARF-14	Accuracy: overall classification accuracy.	Reference data.	72.3% - 80.9%.	Pass	-
Afforestation/ Reforestation Module	ARF-15	Precision: proportion of true positives per class.	Prediction vs ground truth.	Low (0.15-0.53), Medium (0.14-0.89) and High (0.66-0.98)	Pass	-
Afforestation/ Reforestation Module	ARF-16	Recall: proportion of true positives per class.	Prediction vs ground truth.	Low (0.77-0.83), Medium (0.81-0.84) and High (0.70-0.72)	Pass	-
Afforestation/ Reforestation Module	ARF-17	F1-Score: harmonic mean of precision and recall per class.	Precision & recall.	Low (0.25-0.65), Medium (0.25-0.87) and High (0.68-0.83)	Pass	-
Afforestation/ Reforestation Module	ARF-18	Inference time: prediction speed on new data (in GEE).	Full GEE run.	Fast: 5-10 for large area.	Pass	-
Afforestation/ Reforestation Module	ARF-19	Resource consumption: computational requirements.	GEE runtime.	Low – uses GEE; suitable for operational scaling.	Pass	-
Deforestation Module	DF-01	S2 Pre/Post: data availability & cloud masking.	Raw S2 imagery.	Cloud-masked composites.	Pass	-
Deforestation Module	DF-02	Spectral indices calculation: indices & thresholding.	S2 bands.	Normalized indices.	Pass	-
Deforestation Module	DF-03	Normalization: normalize spectral index values.	Spectral indices.	MinMax scaled data.	Pass	-
Deforestation Module	DF-04	Change detection: Euclidian spectral distance.	Normalized pre/post images.	Spectral distance map.	Pass	-
Deforestation Module	DF-05	Otsu thresholding: adaptive thresholding.	Spectral distance histogram.	Binary change mask.	Pass	-
Deforestation Module	DF-06	Land cover filtering: mask using CORINE land cover.	CORINE 2012/2018.	Masked change areas.	Pass	-

Deforestation Module	DF-07	Change reclassification.	Change mask.	Change categories: 1: Fire, 2: Forest, 3: Agriculture, 4: Water, 5: Urban	Pass	-
Deforestation Module	DF-08	Tree density reclassification.	TD datasets (TD_2012, TD_2015, TD_2018)	Reclassified TD.	Pass	-
Deforestation Module	DF-09	Vegetation Loss/Gain reclassification: threshold-based differencing.	Spectral indices.	Loss/gain categories.	Pass	-
Deforestation Module	DF-10	Visualization: render change maps.	Classified layers.	Layer in UI.	Pass	-
Deforestation Module	DF-11	Accuracy: overall proportion of correctly classified instances.	Reference data.	78.6%	Pass	-
Deforestation Module	DF-12	Inference time: prediction speed on new data (in GEE).		Fast: 5-10 for large area.	Pass	-
Deforestation Module	DF-13	Resource consumption: computational requirements.		Low – uses GEE; suitable for operational scaling.	Pass	-

3. Green-HIT Intelligence: Fire Detection, Prevention, and Reaction Modules

Module Name	Unit Test ID	Description	Input	Expected Output	Result (Pass/Fail)	Remarks
Fire Prediction Module	FP-001	Validate XGBoost model accuracy on historical weather and fire data.	Temperature, relative humidity, date, location.	Prediction of fire occurrence (Yes/No) with >80% accuracy.	Pass	Achieved 83.03% accuracy after feature engineering.
Fire Detection Module	FD-001	Trigger fire alert based on CO2 thresholds and prediction score.	CO2 level, fire risk score.	Alert triggered under high CO2 and high risk.	Pass	Adaptable threshold depending on fire risk.
Fire Propagation Module	FPR-001	Compute new fire front location based on wind direction and distance.	Initial fire coordinates, wind bearing.	New lat/long coordinates 150m away in wind direction.	Pass	Uses Great-Circle Navigation calculations
Fire Propagation Module	FPR-002	Calculate rate of spread based on wind and slope.	Flat ROS, wind factor, slope factor.	Adjusted ROS value.	Pass	ROS increases realistically with both parameters.
Fire Propagation Module	FPR-003	Identify nearest weather station using Haversine formula.	Sensor coordinates, list of station coordinates.	Closest station ID.	Pass	Ensures accurate environmental data matching.

4. Green-HIT Intelligence: Illegal Logging, Hunting, and Trespassing Detection Modules

Module Name	Unit Test ID	Description	Input	Expected Output	Result (Pass/Fail)	Remarks
In-situ Logging & Hunting Detection	ILH-01	Detect chainsaw sound.	Audio sample with chainsaw noise.	Classified as Chainsaw.	Pass	98.1% accuracy.
In-situ Logging & Hunting Detection	ILH-02	Detect gunshot sound.	Audio sample with gunshot.	Classified as Gun.	Pass	91.2% accuracy.
Cloud Logging & Hunting Detection	CLH-01	Classify ESC-10 audio clips.	ESC-10 test dataset.	Accurate classification.	Pass	98.75% accuracy with YAMNet.
In-situ Trespassing Detection (Audio)	ITA-01	Detect vehicle engine sound.	Audio sample with vehicle engine noise.	Classified as Engine.	Pass	100% accuracy, 8% False Positives.
In-situ Trespassing Detection (Camera)	ITC-01	Capture trespassing vehicle.	Motion detection at trail entrance.	Capture image and log event.	Pass	Validated via platform logs.
Cloud Trespassing Detection	CTD-01	Detect vehicle-related audio activity.	Uploaded audio with vehicle engine sounds.	Classified as vehicle-related activity.	Pass	Classified using YAMNet.

5. Green-HIT Hardware Components

Module Name	Unit Test ID	Description	Input	Expected Output	Result (Pass/Fail)	Remarks
Composite Sensors - Network	HW-01	Check stable LoRaWAN coverage and packet loss under 10%.	Installed sensors and gateways.	Packet loss ≤ 10%, stable signal.	Pass	Relocation done for devices exceeding threshold.
Composite Sensors - Data Output	HW-02	Evaluate sensor accuracy and data integration.	CO2, Weather sensors; platform connectors.	Accurate values, data visible on platform.	Pass	Tested with real events and alarms triggered
Audio Module - Accuracy	HW-03	Measure detection accuracy of models in real conditions.	Gunshot, Chainsaw, Engine sounds.	95.9% (hunting/logging), 97.2% (trespassing).	Pass	Gunshot accuracy drops slightly in field.
Audio Module - Effective Range	HW-04	Test sound detection based on distance,	Audio sources at various ranges.	Accurate detection within expected coverage.	Pass	Gunshot: long range OK; Chainsaw: needs elevation.
Audio Module - Power Autonomy	HW-05	Verify solar-powered continuous operation.	Solar-powered modules.	One week autonomy without sun.	Pass	Hourly keep-alive signals confirm uptime.
VTOL UAV - Ground Testing	HW-06	Test motor, tilt system, and control calibration,	Cube Orange + tilting motors.	Stable motor response & actuator cycles.	Pass	Minor tilt issue resolved via calibration.
VTOL UAV - Flight Testing	HW-07	Validate vertical and forward flight + payload ops.	Full VTOL UAV	Stable hover, 60+ min endurance.	Pass	Smooth transitions after PID tuning.
Quadcopter - Ground Testing	HW-08	Check system integration, GPS, LiDAR, telemetry.	Cube Orange, sensors, FPV.	All subsystems respond correctly.	Pass	Interference resolved via calibration.
Quadcopter - Flight Testing	HW-09	Evaluate camera, gimbal, low-hover stability.	Visual/Thermal camera gimbal.	Stable image capture, obstacle avoidance.	Pass	All systems validated.
Starlink - UAV Comm	HW-10	Test connectivity in remote areas using Starlink.	Starlink router at control center.	Low latency, no disconnections.	Pass	Solved cellular issues.

Crash Tolerance	HW-11	Report outcome and recovery after UAV crash.	Damaged quadcopter.	Alternate UAV successfully used.	Pass	No project delay.

6. Green-HIT Web Platform

Module Name	Unit Test ID	Description	Input	Expected Output	Result (Pass/Fail)	Remarks
Web Platform - General Performance	WEB-01	Ensure all platform features load within acceptable time.	Platform UI, maps, dashboards.	Load time under 5 seconds.	Pass	Measured across key pages under normal load.
Web Platform - API Response	WEB-02	Verify API responds within acceptable time frame.	Fetch latest sensor data via API.	Response time under 8 seconds.	Pass	Tested with current server load.
Web Platform - External Algorithms	WEB-03	Check for errors and stability in external calls.	Trigger external ML/AI algorithms	Process completed without crash.	Pass	Timing not enforced; depends on external services.
Web Platform - Scalability	WEB-04	Ensure platform can integrate new sensors without code changes.	Add fire, acoustic, and weather sensors.	Seamless integration.	Pass	Dynamic module handles added sensor data.
Web Platform - Security	WEB-05	Verify secure data transmission and backend integrity.	Sensor and user data interactions.	SSL encryption, secure DB.	Pass	Verified ASP.NET Core + MSSQL configuration.

7. Green-HIT Smartphone Application

Module Name	Unit Test ID	Description	Input	Expected Output	Result (Pass/Fail)	Remarks
Mobile App - Login	MOB-01	Successful login with valid credentials.	Valid username/ password.	Navigates to map page.	Pass	
Mobile App - Login	MOB-02	Login fails with invalid credentials.	Invalid login input.	Error message shown, access denied.	Pass	
Mobile App - Map Page	MOB-03	Map loads correctly with markers.	Open map screen.	Map and markers visible.	Pass	
Mobile App - Map Page	MOB-04	Tap sensor marker displays details.	Tap on sensor icon.	Sensor ID and timestamp shown.	Pass	
Mobile App - Reporting	MOB-05	Submit report with all fields filled.	Filled form + image/audio.	Report submitted to backend.	Pass	
Mobile App - Reporting	MOB-06	Submit report with missing title.	Form with missing required field.	Validation error shown.	Pass	
Mobile App - Reporting	MOB-07	Image/audio attachment handling.	Select/upload/ delete media.	Media handled correctly.	Pass	Audio recorded and played back.
Mobile App - Reporting	MOB-08	Category dropdown functionality.	Open and select category.	All categories available.	Pass	
Mobile App - Settings	MOB-09	Toggle Dark Mode.	Enable/disable Dark Mode.	Theme changes immediately.	Pass	
Mobile App - Settings	MOB-10	Logout functionality.	Tap Logout.	Returns to login screen.	Pass	
Mobile App - Security	MOB-11	Credentials securely stored.	Login and check local storage.	Encrypted credentials.	Pass	
Mobile App - Security	MOB-12	API communication uses HTTPS.	App-server communication.	All calls over HTTPS.	Pass	

8. Conclusions

The unit testing and verification efforts detailed in this deliverable have confirmed the functional soundness of the Green-HIT platform's modular components. The testing process identified and resolved minor issues, each of which was adequately documented and addressed. All modules have passed their respective verification criteria, demonstrating compliance with the initial design specifications. D5.3 thus substantiates the system's readiness for further integration and full-scale testing activities as planned in subsequent phases of the project.