# EARTH OBSERVATION FOR SDG TARGETS AND INDICATORS, LOT-1

# SDG 15.2.1 EO PATHFINDER: EO FOR SUSTAINABLE FOREST MANAGEMENT

## D8.3 Final Report

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# Acronyms and Abbreviations

| Abbr. | Description |
|---|---|
| EA | Early Adopter |
| EO | Earth Observation |
| ESA | European Space Agency |
| SDG | Sustainable Development Goals |

| Abbr. | Description |
|---|---|
| TEP | Forestry Thematic Exploitation Platform |
| WB | World Bank |
| SWIR | short wavelength infrared |
| NIR | Near infrared |

| Abbr. | Description |
|---|---|
| VI | Vegetation Index / Indices |
| NDVI | Normalized Difference Vegetation Index |
| CVA | Change Vector Analysis |
| BFAST | Breaks For Additive Seasonal and Trend |

# Applicable Documents

| Ref. | Title | Version | Date |
|---|---|---|---|
| [AD01] | McGarigal K., SA Cushman, and E Ene. 2023. FRAGSTATS v4: Spatial Pattern Analysis Program for Categorical Maps. Computer software program produced by the authors; available at the following web site: https://www.fragstats.org | V4 | 2023 |

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| [RD01] | Transforming our world: the 2030 Agenda for Sustainable Development, 2015 https://documents-dds-ny.un.org/doc/UNDOC/GEN/N15/291/89/PDF/N1529189.pdf?OpenElement | 2015/10/21 |
| [RD02] | FACTSHEETS ON THE 21 SDG INDICATORS UNDER FAO CUSTODIANSHIP https://www.fao.org/3/ca8958en/CA8958EN.pdf | 2020 |
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| Ref. | URL | Description | Last access |
|---|---|---|---|
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| [URL02] | https://land.copernicus.eu/en/faq/general-questions/what-is-the-nuts-classification | What is the NUTS classification? | 2024/06/26 |
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| [URL04] | https://f-tep.com/wp-content/uploads/2020/10/F-TEP_User_Manual_v2019.12.pdf | F-TEP User Manual | 2024/06/28 |
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| [URL06] | https://www.globalforestwatch.org/ | Global Forest Watch | 2024/12/12 |
| [URL07] | https://www.fao.org/forest-resources-assessment/past-assessments/fra-2020/en/ | Global Forest Resources Assessment 2020 | 2023/04/18 |
| [URL08] | https://www.fao.org/forest-resources-assessment/en/ | Global Forest Resources Assessments | 2023/04/18 |

# 1 Executive summary

The project, "Earth Observation for Sustainable Development Goals - Forest management," aimed to leverage Earth Observation (EO) technologies to support reporting and decision-making under Sustainable Development Goal (SDG) 15, specifically focusing on sustainable forest management. SDG 15 targets the preservation, restoration, and sustainable use of terrestrial ecosystems, with forest ecosystems playing a pivotal role. Accurate monitoring and reporting are essential for addressing deforestation, forest degradation, and biodiversity loss.

This project worked on developing cutting-edge EO solutions aligned with SDG indicators, particularly 15.1.1 (forest area change) and 15.2.1 (progress toward sustainable forest management). The project was designed to bridge the gap between advanced EO technologies, and the practical needs of national and international stakeholders involved in forest management and SDG reporting. It leveraged modern computational techniques and cloud infrastructure to provide scalable solutions that could be adapted to various contexts and challenges faced by countries striving to meet SDG 15 targets.

**Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss**

The project had a distinct user centric focus. The user engagement phase involved discussions with potential users to understand their needs and priorities. This was followed by a proof-of-concept phase, during which various algorithms were developed and rigorously tested. Users were involved throughout the process of development and testing. Over the course of the project technical teams collaborated with international stakeholders to identify and refine specific EO requirements. The final implementation phase saw the most prospective solutions deployed with further iterative improvements based on feedback and evolving requirements. Together, all phases ensured the creation of a comprehensive and effective EO solution tailored to SDG 15 reporting requirements.

The Project worked on the development included the following products:

1. Forest Mask: This workflow generated maps of forest cover using satellite imagery and machine learning techniques. It enabled the identification of deforestation hotspots, aiding policymakers in prioritizing conservation efforts.

2. Above-Ground Biomass: Advanced radar and optical data analysis provided reliable biomass estimates, which are critical for understanding carbon stock dynamics.

3. Forest Condition Monitoring: Metrics for vitality and disturbance were developed using vegetation indices and time-series analysis. These metrics helped assess ecosystem health and resilience.

4. Erosion and Landslide Risk Mapping: Risk models leveraged topographic and land-cover data to predict vulnerable areas, supporting proactive risk mitigation strategies.

5. Landscape metrics: metrics on the patch, class, and landscape level useful for the study of landscape patterns, the interactions between patches within a landscape mosaic, and how these patterns and interactions change over time.

This report summarizes the work done and discuses the technical and institutional challenges encountered. It also outlines a roadmap for future development in the context of application of EO technologies for SDG 15 reporting.

# 2 User engagement

The initial phase of the project emphasized engaging with stakeholders to ensure that the solutions met practical needs. This involved a detailed review of global and regional SDG reporting frameworks combined with networking with prospective early adopters. An initial list of candidate users was compiled and narrowed down in the first months of the project to 3 main user groups - the Forest Inventory Institute of Vietnam (FIPI), the Ethiopian Forestry Development (EFD), and a non-profit organisation operating in central African region.

A comprehensive literature review was conducted for each user country to establish the baseline status of sustainable forest management practices in those countries. This was complemented by interviews with key stakeholders, including forestry officials and environmental policymakers, to gain a nuanced understanding of their needs and constraints. Additionally, questionnaires were distributed to assess the current practices and challenges in sustainable forest management, providing valuable insights into data availability, technical capacities, and institutional priorities. Workshops, consultations, and surveys were conducted with forestry agencies, national statistical offices, and international organizations. Through these engagements, the project team identified key user needs, such as the demand for high-resolution, reliable, and scalable EO technologies to support SDG reporting.

Outcomes from these discussions played an important role in shaping the project's scope, focusing on addressing specific indicators such as forest area change (15.1.1) and progress toward sustainable forest management (15.2.1). Stakeholder input highlighted the importance of interoperability, ease of use, and integration into existing workflows, which guided the design and implementation phases of the project.

# 3 SDG Reporting

The Sustainable Development Goals (SDGs), also known as the Global Goals, were adopted by the United Nations in 2015 as a universal call to action to end poverty, protect the planet, and ensure that by 2030 all people enjoy peace and prosperity. The 2030 Agenda for Sustainable Development [RD01] includes 17 SDGs and 169 associated targets. All 193 United Nations member states have committed to achieve sustainable development across its three dimensions – economic, social, and environmental – in a balanced and integrated manner.

The 17 SDGs are integrated—they recognize that action in one area will affect outcomes in others, and that development must balance social, economic, and environmental sustainability. Goal 15 Life on Land is concerned with the protection, restoration and sustainable use of terrestrial ecosystems, and sustainable forest management. Within Goal 15 Targets 15.1 and 15.2 are directly related to forest ecosystems.

The 2030 Agenda has established a reporting framework with goals, targets and indicators, which relies on inputs from local, national and regional levels. The Food and Agriculture Organization of the United Nations (FAO) is the custodian agency for SDG indicators related to Goal 15 Living on land [RD02].

As a custodian agency, FAO is responsible for:

- developing methodologies to measure progress
- collecting data from countries
- compiling and submitting data and storylines to the United Nations Statistical Division; and
- contributing to developing countries' reporting capacity.

Data collection and reporting for SDG Indicators 15.1.1 and 15.2.1 (Table 2 and Table 3) is conducted through the Global Forest Resources Assessment (FRA). FRA is a well-established programme led by FAO's Forestry Department since 1946 [URL08]. It reports on the extent and changes of the world's forest area, as well as on other variables, including forest ownership and management rights, and legal and institutional frameworks for sustainable forest management. The last FRA Report was published in 2020 [URL07]

The process of reporting (to the FRA Programme) on Indicators 15.1.1 and 15.2.1 involves the following steps:

- National Correspondents (NCs), officially nominated by National Forest authorities, compile and submit official national data to FAO, in coordination with National Statistical Offices.
- The FRA team reviews data and reverts to NCs if necessary.
- Countries validate the data. Once finalized by FAO, the data are sent back to the countries for official validation.
- SDG Indicators 15.1.1 and 15.2.1 are compiled by FAO and submitted to the UN Statistics Division.


Figure 1 **Reporting workflow for Forest Resource Assessment (FRA)**

## 3.1 Use of EO for SDG reporting

Earth Observation (EO) technologies have revolutionized the ability to monitor, understand, and manage natural resources. In the context of the United Nations' Sustainable Development Goals (SDGs), particularly SDG 15: Life on Land, EO provides data and insights critical for tracking progress toward sustainable forest management. By enabling the mapping and monitoring of deforestation, forest degradation, and land-use change, EO supports key SDG indicators which measures progress toward sustainable forest management.

Satellite imagery, including data from Sentinel-2 and Landsat missions, offers global and local-scale insights into forest health, biomass, and carbon stock assessments. These data support carbon accounting, emission reduction strategies, and policy implementation by providing standardized, cost-effective monitoring solutions, particularly in remote and inaccessible areas.

Platforms such as Forestry Thematic Exploitation Platform (F-TEP) [URL05] and Global Forest Watch (GFW) [URL06] exemplify how EO applications can be made available to various stakeholder groups and enable governments, researchers, and policymakers to make data-driven decisions. These platforms provide accessible, high-resolution imagery and analytics to detect and monitor deforestation in near real-time, helping countries streamline reporting on forest conservation and restoration efforts.

## 3.2 The Vietnam Case

Vietnam has made significant strides in sustainable forest management, driven by national policies such as the "Vietnam Forestry Development Strategy" and its commitment to international initiatives like REDD+ (Reducing Emissions from Deforestation and Forest Degradation). The framework for forest management in Vietnam includes a blend of legal, institutional, and policy measures aimed at ensuring sustainable forestry practices.

### 3.2.1 Policy Framework and National Strategies

The "Vietnam Law on Forestry 2017" serves as the cornerstone for forestry governance, encompassing sustainable use, conservation, and development of forest resources.

Vietnam's forestry strategy for the 2021–2030 period emphasizes the restoration and sustainable management of degraded forests, aiming to increase forest coverage and contribute to climate change mitigation.

### 3.2.2 Institutional Setup

The Ministry of Agriculture and Rural Development (MARD) oversees forestry management and policy-making, supported by provincial and district-level forestry authorities.

Partnerships with NGOs and international organizations play a crucial role in capacity-building and technical support.

### 3.2.3 Current Practices and Technologies

Vietnam employs a mix of traditional forestry practices and modern technologies. Geographic Information Systems (GIS) and remote sensing are widely used for forest monitoring and planning.

The National Forest Inventory (NFI) provides critical data for assessing forest resources and trends.

### 3.2.4 Key Challenges

Gaps in technical expertise and infrastructure limit the effective implementation of advanced EO technologies.

There is a need for better alignment of forestry policies with SDG indicators to enhance monitoring and reporting capabilities.

Data-sharing constraints among national institutions impede collaborative efforts.

### 3.2.5 Achievements and Progress

Vietnam has successfully increased its forest coverage to over 40%, achieving one of the highest reforestation rates in Southeast Asia.

Initiatives such as Payments for Forest Environmental Services (PFES) have provided financial incentives for sustainable forest management.

# 4 Algorithm proof of concept

In the proof-of-concept phase, multiple EO algorithms were developed, tested, and validated to address specific challenges in monitoring forest ecosystems. The project team carefully selected methods based on theoretical robustness, computational efficiency, and operational feasibility. Advanced machine learning models, such as random forests and convolutional neural networks, were applied to high-resolution satellite imagery for forest cover monitoring. Additionally, time-series analysis methods were tested to detect temporal changes in forest health and cover, allowing for the identification of degradation trends. For above-ground biomass estimation, both optical and synthetic aperture radar (SAR) data were employed, with algorithms such as regression-based models and neural networks used to calculate biomass metrics. Alternative approaches like object-based image analysis (OBIA) and spectral unmixing were also evaluated to improve accuracy in heterogeneous forest landscapes. These comparative tests ensured that the selected methods were not only accurate but also adaptable to the diverse ecological conditions of the user countries. A significant effort was also made to ensure the scientific validity of these methods, with thorough testing conducted in different ecological contexts. These efforts culminated in the identification of the most effective approaches for scaling and operational use, providing a strong foundation for subsequent implementation.

# 5 Solution Development

The Earth Observation solution developed under this project is a robust and versatile tool designed to support SDG 15 reporting. At its core, the solution leverages satellite imagery or other spatial data to monitor forest dynamics and assess sustainable forest management practices. The system enables continuous monitoring of forest cover, providing actionable insights into trends such as deforestation rates, forest degradation, and the success of reforestation efforts.

The implementation phase focused on operationalizing the EO solutions by integrating the selected algorithms into the Forestry Thematic Exploitation Platform (F-TEP). This cloud-based platform provided an end-to-end workflow, enabling users to process raw satellite data into actionable insights. The workflows included automated steps for data preprocessing, classification, and reporting, ensuring consistency and scalability across applications.

This phase also involved iterative improvements based on user feedback and validation studies. The algorithms selected for the project underwent rigorous testing and validation to ensure their reliability and accuracy. For example, machine learning-based classification algorithms were employed for land cover mapping, while radiometric correction techniques ensured the consistency of satellite imagery across temporal datasets. These workflows were systematically documented to facilitate reproducibility and scalability, allowing other countries to adopt similar approaches for their SDG reporting.

From a scientific and technological perspective, the EO solution demonstrates a high level of maturity. The System Readiness Level (SRL) is well-defined, reflecting the comprehensive integration of algorithms, workflows, and cloud-based systems into operational settings. The Technology Readiness Level (TRL) is equally advanced, with the solution validated through extensive pilot studies and feedback from end-users. This maturity underscores the reliability and robustness of the solution for long-term application in SDG 15 monitoring. The Solution Development included the following products.

## 5.1 Forest Mask

This workflow generated maps of forest cover using satellite imagery and machine learning techniques. It enabled the identification of deforestation hotspots, aiding policymakers in prioritizing conservation efforts.

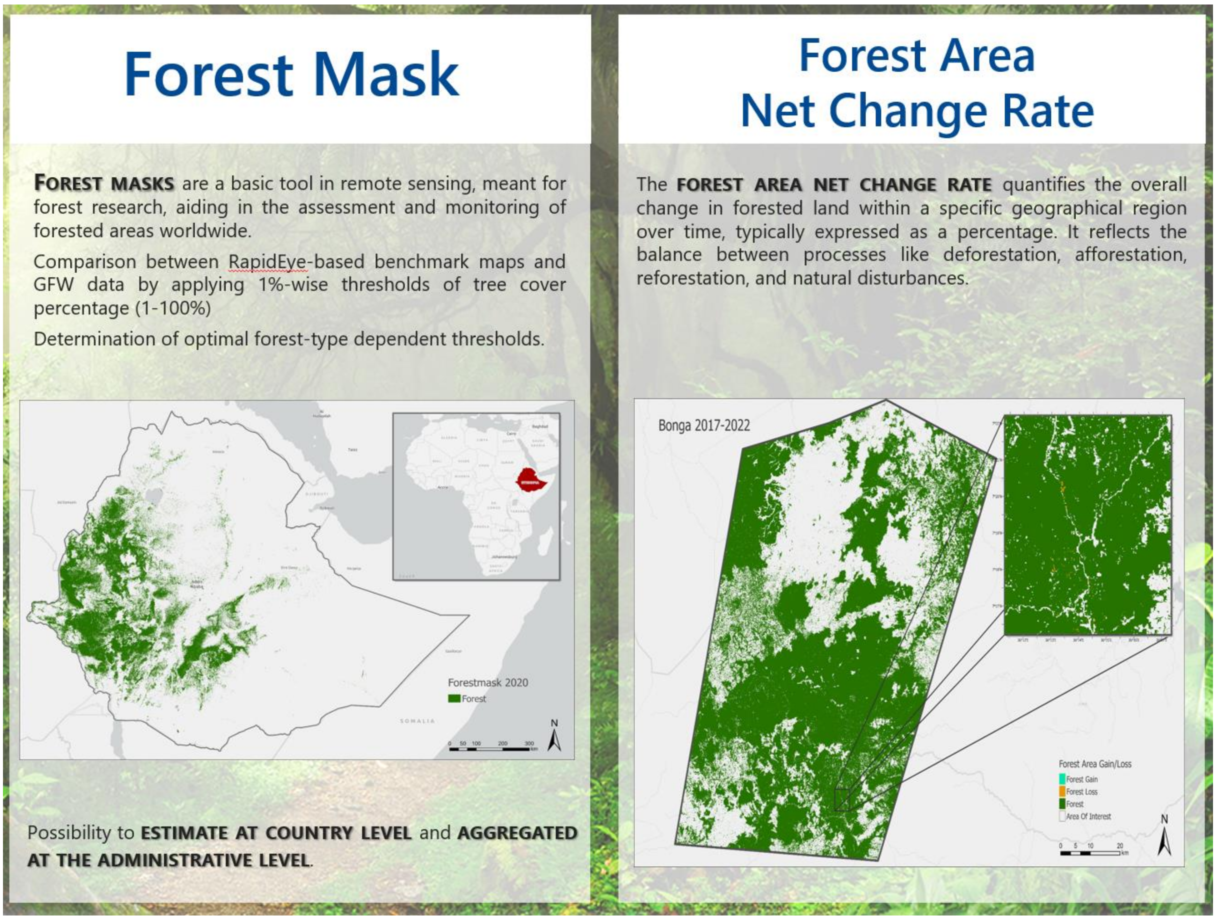


Figure 2. Forest Mask

## 5.2 Aboveground Biomass

Advanced radar and optical data analysis provided reliable biomass estimates, which are critical for understanding carbon stock dynamics.

## 5.3 Forest Condition Monitoring

Metrics for vitality and disturbance were developed using vegetation indices and time-series analysis. These metrics helped assess ecosystem health and resilience.

## 5.4 Erosion and Landslide Risk

Risk models leveraged topographic and land-cover data to predict vulnerable areas, supporting proactive risk mitigation strategies.

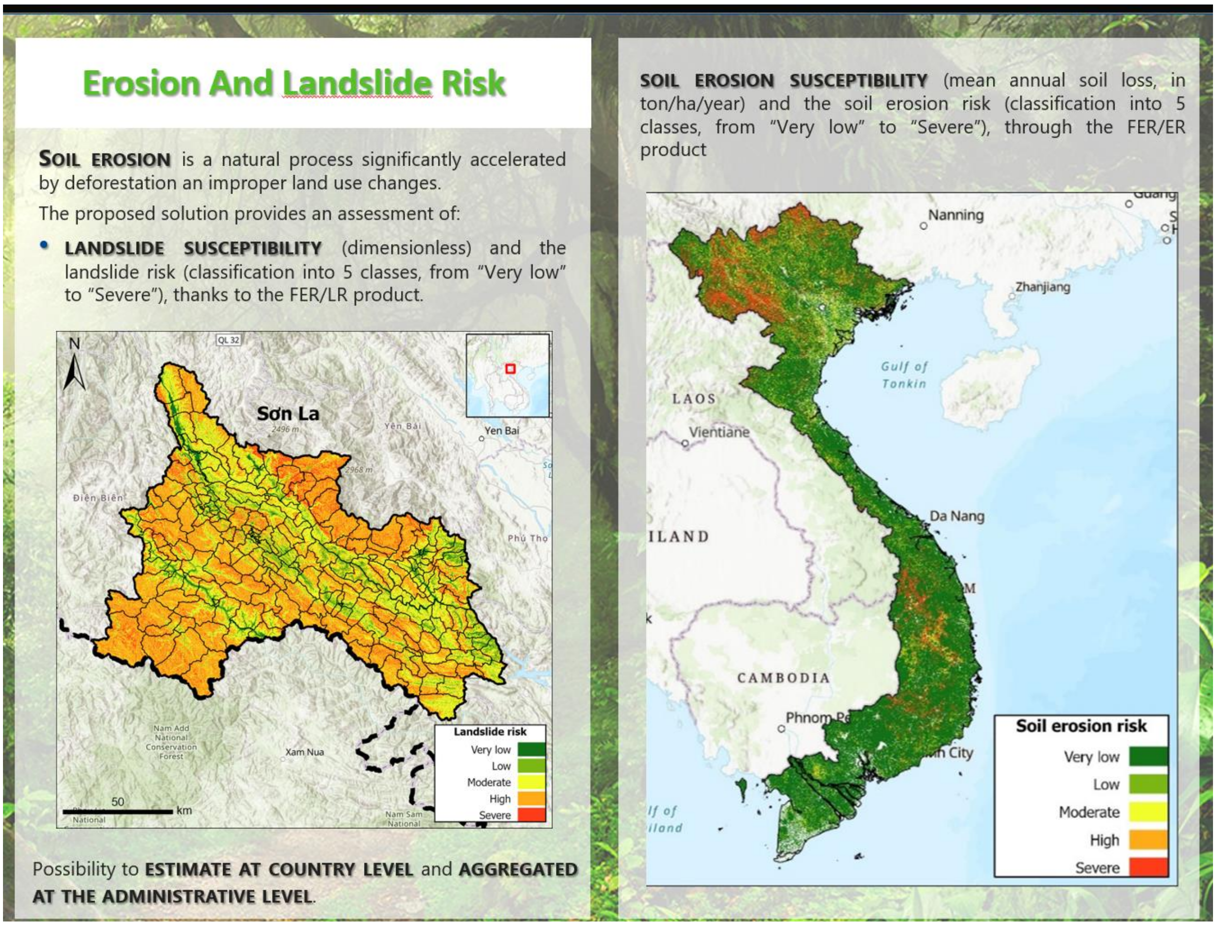


Figure 3. Erosion and Landslide Risk

## 5.5 Landscape Metrics

Metrics on the patch, class, and landscape level useful for the study of landscape patterns, the interactions between patches within a landscape mosaic, and how these patterns and interactions change over time.

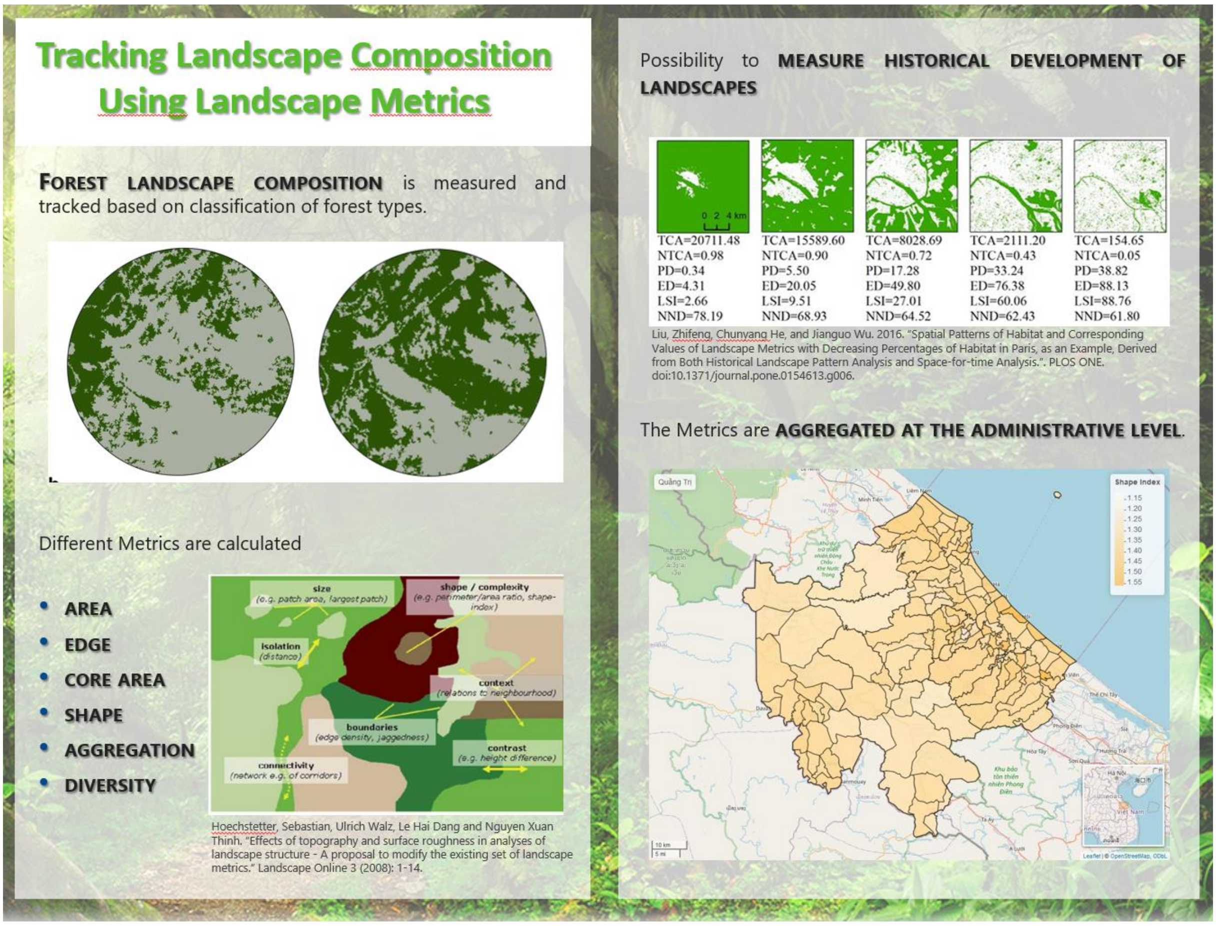


Figure 4. Landscape Metrics

# 6 Challenges

Throughout the project, several institutional and technological challenges arose, underscoring the complexities of integrating Earth Observation (EO) technologies into national and international frameworks for sustainable forest management. These challenges ranged from limited technical expertise and infrastructure gaps to issues of interoperability and data-sharing reluctance. Addressing these obstacles required a multifaceted approach, including capacity-building initiatives, the adoption of open standards, and fostering trust among stakeholders. This chapter delves into the key hurdles encountered during the project and discusses various strategies to overcome them.

One significant institutional challenge was the limited capacity of some national authorities to adopt EO technologies due to gaps in technical expertise, infrastructure, or policy alignment. Furthermore, institutions were primarily focused on activities such as conducting forest inventories, practical mitigation deforestation, and participating in carbon trading initiatives, which often took precedence over SDG reporting. To address these issues, the project emphasized capacity-building initiatives, including targeted training sessions and interactive workshops, to equip stakeholders with the necessary skills to interpret EO data and integrate it into their decision-making processes. Additionally, user manuals and guidelines were provided to ensure seamless implementation and to highlight the relevance of EO technologies in complementing existing forestry and climate-focused initiatives while addressing SDG reporting requirements.

From a technological perspective, ensuring interoperability between EO systems and existing national data infrastructures posed a significant challenge. Addressing this required the adoption of open standards and the development of customizable workflows that could integrate diverse datasets. The Forestry

Thematic Exploitation Platform (F-TEP) was instrumental in achieving this goal, offering a flexible environment where pre-processed data and algorithms could be adjusted to meet specific national requirements. However, the closed nature of the platform is a challenge that must be addressed. As mentioned above, interoperability and integration into existing institutional infrastructures are paramount. Future solutions must account for the state infrastructure of national authorities to ensure seamless adoption. For instance, the European Union has initiated efforts to create a unified European data space ecosystem, setting a precedent for fostering interoperability and standardization. Such international data standards would not only facilitate integration but also enhance the scalability and adaptability of EO solutions within diverse institutional frameworks.

Another significant challenge was gaining access to national datasets for calibration and validation of proof-of-concepts. Data was often unavailable or significant hurdles existed due to institutional reluctance to share data. This is due to various factors, including legal and policy constraints regarding data governance, concerns over data sensitivity, institutional inertia. Addressing this issue required building trust and fostering collaboration with national authorities. Demonstrating the added value of data sharing for development of innovative EO based solutions for monitoring and reporting on SDG is essential. Additionally, the project underscored the importance of establishing clear data-sharing agreements and aligning solutions with international standards to ensure transparency and interoperability.

From a technological standpoint, ensuring interoperability between the Forestry Thematic Exploitation Platform (F-TEP) and national systems was crucial. The project advocates for the future adoption of open standards to enable seamless integration, allowing EO solutions to function harmoniously with existing infrastructures. This posed a significant challenge, requiring the development of customizable workflows capable of integrating diverse datasets. The cloud-based architecture of F-TEP optimized processing capabilities, reducing the reliance on extensive local infrastructure and ensuring accessibility for users in diverse regions. However, the platform's closed nature remains a challenge that must be addressed to achieve full interoperability and integration into existing institutional frameworks. Future solutions must account for the state infrastructure of national authorities to ensure seamless adoption. Efforts such as the European Union’s initiative to create a unified European data space ecosystem provide a valuable precedent, emphasizing the importance of fostering interoperability and standardization. These international data standards not only enhance integration but also improve the scalability and adaptability of EO solutions across varied institutional contexts.

# 7 Roadmap

This roadmap outlines a comprehensive approach to embedding EO technologies into sustainability reporting for forestry. It addresses the abovementioned technical, institutional, and data-sharing challenges and focuses on fostering collaboration. This way, EO can play a transformative role in global efforts to achieve Sustainable Development Goal 15 and beyond.

On the technical side, future development of EO technologies must focus on enhancing accuracy of algorithms and ensuring scalability. Future efforts should prioritize advancing algorithms to handle diverse ecological conditions. The selected algorithms must be tested in different geographical regions and edge cases.

In parallel, algorithms must be scaled up to function efficiently at larger scale to ensure long-term impact. EO systems must be designed to scale and adapt to evolving needs. This requires leveraging cloud computing and distributed infrastructure to handle increasing data volumes, ensuring flexibility in workflows to accommodate changes in policy and technological advancements, embedding EO systems into national and international policies for sustainable forest management and reporting.

Concerning interoperability between EO platforms and national systems it is essential to work on integration into existing workflows including advocating for global adoption of open standards to ensure compatibility across data infrastructures. Developing customizable workflows that align with the technical and institutional capacities of diverse stakeholders. Collaborating with international initiatives, such as the European Union's unified data space ecosystem, to establish shared frameworks for data sharing and reporting.

EO adoption requires robust institutional support and capacity building. This step includes conducting targeted training programs to enhance technical expertise in using EO tools. Creating user-friendly platforms and interfaces tailored to the needs of both technical and non-technical stakeholders. Developing policy frameworks that integrate EO outputs into decision-making and reporting mechanisms.

Capacity building emerged as a critical focus during the project as it became evident that integrating EO technologies into the daily operations of institutions like government agencies required substantial skill enhancement and knowledge transfer. The project's initial focus was not centred on capacity building; however, this shifted as the lack of technical expertise and operational familiarity with EO tools was identified as a major bottleneck.

These efforts underscored the necessity of aligning technical development with institutional readiness to facilitate seamless adoption and long-term impact. Additionally, it is recommended that ESA should take an active role in capacity-building activities, providing resources, expertise, and direct involvement in user engagement efforts. By participating more closely with stakeholders, ESA can help bridge knowledge gaps and ensure the successful integration of EO technologies into operational workflows, fostering sustainable development outcomes.

Achieving global adoption of EO solutions requires active collaboration across sectors. This involves strengthening partnerships with national governments, NGOs, and private organizations to co-develop and validate EO tools, engaging end-users during the development process to ensure solutions meet their practical needs and constraints, encouraging contributions from international organizations like ESA to actively support user engagement and capacity-building initiatives.

The availability and accessibility of EO data are crucial for widespread adoption. Efforts should include expanding cloud-based platforms to provide scalable and remote data processing capabilities, establishing clear data-sharing agreements and governance structures to build trust among institutions, reducing the financial and technical barriers to accessing EO data for developing nations and under-resourced regions.

# 8 Conclusion

This project demonstrated the transformative potential of EO technologies in addressing sustainable forest management challenges and supporting SDG reporting. The solutions developed are robust, scalable, and aligned with global sustainability objectives. By fostering collaboration among stakeholders, advancing technical capabilities, and promoting sustainable practices, the project established a strong foundation for continued progress toward achieving SDG 15. Further work needs to focus on establishing tight collaboration between service providers and SDG practitioners.

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