LEON

LEVERAGING EARTH OBSERVATION FOR NATURE FINANCE

Opportunities, Enablers and Requirements in Advancing Earth Observation for Scaling Nature Finance

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As part of related surveys, respondents agreed for their responses to be used, stored and shared.

Contents

1. EXECUTIVE SUMMARY

The Leveraging Earth Observation for Nature Finance (LEON) project, supported by the European Space Agency (ESA), seeks to transform the use of Earth Observation (EO) data in enabling, mobilising and scaling nature-positive finance globally. This report builds upon six months of structured research, landscape analysis and multi-stakeholder engagement to map the opportunities and requirements for EO data within financial decision-making. It establishes the conceptual and operational foundation for the LEON project and its six thematic pilots.

Nature finance, as defined within LEON, encompasses activities and financial instruments that shift financial flows away from nature-negative impacts and towards the conservation, sustainable use and restoration of natural ecosystems, aligned with the Kunming–Montreal Global Biodiversity Framework (GBF) and the Paris Agreement. Despite growing policy momentum, a substantial financing gap persists. The European Union alone is estimated to require €200 billion per year to meet its biodiversity and ecosystem restoration targets. At the same time, financial flows that negatively impact nature remain extremely large. Global estimates suggest that more than $7 trillion annually supports activities that degrade ecosystems, concentrated in sectors such as construction, energy, agrifood and extractives. Closing the gap therefore requires both financing nature - mobilising investment in conservation and restoration - and greening finance, meaning the systematic integration of nature-related risks, dependencies and impacts into mainstream financial decision-making.

Earth Observation technologies offer a critical opportunity to support both objectives. Satellite data provide globally consistent, spatially explicit and increasingly high-frequency insights on land use change, ecosystem condition, water systems and environmental pressures. These capabilities can support financial institutions, regulators and investors in identifying risks, verifying sustainability claims and monitoring the environmental performance of investments. However, despite rapid advances in EO capabilities, their operational integration into financial systems remains limited. Financial actors frequently lack validated, asset-level environmental intelligence that can be incorporated into risk assessment, disclosure frameworks and investment.

This report provides the analytical foundation for addressing this gap. It combines five principal strands of analysis:

- assessment of the policy and regulatory landscape for nature finance in Europe
- synthesis of relevant standards, taxonomies and initiatives shaping nature finance markets
- user requirements analysis based on surveys and consultations with financial institutions and stakeholders
- examining the political, economic, social, technological, legal and environmental drivers affecting EO uptake
- early insights from six thematic pilot domains designed to test EO applications in real financial contexts.

Key Findings

Nature finance markets are expanding but constrained by data gaps: Demand for nature-related information within financial markets is increasing rapidly, driven partly by disclosure frameworks such as the EU Corporate Sustainability Reporting Directive (CSRD), Sustainable Finance Disclosure Regulation (SFDR) and the Taskforce on Nature-related Financial Disclosures (TNFD). These frameworks require firms and financial institutions to assess and disclose their dependencies, impacts and risks related to ecosystems. However, respondents consistently identified several structural barriers to scaling nature finance:

- lack of granular environmental data
- absence of standardised metrics and taxonomies
- insufficient asset-level geolocation data linking financial exposures to ecosystems
- fragmented environmental data platforms.

These constraints limit the ability of financial institutions to assess nature-related risks, monitor environmental outcomes and design investable nature-positive projects.

Earth Observation is widely recognised as a key enabling technology: Survey respondents widely recognised EO as a critical tool for addressing these data challenges. EO data can support several core financial functions, including:

- monitoring land-use change and ecosystem condition
- identifying environmental risks in global supply chains
- verifying corporate sustainability disclosures
- monitoring environmental performance of investments and projects.

However, operational adoption remains limited. Most financial institutions (FIs) prefer processed, decision-ready datasets rather than raw satellite imagery. Medium spatial resolution data (approximately 10–30 metres) and update frequencies of monthly or annual intervals were considered sufficient for many applications. Respondents also emphasised the importance of ground-truth validation, transparent methodologies and alignment with international standards to ensure credibility and usability.

The regulatory and policy landscape is evolving rapidly with implications for nature finance and EO adoption: The EU currently provides one of the most advanced policy environments globally for nature finance. Frameworks such as the EU Taxonomy, CSRD, and SFDR are creating strong incentives for firms and investors to measure and manage environmental risks.

At the same time, the policy landscape remains complex and dynamic. Ongoing developments, including proposals under the EU Omnibus package, evolving national environmental regulations and wider economic pressures, may alter the strength or implementation of sustainability disclosure requirements. Firms therefore face a rapidly evolving incentive environment in which regulatory expectations, investor demands and reputational considerations are changing simultaneously. In this context, robust and scalable environmental data will be essential to help firms navigate regulatory uncertainty while managing nature-related risks and opportunities.

The LEON project explores how EO can be leveraged to scale nature finance through focussing on six thematic pilots. The table below summarises initial high level findings from scoping work and consultations. Together, these pilots demonstrate that EO can support both financing nature and greening finance, helping to mobilise capital for nature-positive investments while enabling financial institutions to better understand and manage nature-related risks.

Strategic Implications

The findings of this baseline analysis suggest that EO could become foundational infrastructure for nature finance, enabling financial markets to integrate environmental intelligence into economic decision-making. Realising this potential will require several enabling steps:

- development of standardised EO-derived environmental indicators aligned with disclosure frameworks
- improved asset-level geolocation data linking companies, projects and ecosystems
- integration of EO datasets into financial analytics platforms and risk management tools

- strengthened interoperability with sustainability reporting standards and taxonomies
- expanded capacity building across financial institutions, regulators and data providers.

If these challenges can be addressed, EO technologies have the potential to play a central role in enabling the transparency, accountability and scalability required to mobilise nature-positive finance globally

Pilot Domain	Financial Use Case	Decision Problem	Role of EO Data	Key Data Requirements	Strategic Insight
Mining Supply Chains	Environmental risk assessment for mining finance and project due diligence	FIs face limited visibility over environmental impacts of mining assets, particularly related to water pollution, tailings management and degradation.	EO enables monitoring of land disturbance, tailings expansion and water quality indicators around mining sites.	Medium–high spatial resolution; watershed-level monitoring; multi-year time series linked to specific assets.	EO can significantly improve environmental due diligence and monitoring for extractive sectors, supporting risk pricing and regulatory disclosures
Agrifood Supply Chains	Sustainable commodity sourcing, deforestation-free finance and supply-chain risk management	FIs and firms often lack transparency over land-use change, deforestation and ecosystem degradation across complex global supply chains.	EO enables monitoring of land-use change, crop systems, deforestation and ecosystem condition in production landscapes.	Medium-resolution land cover data (10–30m); global coverage; regular updates to track seasonal or annual changes.	EO can help address traceability challenges and support compliance with regulations and corporate sustainability commitments.
Nature-related Financial Risk	Portfolio-level risk assessment and disclosure (e.g. TNFD-aligned analysis)	Investors and regulators lack spatial indicators linking financial assets to ecosystem degradation and nature-related physical and transition risks.	EO provides spatial indicators of ecosystem condition, land-use change and environmental pressures that can be linked to financial exposures.	Global coverage datasets; integration with economic and sectoral data; multi-year time series.	EO can enable scalable nature-risk analytics across financial portfolios, supporting emerging risk frameworks used by regulators, central banks and investors.
Biodiversity Credits	Nature markets and verification of biodiversity outcomes	Emerging biodiversity credit markets require credible measurement, monitoring and verification to ensure market integrity.	EO supports baseline ecosystem assessment, habitat monitoring and detection of environmental change.	High spatial resolution; site-specific monitoring; integration with ecological datasets and ground validation.	EO can help build credibility and transparency in biodiversity markets by providing independent, scalable monitoring of ecological outcomes.
Natural Capital Accounting	National and corporate natural capital accounting	Governments and firms require consistent metrics to measure ecosystem condition and track changes	EO provides spatial datasets on ecosystem extent, vegetation productivity and environmental condition	Long-term time series; harmonised datasets; integration with accounting frameworks.	EO can support the development of consistent, globally comparable natural capital accounts
Sovereign Finance	Sustainability-linked bonds, debt-for-nature swaps and sovereign environmental performance monitoring	Investors and governments require transparent monitoring of environmental indicators linked to sovereign financing instruments.	EO enables monitoring of environmental indicators and can support spatial planning of conservation	National-scale datasets; consistent long-term monitoring; integration with policy indicators.	EO can provide credible, independent monitoring of environmental performance

Acronyms

Acronym	Expansion
ATBD	Algorithm Technical Baseline Document
CDSE	Copernicus Data Space Ecosystem
CEOS	Committee on Earth Observation Satellites
CHIRPS	Climate Hazards Group InfraRed Precipitation with Station
CRCF	Climate Financial Risk Forum
ECMWF	European Centre for Medium-Range Weather Forecasts
EO	Earth Observation
ERA5	ECMWF Reanalysis v5
ESA	European Space Agency
FAIR	Findable, Accessible, Interoperable, and Reusable
FAPAR	Fraction Absorbed of Photosynthetically Active Radiation
FI	Financial Institution
LAI	Leaf Area Index
LEON	Leveraging Earth Observation for Nature Finance
MODIS	Moderate Resolution Imaging Spectroradiometer
NbS	Nature-Based Solutions
NF	Nature Finance
NGFS	Network for Greening the Financial System
OLCI	Ocean and Land Colour Instrument
QA4EO	Quality Assurance framework for Earth Observation
RMSE	Root Mean Square Error
STAC	SpatioTemporal Asset Catalogue
WGCV	Working Group on Calibration and Validation

Glossary of Key Cross-Cutting Terms (Source: IPBES 2019 unless otherwise stated)

Term	Meaning
Biodiversity	Biodiversity is defined as the variety of life in all its forms, and at all levels, including genes, species, and ecosystems. The CBD defines biodiversity as 'the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems' (Convention on Biological Diversity). (Dasgupta, 2021)
Biodiversity Offset	Measurable conservation outcomes that result from actions designed to compensate for significant residual biodiversity loss that arise through development projects
Biodiversity Credit	An asset created through investments in the restoration, conservation and development of biodiversity in a specific landscape (UNDP/UNEPFI2023)
Ecosystem Services	The flow of goods and services for people produced by ecosystems. These support jobs and provide raw materials that people need to survive, manage local climate impacts and contribute to carbon storage and emissions reductions. The term 'ecosystem services' includes: (i) **provisioning services** (e.g. food, freshwater, fuel); (ii) **regulating and maintenance services** (e.g. climate regulation, pollination, soil quality, the flow and purification of water); and (iii) cultural services (e.g. recreation and spiritual enrichment). (Dasgupta, 2021)
Financing Green	Accelerating finance to support the delivery of sustainable growth, resilience and environmental ambitions, as well as international objectives
Greening Finance	Ensuring current and future financial risks and opportunities from climate and environmental factors are integrated into mainstream financial decision making, and that markets for green financial products are robust
Natural Assets	Naturally occurring living and non-living entities that together comprise ecosystems and deliver ecosystem services that benefit current and future generations. This stock of renewable and non-renewable natural assets yield flow of benefits to people (i.e. ecosystem services).
Natural Resources	Resources which are naturally occurring, including renewable resources such as forests and non-renewable resources such as minerals and which are necessary e.g.

Term	Meaning
	to support jobs and provide raw materials that people need to survive, manage local climate impacts and contribute to carbon storage and emissions reductions (Dasgupta, 2021)
Natural Capital	The stock of renewable and non-renewable natural assets (e.g. ecosystems) that yield a flow of benefits to people (i.e. ecosystem services). The term 'natural capital' is used to emphasise it is a capital asset, like produced capital (roads and buildings) and human capital (knowledge and skills). (Dasgupta, 2021)
Nature	Nature is defined as the natural world (Dasgupta, 2021) with an emphasis on its living components. Within the context of western science, it includes categories such as biodiversity, ecosystems (both structure and functioning), evolution, the biosphere, humankind's shared evolutionary heritage, and biocultural diversity. Within the context of other knowledge systems, it includes categories such as Mother Earth and systems of life, and is often viewed as inextricably linked to humans, not as a separate entity
Nature-based Solutions	Nature based Solutions (NbS) are 'actions to protect, conserve, restore, sustainably use and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems which address social, economic and environmental challenges effectively and adaptively, while providing human well-being, ecosystem services, resilience and biodiversity benefits." (IUCN, 2022).
Nature's Contribution to People	Nature's contribution to people "are all the contributions, both positive and negative, of living nature (i.e., all organisms, ecosystems, and their associated ecological and evolutionary processes) to people's quality of life"
Nature Finance	Finance that contributes to activities that conserve, restore or sustainably use nature, and that aligns financial flows with the goals of the Global Biodiversity Framework and Paris Agreement (LEON definition, see text).
Nature Positive	A high-level goal and concept describing a future state of nature (e.g. biodiversity, ecosystem services and natural capital) that is greater than the current state (UNEPFI 2023).
Nature-related dependencies, impacts, risks and opportunities.	Dependencies – of the economy/organisation on nature; Impacts – on nature caused, or contributed to, by the economy/organisation; risks – to the economy/organisation stemming from their dependencies and impacts; and opportunities – for the economy/organisation that benefit nature through positive impacts or mitigation of negative impacts on nature (TNFD 2023).
Nature-related financial risks	Risks of negative effects on economies, financial institutions and financial systems that result from: i. the degradation of nature, including its biodiversity, and the loss of ecosystem services that flow from it (i.e., physical risks); or ii. The misalignment of economic actors with actions aimed at protecting, restoring, and/or reducing negative impacts on nature (i.e., transition risks) (NGFS 2023).

2. INTRODUCTION

The goal of LEON is to mobilize and scale nature finance globally by embedding Earth Observation (EO) data into financial decision-making. This report consolidates the outcomes of the first six months of background research and user engagement to assess the opportunities, enablers and requirements for EO for Nature Finance.

The first part of this report (Section 2) outlines the policy and environmental context for nature finance in Europe. It defines nature finance and describes the main modalities and actors. It then provides a detailed review of the legal and regulatory enabling drivers of nature finance across Europe and relevant cross-cutting standards and frameworks. It gives the cross-cutting findings of a survey of user needs and draws out initial conclusions. It also reviews the major projects and initiatives operating in parallel with LEON. The first section then culminates in a PESTLE analysis of the political, economic, social, technological, legal and environmental threats and opportunities for nature finance. Section 3 describes early findings of requirements in each pilot domain. Section 4 provides an initial review of EO best practices, focussing on biodiversity, water and climate.

2.1. Policy and Environmental Context for Europe

Analyses by the European Commission and the European Environment Agency (EEA) reveal the significant decline in Europe's biodiversity and natural habitats. For example, 81% of protected habitats and 63% of protected species in the EU are in poor or bad conservation status[1]. Only 37% of Europe's surface waters achieved 'good' or 'high' ecological status, and 29% reached 'good' chemical status between 2015 and 2021[2]. Water scarcity affects a fifth of EU land and nearly a third of its population annually, exacerbated by pollution and climate change. These changes undermine core systems including water and food and jeopardise economic output. Intensive agriculture, urban sprawl, pollution, unsustainable forestry, and climate change are the main pressures degrading Europe's ecosystems. Landscape fragmentation due to infrastructure development hinders species movement and ecosystem connectivity. These assessments by the European Commission and the European Environment Agency (EEA) underscore the urgent need for restoration and conservation efforts across the continent.

In response, the European Commission has made major commitments to protect and restore nature, including the Nature Restoration Law and the EU Biodiversity Strategy. Adopted in 2024, this regulation mandates EU Member States to restore 30% of degraded habitats by 2030, in line with the Kunming-Montreal Global Biodiversity Framework (GBF). As part of the European Green Deal, the EU Biodiversity Strategy sets targets to protect 30% of EU land and sea areas, restore at least 25,000 km of rivers to a free-flowing state, reverse the decline of pollinators and plant 3 billion trees by 2030. As part of its commitments to the GBF, the EU has also committed to identifying and eliminating subsidies that are harmful to biodiversity (GBF Target 18), reducing invasive species and working to mainstream biodiversity considerations across all sectors, including agriculture, forestry, and fisheries, to ensure coherent and effective implementation of the GBF.

[1] https://www.eea.europa.eu/en/newsroom/news/ecosystems-need-restoration

[2] https://www.eea.europa.eu/en/topics/at-a-glance/state-of-europes-environment

Figure 2.1: Finance-related targets of the Kunming-Montreal Global Biodiversity Framework

However, estimates suggest that an additional €200 billion is needed to meet the EU's biodiversity objectives by 2030 (WWF 2025). In addition, the EU has committed to contribute to the mobilisation of $200 Billion per year for biodiversity as part of the GBF (Target 19 and relatedly, 14, 18 and 19, see Figure 2.1). In response, the European Union (EU) has made significant commitments to mobilise financing for nature restoration within its borders and internationally, integrating both public funding mechanisms and the development of biodiversity and nature markets. The following sections introduce the concept of nature finance and overview the nature finance landscape across Europe in the context of current literature.

As part of the European Green Deal, the EU Biodiversity Strategy for 2030 aims to allocate substantial financial resources to biodiversity conservation and restoration. For example:

- **Nature-related spending:** The LIFE Programme is the EU's primary funding instrument for environmental and climate action. For the 2021–2027 period, it has a budget of €5.45 billion, with a significant portion dedicated to nature and biodiversity projects.
- **Biodiversity Credits:** The EU is exploring the development of biodiversity credits as a market-based mechanism to finance nature restoration. These credits represent measurable conservation outcomes that can be purchased by entities seeking to offset their environmental impacts, or to contribute to broader biodiversity goals in a way that is unrelated to impacts. The Nature Restoration Law provides a framework that could facilitate the establishment of such markets.
- **Alignment of wider public finance flows:** The EU has committed to integrating biodiversity considerations across its budget, ensuring that a significant share of EU funding supports biodiversity objectives. This includes aligning the Common Agricultural Policy (CAP) and other funding instruments with biodiversity goals[3].
- **Phasing out environmentally harmful subsidies (EHS).** Under the 8th Environment Action Programme, the EU aims to phase out all EHS including non-energy, by 2027[4].
- **Blended finance:** The European Investment Bank (EIB)'s Natural Capital Financing Facility (NCFF) pilot programme deployed just over €80 million for nature-based projects through its project financing facility between 2015 to 2022, and additional grant financing through its technical assistance facility[5].
- **External funding:** In addition, the EU has pledged to double its external funding for biodiversity to €7 billion for the period 2021–2027 and announced additional initiatives totalling nearly

[3] https://environment.ec.europa.eu/strategy/biodiversity-strategy-2030

[4] https://environment.ec.europa.eu/economy-and-finance/phasing-out-environmentally-harmful-subsidies_en

[5] https://www.eib.org/attachments/lucalli/20230095_investing_in_nature_based_solutions_en.pdf

€160 million to support global biodiversity efforts[6].

These programmes and initiatives operate in the context of a wider legal and regulatory enabling framework, and supported by voluntary and mandatory standards, that aims to both align public and private financial flows with EU nature and biodiversity goals and mobilise private capital. Importantly, these wider frameworks can have a much greater influence on nature finance than nature-finance specific policies, through for example influencing demand for nature finance, feasibility and returns on investments. Parallel climate policies, for example the rules concerning credits of the EU Emission Trading Scheme, voluntary carbon markets or initiatives like CORSIA, can also have a major impact by creating revenue streams for nature (or indeed, creating incentives that may not align with nature positive). These wider enablers are described in detail in Section 2.3. However, it is first necessary to define nature finance and provide the conceptual framework for nature finance relevant to assessing the opportunities, enablers and requirements for EO to scale nature finance.

2.2. Nature Finance: Definitions, Concepts and Actors

To date, the European Commission does not have a formal, standalone definition for "nature finance". Nature finance can be considered a subset of sustainable finance, which in the EU's policy context, is understood as *"finance to support economic growth while reducing pressures on the environment to help reach the climate- and environmental objectives of the European Green Deal, taking into account social and governance aspects"*[7]. Nature finance is a newer concept without a well-accepted definition. The World Bank defines nature finance as: *"finance contributing to the nature positive goal of halting and reversing nature loss and supporting the implementation of the Kunming-Montreal Global Biodiversity Framework (KMGBF) through one or more of the following activity groups: Restoration and conservation of biodiversity or ecosystem services; Reduction of the direct drivers of biodiversity or ecosystem services loss; Integration of nature-based solutions across economic sectors; and Design and implementation of policy, tools, or other sectoral instruments enabling the other categories"*. The latter definition was adopted by UNEP FI and the Finance for Biodiversity Foundation[8].

Importantly, for the LEON project, we define nature finance as incorporating both aspects of 'greening finance' and 'financing green'. Both aspects are required to scale up nature finance across the European Union. For example, the World Bank further explains that *"Nature Finance captures the broad range of transformative actions that need to take place to achieve the nature positive goal, including: (i) delivering measurable positive gains for nature; and (ii) enabling a broader transition of economic activity away from harmful practices that are driving nature loss toward those aligned with the goal, by mainstreaming nature considerations into policies and investments"* [9].
This is consistent with the definitions laid out in the UK's 2019 Green Finance Strategy, for example, which defines 'Financing Green' as *"accelerating finance to support the delivery of the UK's carbon targets and clean growth, resilience and environmental ambitions, as well as*

[6] https://international-partnerships.ec.europa.eu/news-and-events/news/eu-delivers-its-global-financing-commitments-protect-nature-cop-16-2024-10-31_en
[7] https://finance.ec.europa.eu/sustainable-finance/overview-sustainable-finance_en#:~:text=In%20the%20EU's%20policy%20context,account%20social%20and%20governance%20aspects.
[8] Finance for Biodiversity Foundation and United Nations Environment Programme (2024) Finance for Nature Positive: Building a working model. https://www.unepfi.org/wordpress/wp-content/uploads/2024/10/Finance-for-Nature-Positive-3-1.pdf
[9] *https://documents1.worldbank.org/curated/en/099020524182036310/pdf/BOSIB1722f330c0fd18f8818b41d9bbe465.pdf*

international objectives" and 'Greening Finance' as *"Ensuring current and future financial risks and opportunities from climate and environmental factors are integrated into mainstream financial decision making, and that markets for green financial products are robust"*. The EU Taxonomy serves as the de facto definition of what qualifies as "green." Four of the EU Taxonomy's six environmental objectives have a strong nature component, including (6) Protection and restoration of biodiversity and ecosystems, (3) sustainable use and protection of water and marine resources, (4) transition to a circular economy and (5) pollution control. Indeed, nature is also highly relevant to its objectives on mitigation and adaptation also.

Given that the **European Commission does not have a formal definition of nature finance**, in LEON we adopt the following working definition:

"Finance that contributes to activities that conserve, restore or sustainably use nature, and that aligns financial flows with the goals of the Global Biodiversity Framework and Paris Agreement"[10]

Figure 2.2: Intersection of concepts: 'financing green', 'greening finance' and 'nature finance'. Source: authors (definitions taken from the UK 2019 Green Finance Strategy and Centre for Global Commons, 2024).

This definition originates from the Centre for Global Commons and builds upon definitions proposed by the OECD and Convention on Biological Diversity. Indeed, under the World Bank's definition, it goes a step further and defines two additional forms of nature finance: *Nature Positive Finance* is finance that is expected to deliver measurable positive outcomes for biodiversity or ecosystem services, relative to business-as-usual; and *Nature Mainstreaming Finance* is finance that is expected to enable a broader economic transition toward practices aligned with delivering the nature positive goal.

We see this as a form of *transition finance*. The EU sustainable finance platform defines transition finance as about financing *"what is transitioning to environment-friendly performance levels over time - Transition finance is about financing private investments to reduce today's high greenhouse gas emissions or other environmental impacts and transition to a climate neutral and sustainable economy"*[11]. This set of definitions is also consistent with others, such as CISL et al. (2024), which defines nature finance as well beyond '*nature conservation finance'* and includes finance related to actions that offset, protect, restore, or minimise pressures on nature . We adopt the World Bank definition of 'Nature Positive Finance' to describe the 'financing green' aspect of nature finance and we refer to the 'greening finance' component as 'greening finance for nature'. Examples are given in Fig 2.2.

2.3. Nature Finance: Status and Trends

Arguably, few concepts have created so much potential for communities to profoundly misunderstand each other than nature finance. For many in the ecological community, the historical focus has been mainly on conservation finance; that is, funding specific conservation (or protection and recovery) projects for species or

[10] https://www.systemiq.earth/wp-content/uploads/2023/12/CGC_NatureFinanceReport_summary_compressed.pdf

[11] https://finance.ec.europa.eu/sustainable-finance/overview-sustainable-finance_en

landscapes. This is closely related to the concept of biodiversity finance; that is, the use of private capital to finance biodiversity conservation and restoration (Flammer et al. 2025). The key common principle here is that the conservation of biodiversity and the protection and recovery of landscapes and ecosystem services is the primary objective.

Analyses by UNEPFI and partners determined that in 2022, annual financial flows to nature-based solutions were US$200 billion. Of this 82% came from the public sector and the largest component was the protection of biodiversity and landscapes – approximately US$76 billion per year – followed by sustainable agriculture, fisheries and forestry - $42 billion per year. Other public finance related to water, pollution and environmental policies. The size of public finance for biodiversity protection is generally less than 1% of national budgets.

Private finance flows remain modest at around $35 billion per year (18% of the total). A central challenge, as discussed by many previous authors - for nature finance where biodiversity and nature protection and recovery are the primary objectives - is how to derive sufficient revenues to motivate private investment when biodiversity and nature are not 'priced' in markets. In 2022, over half (57 per cent) of private finance flows were via biodiversity offsets ($12 billion, based on Bennett et al.'s 2017 review of 99 regulatory offsetting programmes across 33 countries) and sustainable supply chains ($9 billion, including certified forestry, palm oil, agricultural goods, seafood, soy, coffee and cocoa based on multiple sources); other contributions including impact investing, philanthropy, payment for ecosystem services, carbon markets and farmer investments are smaller, however these flows can be more difficult to track.

However, it is important to avoid the mistake of putting all nature-related investments into 'one bucket' or to assume that revenues can only be derived from an *explicit* pricing mechanism on nature, such as a biodiversity credit or offset market. Building upon detailed analyses by van Raalte and Ranger (2023) and Flammer et al. (2025), we define three broad categories of projects, each of which have very different characteristics in terms of risks and returns (Table 2.1). The table includes different mechanisms of revenue generation that go well beyond biodiversity markets. For example, revenue generation from selling agricultural, forestry or fisheries products (with or without certification, where 'biodiversity friendly' certification could score higher returns), ecotourism or generation of ecosystem services, such as water quality or flood protection.

Law and regulation can also put *implicit* prices on biodiversity and catalyse more investment. For example, the EU deforestation regulation is expected to drive significant increases in demand for sustainable and certified deforestation-free products in oil palm, soya, wood, cocoa, coffee, cattle and rubber. Regulations on water quality have driven innovations in payments for ecosystem services that have benefitted landowners and insurance pricing can drive demand for NbS for flood protection. Other forms of policy tools have been successful in mobilising finance into areas where returns may be too risky, such as early renewables deployment in Europe, such as *offtake guarantees*, *contracts for difference* and *regulated asset bases*.

Category	Project Type	Revenue Generation Mechanism
Agriculture, Fisheries and Forests	Agriculture: soils and pollinators	Agricultural productivity; price of farmland; certification as "biodiversity-friendly" agricultural products (higher prices); carbon credits; fire suppression; water quality services
	Forests	Ecotourism (hotel nights, tour guide services); carbon credits (carbon capture and storage); biodiversity credits; health; recreational value; bioprospecting for medicine; certification as "biodiversity-friendly" wood (higher prices); hydropower (pay for success)
	Fisheries	Food production; certification as "biodiversity-friendly" seafood products (higher prices)
Green Infrastructure	Urban parks and other green structures in urban areas	Value of real estate (proximity to park, green roofs provide heat isolation); prevention of flooding; cooling; carbon credits (carbon capture and storage); recreational value (e.g., birdwatching, sports etc.)
	Watersheds	Green infrastructure services; water purification; flood mitigation
	Coastal ecosystems, including coral reefs and mangroves	Ecotourism (hotel nights, tour guide services); value of real estate and insurance affordability and availability (prevention of coastal flooding); carbon credit (carbon capture and storage); biodiversity credits; food production; disaster avoidance
'Pure play' Conservation, Landscape Restoration and Oceans Protection	Natural parks & wildlife protection	Ecotourism (hotel nights, tour guide services); value of real estate around the park; biodiversity credits
	Species	Protection against diseases (humans, plants, food, animals); bioprospecting for medicine; biodiversity credits
	Oceans	Ecotourism (hotel nights, tour guide services); carbon credits; biodiversity credits; fisheries

Table 2.1: Typology of nature-positive investments, building upon van Raalte and Ranger (2023) and Flammer et al. 2025

A substantial number of dedicated investment funds for nature exist and often blend public and public finance. Van Raalte and Ranger (2023) reviewed around 30 existing nature funds and individual case studies to draw lessons for the mobilisation of private finance for nature. In all but two cases, each fund included a blend of public and private finance: with public financiers (often development finance institutions or public development banks) providing support in terms of technical assistance, seed grants or first-loss capital. This highlights the important role of *blended finance*. Specialist investment managers also played an important role in many funds in contributing the experience and expertise necessary to build viable project pipelines and work with projects that are more novel with higher complexity. Most funds were operating in agriculture and forestry sectors where there are clear returns, albeit some included conservation projects that utilised revenues from voluntary carbon markets. Individual projects were less than $50 million size and had medium to long-term timescales; the size and duration of projects, as well as risk and complexity, is seen as a key barrier for many institutional investors.

Fund Name	Investment Manager Name	HQ	Est.	Status	AUM	Capital			Regional Focus					Sector Focus							Investees			Instrument			Tenor			Size			Other			
						Non-Private Sector	Private Sector	East Asia and Pacific	Europe	Latin America and Caribbean	North America	Sub-Saharan Africa	South Asia	Agriculture	Forestry	Aquaculture & Fishers	Ecotourism	Infrastructure (incl. Water)	Conservation (Terrestrial)	Conservation (Aquatic)	Private Sector	Public Sector	Third Sector	Grants (excl. TA)	Debt	Equity	Short term (<3 years)	Medium term (3-10 years)	Long term (>10 years)	<$ 5 million	US$ 5-50 million	>US$ 50 million	DFI Investor	Separate TA Facility	Regional Offices	Invested in the last year
Climate Investor Two	Climate Fund Managers	NL	2021	Active	855																															
Eco.Business Fund	Finance in Motion	DE	2014	Active	750																															
Natural Capital & Nature Based Strategies	Climate Asset Management	UK	2020	Active	750																															
Sustainable Water Impact Fund	RRG Capital Management	US	2019	Active	710																															
Aqua-Sparks	Aqua-Spark Management	NL	2013	Active	470																															
&Green Fund	Sail Ventures	NL	2017	Active	410																															
Tropical Asia Forest Fund I & II	New Forests Asset Management	AU	2008	Active	370																															
African Forestry Impact Platform	New Forests Asset Management	AU	2022	Active	300																															
AgDevCo	AgDevCo	UK	2008	Active	280																															
Land Degradation Neutrality Fund	Mirova	FR	2018	Active	210																															
Global Fund for Coral Reefs	Pegasus Capital Advisors	US	2020	Active	205																															
Restore Fund I	Goldman Sachs Asset Management	US	2021	Active	200																															
Restore Fund II	Climate Asset Management	UK	2023	Active	200																															
Subnational Climate Fund	Pegasus Capital Advisors	US	2020	Active	170																															
Livelihoods Carbon Fund #3	Livelihoods Venture	FR	2021	Active	150																															
Althelia Sustainable Ocean Fund	Mirova	FR	2018	Active	130																															
Althelia Climate Fund	Mirova	FR	2013	Active	120																															
EcoEnterprises Partners III	EcoEnterprises Management	US	2018	Active	110																															
Arbaro Fund	Finance in Motion | UNIQUE Group	DE	2018	Active	110																															
Latin American Green Bond Fund	Finance in Motion	DE	2021	Active	100																															
AGRI3 Fund	Mirova | FOUNT | Cardano Development	FR/NL	2017	Active	95																															
IDH Farmfit Fund	IDH Investment Management	NL	2020	Active	90																															
Livelihoods Fund for Family Farming	Livelihoods Venture	FR	2015	Active	85																															
The Livelihoods Carbon Fund #2	Livelihoods Venture	FR	2017	Active	65																															

Figure 2.3: Summary analysis of nature funds. Source: van Raalte and Ranger 2023

Private investors can also finance public expenditures through for example, green and sustainability-linked sovereign bonds or debt for nature instruments (Section 3). Such transactions are larger, lower risk, more standardised and entail more liquid assets, so can be more amenable to large non-specialist institutional investors. In 2025, China issued its first global green sovereign bond on the London Stock Exchange at $0.8 billion alone, including activities such as natural resource and biodiversity conservation, as well as pollution prevention[12]. At COP16 in 2024, Colombia issued two 'biodiversity bonds' issued for US$50 million (Banco Davivienda & IFC) and US$35 million (BBVA Colombia, IDB Invest & IFC). Various international public entities and civil society organisations have also issued bonds. For example, the 'Rhino Bond' – a $150million outcome-bond issued through the World Bank's global debt issuance facility[13] - and green bonds issued by The Nature Conservancy (invested in conservation projects and repaid from TNC's fundraising, i.e. philanthropy). Debt for Nature swaps are also examples of sovereign issuances, but where the issuance is part of a restructuring of debt. The ICMA Sustainable Bonds for Nature guide (June 2025) introduces a 'Nature Bond' concept within international green bond standards, encouraging focused biodiversity outcomes. One new financing modality currently under discussion is the Tropical Forest Forever Facility (TFFF); this proposes an endowment model that would pay an annuity to heavily forested countries. It aims to raise US $125 billion from public sponsors and private investors.

In LEON, as described above, nature finance is defined more broadly than just financing for conservation projects, and includes activities to integrate nature into business and financial flows to reduce their impact on biodiversity and ecosystem services and seek win-wins through more sustainable use of natural resources. In these activities, biodiversity conservation and the restoration and protection of nature may not be the primary objective, however there is an explicit focus on reducing harm (reducing or avoiding pressures, Fig 2.3) and maximising co-benefits for nature. UNEPFI 2023 demonstrates why this is important - today, at least $7 trillion a year financial flows are to activities with negative impacts on nature. According to UNEPFI2023, at least $1.7 trillion comes from the public sector in the form of environmentally harmful subsidies related to agriculture, fossil fuels, fisheries and forestry. Findings of other studies suggest these estimates may be too low (the IMF estimated explicit fossil fuel subsidies alone at $1.26 trillion in 2022[14]). Environmentally harmful energy-related subsidies in the EU are estimated by the European Commission at 136 billion euros[15].

The largest damaging sectors, with over $200 billion a year of activities with negative impacts are: construction and engineering ($570 billion), electric utilities ($445 billion), real-estate ($424 billion), oil and gas ($390 billion); food and tobacco ($295 billion); chemicals ($227 billion); and metals and mining ($224 billion). These are all large sectors, so represent significant opportunities for investors to invest in more nature-positive practices.

In terms of size of biodiversity footprint, the most damaging sectors are food and beverages, materials and energy (Finance for Biodiversity Foundation, 2024[16]). Indeed,

[12]https://www.reuters.com/sustainability/sustainable-finance-reporting/chinas-sell-first-global-green-sovereign-bond-wednesday-2025-04-01

[13] Importantly, no additional finance is raised from the private sector. The IBRD pays back within 5 years.

[14] https://www.imf.org/en/Topics/climate-change/energy-subsidies

[15] European Commission 2025 Report from the Commission to the European Parliament, the Council, The European Economic and Social Committee of the Regions. 2024 Report on Energy subsidies in the EU

[16] https://www.financeforbiodiversity.org/wp-content/uploads/Top10_biodiversity-impact_ranking.pdf

research by the Finance for Biodiversity Foundation suggests that the footprint is very concentrated; the top 250 high-impact companies represent 73% of the total MSCI World Index footprint (more than 1,500 companies). Hawkins et al. 2025[17] identified 180 'keystone corporations' – in sectors such as animal pharmaceuticals, bananas, cement, cocoa, coffee, seeds, fertilisers, mining, oil and gas, palm oil, paper and pulp, pesticides, salmon, and soya – all in highly concentrated sectors with significant environmental impacts. They found that while 79% of the firms have made some form of biodiversity pledge, only 13% provide detailed, transparent and specific commitments.

One of the ways in which such firms can raise capital to invest in more nature-positive practices is through the issuance of corporate bonds or through sustainability-linked finance. The Institute of International Finance, found that bonds incorporating biodiversity loss prevention and protection objectives accounted for nearly a quarter of total ESG-labelled debt issued in 2024[18]. Corporate bonds come in two main types - sustainability-linked bonds (SLBs) and use of proceeds bonds. Use of proceeds bonds allocate funds to specific sustainability projects. Recent examples include the Chilean pulp and paper manufacturer CMPC, which has issued bonds for sustainable forest and water management, and Finnish forestry company Stora Enso, which has allocated proceeds to forest management, water conservation and pollution control. SLBs are not tied to specific activities (like the use of proceeds bond) but instead typically include an interest rate reduction if the issuer meets predefined sustainability-related targets, measured in the form of key performance indicators (KPIs). Danish energy company Ørsted issued a €100mn blue bond in June 2023 aimed at financing ocean biodiversity conservation efforts. Brazilian pulp and paper company Klabin, which has issued an SLB with nature and biodiversity objectives. Research at the London School of Economics (Resendiz et al. 2025) shows that while such bonds and loans are still a relatively small part of the overall market, they are growing rapidly and analyses of targeting being set by firms suggests a significant potential for more investment in this area.

2.4 Nature Finance Instruments

Drawing upon the framing outlined above, to guide LEON, we develop a framework for analysing nature finance instruments and mechanisms. Multiple previous studies have proposed such frameworks but this framework is different in that we create a typology that separates different instruments by their function in the context of mobilising nature finance, not just their type. In particular, we separate mechanisms that aim to generate revenues, from those that aim to facilitate investment or to manage risks. We also separate mechanisms by who is providing the finance and who is deploying it to fund activities related to sustainability. This is important as the role of EO, who will be using it and for what, will be different in each case, and this influences the user requirements for EO and the impact that EO can have. The typology is not exhaustive, but aims to include sufficient mechanisms to guide LEON in its deployment of EO.

[17] Hawkins et al, 2025. The Biodiversity Commitments of Earth's Keystone Corporations: Current Limitations, Untapped Potential, and Future Directions. https://osf.io/preprints/socarxiv/k6985_v1

[18] Note that this includes sovereign bonds. https://www.sustainableviews.com/more-nature-related-risks-and-opportunities-in-investor-portfolios-806ab23b

REVENUES FOR NATURE		
	Who receives and for what	**Who pays**
Revenue Generation Mechanisms		
Biodiversity Credits and Offsets	Received by project developers or companies that are undertaking activities to enhance biodiversity	Generally bought by companies to offset impacts, meet goals or regulatory requirements, or to support CSR
Carbon Credits	Received by project developers or companies that are undertaking activities to remove or avoid carbon emissions, with potential co-benefits	Bought by companies to offset their impacts or meet goals or regulatory requirements. Biodiversity co-benefit may entail higher price
Payment for Ecosystem Services (PES)	Companies or landowners providing the ecosystem service, e.g. pollution control or flood mitigation.	Companies or government who want the service. E.g. a water company.
Natural resource or service revenues	Farmers or companies providing the resource, e.g. food, timber, fish or services e.g. tourism, leisure	Individuals or companies who want the resource or want the service
Performance-based funding/pay for performance/ outcome-based contracts	Company, landowner paid for successful implementation of nature-related activities to achieve defined outcomes	Paid if the outcomes are achieved e.g. watershed restoration contracts – utilities/beverage firms
RISCO (Restoration Insurance Service Company)	As above, but a company is established to deliver a service that reduces insurance premiums or risks to asset owners	Asset owner (e.g. a hotel protected by mangroves) or other beneficiary of RISCO services.
Subsidies, grants or tax breaks	Project developers, farmers or companies enhancing nature	Government (ultimately tax payers), philanthropy, international agencies (donors)
Offtake agreement (e.g. power purchase agreement, biodiversity credit contract) (contracted project finance)	The company or project developer who is undertaking activities to enhance biodiversity	Recipient of service or product. Government.
Feed-in tariffs	Project developers in nature-based projects receive a fixed guaranteed price	Governments
Auction mechanisms	Project developers bid to deliver projects that supply a service at the lowest price	Governments, philanthropy, companies
Advance market commitments	Project developers, companies to invest in projects to generate services, credits or products	Buyers (e.g., companies or governments) commit in advance to purchase volumes of ecosystem services or credits, giving developers confidence to invest.
Revenue Protection and Pre-Financing Mechanisms (risk financing)		
Offtake guarantee (including biodiversity contracts for difference, carbon price guarantee)	The company or project developer who is undertaking activities to enhance biodiversity but faces a risk related to revenues	Could be a government or philanthropy
Insurance	The company or project developer takes insurance to cover delivery risks or performance risks of a nature project. Insurance could also cover	Insurer, but ultimately the company or project developer paying premiums

REVENUES FOR NATURE		
	costs for a specific asset if damaged e.g. coral reef	
Upfront loans or grants for nature-related activities that will generate revenues	The company or project developer receives upfront finance, e.g. from a bank, to enable them to conduct the activities that will generate credits	Ultimately the company or project developer repays once revenues are generated
Supply chain financing	Received by company, helping them get paid faster and with lower risk and enabling/incentivising them to invest in more sustainable activities to produce the products	Financial product provided by a bank, insurer or the buyer, ultimately revenues provider by the buyer of the product. Can be linked to sustainability outcomes.
PUBLIC INVESTMENT IN NATURE		
Financing (repaid)		
Green bonds (also biodiversity bonds, blue bonds etc)	Government (or municipality). Pays for public spending on defined nature-related projects meeting specific criteria	Bond investors (ultimately repaid from government, e.g. tax revenues)
Sustainability-linked sovereign bonds	Government (or municipality). Pays for any public spending but with defined sustainability KPIs (e.g. forest area)	As above
Environmental impact bonds (outcome-based financing)	Governments.	Performance-based financing where investors are repaid (often with a return) only if nature-related outcomes are achieved
Concessional loans	As above	Multilateral development banks (ultimately shareholders)
Debt for Nature swaps	As above	Commercial, bilateral or multilateral creditors. Linked to bond restructuring.
Funding		
Tax (or other) revenues	As above	Taxpayers (could also be e.g. Paris Article 6 revenues or VCM)
Grants e.g. ODA	As above	Bilateral donors, philanthropy
Risk Finance		
Credit enhancement or guarantees	Used by government when issuing bonds to secure improved interest rates	Often provided by international public finance institution e.g. DFC
Insurance/Parametric	Could cover specific assets, e.g. coral reef or be a parametric payment in the event of a natural disaster to recover	Insurer. Premiums ultimately paid by the government.
PRIVATE INVESTMENT IN NATURE		
Financing (repaid/returns/dividends)		
Green loan or bond issuance	Received by a company and used to invest in defined nature positive projects/capital meeting specific criteria	Capital markets (institutional investors), banks
Sustainability-linked bonds or loans	Received by a company and used for all activities but with defined KPIs	As above
Performance-based financing	Received by company to fund activities	Investors are repaid only if nature-based outcomes are achieved

REVENUES FOR NATURE		
Project Finance with Environmental Covenants	Traditional project finance with specific environmental performance conditions (e.g., biodiversity impact thresholds). Common in infrastructure, mining, and energy projects intersecting with nature.	Investors, banks, government (PPPs)
Credit lines, working capital	Received by company and used flexibility for operating costs	Banks
Concessional debt (lower interest rate) or grants (blended finance)	As above	Impact investors, outcome-bond funders, development finance
Green equity	As above	Investors, development finance
Risk Finance		
Trade finance	Working capital or payment security is received by company/exporter to de-risk early-stage investment in natural capital	Banks, export credit agencies and insurers. Finance can be tied to sustainability outcomes.
Risk Sharing/First Loss	Company receives a guarantee that shares risks with a benefactor/investor allowing them to invest upfront. Could also cover a specific asset, e.g. carbon	Investor, development finance institution
PUBLIC-PRIVATE PARTNERSHIPS		
Co-financing/investment	Government collaborates with private sector to finance and operate projects. Ownership and risk-sharing vary (e.g., Build-Operate-Transfer, Design-Build-Finance-Operate).	Blend of public and private. Public banks.
Blended Finance with Revenue Floors	Project developer or company	Governments or DFIs provide revenue floors or first-loss guarantees for nature-based investments, much like CfDs.
Regulated Asset Base	Public infrastructure owner and/or operator – financing to invest in the infrastructure (e.g. green infrastructure or other high capex, long-life, low risk).	Investors earn a regulated return on capital invested in large infrastructure projects (typically utilities), even during construction.
INVESTORS IN NATURE (INCLUDING NATURE FUNDS)		
Co-financing (debt, equity)	Investors co-finance a portfolio of companies to share risk. Received by a fund, asset manager or company	Investors (impact investors, development finance, institutional investors)
Concessional capital (blended finance)	As above, but provided at lower interest rates or grants to de-risk other investors	Development finance, donors, philanthropy, public sector
Guarantees/first loss (blended finance)	Investors are de-risked through provision of guarantee or first loss to protect them	As above
GREENING FINANCE FOR NATURE (Aligning financial flows with nature-related targets)		
Stewardship and engagement	Stewardship refers to how investors use their influence as shareholders to promote good governance, sustainable practices, and long-term value creation in the companies they invest in.	Investors (asset managers and owners, active)

REVENUES FOR NATURE		
Benchmarks/indices for nature	Sustainability indices are benchmarks composed of companies screened and weighted based on ESG or sustainability criteria. Passive investors use these indices to replicate or track performance, rather than selecting individual stocks.	Investors (asset managers and owners, passive)
Labelling (of investment funds or products) (SFDR, SDR, ESG fund labels, sustainability verification schemes)	Sustainability labelling refers to the use of official or market-recognized classifications to indicate that an investment fund or financial product aligns with certain environmental, social, or governance (ESG) standards.	Investors (asset managers and owners)
Risk pricing	Risk pricing is the process of assigning a financial cost/premium to the risks a borrower, investment, or insured asset poses, reflected through interest rates, capital charges, insurance premiums, credit spreads, required returns	Insurers, investors, banks, regulators, Central Banks
Strategic asset allocation	Strategic asset allocation is the process of determining the long-term mix of asset classes in a portfolio (e.g., equities, bonds, real estate, alternatives)	Investors (asset managers and owners, active and passive)
Capital requirements (and funding requirements on pensions funds) (and wider supervisory requirements)	Capital requirements are regulatory rules that require financial institutions — especially banks and insurers — to hold a minimum amount of capital (equity) as a buffer against potential losses. Supervisory requirements including stress testing and scenario analyses.	Banks, insurers
Disclosure and reporting	Mandatory or voluntary disclosure of environmental risks, impacts, and dependencies by firms. Helps investors and regulators assess exposure to nature and biodiversity loss.	Regulators, banks, investors

Table 2.2: Typology of Nature Finance (in bold are those explicitly included in pilots)

A clear conclusion from the table above is that there are vastly different modalities for mobilising and aligning finance for nature, many of which will have quite different requirements from EO in terms of assessing, designing, informing, monitoring and evaluating the mechanisms. Common themes of relevance to EO include:

- Assessing nature-related risks, dependencies and impacts
- Identifying and appraising opportunities
- Monitoring the state of nature and trends over time
- Assessing performance and outcomes of projects or interventions, including risks
- benchmarking firms performance across a global investment portfolio

2.5 Nature Finance Actors

This sub-section maps the key actors involved in EO for Nature Finance given the conceptual framework outlined above. From the conceptual framework laid out above, it is clear that a complex landscape of actors are involved in nature finance. These are summarised in Figure 2.6 and the main types are described briefly below. Each has different needs and entry points for EO, which are considered in detail in the following sections. The subsequent survey of actors allows us to draw out the key knowledge or capacity gaps, data issues or methodological challenges, with specific relevance to the potential role of EO data.

Real Economy Firms: Ultimately, the activities that either damage, protect or restore nature are conducted by real-economy firms and landowners, so in many ways these are the most important stakeholders and those that can benefit most directly from use of EO data. As described above, those sectors with the greater impacts on nature (and also the greatest risks) are real-estate and construction, energy, agri-foods, textiles and mining; these are commonly identified themes in other similar studies, with some additions (e.g. water, wild-caught fisheries; Maxwell et al., 2016) .

Financial Institutions: This includes banks, asset owners (pensions funds, insurers, sovereign wealth funds), asset managers, insurers, funds, private equity, impact investors, venture capitalists etc. These institutions may be financing or funding real economy firms or projects linked to nature directly or indirectly, or providing risk financing in some way. They can include private but also public financial institutions, including Ministries of Finance and public banks.

Data Providers and Specialists (including credit ratings agencies): Data providers provide an essential role in the ecosystem in providing information to financial institutions, real economy firms and regulators. Their role is particularly strong for mid-sized institutions who can afford to invest in data but are not large enough to have strong in-house capability. However, almost every financial institutions will be using one or multiple sustainability and other financial datasets. Credit ratings firms also play a vital role and their ability to represent nature-related risks and impacts effectively is essential so that risks are priced properly in the market.

Enablers (governments, regulators standard setters): It is also essential that the enablers have access to good information to ensure that the enabling environment is established in full alignment with the science and that regulators have sufficient capability to monitor firms. Often these types of organisations have the least internal technical capability. An exception to this is Central Banks, which tend to maintain strong capability on macroeconomic modelling and data, yet are unlikely to have significant environmental and EO expertise so may be relying on partners such as universities and the data providers.

Around these core actors are a large ecosystem of supporting actors that play a particularly important role in bridging between EO and finance. This includes universities and researchers as well as private sector specialist EO companies, industry bodies and programmes (e.g. UNEPFI) and value-add specialist service providers. LEON will focus on the core actors, but engage with the wider ecosystem of actors to ensure that the knowledge and tools are fully embedded.

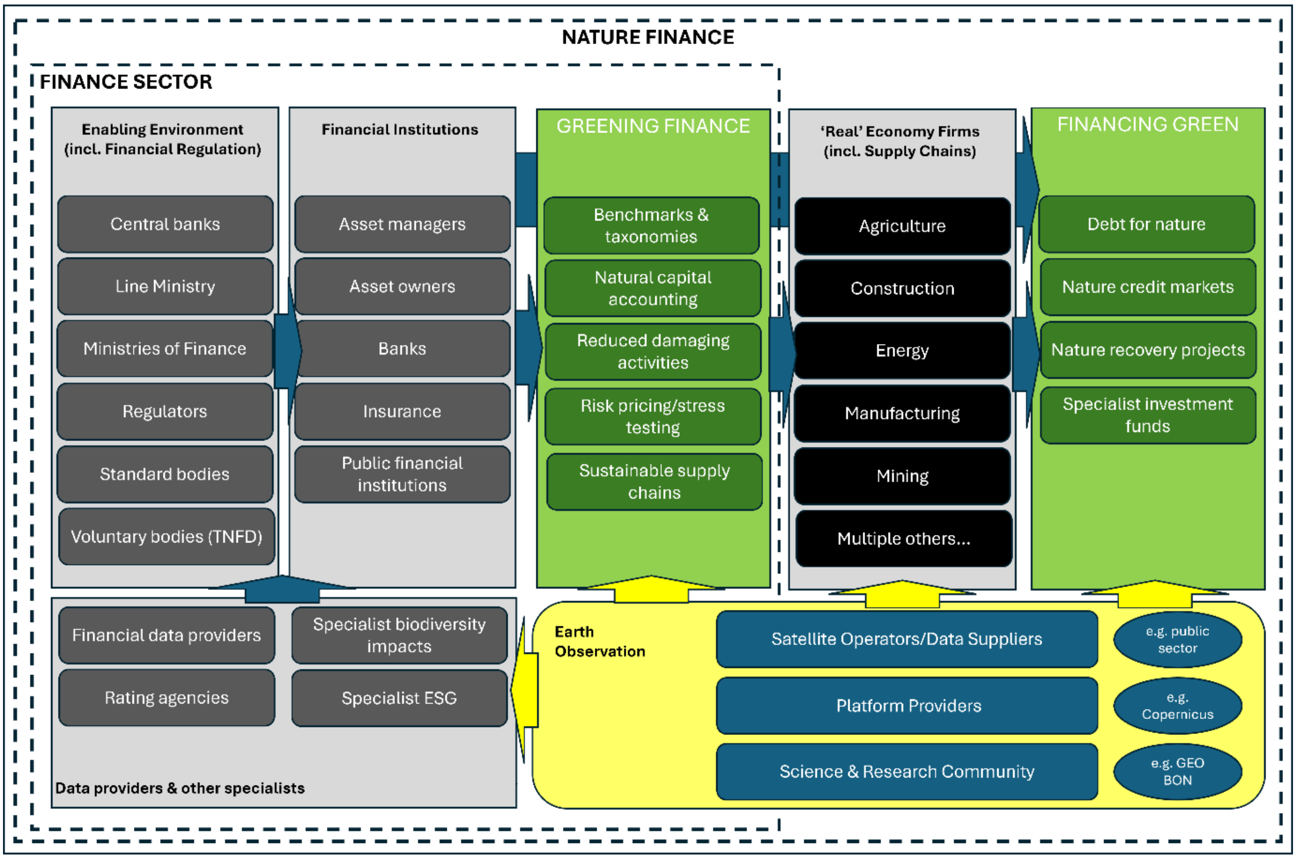

Figure 2.6: Summary of nature finance actors

2.6 Enabling Environment for Nature Finance across Europe

Europe has one of the most advanced sustainability regulation and policy frameworks in the world, including on nature. It is important to map this environment to understand the entry points for EO to support key actors. Nature comprises a large topic area with countless policies and standards, however these vary in their degree to which they directly or indirectly affect nature finance specifically. The analysis presented in this section is limited to instruments directly targeting nature finance and a handful of notable indirect instruments. We focus here on the EU enabling environment and relevant global frameworks. However, it is important to note that financial institutions operating in the EU will be exposed to legal and regulatory frameworks all over the world given the significant interconnectedness of the EU economy.

Non-Financial Policy, Legislation and Regulation

Europe is one of the most advanced jurisdictions for nature-related policy. The EU has set out various strategies including the EU Biodiversity Strategy for 2030, the European Green Deal, and the EU Green Infrastructure Strategy. The goals included in these provide strong signalling to markets for future nature finance demand, which are then specified further in dedicated legislation such as the EU Nature Restoration Law, the EU Soil Health Law and others. Plans and policies specific to high-risk or high-impact industries, such as agri-food, forestry, water, and infrastructure, are another cornerstone for the broader nature finance context, as these can include subsidies, penalties or compensation schemes that incentivise certain types of natural capital use, or provide opportunities to generate revenues for nature. An overview of key legislation

and their relevant is provided in Table 2.3
below.

Policy	Jurisdiction	Impact
EU Biodiversity Strategy for 2030	EU	Provides overarching targets for land and sea use and outlines a need to unlock EUR20 billion per year to meet investment priorities set out in the strategy.
EU Strategy on adaptation to climate change	EU	Sets a goal for the European Commission to "develop the financial aspects of nature-based solutions and foster the development of financial approaches and products that also cover nature-based adaptation"
EU Nature Restoration Law	EU	Sets binding targets for restoring degraded ecosystems across the EU and requires member states to develop nature restoration plans. The European Commission is tasked with identifying funding gaps within one-year of the law's entry to force and proposing management responses.
EU Soil Health Law	EU	Seeks to protect and restore soils to ensure sustainable land use across the EU and encourages financial flows toward soil restoration projects and sustainable land management initiatives.
Common Agricultural Policy	EU	Provides direct financing to farmers with conditionality attached for sound environmental management. Introduces voluntary eco schemes for specific nature-positive actions such as organic farming, agroecology, and other biodiversity measures. The policy also supports longer-term investments on ecosystem services via its Rural Development pillar.
EU Regulation on deforestation-free products (EU DR)	EU	Requires companies that place relevant commodities on EU markets or export these from within the EU to other markets to carry out due diligence and record how this ensures deforestation-free supply chains.
2021-2027 Long-term EU budget & NextGeneration EU	EU	Sets out goal to increase financing to biodiversity-related outcomes to 10% of total budget by 2027.
European Green Deal	EU	The EU's high-level roadmap for making its economy sustainable with specific areas of work and targets related to biodiversity, pollution and natural resource use.
EU Green Infrastructure Strategy	EU	Promotes the development of green infrastructure across Europe with specific provisions for integrating nature-based solutions into urban and rural planning and investing into ecosystem services.
EU Circular economy action plan	EU	Sets out areas of work and targets to reduce waste and pollution in the economy in general and across high-impact sectors. This encourages investment into innovative technology as well as nature restoration activities where necessary.
EU Forestry Strategy	EU	Promotes the multi-functional use of forests including their contribution to biodiversity conservation.
LULUCF Regulation (Regulation (EU) 2018/841, amended in 2023 by Regulation (EU) 2023/839)	EU	The EU LULUCF Regulation governs how greenhouse gas emissions and removals from land use, land-use change, and forestry (LULUCF) are accounted for in the EU's climate policy framework. It's a key piece of the EU's plan to achieve climate neutrality by 2050. Emissions from deforestation must be offset by afforestation, forest growth, or improved land management. Starting in 2026, EU countries face binding national targets for carbon

Policy	Jurisdiction	Impact
		removal from LULUCF activities. LULUCF is the main EU mechanism that accounts for NbS, Supporting voluntary carbon markets and EU Carbon Removal Certification (CRCF)
EU Emissions Trading Scheme	EU	The EU Emissions Trading System is a cap-and-trade scheme covering: power and heat generation; energy-intensive industry; aviation (intra-EEA); shipping and buildings/transport via ETS2. Entities covered by the EU ETS receive or buy emissions allowances (EUAs) and must surrender allowances to match their verified emissions. The total cap decreases annually, ensuring emissions reduction over time. Historically, the EU ETS has not allowed credits related to nature-based solutions.
Paris Article 6	Global	Some EU countries might support international NbS projects and count them toward Nationally Determined Contributions (NDCs) under Article 6 mechanisms.
CORSIA (Carbon Offsetting and Reduction Scheme for International Aviation)	Global	CORSIA applies to international routes, with EU airlines affected for non-EU flights. CORSIA may encourage demand for high-integrity NbS credits, but the EU is cautious about their environmental integrity. NbS projects are eligible, if they meet criteria under approved carbon programs (e.g. Verra, Gold Standard). Examples: REDD+, reforestation, soil carbon, mangroves.

Table 2.3. Non-financial policies, strategies and regulations influencing nature finance in Europe

Financial Policies and Regulation

The EU also boasts one of the most advanced sustainable finance regulations globally, which has been instrumental in driving broader regulation across the world. EU financial regulation, including the taxonomy, the Corporate Sustainability Reporting Directive, Sustainable Finance Disclosure Requirement, and the Corporate Sustainable Due Diligence Directive, targets six environmental objectives: climate mitigation, climate adaptation, biodiversity, sustainable resource use, pollution, and circular economy. These instruments serve to structure information flows and so enhance decision-making to reduce nature-negative finance flows and increase nature positive flows both in the EU and the UK more broadly. However, while all objectives are included, the focus has often been first on climate, followed by biodiversity and then the other objectives. For example, the EU taxonomy focuses on emissions-intensive sectors and does not include agriculture as an industry in its framework. Nonetheless, these policies coupled with the non-financial policies across Europe have set up a promising framework both for greening finance and financing nature. An overview of relevant financial policies is presented in Table 2.4.

Policy	Jurisdiction	Impact
EU Corporate Sustainability Reporting Directive (CSRD)	EU	The CSRD sets sustainability reporting rules for large companies. EU CSRD explicitly states that eligible entities must disclose information as established in the European Sustainability Reporting Standards (ESRS), including on water and marine resources, resource use and the circular economy, pollution and biodiversity and ecosystems.

Policy	Jurisdiction	Impact
Sustainable Finance Disclosure Regulation (SFDR)	EU	The SFRD requires financial institutions and advisors to disclose the environmental risks and impacts of their portfolios. When selling financial products, these are labelled according to their alignment with the taxonomy
EU Taxonomy	EU	The EU taxonomy is a cornerstone of the EU's sustainable finance framework. It helps direct investments to the economic activities most needed for the transition, in line with the European Green Deal objectives. The taxonomy is a classification system that defines criteria for economic activities that are aligned with a net zero trajectory by 2050 and the broader environmental goals other than climate.
Corporate Sustainability Due Diligence Directive (CSDDD)	EU	The Corporate Sustainability Due Diligence Directive (CSDDD) requires companies to identify, prevent, and mitigate adverse human rights and environmental impacts within their operations and across their value chains.
Basel III / CRD & CRR (Banking)	Global/EU	A global regulatory framework developed by the Basel Committee on Banking Supervision to strengthen regulation, supervision, and risk management in the banking sector after the 2008 crisis. In Europe, these are implemented via the Capital Requirements Directive V / Capital Requirements Regulation II and affects capital requirements/buffers, liquidity ratios and disclosures. Basel III doesn't explicitly address nature risks, but regulators (e.g. ECB, EBA) are integrating climate and environmental risks into supervisory expectations.
Solvency II (Insurance)	EU	An EU-specific regulation for insurance and reinsurance companies. Inspired by Basel principles but tailored to insurers, it aims to ensure insurers hold adequate capital relative to their risk profile. Solvency II encourages insurers to assess long-term sustainability, though explicit nature risk integration is still evolving. Under ORSA, insurers can voluntarily consider biodiversity loss as part of forward-looking risk assessments.
IORP II Directive	EU	In the EU, pension funds under IORP II Directive must regularly assess solvency and risk. This is regulated via actuarial assessments (not capital buffers like banks and insurers).
AIFMD (Alternative Investment Fund Managers Directive)	EU	Enhance transparency and oversight of alternative fund managers. Applies to managers of hedge funds, private equity, and other alternative investment funds. Funds integrating nature-positive investments or excluding biodiversity-harming activities must disclose this. Funds marketing themselves under Article 8 or 9 SFDR need to assess impacts on ecosystems.
MiFID II (Markets in Financial Instruments Directive II)	EU	Increases transparency, improves investor protection, and strengthens governance for investment firms, trading venues, and data reporting services. Firms must assess client sustainability preferences, which may include products aligned with nature-related goals.
AMLD (Anti-Money Laundering Directives)	EU	Combat money laundering and terrorist financing. Applies to all obliged entities, including banks and investment firms. Under 6AMLD (Directive (EU) 2018/1673), the EU explicitly includes environmental crime as a predicate offense to money laundering.

Table 2.4. Financial policies and regulation directly affecting nature finance in Europe

Relevant Nature Finance Standards and Principles

Various nature-related standards and principles, launched by initiatives as well as by governments, have served as pioneering reference points for subsequent policy and other instruments. They can guide opportunity identification, monitoring and evaluation of activities, target-setting, and disclosure of information. Their relevance and success often hinges on their legitimacy and credibility. As such, they are able to bring integrity to otherwise unregulated activities, such as carbon markets or nature credit markets. Table 2.5 and 2.6 highlight key initiatives both for greening finance and financing nature respectively below.

Category	Standard/principle	Summary (from websites)
Markets and projects	BSI Flex 701 v2.0 Nature Markets – Overarching Principles and Framework[10]	Sets out principles and foundational requirements for the design and operation of UK nature markets, intended for use by market participants, such as suppliers and intermediaries.
	IAPB Framework for high integrity biodiversity credit markets[11]	Framework to define, guide and encourage the development of high integrity biodiversity credits and credit markets, providing guidance for these market actors at both project and market level.
	Principles for voluntary carbon and nature market integrity[12]	Principles to guide responsible participation in voluntary markets for buying and selling carbon and nature credits.
	Nature Finance Certification Alliance Community Inclusion Standard[13]	Standard is to provide project developers a reliable and value-adding approach to working with communities.
	BSI Flex 703 v1.0 Supply of nature-based carbon benefits[14]	Specifies requirements for high quality carbon removals and greenhouse gas (GHG) reductions delivered by UK nature-based projects.
	Green Infrastructure Standards and Principles[15]	Define what good green infrastructure 'looks like' for local planners, developers, parks and greenspace managers and communities, and how to plan it strategically to deliver multiple benefits.
	EU Green Bond Standard	Uses the EU taxonomy to classify sustainable activities addressing each of the environmental objectives: climate mitigation, adaptation, natural resource use, pollution, circular economy and biodiversity.
	EU *Nature Credit System*	Still under discussion.
Carbon certification	Wilder Carbon Standard[19]	Nature-based carbon standard for minimum-intervention projects aiming to create carbon benefits through the restoration of native habitat.
	EU Carbon Removals and Carbon Farming Certification Regulation (CRCF)	The Carbon Removals and Carbon Farming (CRCF) Regulation (EU/2024/3012) was published in the Official Journal of the EU on 6 December 2024, creating the first EU-wide voluntary framework for certifying carbon removals, carbon farming and carbon storage in products across Europe. By establishing EU quality criteria and laying down monitoring and reporting processes, the CRCF Regulation will facilitate investment in innovative carbon removal technologies, as well as sustainable carbon farming solutions, while addressing greenwashing. The EU-wide voluntary certification scheme includes peatland restoration,

Category	Standard/principle	Summary (from websites)
		agroforestry, soil protection measures, and reforestation following ecological principles.
	Voluntary Carbon Markets (Verra, Gold Standard)	Corporate net-zero, offsetting including nature-based carbon standards. Used widely by EU companies, under scrutiny. CRCF may supersede or replace VCM reliance for EU-based actors over time.
	ISO 14064	A series of standards related to GHG accounting in emissions reductions projects.
Financing Principles	Equator Principles	The Equator Principles (EPs) serve as a common baseline and risk management framework for financial institutions to identify, assess and manage environmental and social risks when financing Projects.
	PRI: Investing for Sustainability Impact[19]	Four-part framework guidance for investors on investing for sustainability impact

Table 2.5. Financing Nature-related standards and principles relevant to Europe (plus relevant UK)

Category	Standard/principle	Summary (from websites)
Corporate Disclosures, Standards and Ambition	Science-based Targets Initiative[20]	Provide a clearly defined pathway for companies to reduce greenhouse gas (GHG) emissions, with the end goal of achieving net zero. Incorporates NbS but with limits.
	Science-Based Targets Network (SBTN)	SBTN focuses on setting science-based targets for nature
	Taskforce on Nature-related Financial Disclosures (TNFD)[21]	A set of disclosure recommendations and guidance that encourage and enable business and finance to assess, report and act on their nature-related dependencies, impacts, risks and opportunities.
	Nature Action 100[22]	Nature Action 100 is a global investor-led engagement initiative focused on supporting greater corporate ambition and action.
	CSRD – ESRS E4: Biodiversity and Ecosystems	Part of the European Sustainability Reporting Standards (ESRS) under the CSRD. ESRS E4 focuses specifically on biodiversity and ecosystems, aiming to make companies report their impacts, risks, and dependencies on nature.
	International Sustainability Standards Board (ISSB): IFRS Sustainability Disclosure Standards	The ISSB is responsible for developing IFRS Sustainability Disclosure Standards, to provide a global baseline of sustainability disclosures to further inform economic and investment decisions.
	Sustainability Accounting Standards Board (SASB) (SASB was integrated as part of ISSB)	SASB Standards help companies disclose relevant sustainability information to their investors. Available for 77 industries, the SASB Standards identify the sustainability-related risks and opportunities most likely to affect an entity's cash flows, access to finance and cost of capital over the short, medium or long term and the disclosure topics and metrics that are most likely to be useful to investors.
	Global Reporting Initiative	Common global language to assess and report on environmental, social, and economic impacts
	Transition Plans (multiple)	Multiple transition planning guidance and standards are becoming available. ISSB published its initial guidance in June

[19] https://www.unpri.org/a-legal-framework-for-impact/investing-for-sustainability-impact-guidance/12864.article

Category	Standard/principle	Summary (from websites)
		2025[20] which mentions nature and biodiversity only in the context of physical climate risks and resilience and carbon crediting approaches. Such standards guide businesses in how to develop and disclose plans for how they will meet their stated environmental targets e.g. to 2050. These are intended to give a forward-view on current climate and nature disclosures to facilitate transition finance and alignment. Standards have tended to focus on mitigation targets but are beginning to consider how to incorporate nature (e.g. GFANZ and TNFD).

Table 2.6. Greening Finance-related standards and principles relevant to Europe

[20] https://www.ifrs.org/content/dam/ifrs/supporting-implementation/ifrs-s2/transition-plan-disclosure-s2.pdf

Factor	Key Issues/Trends	Impact on Nature Finance	Opportunities	Threats
Political	- EU Green Deal and Biodiversity Strategy 2030 - Global Biodiversity Framework - Political will for Green Finance - CAP reform debates	High – sets policy direction and funding flows	- Strong policy support can drive public-private investment - EU leadership role	- Political shifts or lobbying from sectors with high impacts, e.g. agri and extractives. - Policy fragmentation and rollback due to 'backlash' on ESG and climate. - US politics and global trade issues
Economic	- Challenging macroeconomic environment in Europe and globally - Need for large-scale investment (est. €200+ billion/year for nature)	Medium to High – funding gaps limit scaling	- Green jobs in restoration economy - Green competitiveness globally - Green finance leadership	- Emphasis on growth – challenging period for some European countries economically - Perceived low ROI in nature relative to risks - Competing priorities eg defence spending
Social	- Public concern for biodiversity, especially in younger groups - Investor appetite in nature-positive - 'Anti-woke' agenda	Moderate – growing public and investor awareness	- Social license and legitimacy for projects - Eco-tourism and local benefits	- NIMBYism or community pushback - Inequity in benefit distribution
Technological	- Growth in ESG and biodiversity monitoring tools - Remote sensing, AI for tracking impact	Low to Medium – enabling, but not core driver	- Better data improves accountability and investor confidence	- Data gaps and lack of standardisation may deter investment
Legal	- EU Taxonomy - Corporate Sustainability Reporting Directive (CSRD) - EU Deforestation Regulation	High – mandatory disclosure drives corporate behaviour	- Legal clarity improves investor confidence - Enforcement mechanisms exist	- Legal uncertainty or slow implementation, limits to resources for full implementation - Risk of greenwashing - Ongoing discussions on regulation including EU Omnibus and Basel III
Environmental	- Rapid biodiversity loss - Ecosystem degradation (soil, water, forests) - Climate-nature nexus	Very High – foundational rationale for nature finance	- More understanding of nature risk - Nature-based solutions for climate adaptation/mitigation - Long-term resilience	- Irreversible damage if action delayed - Ecosystem service collapse

Table 2.7: Summary results, project PESTLE Analysis

2.7 PESTLE Analysis

The results of the PESTLE analysis (Fig 2.7) highlight the complex and evolving landscape in which the LEON project operates, underscoring both enabling conditions and systemic barriers for the integration of Earth Observation (EO) in nature finance.

From a political perspective, despite some notable current setbacks, there is long-term increasing policy support for biodiversity and climate-related financial disclosures presents a strong alignment with LEON's objectives. However, varied levels of regulatory maturity across jurisdictions may limit early-stage adoption and require tailored engagement strategies.

Economic conditions, including heightened interest in green and blended finance mechanisms, offer opportunities for EO-informed investment tools. Yet, macroeconomic volatility and constrained public budgets could impede the scale-up of nature-positive investments unless EO services demonstrate clear cost-benefit advantages.

The sociocultural dimension reveals growing awareness of nature-related risks but also limited institutional capacity and awareness of EO tools among financial actors. This necessitates LEON to prioritise usability, transparency, and capacity-building alongside technical innovation.

In the technological domain, the proliferation of EO platforms and analytics capabilities supports LEON's ambition to develop scalable services. Nevertheless, the lack of standardised data infrastructures and interoperability remains a critical bottleneck. LEON must therefore advocate for and align with emerging best practices in data architecture and semantic standards.

From a legal standpoint, evolving disclosure mandates (e.g. CSRD, TNFD) incentivise nature-related reporting, creating a potential market pull for EO-derived indicators. However, legal ambiguity around biodiversity crediting and sovereign-linked instruments introduces uncertainties that LEON must navigate through adaptive design.

Finally, environmental pressures - from climate change to ecosystem degradation - intensify the urgency for reliable, actionable nature data. LEON is uniquely positioned to bridge the gap between satellite-based monitoring and financial decision-making, enabling more timely, granular, and evidence-based investment decisions.

Overall, the PESTLE findings affirm the strategic relevance of scaling EO for nature finance while signalling the importance of adopting flexible, cross-sectoral design approaches that address regulatory fragmentation, institutional knowledge gaps, and data standardisation challenges.

3. USER REQUIREMENTS

Core to the success of LEON is the role of our partners (Figure 3.1). The LEON consortium includes a group of strategically assembled supporting organisations that represent the breadth of Nature Finance activities – covering all the key types of actors involved in nature finance from Section 2 – and with financial interests, data and projects across the globe. Stakeholders span geographical regions including Europe, Latin America, North America, Africa and Southeast Asia, to deliver the pilots and ensure the results scale to maximise impacts.

Early Adopters co-design and evaluate solutions on the pilots. Wider stakeholders also play a critical role in transferring and adopting results for wider scale and impact, allowing LEON to map requirements across sectors, gain feedback, and seek broad adoption. Wider impact partners help us connect to wider community of EO providers and users, as well as regulators and governments.

User requirements capture and analysis is conducted through a multi-stage process:

1. Initial survey of user requirements across all the pilots, focussed on the Early Adopters, but sharing with the wider network of stakeholders and partners (Figure 3.1).
2. Dedicated consultation meetings (remotely and/or in person, one to one and collegial) with set of focal Early Adopters, ensuring a global applicability and relevance of the requirements, and of the project outcomes.
3. Engagement of more than 50 ‘Supporting Stakeholders’. This group includes (i) further finance community user representatives, (ii) biodiversity science community (via GEOBON), and (iii) EO industry community (via EARSC). In addition, we also engage with regulators, Central Banks, ESG data providers, ratings agencies, governments and standard setters to ensure EO solutions are operationalised within relevant regulations, standards and policies needed for impact.
4. In addition to the formal project stakeholders, the project has attracted around 500 subscribers that provide additional inputs essential to shaping and disseminating the LEON research.

It is noted that these user requirements expressed in this report are preliminary, as more detailed requirements are expected to surface and be refined during the ongoing development of the LEON pilots.

3.1. High-level survey findings

The LEON User Requirements Survey 2025 provides important insights into how financial institutions and related stakeholders currently engage with EO data in the context of nature finance and where critical data gaps remain. The full findings are documented in the accompanying report: *Earth Observation to Scale Nature Finance: Survey 2025*. This section summarises the cross-cutting findings and findings for individual thematic pilots are discussed below.

Growing Demand for Spatial Environmental Data: Survey results indicate strong and growing demand for spatial environmental data among financial institutions. Many respondents reported that their organisations are already beginning to collect and analyse nature-related information, particularly regarding: nature-related risks, dependencies and impacts; biodiversity commitments; sustainability targets; and nature-related investment strategies.

However, the survey also revealed that institutional integration of nature considerations into financial decision-

making remains at an early stage. For example, few organisations currently maintain nature-related transition plans or systematic frameworks for integrating biodiversity risks across portfolios. This suggests that while awareness of nature-related issues is increasing rapidly, the operational use of environmental data in financial risk management and investment decision-making remains limited.

Key Drivers of Nature Finance: Respondents identified several important drivers that could accelerate the development of nature finance markets. Regulatory frameworks and sustainability disclosure requirements were widely cited as major catalysts for action. These regulatory drivers are complemented by growing interest in financial instruments such as: blended finance structures; sustainability-linked loans and green bonds; market-based mechanisms including biodiversity credits; sovereign financing instruments such as sustainability-linked bonds. These instruments are seen as important channels for mobilising private capital toward nature-positive activities.

Persistent Barriers to Scaling Nature Finance: Despite growing interest in nature-related investment, respondents identified several major barriers that continue to limit the scale of nature finance. The most frequently cited challenges include:

- lack of granular environmental data
- absence of standardised metrics and taxonomies for nature-related information
- insufficient asset-level geolocation data
- fragmented environmental data platforms.

These challenges limit the ability of financial institutions to quantify nature-related risks, monitor environmental impacts, and comply with emerging disclosure frameworks.

Respondents also highlighted structural barriers affecting nature investment markets more broadly. In particular, respondents emphasised:

- limited availability of investable nature-positive projects
- lack of financial mechanisms capable of generating stable returns from nature-based investments
- insufficient policy incentives to mobilise private capital.

Data availability challenges are particularly acute in the Global South and in complex sectors such as agri-food supply chains and marine ecosystems, where environmental risks are difficult to monitor and attribute.

Earth Observation as a Key Enabling Technology: Survey respondents widely recognised the potential value of Earth Observation technologies in addressing many of the current data challenges facing nature finance. EO data was considered particularly valuable for:

- monitoring land-use change and ecosystem condition
- assessing environmental risks within global supply chains
- verifying corporate sustainability disclosures
- monitoring environmental performance of projects and investments.

However, the survey also indicates that operational use of EO data within FIs remains limited. While many organisations have experimented with EO datasets, relatively few institutions currently integrate EO data systematically into risk assessments or investment analysis.

EO Data Requirements: Respondents identified several key characteristics required for EO data to be useful for financial decision-making.

- First, users strongly prefer processed and accessible datasets rather than raw satellite imagery. Preferred formats include: CSV datasets; raster or vector geospatial datasets; visual dashboards or analytical platforms.

- Second, respondents indicated that medium spatial resolution datasets (10–30 metres) are generally sufficient for many financial applications.
- Third, most respondents considered monthly or annual update frequencies appropriate for monitoring environmental trends relevant to financial portfolios.
- Finally, respondents emphasised the importance of ground-truth validation and methodological transparency. Approximately 78% of respondents indicated that EO datasets should be validated using ground-truth data or independent verification in order to build confidence in their use for financial decision-making.

Data Integration Challenges: Beyond data availability, respondents highlighted several operational challenges in integrating environmental data into financial workflows. In particular, respondents emphasised difficulties linking environmental datasets to financial exposures due to:

- limited availability of asset-level geolocation data
- incomplete supply-chain traceability
- fragmented land registries and ownership information.

These challenges are particularly significant in sectors with complex supply chains such as agriculture, forestry and mining.

Overall, the findings highlight that improving the integration of EO data with asset-level and supply-chain datasets is likely to be critical for enabling nature finance at scale.

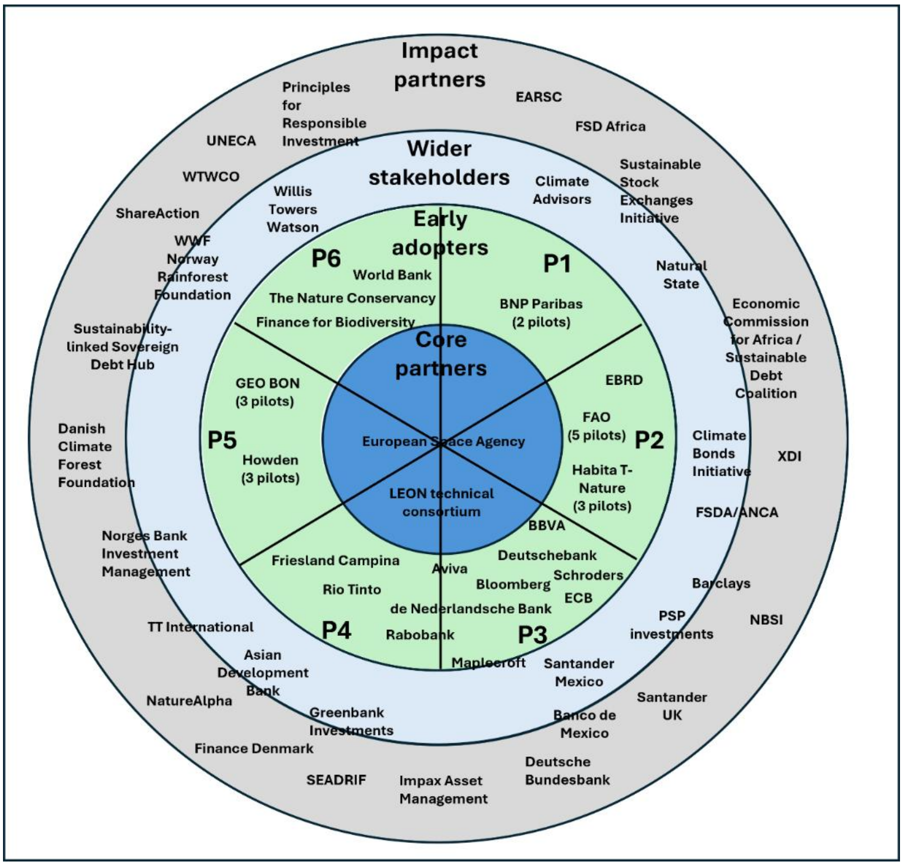

Figure 3.1: Early adopters and stakeholders involved in LEON

3.2. Thematic Findings

The LEON project is structured around six thematic pilot areas designed to explore how Earth Observation (EO) data can support the mobilisation and scaling of nature-positive finance across different sectors, financial instruments, and decision-making contexts. These pilots were selected to reflect diverse entry points into nature finance, spanning both **"greening finance"** (integration of nature-related risks into financial decision-making) and **"financing green"** (mobilising capital toward activities that conserve or restore ecosystems).

Each pilot examines a distinct domain where nature-related risks, impacts, and opportunities are particularly material for financial institutions and where EO technologies have the potential to provide decision-relevant information that is currently lacking. The pilots address different actors, spatial scales, and financial mechanisms. For example, biodiversity credit markets require highly localised monitoring of ecological outcomes, while financial risk analysis for institutional investors often requires global datasets capable of supporting portfolio-level assessments.

Across all pilots, the analysis draws upon results from the LEON user survey and consultations with Early Adopters and stakeholders as well as background literature review and analysis. These findings indicate that financial institutions are increasingly aware of nature-related risks but lack the granular, spatially explicit data required to operationalise these insights in financial decision-making. In particular, respondents emphasised persistent challenges relating to the lack of standardised metrics, limited availability of asset-level geolocation data, and fragmented environmental data infrastructures. The following sections introduce each pilot area and outline the key analytical questions, user needs, and opportunities for EO data.

Pilot 1: Mining Supply Chains

The LEON mining pilot develops and tests an Earth Observation (EO)-based approach to monitor mining-related impacts on freshwater systems and associated biodiversity, with the aim of supporting financial institutions in environmental risk assessment, due diligence, stewardship, and disclosure. The pilot focuses on two linked analytical objectives. First, it tracks key water quality parameters to identify pollution hotspots and understand the spatial and temporal dynamics of water quality near mining sites at watershed scale. Second, it assesses biodiversity impacts by examining the overlap between mining-affected freshwater systems and the habitats of endemic, rare, sensitive, or threatened species. In doing so, the pilot seeks to move financial analysis beyond sector-average risk screening towards geospatially explicit, asset-level intelligence that can support investment decisions, lending assessments, and regulatory reporting. The pilot focuses specifically on lithium mining operations in Brazil, where open-pit extraction and associated processing activities create material risks to freshwater ecosystems through sediment mobilisation, chemical contamination, and changes in hydrological regimes. While the empirical work focuses on Brazil, the methodological approach is intended to be applicable across mining geographies and commodity types.

Context and Relevance for Nature Finance

Mining plays a central role in the global economy by supplying minerals essential for infrastructure development, industrial production, and the energy transition. Demand for metals such as lithium, cobalt, nickel, copper, and rare earth elements is expected to increase significantly as countries pursue decarbonisation strategies and the electrification of transport and energy systems. Yet mining operations are also associated with significant environmental pressures, including land degradation, freshwater contamination, biodiversity loss, and waste generation. These environmental impacts create both physical risks and transition risks for financial institutions that finance or invest in mining companies.

The Taskforce on Nature-related Financial Disclosures (TNFD) identifies extractive industries and mineral processing as sectors with high impacts and dependencies on nature, particularly through land use change, water use, water pollution, and waste generation (TNFD, 2023). While land use change and deforestation have received considerable attention in sustainability frameworks, water-related impacts remain comparatively less well explored, despite carrying significant implications for biodiversity and local communities.

Mining operations are also heavily dependent on ecosystem services, particularly water purification and water supply. Tools such as ENCORE (Exploring Natural Capital Opportunities, Risks and Exposure) illustrate the extent to which mining activities both depend upon and exert pressure on ecosystem services. ENCORE data indicate that mining exerts high levels of pressure on nature through terrestrial ecosystem use and water pollution while also exhibiting strong dependencies on freshwater ecosystem services (UNEP-WCMC et al., 2022). This dual character - as both a driver of water quality degradation and a sector reliant on clean water - makes water quality a particularly important focus for environmental risk assessment from both an impact and a dependency perspective.

Financial Sector Exposure and User Requirements

Ten respondents participated in the mining section of the LEON user requirements survey, providing evidence of significant financial sector exposure to mining supply chains across a wide range of commodities. Eight respondents reported exposure to large-scale industrial mining, five to junior or mid-tier mining companies, one to artisanal or small-scale mining, and three to mine rehabilitation or closure financing. Respondents indicated exposure to a diverse range of mineral commodities, including precious and base metals (gold, silver, copper, nickel), battery minerals (lithium, cobalt, graphite), bulk commodities (iron ore, bauxite, coal), and industrial minerals such as phosphate and potash. This breadth of exposure highlights the importance of robust environmental risk assessment frameworks capable of addressing diverse mining activities.

Respondents identified several major environmental risks associated with mining operations. The most frequently cited sources of freshwater pollution included tailings dam failures and spills, chemical leaching from processing activities, and excessive water withdrawals. Broader environmental risks highlighted included land degradation and habitat destruction, waste management issues, and air pollution or greenhouse gas emissions.

Survey responses also suggest that financial institutions are beginning to engage with geospatial approaches to environmental risk analysis. Two thirds of respondents reported having experimented with EO data, although not yet systematically, indicating emerging but still immature adoption of satellite-based monitoring tools. Existing uses of spatial data already include geospatial risk assessments and GIS-based mapping as well as broader spatial analysis, each cited by approximately half of respondents. This suggests that EO-based tools could potentially be integrated into existing institutional workflows if decision-relevant datasets become available. At present, financial institutions rely primarily on financial and operational data, sustainability reports, and regulatory compliance datasets to assess environmental risks. Despite strong interest in EO data, only three institutions reported actively using EO datasets in environmental risk assessments, six indicated they were experimenting with EO applications, and only two reported systematic integration of EO data into decision-making processes. These findings suggest that EO adoption within the mining finance sector remains at an early stage.

Respondents indicated that global spatial coverage combined with high spatial resolution is typically required for effective monitoring. Preferences for spatial resolution varied depending on the use case. For assessing Scope 1 risks and impacts at site level, three respondents preferred ultrahigh resolution datasets, two preferred high resolution, one preferred medium resolution, and one preferred low resolution, while several respondents indicated uncertainty about resolution requirements. These responses suggest that while asset-level monitoring is highly valued, technical requirements vary depending on the decision context.

For assessing Scope 3 risks and impacts at corporate level, most respondents considered direct supply-chain data linking corporations to specific operational assets to be the most relevant spatial scale for analysis.

Survey respondents also identified several priority use cases for EO data in the mining sector. These included identifying high-risk assets for financial risk mitigation, monitoring environmental risks associated with mining operations, supporting engagement with mining companies regarding environmental performance, and informing lending and investment decisions.

Earth Observation Opportunities and Requirements

Conventional approaches to environmental monitoring in the mining sector suffer from significant limitations when applied to financial risk assessment. Sustainability reports and regulatory disclosures are typically produced annually, rely on self-reported company data, and offer limited spatial granularity below the site or national level. Ground-based water quality monitoring can provide detailed local information but is resource-intensive, geographically constrained, and often unavailable in remote jurisdictions where mining activity is concentrated. As a result, financial institutions often lack the ability to assess the real-time environmental performance of mining assets within their portfolios. Tools such as ENCORE provide valuable high-level screening but rely on sector-average metrics and cannot distinguish between operations with strong environmental management and those with poor environmental performance.

For financial institutions to meet the geospatially specific disclosure requirements embedded in TNFD, CSRD/ESRS E4, and SFDR, significantly improved spatial data are required. TNFD LEAP guidance defines priority locations as areas of rapid decline in ecosystem integrity and areas exposed to high physical water risks. EO-based monitoring systems are particularly well suited to identifying such locations. Satellite datasets from the Copernicus Sentinel programme provide a scalable and globally consistent monitoring capability. With revisit frequencies of approximately five days, Sentinel missions enable near-continuous monitoring of surface water conditions across entire watersheds, allowing detection of pollution events that may otherwise remain invisible within annual reporting cycles.

EO Capabilities and Applications in Mining Contexts

EO-based water quality monitoring enables the derivation of several optically active water quality parameters from satellite reflectance data. These include turbidity, total suspended solids (TSS), chlorophyll-a concentration, and spectral colour indices, all of which serve as proxies for different forms of water contamination relevant to mining activities. For open-pit hard-rock lithium mining in Brazil - the focus of this pilot - key freshwater pollution pathways include sediment mobilisation, acid mine drainage, and chemical processing effluent. EO-derived turbidity and TSS indicators can therefore provide direct signals of sediment loading and runoff dynamics associated with mining operations. Chlorophyll-a retrievals may indicate downstream eutrophication processes resulting from nutrient enrichment linked to land disturbance or waste storage. Spectral colour anomalies can provide early indicators of acute contamination events that alter the optical properties of water bodies.

Beyond water quality monitoring, EO datasets can support several additional analytical capabilities relevant to mining impact assessment. Multispectral satellite time series enable monitoring of land surface disturbance, expansion of tailings storage facilities, and changes in surface water extent. Vegetation indices derived from near-infrared spectral bands can capture ecosystem condition changes in riparian zones downstream of mining sites.

Together, these capabilities enable a shift from reactive environmental reporting toward proactive and continuous environmental monitoring, significantly improving the information available to financial institutions managing nature-related risks.

Requirements and Constraints

To be operationally useful for financial institutions, EO-derived environmental indicators must meet several practical requirements identified through survey responses and stakeholder consultations. First, datasets must provide global coverage while maintaining sufficient spatial resolution to attribute impacts to specific mining assets. Second, multi-year time series are required to distinguish pollution events from natural variability and to assess trends in environmental performance over financing cycles. Third, EO-derived indicators must be interpretable and translatable into financial risk metrics that can be incorporated into existing analytical workflows. Finally, indicators must align with disclosure frameworks used by financial institutions.

Important constraints must also be acknowledged. Cloud cover can interrupt optical satellite time series, particularly in tropical regions during wet seasons, requiring compositing or gap-filling approaches. Optically complex waters affected by multiple simultaneous pollution types may reduce the accuracy of parameter retrieval algorithms, meaning that local validation is often required before operational deployment. EO methods are also best suited to monitoring surface water conditions; groundwater contamination and dissolved pollutants without optical signatures require complementary in-situ monitoring.

Regulatory and Disclosure Framework Alignment

The LEON mining pilot is closely aligned with several international disclosure frameworks and sustainability standards relevant to environmental monitoring in the mining sector. For financial institutions to issue TNFD-aligned disclosure statements and comply with the Corporate Sustainability Reporting Directive (CSRD) - specifically the European Sustainability

Reporting Standard on biodiversity (ESRS E4) - they require geospatially explicit environmental information for financed activities rather than sector-level averages.

In addition, emissions to water constitute one of the mandatory principal adverse impact indicators under the Sustainable Finance Disclosure Regulation (SFDR), further reinforcing the regulatory relevance of water quality monitoring in the mining sector. The standards and frameworks relevant to this pilot include:

- TNFD (Taskforce on Nature-related Financial Disclosures)
- CSRD and ESRS E4 biodiversity reporting requirements
- Sustainable Finance Disclosure Regulation (SFDR)
- CDP Water Security Questionnaire
- GRI 303 Water and Effluents Standard
- SASB Metals and Mining Standard
- ICMM Water Stewardship Position Statement

Together these frameworks increasingly require companies and their financiers to disclose impacts on water and marine ecosystems, pollution outputs, and dependencies on water availability and quality.

Pilot Scope and Methodology

The pilot develops an EO-based monitoring framework for mining-related water pollution in Brazil. Using time series from Sentinel satellite datasets, the analysis tracks several key water quality indicators at watershed scale. These indicators include:

- **Turbidity** – indicating suspended sediments generated by mining disturbance and runoff.
- **Total Suspended Solids (TSS)** – indicating sediment transport and potential waste discharge into freshwater systems.
- **Chlorophyll-a** – indicating eutrophication and nutrient enrichment potentially linked to mining-related land disturbance.
- **Colour anomalies** – indicating chemical contamination, sediment plumes, or algal blooms detectable through multispectral imagery.

In addition to water quality monitoring, the pilot evaluates biodiversity risks by quantifying the spatial overlap between mining-affected freshwater systems and habitats of endemic, rare, sensitive, or threatened species. This enables financial institutions to assess potential biodiversity impacts associated with mining activities at both ecosystem and species levels.

Through these approaches, the pilot demonstrates how EO data can support more granular environmental monitoring, improve nature-related financial risk assessment, and strengthen alignment with emerging regulatory frameworks for nature-related disclosure.

Pilot 2: Agrifood Supply Chains

The LEON agri-food pilot develops and tests an Earth Observation (EO)-based approach to monitor environmental impacts and dependencies associated with oil palm supply chains in Indonesia and Malaysia, with the aim of supporting financial institutions in environmental risk assessment, due diligence, stewardship, and disclosure. Like the mining pilot, the agri-food pilot seeks to move financial analysis beyond sector-average risk screening - such as that offered by ENCORE and the WBCSD framework - towards geospatially explicit, asset-level intelligence capable of supporting investment decisions, lending assessments, and regulatory reporting.

The pilot focuses on a single investee company and its oil palm supply chain. The geographic scope is constrained by the availability of geolocation data, which is limited to publicly available company disclosures. The analysis is structured around four linked analytical objectives, each translating a potential impact or dependency identified in the ENCORE framework into a quantified, mill-level EO-derived metric: deforestation and oil palm extent; water quality; carbon stock and peatland condition; and fire incidence. Together, these metrics enable the construction of an environmental performance profile for each mill asset and its associated supply shed. Although the empirical work focuses on oil palm in Southeast Asia, the methodological approach is intended to be applicable across agri-food commodities and geographies.

Sector Context and Environmental Significance

Agriculture is the largest driver of terrestrial biodiversity loss globally and is responsible for approximately 80% of tropical deforestation, while also contributing significantly to freshwater pollution, greenhouse gas emissions, and soil degradation (IPBES, 2019). The agri-food sector depends heavily on ecosystem services—including pollination, water regulation, soil formation, and climate regulation—that are simultaneously being degraded by agricultural expansion and intensification. These dynamics create material physical and transition risks for financial institutions with exposure to agri-food supply chains.

Oil palm is among the most environmentally significant globally traded agricultural commodities. Indonesia and Malaysia together account for approximately 85% of global palm oil production. Historically, the expansion of oil palm plantations has been associated with tropical deforestation, peatland conversion, and biodiversity loss in some of the most ecologically sensitive landscapes in Southeast Asia (Gaveau et al., 2016). Conversion of forests and peatlands releases substantial quantities of stored carbon, degrades water quality through fertiliser runoff and Palm Oil Mill Effluent (POME), and threatens endemic species with restricted ranges.

The Taskforce on Nature-related Financial Disclosures (TNFD) identifies food, agriculture, and beverages as a sector with high impacts and high dependencies on nature, particularly through land use change, water use, water pollution, and soil disturbance (TNFD, 2023). Tools such as ENCORE similarly demonstrate that agricultural activities—including oil palm cultivation—exert significant pressures on nature through terrestrial ecosystem use, water consumption, and pollution, while simultaneously depending on ecosystem services such as soil quality, water regulation, and climate stability (UNEP-WCMC et al., 2022). This dual exposure - as both a driver of ecosystem degradation and a sector reliant on healthy ecosystems - is a defining characteristic of nature-related financial risk in the agri-food sector.

While high-level screening tools can identify sectors with elevated nature-related risk profiles, they cannot provide the asset-level, geospatially specific data required to assess the environmental performance of individual supply chain actors or meet emerging regulatory disclosure requirements. Translating sector-average potential impacts into quantified, location-specific metrics is therefore a central challenge addressed by this pilot.

Financial Sector Exposure and User Requirements

Fifteen respondents participated in the agri-food and forestry sections of the LEON user requirements survey. Most reported exposure to the agri-food sector through bank lending to producers or through equity and debt investments in listed food retailers and processing companies. Survey responses indicate that financial institutions are increasingly exposed to nature-related risks through agricultural supply chains, particularly commodities associated with deforestation and land-use change.

Many institutions reported collecting information on land conversion policies and deforestation risks associated with investee companies. However, the spatial granularity of this information varies considerably. A key challenge identified by respondents is the lack of supplier-level geolocation data, which limits the ability to link supply chains to environmental risks detectable through EO or other spatial datasets. This gap constrains both the credibility of environmental risk assessments and the ability of financial institutions to engage meaningfully with portfolio companies on nature-related performance.

Respondents identified several priority EO use cases in agri-food supply chains:

- monitoring deforestation and forest degradation linked to agricultural expansion
- identifying high-risk sourcing regions within commodity supply chains
- supporting due diligence and supply chain traceability
- verifying corporate sustainability disclosures.

High-resolution EO data was considered necessary for site-level analysis, while semi-annual or annual monitoring frequencies were regarded as sufficient for most strategic decision-making applications. These preferences reflect the need for EO products that provide asset-level intelligence while remaining manageable within institutional workflows.

Consultations with Early Adopters identified additional priorities for EO-based tools in the agri-food sector. These include moving beyond high-level potential impact assessments toward quantification of asset-level environmental impacts and dependencies, constructing integrated environmental performance profiles for mill assets, and providing financial institutions with auditable geospatial data to support targeted engagement with portfolio companies. These consultations highlighted several potential applications for EO-based analytics:

- **Enhanced risk assessment.** Integrated environmental profiles enable more precise assessment of transition, physical, and operational risks within financial portfolios, including deforestation-related transition risks and water-related operational risks.
- **Corporate engagement.** Asset-level environmental data provides a credible basis for dialogue with portfolio companies on environmental performance, supply chain management, and sustainability commitments.
- **Innovative financial products.** EO-verified environmental metrics may support sustainability-linked loans or other financial instruments with key performance indicators tied to verified environmental outcomes.
- **Due diligence and compliance.** EO-based monitoring can support due diligence under deforestation-free supply chain regulations and align with reporting frameworks such as TNFD, SFDR, and the EU Deforestation Regulation (EUDR).

Earth Observation Opportunities and Requirements - The Data Gap: Limitations of Conventional Monitoring

Conventional monitoring approaches in agri-food supply chains face significant limitations when applied to financial risk assessment. Corporate sustainability reports typically rely on self-reported data, are produced annually, and rarely provide spatial information at the level of individual mills or sourcing areas. Certification schemes such as the Roundtable on Sustainable Palm Oil (RSPO) provide important standards but have been criticised for incomplete coverage, inconsistent verification, and limited transparency at the mill or plantation level.

Ground-based monitoring can generate detailed environmental data but is resource-intensive and difficult to apply systematically across geographically dispersed supply chains. As in the mining sector, sector-level screening tools such as ENCORE (UNEP-WCMC et al., 2022) and the WBCSD framework provide useful context but cannot attribute environmental impacts to specific companies, mills, or supply sheds. For financial institutions to meet geospatially specific disclosure requirements under TNFD, CSRD/ESRS E4, SFDR, and the EU Deforestation Regulation (EUDR), they require datasets capable of linking financed activities to specific geographic locations and ecosystems (TNFD, 2023; European Commission, 2023a; European Commission, 2019; European Commission, 2023b). EO-based monitoring is particularly well suited to bridging this gap. Satellite datasets from the Copernicus Sentinel programme, combined with higher-resolution imagery and established land cover products, enable systematic and spatially explicit monitoring of supply chain environmental performance (ESA, 2023).

EO Capabilities and Applications in Agri-Food Contexts

EO-based monitoring enables the derivation of several environmental indicators relevant to oil palm supply chain risk assessment.

- First, multispectral satellite time series can be used to map and quantify deforestation and forest degradation within mill supply sheds. This provides asset-level metrics on forest loss since a defined baseline year. Combined with mapping of oil palm plantation extent over time, this analysis enables assessment of landscape-level drivers of land-use change and their relationship to mill operations (Hansen et al., 2013).
- Second, EO-based water quality monitoring can detect downstream impacts of fertiliser runoff and Palm Oil Mill Effluent (POME). Chlorophyll-a concentration derived from satellite reflectance provides an indicator of eutrophication and nutrient enrichment in freshwater bodies within mill watersheds.
- Third, EO-derived aboveground biomass estimates—using products such as ESA Climate Change Initiative (CCI) Biomass datasets—enable quantification of carbon stocks at the supply shed level. Biomass and vegetation condition may also serve as indirect indicators of ecosystem health. Monitoring of peatland extent and degradation using baseline datasets such as WRI peat maps and satellite observations is particularly important in Southeast Asia due to the significant carbon emissions and fire risks associated with peatland drainage (Miettinen et al., 2016). Fourth, active fire monitoring provides an indicator of land clearing practices and environmental degradation. Fire detection using MODIS and VIIRS satellite sensors enables identification of active fires and burned areas within or near mill supply sheds.

Together, these EO-derived indicators—deforestation extent, water quality, carbon stock, peatland condition, and fire incidence—enable construction of environmental performance profiles for individual mill assets.

Requirements and Constraints

To be operationally useful for financial institutions, EO-derived environmental indicators must meet several practical requirements identified through survey responses and stakeholder consultation.

Datasets must provide sufficient spatial resolution to attribute environmental change to specific mill supply sheds or plantation areas. Multi-year time series are necessary to establish credible baselines and assess trends in environmental performance. Indicators must also be interpretable within financial risk frameworks and compatible with TNFD, CSRD/ESRS E4, SFDR, and EUDR reporting requirements.

A key constraint specific to agri-food supply chains is the availability of reliable mill geolocation data. Without publicly disclosed mill coordinates and supply shed boundaries, EO-derived environmental indicators cannot be linked directly to financial exposures. The scope of this pilot is therefore constrained to publicly available company disclosures.

Additional technical constraints include cloud cover in tropical regions, which can interrupt optical satellite observations and require compositing or gap-filling approaches. The accuracy of deforestation mapping and biomass estimation also depends on the resolution of available imagery, and local validation is required before EO-derived indicators are used operationally in new geographies.

Regulatory and Disclosure Framework Alignment

The LEON agri-food pilot aligns with several international disclosure frameworks and sustainability standards relevant to agricultural supply chains.

For financial institutions to issue TNFD-aligned disclosures and comply with the Corporate Sustainability Reporting Directive (CSRD)—specifically the European Sustainability Reporting Standard on biodiversity (ESRS E4) (European Commission, 2023a)—they require geospatially explicit environmental information rather than sector-level averages. The TNFD LEAP guidance explicitly identifies agri-food supply chains as a priority context for location-specific nature risk assessment (TNFD, 2023).

The EU Deforestation Regulation (EUDR), which requires companies placing specified commodities—including palm oil—on the EU market to demonstrate deforestation-free production (European Commission, 2023b), further increases demand for geolocation-based environmental monitoring. EO-based deforestation monitoring provides a natural tool for supporting such due diligence.

Emissions to water are also a mandatory principal adverse impact indicator under the Sustainable Finance Disclosure Regulation (SFDR) (European Commission, 2019), making water quality monitoring in mill watersheds directly relevant for financial institutions.

Relevant standards and frameworks include:

- TNFD sector guidance (TNFD, 2023)
- CSRD and ESRS E4 biodiversity reporting requirements (European Commission, 2023a)
- Sustainable Finance Disclosure Regulation (European Commission, 2019)
- EU Deforestation Regulation (European Commission, 2023b)
- Science Based Targets initiative FLAG guidance for land-related

emissions (Science Based Targets initiative, 2023)
- Science Based Targets Network land target-setting methods (Science Based Targets Network, 2023)
- GRI 13 Agriculture, Aquaculture and Fishing (GRI, 2022)
- SASB Food and Beverage sector standards (SASB, 2022)

Pilot Description: Scope, Geography, and Methodology

This pilot develops an EO-based monitoring framework for environmental impacts and dependencies associated with oil palm supply chains in Indonesia and Malaysia. The analysis is structured around four analytical components, each translating a potential impact or dependency identified in the ENCORE framework into an asset-level EO-derived metric.

The pilot focuses on oil palm producing regions in Indonesia and Malaysia, the world's two largest palm oil producers. The unit of analysis is the individual palm oil mill and its supply shed—the geographic area from which a mill sources fresh fruit bunches.

Four EO-derived analytical components form the monitoring framework:

Deforestation and oil palm extent. Satellite time series quantify deforestation within mill supply sheds since a 2020 baseline and map oil palm plantation extent over time.

Water quality. Watershed boundaries are delineated using EO data, and freshwater bodies are monitored for chlorophyll-a concentration as an indicator of nutrient enrichment from fertiliser runoff and mill effluent.

Carbon stock and peatland condition. Aboveground biomass is estimated using EO datasets such as ESA CCI Biomass maps. Peatland extent and degradation are monitored using baseline datasets and satellite observations.

Fire incidence. Active fire monitoring using MODIS and VIIRS sensors identifies fire events within or near mill supply sheds.

Integration of these EO-derived datasets enables construction of environmental performance profiles for mill assets and provides financial institutions with granular, auditable information to support risk assessment, due diligence, engagement, and regulatory reporting.

Indicator	Unit	Scale	Purpose
Area of Deforestation	Square kilometres (km^2)	Calculated per supply shed (the defined radius around each mill)	To quantify the direct impact of land conversion on terrestrial ecosystems since a 2020 baseline. This metric is essential for assessing a company's transition risk and compliance with deforestation-free commitments.
Water Quality (Chlorophyll-a Concentration)	Milligrams per cubic meter (mg/m^3)	Assessed in freshwater bodies within the mapped watershed of each individual mill	To serve as a direct impact indicator of potential water pollution from agricultural runoff and mill effluent. This helps in assessing operational and regulatory risks related to water management.
Above-Ground Carbon Stock	Megagrams of Carbon per hectare (Mg C/ha)	Estimated per supply shed	To quantify the ecosystem service of biomass provisioning and assess dependencies on it. This is crucial for evaluating climate-related risks (such as Scope 3 emissions) and identifying opportunities for nature-based financial products.
Fire Incidence	Count of active fire detections (hotspots) and/or area of burn scars (km^2)	Monitored per supply shed	To act as a "red flag" indicator for high-risk operational practices, poor governance, or prohibited land clearing methods. This provides data for real-time risk monitoring and immediate engagement.

Pilot 3: Nature-Related Financial Risks & Opportunities

The LEON nature-related financial risks pilot explores how Earth Observation (EO) data can enhance the assessment of nature-related financial risks by financial institutions, enabling improved risk pricing, capital allocation, and engagement with investee companies. Based a key gap identified via the consultations, the pilot focuses on a specific and material environmental risk - soil degradation - and its financial consequences through impacts on agricultural productivity. Using a RUSLE-based modelling approach combined with EO-derived inputs, the pilot generates spatially explicit and temporally consistent estimates of soil erosion across agricultural land. These estimates provide financial institutions with granular hazard data that are currently absent from existing risk assessment tools.

The pilot builds on and extends existing approaches including the ENCORE tool and the Nature Value at Risk (nVaR) framework developed by Ranger et al. (2024). By combining EO-derived soil erosion metrics with proprietary and open asset-level datasets, the pilot seeks to improve the spatial resolution and representativeness of current nature-related risk assessment frameworks. The objective is to enable financial institutions to move beyond coarse, sector-average nature risk screening towards location-specific estimates of soil degradation risk that can be linked to agricultural asset values and supply chain exposures.

Sector Context and Environmental Significance

The regulatory environment surrounding nature-related risks, dependencies, and impacts is evolving rapidly across Europe. Financial institutions are increasingly expected to assess and disclose material financial risks associated with nature. Supervisory expectations from central banks and regulators have increased accordingly. Nature-related financial risk assessments have already been undertaken in the Netherlands, France, the United Kingdom, and Hungary, as well as by the European Central Bank (ECB). These exercises have highlighted the scale and breadth of nature-related financial risks in the financial sector and have begun to incentivise regulatory and supervisory intervention. A major challenge for financial institutions attempting to assess, disclose, price, and manage nature-related risks is the lack of robust, accessible, and granular environmental hazard data and the difficulty of linking such information to asset-level financial exposures. Many existing analyses rely on coarse datasets describing ecosystem services or biodiversity impacts that cannot be easily connected to specific assets or supply chains. As a result, risk analysis is often technically challenging and, in some cases, misleading. Existing tools - including ENCORE, the WWF Water Risk Filter, and nVaR - provide valuable high-level screening but operate at spatial resolutions that limit their usefulness for asset-level financial analysis.

Soil degradation represents one of the most significant and under-recognised nature-related financial risks affecting the agricultural sector. Soil erosion is among the most damaging degradation processes, affecting key soil characteristics including mineral composition, organic matter content, surface roughness, and water retention capacity. While erosion can arise from natural processes such as wind and water movement, anthropogenic drivers, including unsustainable agricultural practices and land-use change driven by deforestation, have become increasingly important contributors to declining soil health in recent decades (Borrelli et al., 2017). Soil erosion therefore represents a material financial risk, primarily through its effects on agricultural productivity and the consequent impacts across food supply chains. In England and Wales alone, soil degradation is estimated to generate economic losses equivalent to between 8 % and 12.5 % (£0.9–£1.4 billion) of Gross Value Added from agriculture annually (Ranger et al., 2024). Beyond direct productivity losses, declining soil health increases vulnerability to climatic shocks and anthropogenic disturbances, with compounding impacts on ecosystem services and wider societal outcomes (Kraamwinkel et al., 2021).

Financial Sector Exposure and User Requirements

Twenty-one respondents answered survey questions related to nature-related risks, dependencies, and impacts, indicating broad engagement across the financial sector with this emerging risk category. Survey responses reflect growing interest among financial institutions in developing analytical frameworks capable of assessing nature-related risks. The majority of respondents -18 out of 21 -reported being equally concerned about physical nature risks and transition risks, and most indicated that they are already attempting to measure these risks to some degree. Priority environmental themes identified by respondents included water, biodiversity, soil, and land use.

Respondents highlighted several important applications for EO data in nature-related risk assessment, including:

- monitoring environmental degradation affecting asset values
- identifying geographic exposure to biodiversity and ecosystem service risks
- supporting portfolio-level nature-related risk assessments.

Survey responses also identified several drivers of transition risk and opportunity. The most significant drivers included evolving supply-chain regulations, changing sectoral policies and regulations, and reputational risks. Changing consumer preferences and investor sentiment were also identified as potential drivers, although responses varied across institutions. Despite this growing engagement, respondents also highlighted substantial challenges in integrating nature-related risks into financial models. These challenges include the absence of standardised metrics, limited availability of asset-level environmental data, and reliance on fragmented third-party datasets. A consistent theme across responses was the need for improved, openly accessible approaches to assessing nature-related risks, dependencies, and impacts. Respondents highlighted the importance of more standardised environmental metrics, better integration of spatial data, and improved datasets from third-party providers.

Consultations with Early Adopters and other stakeholders identified several specific analytical requirements for assessing soil-related financial risks:

- globally consistent assessment of the spatial distribution of soil quality risks affecting agricultural productivity
- the ability to assess changes in soil quality over time and identify drivers of degradation
- the ability to explore the financial benefits of soil improvement interventions at sub-national scale
- EO-derived outputs capable of communicating risk trends in formats accessible to Board-level decision-makers and front-line client teams.

Earth Observation Opportunities and Requirements - Data Gaps in Existing Risk Assessment Tools

Current approaches to nature-related financial risk assessment rely heavily on screening tools that aggregate environmental information at sectoral or national scales. Tools such as ENCORE and the WWF Water Risk Filter provide useful initial insights but operate at spatial resolutions that prevent asset-level analysis and rely largely on static datasets that cannot capture temporal changes in environmental conditions.

For soil degradation specifically, existing datasets vary substantially in spatial resolution, temporal coverage, and methodological consistency across geographies. This lack of consistency makes it difficult for financial institutions with global portfolios to conduct comparable assessments of soil erosion risk across regions. The absence of temporally consistent and spatially explicit soil erosion data at scales relevant to agricultural assets or supply sheds therefore represents a key limitation in current nature-related financial risk analysis. Recent advances in remote sensing and global soil datasets provide an opportunity to address this gap. The combination of satellite-derived land-cover data, precipitation datasets, and newly published global soil characteristic datasets (Hengl et al., 2025) enables the generation of spatially explicit soil erosion estimates across agricultural land globally. These EO-derived hazard maps can be linked to asset-level financial exposures through the nVaR framework (Ranger et al., 2024), helping bridge the gap between environmental hazard data and financial risk analysis.

EO Capabilities and Applications

This pilot implements a modelling framework based on the Revised Universal Soil Loss Equation (RUSLE) to estimate soil erosion risk using EO-derived inputs combined with global soil datasets (Hengl et al., 2025). RUSLE estimates are generated for agricultural land across the past decade, producing a time series that allows assessment of both the spatial distribution of erosion risk and changes in that risk over time. The RUSLE model requires five input parameters:

- **Rainfall erosivity (R-factor)**
  Derived from precipitation datasets, this parameter captures the intensity and erosive potential of rainfall events.
- **Soil erodibility (K-factor)**
  This parameter describes the susceptibility of soils to erosion based on properties such as texture, structure, and organic matter content.
- **Cover-management factor (C-factor)**
  Derived from satellite-based land-cover datasets, this factor captures the protective influence of vegetation cover and land-management practices.
- **Topographic factor (LS-factor)**
  Derived from digital elevation models, this factor captures the influence of slope length and steepness on erosion processes.
- **Support practice factor (P-factor)**
  This parameter reflects the impact of soil conservation practices such as terracing or contour farming.

A key strength of this approach is the temporal dimension of the analysis. By producing erosion estimates across a decade-long time series, the pilot enables identification of areas where erosion risk is increasing or declining over time. This temporal capability directly addresses the requirements identified by survey respondents for tracking changes in soil quality and identifying emerging risk hotspots.

Requirements and Constraints

For EO-derived soil erosion metrics to be operationally useful for financial institutions, several practical requirements must be met. First, outputs must be globally consistent and methodologically standardised to enable comparisons across geographies within financial portfolios. Second, time series must be sufficiently long and consistent to distinguish long-term degradation trends from inter-annual variability driven by weather conditions. Third, indicators must be interpretable within financial risk frameworks and easily communicable to non-technical audiences.

Several constraints must also be acknowledged. The RUSLE approach estimates potential soil erosion rather than net soil loss after sediment deposition. As such, outputs should be interpreted as relative indicators of erosion hazard rather than precise measurements of soil loss.

The spatial resolution of approximately 300 × 300 m represents a significant improvement on many existing datasets but may still be insufficient for site-level analysis of individual agricultural fields. Furthermore, linking EO-derived erosion estimates to financial exposures requires geolocation data for agricultural assets, which remains a major constraint for many financial institutions.

Regulatory and Disclosure Framework Alignment

The pilot contributes to a regulatory context in which financial institutions across Europe are increasingly expected to assess and disclose material nature-related financial risks. Supervisory exercises conducted by central banks and regulators in the Netherlands, France, the United Kingdom, Hungary, and by the European Central Bank have established precedents for portfolio-level nature risk assessment and increased demand for spatially explicit hazard data. Soil degradation and its effects on agricultural productivity are directly relevant to several disclosure and reporting requirements. Under the Taskforce on Nature-related Financial Disclosures (TNFD), financial institutions are expected to identify and disclose nature-related physical risks in priority locations characterised by declining ecosystem integrity and exposure to environmental hazards. Soil erosion is a direct indicator of ecosystem degradation in agricultural landscapes and therefore an important component of nature-related risk analysis. Under the Sustainable Finance Disclosure Regulation (SFDR), land degradation and soil quality are relevant to principal adverse impact indicators associated with activities affecting biodiversity-sensitive areas and broader exposure to nature-related risks. The EO-derived hazard maps and financial risk metrics produced by this pilot are therefore designed to support financial institutions in meeting these disclosure requirements with greater spatial precision than existing tools.

Pilot Description: Scope and Methodology

The pilot generates RUSLE-based estimates of soil erosion on agricultural land over the past decade, producing spatially explicit hazard maps at approximately 300 × 300 m resolution. These outputs are used to:

- assess the current spatial distribution of soil erosion risk globally
- identify temporal trends in erosion risk and emerging degradation hotspots
- explore the relationship between soil loss and nature-related financial risks through impacts on agricultural productivity.

The analytical pipeline combines historical land-cover data, precipitation datasets, and global soil datasets (Hengl et al., 2025) to estimate RUSLE parameters across agricultural landscapes. EO-derived soil erosion metrics are subsequently integrated into financial risk analysis through the Nature Value at Risk (nVaR) framework (Ranger et al., 2024). This approach combines environmental hazard data with proprietary asset-level datasets, open asset databases, and financial portfolio information to estimate potential impacts on agricultural output and financial exposures.

Indicators and Metrics

The primary output of the pilot is a temporally consistent time series of soil erosion estimates across global agricultural land. These estimates are derived from the five RUSLE parameters -rainfall erosivity, soil erodibility, cover management, topography, and conservation practices - each estimated using EO-derived or global datasets.

From this base dataset, the pilot generates several indicators relevant to financial risk assessment:

- spatial distribution of current soil erosion intensity across agricultural land
- direction and rate of change in erosion risk over the analysis period
- estimated financial risk metrics linking soil degradation to impacts on agricultural productivity through the nVaR framework.

A sub-national case study further explores the relationship between soil erosion and agricultural productivity, illustrating how EO-derived soil metrics can inform lending assessments, supply-chain risk analysis, and engagement with agricultural counterparties.

Pilot 4: Biodiversity Credits

The LEON biodiversity credits pilot explores how Earth Observation (EO) approaches can support emerging global nature markets based on biodiversity credits. Biodiversity credits - defined here as instruments that measure measurable improvements in biodiversity outcomes, distinct from regulatory offsets that compensate for specific environmental impacts - are attracting increasing interest from financial institutions, conservation organisations, and standard-setting bodies.

The pilot examines how EO can contribute to biodiversity credit systems by supporting biodiversity measurement, monitoring, and verification, as well as strengthening the broader credibility of nature markets. This includes potential EO applications in counterfactual estimation, additionality assessment, leakage monitoring, and early detection of non-compliance.

The pilot focuses on two geographic contexts selected through consultations with Early Adopters. In the Netherlands, the analysis focuses on generating habitat condition and species-level indicators using optical and radar remote sensing combined with ground-based ecological observations. In Mozambique, the pilot focuses on detecting early forest degradation in tropical forests using Synthetic Aperture Radar (SAR). These two contexts represent different types of biodiversity credit systems and illustrate distinct technical challenges for EO-based monitoring.

Sector Context and Market Significance

Demand for biodiversity credits may arise from both voluntary and regulatory drivers. Regulatory biodiversity offsets and compensatory mitigation schemes are outside the scope of this pilot. Instead, the pilot focuses on voluntary biodiversity credit markets and related initiatives for which EO approaches may play a role in supporting credible monitoring and verification (Wunder et al., 2025).

Biodiversity credits are recognised within the broader framework of the Kunming–Montreal Global Biodiversity Framework (GBF), particularly under Target 19, which calls for mobilising at least $200 billion annually for biodiversity from all sources, including “innovative schemes such as biodiversity credits.” Several international initiatives are currently working to develop standards and governance frameworks for biodiversity credit markets.

Key organisations involved in these efforts include the Biodiversity Credits Alliance

(BCA), the International Advisory Panel on Biodiversity Credits (IAPB), and the World Economic Forum (WEF). These initiatives have produced guidance and frameworks intended to promote integrity and consistency within biodiversity credit markets. Examples include the BCA's High Level Principles to Guide the Biodiversity Credit Market (BCA, 2024), the IAPB's Framework for High Integrity Biodiversity Credit Markets (IAPB, 2024), and outputs from the World Economic Forum's Nature Markets and Biodiversity Credits Initiative.

While no single framework has yet achieved universal adoption, these initiatives collectively represent an emerging consensus around core principles for biodiversity credit markets, including additionality, permanence, transparency, and robust monitoring.

The number of biodiversity credit initiatives has increased rapidly in recent years. Reviews of existing schemes highlight significant variation in biodiversity metrics, monitoring approaches, and verification requirements across initiatives (Wunder et al., 2025). The global biodiversity credits database maintained by Bloom Labs provides a continuously updated record of emerging projects and credit methodologies. The selection and standardisation of appropriate biodiversity metrics remains one of the key methodological challenges facing the development of biodiversity credit markets.

Financial Sector Exposure and User Requirements

Nine respondents to the LEON user survey answered questions related to biodiversity credits. Although most respondents were not yet actively involved in biodiversity credit markets—reflecting the early stage of development of these markets—six out of nine indicated interest in participating in the future. Respondents identified two primary motivations for potential engagement: financial return or investment opportunity, and environmental impact or conservation objectives. Regulatory compliance, reputational benefits, and risk management considerations were each identified as priorities by two respondents.

Several respondents highlighted habitat-based approaches to biodiversity measurement as particularly relevant for credit markets. This is consistent with recent reviews of biodiversity credit initiatives, which show that many emerging credit schemes rely on habitat condition or ecosystem function metrics rather than direct species monitoring.

Survey respondents emphasised the importance of robust monitoring and verification systems capable of demonstrating measurable biodiversity outcomes. EO data was identified as a potentially important enabling technology for such systems. Respondents suggested that EO could support several key monitoring tasks, including:

- monitoring ecological restoration outcomes
- verifying biodiversity indicators against baseline conditions
- tracking ecosystem change over time.

However, respondents also noted that many biodiversity indicators require high spatial resolution and site-specific ecological measurements, which can pose challenges for EO-based approaches, particularly when relying on freely available satellite data.

Consultations with Early Adopters and other stakeholders during the initial phase of the LEON project identified several additional requirements for EO-based monitoring systems in biodiversity credit markets. These include:

- improving project-level monitoring of biodiversity outcomes through the integration of EO and in-situ ecological datasets

- increasing confidence in biodiversity credit markets by providing transparent and independently verifiable monitoring systems
- enabling monitoring across potentially large numbers of smaller project sites with relatively small biodiversity improvements
- supporting safeguards in lending or investment decisions where biodiversity gains are a key project objective
- providing early warning systems where biodiversity improvements may be at risk of reversal.

Earth Observation Opportunities and Requirements - Two Distinct Types of Biodiversity Credit Systems

A central conceptual distinction in this pilot is that biodiversity credit systems can broadly be divided into two categories, each presenting different monitoring challenges for EO technologies (Bull & Strange, 2018). The first category consists of large-scale conservation projects generating substantial numbers of credits. These projects are often associated with major infrastructure or development activities, such as mining or transportation projects. Credits may be generated through avoided habitat loss or large-scale habitat restoration. In these contexts, the primary EO requirement is to measure historical trends in biodiversity-related indicators and detect changes over time. Monitoring may not require very high spatial resolution or high-frequency observations, but reliable long-term time series and landscape-scale indicators are essential.

For these large conservation projects, relatively simple indicators such as land-use classification, vegetation cover, or habitat extent may provide meaningful evidence of ecological change. At the same time, there is growing interest in developing EO-derived indicators of structural and functional biodiversity, which may enable identification of landscape features associated with particular species groups or ecological communities.

The second category consists of landscape-scale biodiversity credit markets involving numerous small, geographically dispersed conservation projects. These projects may generate relatively small numbers of credits individually but collectively contribute to biodiversity improvements across broader landscapes—for example through habitat restoration associated with multiple housing developments. In these systems, monitoring requirements differ significantly. Frequent monitoring and high spatial resolution may be required to detect small changes in habitat condition across many sites. These markets often rely on condition–area metrics that capture incremental improvements in habitat quality. EO-based monitoring approaches capable of detecting changes in taxonomic or functional diversity across landscapes may therefore play an important role in supporting such markets (Picard et al., 2024).

Cross-Cutting EO Applications

Across both categories of biodiversity credit systems, EO technologies offer several capabilities relevant to ensuring the credibility and integrity of biodiversity markets. A key challenge for biodiversity credit schemes is demonstrating additionality - that is, confirming that biodiversity improvements would not have occurred in the absence of the credit-generating intervention. EO time series can support this assessment by enabling comparison between project sites and similar control sites across the surrounding landscape. EO data can also support ex-ante projections of biodiversity outcomes during project design. Because EO-derived datasets can be applied consistently across large spatial scales, they can complement limited in-situ ecological data and help generate more robust baseline and projection estimates.

Another critical challenge for biodiversity credit markets is leakage, where conservation actions within a project area result in displacement of environmental pressures to other locations. Detecting leakage requires landscape-scale monitoring extending beyond project boundaries, which EO monitoring systems can provide. EO data may also serve as an early warning system for investors and credit buyers. Continuous monitoring of project sites can enable early detection of habitat degradation or non-compliance with project commitments before such changes become apparent through periodic field surveys.

Requirements and Constraints

Biodiversity credit systems require datasets that extend beyond EO-derived indicators of current ecological conditions. Projects must demonstrate biodiversity gains relative to credible counterfactual baselines, meaning that monitoring systems must also account for broader environmental and socio-economic drivers affecting biodiversity outcomes.

EO-derived indicators therefore need to be complemented with landscape-scale datasets that capture relevant contextual factors. These data are essential for robust causal inference and for assessing whether biodiversity outcomes are attributable to project interventions.

Monitoring requirements also vary substantially across biodiversity credit systems. Landscape-scale markets with numerous small projects require frequent monitoring and high spatial resolution to detect incremental improvements in habitat condition. Large conservation projects, in contrast, may prioritise long historical time series capable of demonstrating changes in ecosystem condition over extended periods.

The suitability of EO monitoring systems also varies by geography. The Netherlands, as a highly monitored temperate landscape, provides a data-rich environment in which EO datasets can be combined with extensive ground-based ecological monitoring. Mozambique presents a contrasting context, where cloud cover and limited ground data create additional monitoring challenges and make SAR-based remote sensing particularly valuable.

Regulatory and Standards Framework

Biodiversity credits, as considered in this pilot, operate within the broader policy context established by the Kunming–Montreal Global Biodiversity Framework. Target 19 of the framework explicitly encourages the mobilisation of financial resources for biodiversity conservation, including through innovative financing mechanisms such as biodiversity credits.

The pilot engages primarily with voluntary biodiversity credit initiatives and emerging standards relevant to such markets (Wunder et al., 2025). These initiatives aim to define principles and governance structures capable of ensuring high-integrity credit markets.

Key frameworks relevant to the pilot include:

- Biodiversity Credits Alliance (BCA): The BCA has published High Level Principles to Guide the Biodiversity Credit Market, which outlines principles for assessing the integrity and effectiveness of biodiversity credit schemes (BCA, 2024).
- International Advisory Panel on Biodiversity Credits (IAPB): The IAPB has published a Framework for High Integrity Biodiversity Credit Markets addressing issues such as additionality, permanence, monitoring, and verification (IAPB, 2024).
- World Economic Forum (WEF): The WEF’s Nature Markets and Biodiversity Credits Initiative has produced guidance

on governance and scaling of voluntary nature markets.

- Kunming–Montreal Global Biodiversity Framework: Target 19 provides the overarching international policy context for biodiversity credit markets and supports the development of innovative financing mechanisms for biodiversity conservation.

Pilot Description: Scope and Methodology

The pilot examines two geographic contexts reflecting the two types of biodiversity credit markets described above. In the Netherlands, the analysis focuses on landscape-scale biodiversity credit systems. The objective is to generate indicators of habitat condition and species richness using structural and functional ecosystem characteristics derived from optical and radar remote sensing combined with ground-based ecological observations. This context reflects markets seeking to detect relatively small biodiversity improvements across agricultural or semi-natural landscapes (Picard et al., 2024). In Mozambique, the pilot focuses on monitoring forest degradation in tropical forest ecosystems using Synthetic Aperture Radar (SAR). This case study represents large-scale conservation projects where avoided habitat loss is a key mechanism for generating biodiversity credits. Early detection of forest degradation is particularly important for maintaining credit integrity and providing timely warnings to investors.

Analytical Approach and Datasets

The pilot considers both species-based and habitat-based biodiversity accounting approaches, reflecting the diversity of metrics used across emerging biodiversity credit systems. It also considers both action-based and outcome-based approaches to credit generation, both of which remain under discussion among standard-setting bodies.

Dataset selection therefore extends beyond EO data capturing current ecosystem conditions. Biodiversity credit projects require robust counterfactual estimation of project outcomes, which in turn requires monitoring of environmental variables both within project areas and across the surrounding landscape.

The methodological framework developed in this pilot integrates EO-derived indicators of habitat condition and landscape change with contextual environmental datasets. This combination enables assessment of biodiversity trends within project areas relative to broader landscape dynamics, supporting causal inference and robust evaluation of biodiversity outcomes.

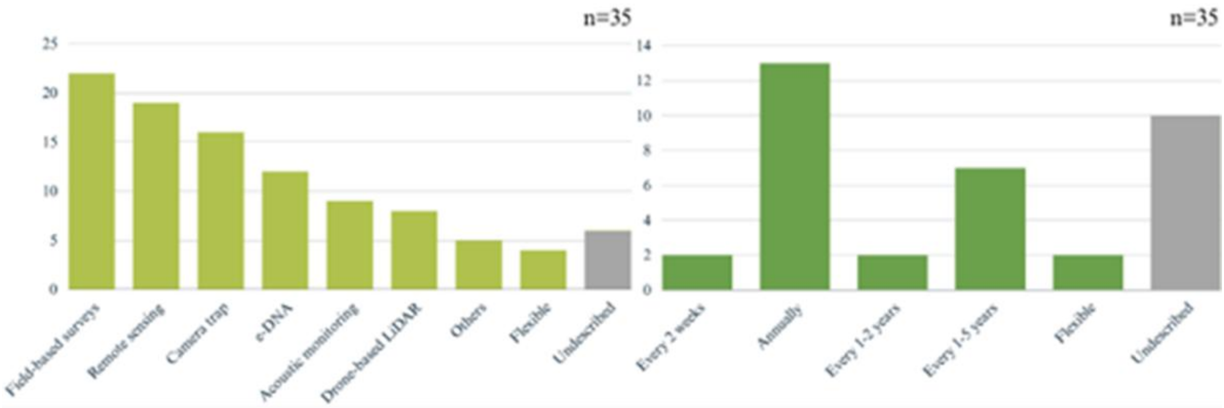

Figure 3.2: methodological approaches to monitoring (light green), and monitoring frequency (dark green) for existing biodiversity credit systems (Wunder et al., 2025)

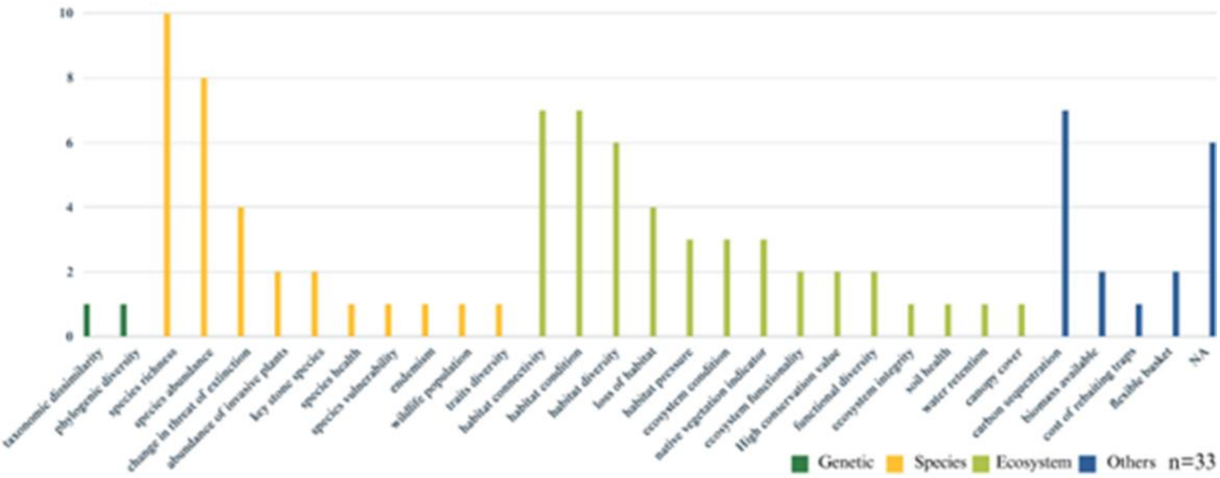

Figure 3.3: biodiversity metrics specified in existing biodiversity credit systems (Wunder et al., 2025)

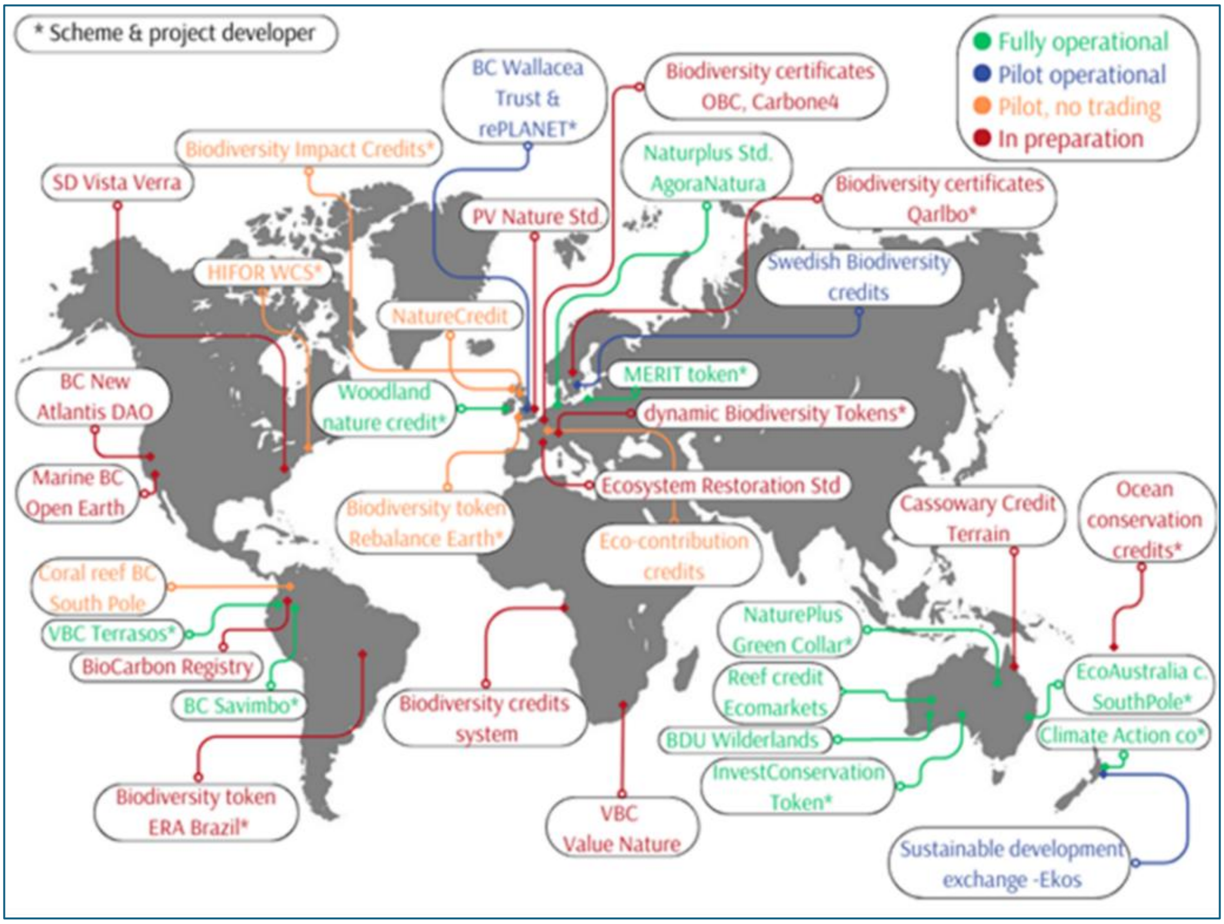

Figure 3.4: Global map of biodiversity credit initiatives: operational state and market function (n=37) (from Wunder et al., 2025)

Pilot 5: Natural Capital Accounting

The LEON natural capital accounting pilot develops and applies a method for integrating biodiversity into green national economic accounting. The pilot explores how Earth Observation (EO) data and spatial biodiversity metrics can support the estimation of Green National Net Income (GNNI), sometimes referred to as "green GDP." The analysis focuses on Denmark as a case study country and applies the GNNI framework to estimate both the economic cost of biodiversity loss and the potential economic gains from investment in nature restoration.

A central methodological contribution of the pilot is the incorporation of the Biodiversity Intactness Index (BII), derived from EO-based land-use data, as a primary biodiversity indicator within the accounting framework. This approach moves beyond exclusive reliance on species-based indicators such as IUCN Red List assessments and introduces a spatially explicit measure of ecosystem condition that can be updated using EO-derived datasets.

Conceptual Context: GDP, Green Accounting, and Biodiversity

Gross Domestic Product (GDP) remains the most widely used measure of national economic activity and is central to economic analysis and policymaking. However, GDP was not designed to capture environmental costs or the benefits of environmental improvement. In conventional national accounts, the depletion of natural capital is typically treated as economically neutral rather than as a form of capital depreciation.

These limitations have long been recognised within ecological economics. Scholars have argued that environmental assets such as biodiversity, climate stability, and ecosystem services are fundamental components of economic welfare and should therefore be incorporated more explicitly into economic accounting frameworks. Conventional market prices also fail to capture many environmental values, particularly those associated with non-market ecosystem services.

Green GDP concepts attempt to address these limitations by incorporating environmental costs and benefits into national economic accounts. Under these approaches, environmental assets—including biodiversity, climate stability, clean water, and clean air—are treated analogously to other forms of capital and incorporated into measures of national wealth and income.

At the same time, ecological economists have raised important caveats regarding monetary valuation of nature. Monetary estimates can reflect existing income inequalities, may fail to capture ecological tipping points, and may be vulnerable to political contestation. These concerns highlight the importance of transparent methodologies and robust empirical data when applying environmental valuation within national accounting frameworks.

The Green National Net Income (GNNI) framework represents one approach to integrating environmental considerations into economic accounts. GNNI begins with GDP and adjusts it by subtracting the depreciation of produced capital and adding net income from abroad to obtain Net National Income (NNI). Environmental adjustments are then incorporated by accounting for the value of environmental goods consumed, investment in natural capital, pollution costs, and the depreciation of natural capital stocks. The resulting indicator provides a broader measure of national economic well-being that reflects both the benefits and the costs of environmental change.

This pilot applies the GNNI framework specifically to biodiversity loss, treating biodiversity decline as a form of natural capital depreciation and estimating the potential economic benefits associated with biodiversity restoration.

User Requirements and Stakeholder Context

Survey respondents identified improved decision-making as the primary potential benefit of natural capital accounting (NCA). However, several barriers to implementation were also highlighted. These included limited data availability and quality, as well as a lack of specialised expertise within organisations responsible for applying NCA frameworks.

These findings reflect broader patterns observed in both public and private sector engagement with natural capital accounting. While there is substantial conceptual interest in NCA approaches, implementation capacity often remains limited due to methodological complexity and data constraints.

Stakeholder consultations conducted during the pilot confirmed that the GNNI framework is particularly relevant for actors seeking to assess the non-use value of biodiversity at national scale. These actors include policymakers, environmental organisations, and financial institutions with sustainability mandates.

Consultations also emphasised the importance of robust and empirically grounded datasets capable of supporting credible valuation exercises. Stakeholders highlighted the advantages of spatially explicit biodiversity indicators, such as the Biodiversity Intactness Index (BII), which provide a more comprehensive representation of biodiversity change than species-list approaches alone.

Feedback from stakeholders further underscored the value of GNNI as a communication tool. By expressing biodiversity loss and restoration gains in economic terms, the framework can help decision-makers balance economic development objectives with ecological sustainability considerations in ways that are both accessible and politically meaningful.

Earth Observation Opportunities and Requirements

Natural capital accounting frameworks have traditionally relied on biodiversity datasets derived either from species-based assessments or from ground-based ecological monitoring programmes.

Species-based datasets, such as IUCN Red List assessments, provide valuable information about extinction risk but do not directly measure changes in species abundance or spatial distribution. Ground-based ecological monitoring can provide more detailed ecological insights but often suffers from limited spatial coverage and infrequent updates. These limitations present challenges for national-scale accounting systems that require consistent and regularly updated datasets.

EO data offers a means of addressing these challenges by providing spatially consistent and temporally repeatable observations of ecosystem condition across national territories. In the context of this pilot, EO data supports the estimation of the Biodiversity Intactness Index (BII), which measures the proportion of original species and their abundance remaining within ecosystems despite human pressures.

BII estimates used in this pilot are derived from satellite-based land-use datasets and modelling approaches based on the PREDICTS database. The BII products generated by Impact Observatory in collaboration with Vizzuality provide 100-metre resolution estimates of terrestrial biodiversity intactness for the period 2017–2020. These datasets combine satellite-derived land-use information with biodiversity observations from more than 32,000 ecological survey sites across over 750 studies. The resulting EO-derived BII products provide spatially consistent estimates of biodiversity intactness suitable for integration into national economic accounting frameworks.

EO-Derived Indicators

In addition to BII, the pilot develops a suite of EO-derived indicators capturing key aspects of ecosystem structure and function relevant to natural capital accounting.

These indicators include:

- Forest cover change (hectares per year): Used as a proxy for habitat loss and changes in carbon sequestration capacity.
- Wetland extent (hectares): Relevant for assessing ecosystem services related to water regulation, carbon storage, and biodiversity habitat.
- Vegetation productivity (NDVI/EVI): Indicators of primary productivity derived from EO data, reflecting changes in ecosystem functioning and provisioning services.
- Habitat fragmentation metrics: Landscape-scale indicators capturing changes in the connectivity and structural integrity of ecosystems.
- Water quality indicators: Including turbidity and chlorophyll-a, which provide information on freshwater ecosystem condition.
- Proxies for species richness: Derived from spectral and structural EO indicators.

Each indicator is defined with a clear spatial scale, measurement unit, and analytical purpose. Integrating these ecological indicators with economic valuation datasets enables the assessment of how biodiversity loss affects ecosystem service provision and, through the GNNI framework, national economic performance.

Requirements and Constraints

The primary requirement for EO data within this pilot is temporal consistency across the analysis period. Reliable time series are necessary for identifying trends in biodiversity change and linking these trends to annual changes in national income indicators.

Current BII products cover the period 2017–2020, providing a useful baseline but limiting the temporal depth available for long-term trend analysis. Extending these datasets or developing complementary EO-based indicators covering earlier periods would significantly strengthen the application of the GNNI framework.

A further challenge arises from the indirect relationship between EO-observable environmental variables and the biodiversity values used in economic valuation. EO can directly measure variables such as land cover change, vegetation condition, and water quality. However, translating these variables into biodiversity intactness estimates—and subsequently into monetary values—requires modelling steps that introduce uncertainty.

Transparent communication of these uncertainties is therefore essential when applying EO-derived biodiversity metrics within national accounting systems.

Pilot Description: Scope and Methodology

The pilot applies the GNNI framework to Denmark, using empirical valuation data developed for that country to estimate the economic costs associated with biodiversity loss (Uggedahl et al., in preparation). Denmark was selected as the case study due to the availability of biodiversity monitoring data, a strong tradition of environmental economics research, and stakeholder interest in applying GNNI as a complement to existing national accounting approaches. The estimation of Denmark's GNNI related to biodiversity loss follows a step-wise methodology.

First, trends in biodiversity loss are estimated using Red List data on species decline since 1990. This establishes a baseline trend in biodiversity change.

Second, national willingness-to-pay (WTP) survey results provide a monetary valuation for biodiversity loss, reflecting the value placed by citizens on species conservation (Jacobsen & Lundhede, 2024).

Third, the economic cost of biodiversity loss is calculated by combining the annual loss of species relative to a reference state set to 1850 with the additional costs associated with species losses affecting future generations.

These cost estimates are then used to adjust GDP, producing the GNNI indicator.

Integration of EO-Derived BII

The pilot extends this established methodology by integrating EO-derived BII estimates into the GNNI framework as an alternative or complementary measure of biodiversity change.

The BII indicator measures the proportion of original species abundance remaining in ecosystems in response to human pressures, particularly land-use change and intensification. Incorporating BII into the GNNI framework enables biodiversity change to be measured using spatially explicit indicators that can be updated regularly using EO datasets.

Applying BII within the GNNI framework allows estimation of both the economic losses associated with biodiversity decline and the potential economic gains resulting from investment in biodiversity restoration.

Reference points derived from BII are used to estimate the annual loss of GNNI attributable to biodiversity depreciation and to quantify the corresponding withdrawal from natural capital stocks.

Pilot 6: Sovereign Finance, Debt-for-Nature Swaps and Sustainability-Linked Bonds

The LEON sovereign finance pilot assesses how Earth Observation (EO) data can support emerging nature-linked sovereign financial instruments that explicitly link environmental outcomes with sovereign fiscal policy. The pilot focuses on two types of instruments: **debt-for-nature swaps (DNS)** and **sustainability-linked bonds (SLBs)**. DNS involve the restructuring or buyback of sovereign debt in exchange for commitments to finance conservation activities, while SLBs link financial terms—typically coupon rates—to the achievement of sustainability performance targets (SPTs) measured through key performance indicators (KPIs).

The pilot focuses primarily on forest-related indicators as the central natural asset within these instruments. Forest ecosystems are among the most widely used environmental metrics in sovereign nature finance because they provide measurable indicators of ecosystem condition, biodiversity conservation, and carbon storage. Building on the experience of Uruguay’s 2022 sovereign SLB - the first sovereign bond to incorporate forest-related KPIs verified using EO data -the pilot explores how EO monitoring can strengthen the design, verification, and monitoring of nature-linked sovereign financial instruments.

In addition to environmental indicators, the pilot integrates socioeconomic data alongside nature metrics, reflecting stakeholder requirements that nature commitments within sovereign instruments must be evaluated within broader development contexts. The analysis therefore also considers drivers of forest loss—such as agricultural expansion and mining—as complementary indicators within forest-relevant sovereign financial instruments.

Background: The Emergence of Nature-Linked Sovereign Finance

Emerging markets and developing economies (EMDEs) face a complex set of interrelated challenges involving environmental degradation, climate change, and rising sovereign debt burdens. Debt levels in the poorest countries have more than doubled since 2012, and debt servicing costs increasingly constrain fiscal capacity for investment in sustainable development. In some countries, interest payments now exceed spending on essential public services such as healthcare. Against this backdrop, innovative sovereign debt instruments are emerging that explicitly link fiscal policy with environmental outcomes. These instruments aim to address both environmental degradation and debt distress simultaneously by creating financial incentives for conservation and restoration activities.

The labelled sustainable sovereign bond market has expanded rapidly in recent years. As of December 2024, approximately $623 billion in labelled sovereign bonds were outstanding, representing roughly 1.2% of total sovereign debt (World Bank, 2025; BIS, 2024). In 2024 alone, annual labelled sovereign issuance reached $137 billion across both use-of-proceeds (UoP) bonds and KPI-linked instruments. Despite this growth, the market remains supply-constrained, with investor demand frequently exceeding available issuance. This imbalance is reflected in the “greenium” observed in sovereign bond pricing (Lindner & Chung, 2023).

Debt-for-Nature Swaps

Debt-for-nature swaps (DNS) are sovereign debt restructuring mechanisms in which debt relief is exchanged for environmental commitments. Typically, existing sovereign debt is repurchased at a discount, and the resulting fiscal savings are redirected to conservation or restoration initiatives.

Although DNS first emerged in the late 1980s, they have experienced renewed momentum in recent years. Countries including the Seychelles, El Salvador, Gabon, and Ecuador have implemented large-scale transactions focused on marine conservation, freshwater protection, and ecosystem restoration. For example, El Salvador’s debt buyback transaction freed approximately $352 million in fiscal resources through a $1 billion debt repurchase (DFC, 2024; Furness, 2024). Ecuador’s 2023 Galápagos transaction swapped $656 million of debt for a use-of-proceeds bond dedicated to marine conservation and protected areas (Global Green Growth Institute, 2023).

Despite their growing popularity, the literature on DNS presents mixed conclusions regarding their effectiveness. Critics have highlighted risks including overstated fiscal and environmental benefits, misallocation of funds by intermediary organisations, limited inclusion of local stakeholders, and restrictions on fiscal flexibility due to earmarked conservation expenditures (Hansen, 1989; Cheng et al., 2022; Jamie Linsley-Parrish, 2024; Kılıç, 2024; Michael Occhiolini, 1990). These concerns underscore the importance of transparent monitoring, consistent metrics, and robust verification systems. To date, DNS transactions have rarely incorporated systematic EO-based monitoring of environmental outcomes.

Sustainability-Linked Bonds

Sustainability-linked bonds (SLBs) represent a different approach to sovereign sustainable finance. Instead of restricting the use of bond proceeds, SLBs link financial terms to the achievement of predefined sustainability performance targets. If targets are achieved, issuers may benefit from lower coupon rates; if targets are missed, coupon penalties may apply.

This structure creates financial incentives for governments to meet environmental or social commitments while allowing flexibility in how bond proceeds are used. Although still a relatively new instrument class, sovereign SLBs are gaining attention. Currently, sovereign SLBs represent roughly 2% of the global labelled sovereign bond market and approximately 10% among emerging economies (World Bank, 2025).

Uruguay issued the first sovereign SLB linked to environmental indicators. Its bond includes two KPIs: preservation of native forest cover and reductions in greenhouse gas emissions. The forest KPI is verified using EO data, making Uruguay's issuance the first example of satellite-based environmental monitoring embedded within a sovereign debt instrument (Ministry of Economy and Finance of Uruguay, 2025). Chile and Thailand have subsequently issued sovereign SLBs with climate and social targets (Ministry of Finance, Chile, 2022; Public Debt Management Office, Thailand, 2024).

While SLBs offer potential benefits—including access to broader investor bases, reduced borrowing costs, and signalling of credible sustainability commitments—they also face several risks. Missed targets could exacerbate debt pressures, while fragmented standards and inconsistent verification frameworks raise concerns regarding credibility and potential greenwashing (Kim & Laskardis, 2025; Lehmann & Martins, 2023; Volz, 2022). These challenges highlight the importance of reliable and transparent monitoring systems.

Financial Sector Exposure and User Requirements

Fourteen survey respondents answered questions related to sovereign finance instruments, nine of whom were asset managers, with others representing investment advisory and investment roles. All respondents manage globally diversified portfolios.

Survey responses suggest that financial sector exposure to nature-linked sovereign instruments remains limited. Among respondents, eight had actively invested in broader thematic or KPI-linked sovereign bonds, five reported limited exposure, and one participated primarily in an advisory capacity. Only five respondents had invested in sovereign instruments explicitly linked to nature outcomes—such as debt-for-nature swaps or nature-linked SLBs—while six reported only limited exposure. Use-of-proceeds instruments such as green or blue bonds were the most common form of engagement.

Respondents identified the lack of reliable and independently verifiable environmental indicators as a key barrier to expanding investment in nature-linked sovereign finance. EO-derived data were identified as a potential solution, particularly for monitoring environmental indicators that underpin sovereign KPIs.

Respondents highlighted several priority EO applications, including:

- national or regional indicators of ecosystem condition
- monitoring of deforestation and land-use change
- verification of environmental performance linked to sovereign financial instruments.

Such applications require datasets that are consistent across jurisdictions and over time. Through bilateral consultations, stakeholders identified two areas where EO could provide particularly significant value. The first is the identification of priority locations for conservation and restoration activities. The second is the monitoring of progress toward predefined KPIs associated with these locations.

Stakeholders also emphasised that environmental indicators should be analysed alongside socioeconomic indicators, such as poverty dynamics, to ensure that nature-related policies embedded within sovereign instruments are aligned with broader development objectives.

Earth Observation Opportunities and Requirements

The credibility of nature-linked sovereign financial instruments depends heavily on the quality and independence of environmental monitoring systems used to verify conservation outcomes. Currently, this represents a major weakness of the market.

Most DNS transactions rely on project-level reporting or third-party verification processes that lack spatial consistency and transparency. Although Uruguay's SLB represents an important precedent for EO-based verification, standardised EO monitoring frameworks for sovereign instruments have not yet been widely adopted.

The absence of robust monitoring systems creates several risks. Environmental outcomes may be overstated, non-compliance may be difficult to detect, and it may be challenging to attribute environmental changes to specific policy interventions. These risks undermine investor confidence and expose the market to accusations of greenwashing.

EO monitoring offers a potential solution. Satellite-based datasets provide spatially consistent, repeatable, and independent observations of environmental change. When applied systematically, EO data can support transparent KPI verification and enable more credible monitoring of conservation commitments embedded in sovereign financial instruments.

EO data can support sovereign nature finance instruments in two principal ways: first, by helping identify priority areas for conservation or restoration during the design phase of financial instruments; and second, by providing transparent monitoring of environmental indicators once instruments are in place.

Applying EO effectively in sovereign finance raises several methodological questions that this pilot seeks to explore.

First, which EO-derived indicators are most appropriate proxies for specific environmental targets, such as forest health or mangrove extent? Different satellite products may vary significantly in accuracy and temporal consistency.

Second, some environmental indicators may be measured directly using EO, while others are modelled using EO-derived inputs. Model-based datasets introduce additional uncertainty, particularly where training datasets are derived primarily from high-income country contexts and may perform less reliably in emerging market environments.

Third, monitoring environmental indicators over time requires datasets that are temporally consistent and capable of detecting change reliably. Some EO-derived datasets have been generated for a single reference year, limiting their usefulness for time-series monitoring.

Fourth, monitoring systems must also consider social safeguards. Conservation commitments embedded in sovereign financial instruments must avoid adverse impacts on communities living within affected landscapes.

Finally, data solutions must be scalable and transferable across countries and financial instruments. Scalability is essential if EO-based monitoring systems are to become standard practice in sovereign nature finance markets.

Requirements and Constraints

For EO-derived indicators to be operationally useful within sovereign financial instruments, several requirements must be met.

Datasets must be globally consistent and methodologically standardised so that KPIs can be compared across sovereign issuers and over time. Indicators must also be reproducible using transparent methodologies, enabling credible monitoring against baseline conditions.

Spatial resolution must be sufficient to identify location-specific environmental changes within countries while also supporting national-level aggregation for reporting purposes.

One important constraint relates to algorithmic bias in EO-derived datasets. Many widely used forest monitoring and biomass estimation products have been trained primarily on datasets from temperate and high-income regions. Their performance in tropical landscapes—particularly where ground-truth data are limited—may therefore be less reliable.

Transparent communication of uncertainty is therefore essential. Inaccurate EO-based KPI verification could have direct financial implications if coupon payments within sovereign SLBs depend on environmental performance metrics.

Market and Regulatory Context

Nature-linked sovereign financial instruments operate within an evolving and relatively fragmented regulatory environment. Unlike corporate sustainability disclosures—which are increasingly governed by frameworks such as TNFD, CSRD, and SFDR—sovereign sustainability-linked instruments do not yet operate under a universally applied regulatory framework governing KPI design or verification methodologies.

Key frameworks relevant to this pilot include the International Capital Market Association (ICMA) Sustainability-Linked Bond Principles, which provide voluntary guidance on KPI selection, SPT ambition, and verification practices. Sovereign green and blue bond frameworks developed by individual governments also provide emerging examples of best practice.

The broader policy context for nature-linked sovereign finance is provided by the Kunming–Montreal Global Biodiversity Framework, which encourages mobilisation of financial resources for biodiversity conservation.

The pilot also engages with emerging practices in EO-based KPI verification, of which Uruguay’s SLB remains the most prominent example.

Pilot Description: Scope and Methodology

Forests represent a critical component of natural capital in many emerging and developing economies and therefore serve as a central indicator within many nature-linked sovereign financial instruments.

This pilot builds on the experience of Uruguay’s 2022 SLB and explores two main analytical questions: which forest-related variables would strengthen the design and monitoring of forest KPIs, and how EO-based monitoring can be improved to meet the requirements of outcome-based financial instruments.

The pilot prioritises simplicity and scalability when selecting indicators. Indicators that are robust, interpretable, and widely available are favoured over technically complex metrics that may be difficult to implement consistently across jurisdictions.

The analysis also examines drivers of forest loss—such as agricultural expansion and mining—to assess their potential relevance for forest-related financial instruments. In addition, geospatial socioeconomic datasets are incorporated alongside environmental indicators in order to reflect the broader development context within which sovereign nature finance operates.

The pilot builds on prior sovereign transactions conducted by Early Adopters to assess how EO-derived indicators could enhance KPI monitoring and improve the design of future nature-linked sovereign financial instruments.

Indicators and Metrics

The pilot generates a set of EO-derived forest indicators relevant to the design and monitoring of sovereign nature finance instruments. These include:

- forest and tree cover extent
- tree canopy cover
- deforestation and forest loss rates
- reforestation and tree gain
- vegetation health indices (NDVI and EVI)
- tree height estimates
- above-ground biomass estimates
- forest fragmentation metrics
- forest fire detection and burned area indicators.

Together, these indicators provide a comprehensive basis for both the design and monitoring phases of sovereign nature finance instruments. EO-derived datasets can help identify priority areas for conservation and restoration and provide transparent monitoring of environmental performance over time, thereby supporting credible KPI verification and strengthening investor confidence.

4. EO Best Practices

4.1. Introduction

The use of EO data and related applications is growing across a range of nature finance topics (see Patterson et al, 2022). Nature Finance institutions increasingly recognise the need to identify and assess nature-related financial risks and this has driven the use of data for risk analysis using approaches such as Nature Value at Risk methodologies. At the same time, the emergence of financial instruments such as Biodiversity Credits is driving the demand for metrics for the definition, monitoring and verification of those instruments. Robust analytical methodologies and risk management practices are still being conceptualised and developed in this sector (NGFS 2023). Consequently, an important part of preparing, conducting and evaluating the LEON Pilots is to define, review and analyse relevant EO best practices that will support the needs of Early Adopters, their relevant ongoing projects/initiatives, and the broader end-users' networks.

4.2. Approach

Given the breadth of pilot topics, the current review is focused on a subset (Pilot 3 Nature Risk and Pilot 4 Biodiversity credits). The intention is to examine how current products using EO adhere to current best practice in EO science and workflows. The analysis is intended to test how a best practice framework can be applied during the LEON pilot programme to ensure alignment between technical standards and end user expectations. The definition of best practices is focussed on the capabilities offered by existing satellite missions, their relative strengths and weaknesses plus consideration of well-founded approaches to data handling, processing and **quality** assurance. Examples of best practice relevant to, and/or demanded by Nature Finance activities are provided along with an indication of where and to what degree they meet the needs of users. The examples have been drawn from a variety of source materials. They are not intended as a definitive list of products and services that will necessarily be applied in in the Pilots. They represent relevant candidate products, and the analysis provides an approach to assessing whether they could potentially be applied in the Pilots depending on their relative merits within the best practice framework. The actual data sets to be included would be considered under the best practice framework and specified in the Pilot definitions and accompanying Input Data Inventory.

The next section outlines the LEON team definition of EO best practice that can be used as an advisory framework for evaluating datasets to include or not in the Pilot workflows. We then summarise a review of published scientific literature and methodologies that have led to the creation of EO products intended for use in nature finance applications. Based on a best practice framework created for this purpose by LEON, a simple scoring is applied to determine how well each product meets best practice. We then assess the scoring to identify common themes and lessons to be applied. Finally, we discuss how the scientific approach to best practice complements or challenges the market understanding of best practice. This acknowledges market acceptance of EO-based approaches may not always need to adhere to scientific best practice. To do this we examine published work by TNFD on experiences within the finance community related to the access and use of data.

4.3. Defining Earth Observation Best Practices for Nature Finance

The aim here is to provide guidance on best practices that are generic enough for each pilot to follow them, regardless of the nature and objectives of that specific pilot.

<u>Consider the Trade-Offs in Selecting the Right EO Data</u>

It is important to consider what will be the best type of EO data to meet the needs of a user. There are often trade-offs in EO capabilities to reconcile when choosing the best EO data for a particular application. This concerns deciding what spatial resolution, spectral resolution, frequency of observation are needed to address the specific feature of interest. This may in turn will have a bearing on thematic information content, data costs and processing effort required. Satellite data can be available at different timeliness levels so establishing whether data is required as quickly as possible or as accurate as possible is an important distinction to make. Is broad geographic coverage required, or very localised, asset-specific information preferred? EO data are available at different processing levels, and different applications can demand different approaches. These can range from having to do basic atmospheric corrections, through extracting derived geophysical variables at highest resolution available for the sensor (which many users may choose) to high level derived or merged products mapped to uniform grid, spatial and temporal composites. A pragmatic approach to data selection focussed on the expected result or end use and available resources is an important first step.

<u>Use science-based, high -quality data</u>

In the context of Nature Finance, using <u>science-based</u>, <u>high-quality</u> EO data is fundamental to producing credible, decision-ready indicators of ecosystem condition and change. EO should deliver "science-based and independent

geospatial data" for quantifying nature risk (CRCF, 2024), this will aid robustness in financial decision-making.
Science-based EO data refers to datasets that are developed using peer-reviewed methods, well-established scientific models, and validated against ground-truth or reference data. These datasets are created through rigorous research protocols and quality control processes that ensure their reliability and reproducibility. A prime example is NASA's MODIS (Moderate Resolution Imaging Spectroradiometer) data suite, which includes products like land cover, vegetation biophysical parameters (e.g., Leaf Area Index (LAI) and Fraction Absorbed of Photosynthetically Active Radiation (FAPAR)), and burned area, all of which are extensively validated by the scientific community, globally harmonised, and updated with consistency and transparency (Morisette et al., 2002). These datasets are accompanied by clear documentation, known limitations, and uncertainty metrics, enabling users to understand how the data was generated and what it can reliably show.

High-quality EO data also means data that meet specific standards of spatial, temporal, and radiometric accuracy, is processed consistently (e.g., atmospheric correction, cloud masking), and is maintained through robust operational systems. Datasets from programs like Copernicus (providing data from all Sentinel missions) and CEOS-endorsed products are examples of such quality, with extensive community support and compliance with international standards such as QA4EO.
Poor-quality or unvalidated EO data risks misrepresenting the state of natural assets, potentially leading to misinterpretation of the environmental processes that those products are aiming to characterise. However, in some cases, depending on the assets or environments under consideration, new/emerging or commercial EO datasets, such as high-resolution imagery from PlanetScope or Maxar, may be used even if they are not yet fully validated through open scientific channels. The full calibration and quality assurance processes may not be available or are constrained by commercial licensing conditions. Nonetheless, these datasets can offer insights, particularly in supporting fine-scale ecosystem analysis, change detection, or site-level monitoring.
When using such data, it is critical to:

- Clearly document their characteristics (e.g. spatial resolution, revisit rate, radiometric calibration),
- Disclose any known limitations or lack of peer-reviewed validation,
- Where possible, cross-reference outputs with validated datasets or in-situ data,
- Avoid using them as primary evidence without appropriate validation.

By treating these datasets as complementary, rather than standalone sources, they could play a useful role in enhancing situational awareness and understanding of localised environmental dynamics.

<u>Adopt open, transparent, measurable definitions and data</u>
Transparent and measurable definitions are essential to ensure that EO-driven data products used in Nature Finance are understandable, replicable, and comparable across regions and timeframes.
A transparent definition clearly explains how a particular EO-derived metric, such as forest loss, wetland extent, or ecosystem integrity, is calculated, including data sources, processing steps, thresholds, and assumptions. The Finance for Nature Positive framework (UN, 2024) emphasises clear definitions and good practices to align private sector finance with global biodiversity goals. A measurable definition ensures that the metric is quantifiable using consistent units and methodologies, allowing for monitoring, benchmarking, and reporting over time. For example, when using EO to track forest cover change, the

definition must specify what constitutes "forest" (e.g. minimum tree cover percentage, canopy height, tree density), the spatial resolution of analysis (e.g. 20m pixels from Sentinel-2), and how changes are detected (e.g. vegetation biophysical parameters thresholding or classification models). This clarity prevents confusion and ensures that different users can interpret EO-derived indicators/metrics in the same way.

Using open datasets such as Sentinel, ERA5, MODIS, Landsat, CHIRPS and open-source code allows others to audit and being able to reproduce results. This aligns closely with the FAIR principles where data should be:

- Findable:
  - enhanced through use of metadata standards such as the SpatioTemporal Asset Catalogs (STAC)
- Accessible:
  - enabled via open archives like Copernicus Data Space Ecosystem (CDSE)
- Interoperable:
  - ensures data can be integrated across platforms and models
- Reusable:
  - depends on proper licensing, documentation, and provenance tracking

FAIR-aligned EO data ensures that nature finance applications can be scaled, trusted, and independently verified.

Implement validation and quality assurance processes

In Nature Finance, validation and quality assurance are considered essential. They are foundational to ensuring that EO-derived metrics/indicators/products are scientifically credible, fit for purpose, and trustworthy for decision-making. They support assessments of where and to what level uncertainty is present in the information being provided.

Validation is the process of comparing EO-derived outputs, such as land cover / land use classifications, forest loss metrics, or biodiversity indicators, against independent reference data, often collected through field measurements, expert-labelled datasets, or trusted third-party sources. This comparison enables users to quantify how accurately a product represents independent/real conditions using established performance metrics such as accuracy, precision, root mean square error (RMSE), or confidence intervals. Without proper validation, there is an unknown about how good – or within what boundaries – the indicators/metrics represent environmental conditions.
Every EO-derived metric, indicator, or map intended for use in nature-related financial instruments, whether for biodiversity credits, risk disclosures or debt swap mechanisms, must be validated and accompanied by clear documentation of its accuracy and limitations. This includes not only spatial accuracy (e.g. does a deforestation alert correspond to actual tree loss on the ground?) but also temporal and thematic accuracy (e.g. is the timing of the event correct? Are the land cover / land use classes correctly distinguished?).
Quality assurance frameworks, such as those promoted by the Committee on Earth Observation Satellites (CEOS) Working Group on Calibration and Validation (WGCV) and QA4EO, emphasise the need for traceability, uncertainty quantification, and transparency in the entire data processing chain.

Follow a structured, reproducible workflow

To ensure that EO data supports high-integrity / high-quality outcomes in Nature Finance, it is advisable to follow a structured, reproducible workflow. This approach promotes consistency, transparency, scientific rigour, and the ability for others to independently verify results. Reproducibility is a key element of credible science and is especially critical when EO-derived indicators that might underpin important financial disclosures, risk analyses, and decision making processes regarding biodiversity credits, investment-grade reporting, risk modelling, etc.

4.3.1. Best Practice Key Components

Based on the discussion above, the following 6 points represent a summarised breakdown of the key components in a best-practice EO workflow for Nature Finance:

1. **Compile high-quality, documented satellite data**
   a. Use data quality flags and/or uncertainty layers: many EO products (e.g. Sentinel-2 and OLCI L2A, MODIS surface reflectance) provide per-pixel quality flags and uncertainty metrics. These should be used systematically to filter out unreliable observations (e.g. cloud-contaminated, saturated, or snow-covered pixels) and to flag any outputs derived from uncertain inputs.
   b. Be aware of spatial resolution and resampling Issues: When combining datasets of different spatial resolutions (e.g. 10m Sentinel-2 with 300m land cover maps), it's essential to account for scaling mismatches, which can introduce errors due to mixed-pixel effects or resampling artifacts. All resampling steps should be documented, and where possible, analyses should be conducted at the native resolution of the most critical dataset.
   c. Consider temporal gaps and interpolation effects: EO datasets often contain missing data due to cloud cover, sensor anomalies, or revisit frequency. Common practices include temporal interpolation, compositing (e.g. median LAI), or filling gaps using ancillary data. While these are necessary, each introduces assumptions and potential bias. Any temporal and/or spatial gap filling should be well documented.
   d. Propagate uncertainties across the workflow: wherever data is filtered, interpolated, or resampled, uncertainties should be tracked and, where possible, propagated into the final EO-derived metrics. For example, if tree cover is estimated with ±10% confidence, downstream indicators (e.g. carbon stock) must reflect this uncertainty.
2. **Describe algorithms in transparent documentation**
   a. Document the algorithms used to derive indicators (e.g., forest loss, wetland extent, habitat condition), for instance in an Algorithm Technical Baseline Document (ATBD). This should include inputs, methods (e.g. machine learning, time series analysis), assumptions, parameter settings, and outputs.
3. **Build modular, version-controlled software**
   a. Develop and publish code using platforms like GitHub or GitLab, using version control (e.g. Git) and consistent programming practices. Code should be modular, documented, and accompanied by configuration files or containers (e.g. Docker) to ensure reproducibility across systems.
4. **Generate experimental datasets**
   a. Produce EO-derived outputs such as land cover / land use maps, habitat quality scores, or ecosystem service indicators. Products should be in open formats (e.g. GeoTIFF,

NetCDF) and accompanied by metadata and provenance tracking.

5. **Perform validation through quantifiable measures**
    a. Compare EO-derived products with in-situ data or high-resolution reference datasets. Report validation metrics such as accuracy, F1-score, or RMSE, model performance, etc. This step is essential for quantifying uncertainty and ensuring scientific credibility. When in-situ data is not available, comparing results against well-validated datasets is a good practice. Additionally, an assessment by an expert could be use as part of the validation exercise.
6. **Publish data and code with FAIR principles**
    a. Ensure that data and code are Findable, Accessible, Interoperable, and Reusable (FAIR). This can be achieved by assigning DOIs (e.g. via Zenodo), including proper licenses (e.g. MIT, CC-BY), and storing datasets in trusted repositories (e.g. Copernicus Data Space Ecosystem, PANGAEA).

In the next section we examine a set of selected nature finance scenarios, related exemplar EO products and services and evaluate their potential suitability under the LEON best practice framework.

4.4. Application to Selected Nature Finance scenarios

Natural Capital Accounting

According to Bateman & Mace (2020) natural capital is "conceptualized as nature's assets, including renewable and non-renewable resources like air, water, and soil, which underpin human well-being and sustainable development". Natural capital therefore represents value, which becomes necessary as both renewable and non-renewable energy sources provide resource intensive services and goods, while the encompassing capacity of the ecosphere combining these resources becomes essential for supporting life (Islam et al., 2019; Costanza et al., 2014). In 1997, Costanza et al., provided a non-exhaustive list of 17 ecosystem services including habitats, water supply and food production. Out of these, ecosystem services such as climate regulation are of paramount importance given the high cost of substitution and topical importance in tackling climate change (Heal et al., 2001). Heins et al., (2016) further argues that ecosystem services cannot be explained merely as services derived from the ecosystem to be viewed as natural capital assets, but need to be explained in terms of their capacity, capability and potential supply as well.

Countries are currently over projecting their economic capabilities using the Gross Domestic Product, as the indicator does not include the use, or even exploitation, of Natural Capital, leaving a major gap in national accounting (Helm, 2015). In the past, when services derived from natural capital did not have a designated value or market, it became hard to identify the risks and dependencies businesses had attached to nature and ecosystem services, and they became undervalued in a supply chain they were sustaining (Barbier, 2021; Helm, 2019). Barbier (2021), further differentiates between ecological scarcity and environmental goods scarcity, as the former has a fixed supply and can suddenly decline. This means that certain natural capital has to be prioritised over others to be protected in the present, without focusing purely on the quantitatively measured utility that can be derived from them. This decision can be made by prioritising natural capital that provides economic returns and has ecological biodiversity attached to it. While this makes sense in theory, in practice it can be a little

convoluted to track the natural capital that provides both economic and ecological utility.
There is extensive evidence that nature conservation interventions - whether preventing further losses, or restoring nature for biodiversity gains - tend to work where implemented (Langhammer et al., 2024); so now, the challenge is to implement them at larger scales.

Implementing conservation efforts requires greater flows of finance away from negative impacts and towards positive impacts on nature; which will, in turn, necessitates the evidence of clear linkages between economic decisions and impacts on nature (Guerry et al., 2015). To establish these linkages, there is a requirement for improved monitoring of nature trends at lower costs and larger scales, using consistent and integrated metrics and monitoring systems. This is where EO data can play a major role in identifying the impact, dependencies and risks, that natural capital and ecosystem services can impose on private market players like businesses, and contribute towards Nature Finance.

Nature Risks

As natural capital gets depleted, it also imposes risks and financial pressures on businesses that derived economic benefits from them (Leach et al., 2019; Gardes-Landolfin; 2024). Due to an intertwined relation between climate change and nature loss, the former can trigger hidden tipping points in the latter leading to sudden ecosystem decline, and cause subsequently exacerbated risk to individual businesses and the larger economic system (Ranger et al. 2024; Gardes-Landolfin; 2024; Armstrong Mckay et al., 2022; Marsden et al., 2024). It has become increasingly relevant for businesses to factor their dependencies, impact and risks from and to nature into their economic decisions (La Notte et al. 2025). This prompted the development of the Taskforce on Nature-related Financial disclosures, aimed at mobilising private finance and innovation for improving nature positive outcomes through a framework for business disclosures and risk management (TNFD).

Biodiversity Credits

As part of our work in in Pilot 4, we are assessing the needs of nature crediting systems, focusing on understanding the types of biodiversity measurements required by these mechanisms, to determine how remote sensing technologies, including airborne and spaceborne measurements, could support these measurement needs. This assessment work provides a useful review here, to frame the discussion here about EO best practices in relation to a variety of different specific biodiversity components. We surveyed 56 nature credit standards listed in recent reviews (Wauchope et al., 2024; Wunder et al., 2025), with a focus on understanding their methodological approaches for generating measurements of biodiversity condition. For standards to be included in our assessment, we required an accessible methodology (i.e. publicly available) with sufficient detail to understand how biodiversity condition metrics are defined, including potential sources of information and instructions for how to quantify them. We also required standards to be active or operational as of May 2025 (i.e. standards in development were excluded; n=21).

We defined metrics of biodiversity condition as parameters collected to assess the state of nature, which are used in the formulation of a biodiversity unit or in quantifying changes in the state of nature, including estimates measured at the species, habitat, and ecosystem levels. We identified 79 metrics or measurements that are either required by standards or included in their methodologies as examples of metrics that can be included in their calculations.

We conducted a focused literature review to identify studies where remote-sensing applications, particularly those using satellite-derived data, have been employed to estimate metrics of biodiversity condition. We classified these metrics using the Essential Biodiversity Variables (EBVs) framework (Skidmore et al., 2021), aiming to align remote sensing products with the measurement needs of nature credit methodologies. The literature review was not systematic; instead, it concentrated on the biodiversity condition metrics identified during the review of the methodologies. Searches were performed in Google Scholar, using combinations of keywords from candidate EBV categories, metrics required by the methodologies, and potential remote sensing biodiversity products measurable at relevant local scales (i.e. avoiding studies where analyses were conducted at coarse resolution).
Our preliminary results show that, for about 50% of the examined metrics, remote sensing applications could partially, or fully, meet the monitoring demands established by nature credit standards (Figure 4.1). Remote sensing applications such as ESA-developed products like the ESA Land Cover, WorldCover, and the Tropical Moist Forests product (Vancutsem et al. 2021), have long been established for measuring land cover changes in habitats, particularly those relevant to Ecosystem function and Ecosystem structure EBV categories. For measuring species population metrics, applications in the literature have been largely trialled for metrics related to terrestrial ecosystems, including examples where advances in AI have enabled the identification of species 'individuals as features', by way of convolutional neural networks or vision transformers. These methods have been applied recently for measuring tree-level biomass and species identification in forest ecosystems. Deep learning has been gaining prominence in recent years for estimating plant-species diversity and habitat classification; for instance, it's been used recently to classify vegetation types in Congo, with estimates correlating with soil humidity and species indicators (Picard et al., 2024), and has also been applied to tracking dominant species in grasslands (Díaz-Ireland et al., 2024; Muro et al., 2022).
Monitoring of marine ecosystems through remote sensing applications faces major limitations due to spectral interference from water (Zeng et al., 2023), however recent approaches have been trialled to upscale shallow-water biodiversity monitoring by combining aerial and satellite imagery with underwater RGB imagery (Lutzenkirchen et al., 2024).
The applications we identified in most instances do not result in the specific measurement required by standards (i.e., in units of analysis or scale); however, they demonstrated the potential for integrating of remote sensing-derived data into biodiversity credit methodologies.

Data Tool	EBV Supported	Satellite Data Used	Source
Copernicus Global Land Service	Ecosystem Structure, Ecosystem Function	Sentinel-2, Proba-V, SPOT-VGT, MODIS	Copernicus CLMS
Biodiversity Intactness Index (BII)	Species Abundance (derived), Community Composition	MODIS land cover	Newbold et al., 2016; Hill et al., 2018
Global Forest Watch – Biodiversity	Ecosystem Structure, Ecosystem Function	Landsat, MODIS	Hansen et al., 2013
Global Mangrove Watch	Ecosystem Extent, Ecosystem Structure	ALOS PALSAR, Sentinel-1, Landsat	Bunting et al., 2018; Global Mangrove Watch

Table 4.2: Example 'biodiversity' products utilising EO data

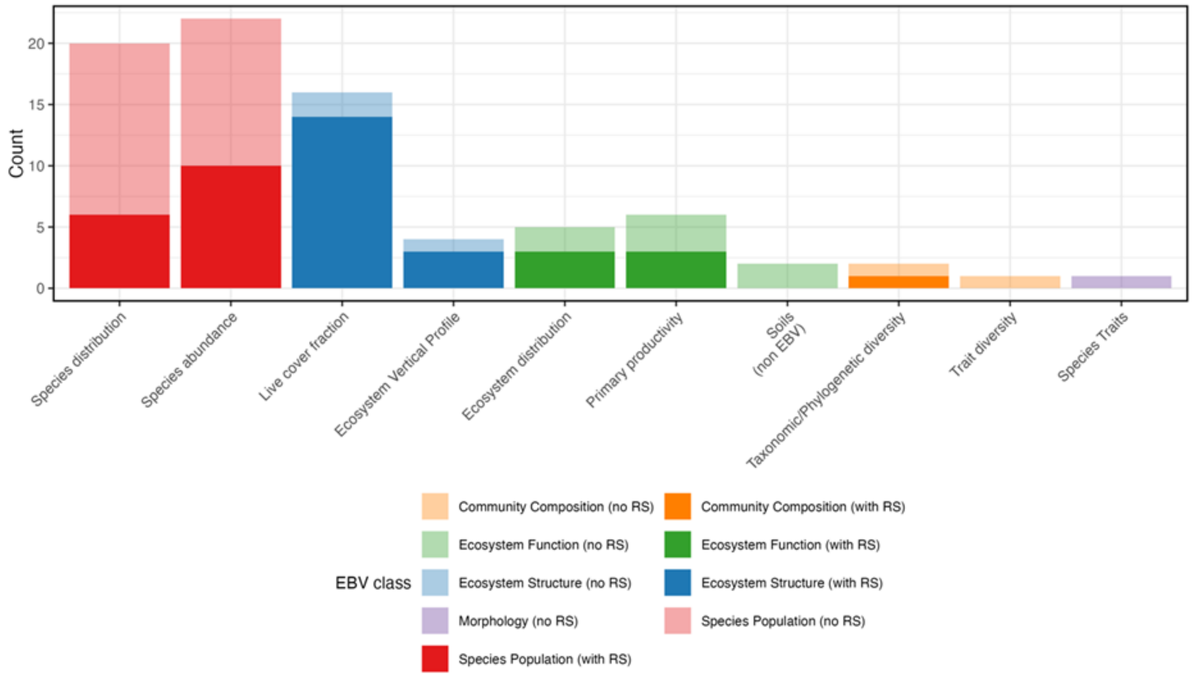

Figure 4.1. Metrics of biodiversity condition examined in the review (n=79). Candidate EBV categories (x-axis) and EBV classes (colours) as described in Skidmore et al. (2021). Darker colours indicate metrics where remote sensing products could be used to partially or fully monitor the selected indicator. We include a separate category related to soil indicators, although these were not mentioned in the Skidmore et al. review.

Products

In addition to the literature review of EBVs, we examined a few well known biodiversity products to see how well they adhere to best practice standards. The products are shown in Table 4.2.

Best practice scoring

The biodiversity products were evaluated according to the 6 key components in a best-practice EO workflow identified above. The scoring is based on a simple presence or absence criterion, codified as 1 or 0 respectively and then totalled. Table 4.2 shows the best practice scoring for relevant biodiversity products.

Of these products, the best known in the nature finance world is the Biodiversity Intactness Index now owned and used by Bloomberg. As the analysis here shows, there are concerns regarding the access to published code and adherence to FAIR data principles. These are likely due to the commercial nature of the product.

	High quality satellite data	Transparent about the algorithms used	Develop and publish code	Experimental dataset - EO derived output	Quantifiably validated	Fair principles	Total Score
Copernicus Global Land Service / CLMS	1	1	1	1	1	1	6
Biodiversity Intactness Index (BII)	1	1	1	1	1	0	5
Global Forest Watch – Biodiversity	1	1	1	1	1	1	6

Global Mangrove Watch	1	1	1	1	1	1	6

Table 4.3: Biodiversity products - Best practice scoring

Atmosphere

Products

Data tool	Nature component	Dependency / Impact use case	Satellite data used	Source
Carbon Monitor Cities	Carbon emissions	Impact - monitors carbon emissions	TROPOMI	Huo et al., 2020
NASA Carbon Monitoring System (CMS)	Carbon emissions	Impact - Monitors carbon emissions for given area or interest point, useful for business MRV	MODIS, Landsat, OCO-2, GEDI	NASA CMS
ClimateTRACE	Greenhouse gases	Impact: Tracks GHG emissions for high-emitting sectors	TROPOMI, VIIRS,	ClimateTRACE.org
Global Forest Watch - Carbon Flux maps	Forest carbon sequestration	Dependency and Impact: How forests are offsetting carbon emissions or risk of lost sequestration potential from deforestation	Landsat, MODIS, Hansen tree cover loss dataset	Harris et al., 2021
Carbon Mapper	Methane and CO2 point-source emissions	Impact: targets super-emitter sites for informing MRV	Tanager-1	Carbon Mapper, 2023
OpenGHG	Atmospheric methane and CO2	Impact - supports open-source analysis of GHG emissions	TROPOMI, OCO-2 (via integration)	OpenGHG.org
Blue Carbon Explorer	Carbon stocks	Dependency- businesses use it to assess carbon offset potential	ESA Biomass, GEDI	The Nature Conservancy and Planet
METER-ML (Stanford ML Group)	Methane emissions	Impact - supports detection of methane super-emitters using EO + ML	GHGSat, TROPOMI	Zhu et al., 2022
Methane Alert and Response System (MARS)	Methane emissions	Impact - identifies major methane leaks in real-time	GHGSat, Carbon Mapper, Sentinel-5P	UNEP-IMEO, 2023

Table 4.4: Example 'atmosphere' products utilising EO data

Best practice scoring

Table 4.5. shows the best practice scoring for biodiversity-relevant products.

	High quality satellite data	Transparent about the algorithms used	Develop and publish code	Experimental dataset - EO derived output	Quantifiably validated	FAIR principles	Total Score
Carbon Monitor Cities	1	1	1	1	1	1	6
NASA Carbon Monitoring System (CMS)	1	1	1	1	1	1	6
Climate TRACE	1	0	0	0	1	1	3
Global Forest Watch - Carbon Flux maps	1	1	1	1	1	1	6
Carbon Mapper	1	1	1	1	1	1	6
Open GHG	1	1	1	1	1	1	6
Carbon Explorer	1	1	1	1	0	1	5
METER-ML (Stanford ML Group)	1	1	1	1	1	0	5
Methane Alert and Response System (MARS)	1	1	0	1	1	0	4

Table 4.5: Atmosphere products - Best practice score

The Climate TRACE product is the lowest scoring product reflecting its more experimental nature and the lack of full transparency on methods. Other lower scoring products indicate either a similar constraint on transparency and validation or the absence of adhering to FAIR principles.

Water

Water, as an integral component of nature and fundamental resource also linked to multiple ecosystem services, is procured as a resource from the surface (lakes), ocean, underground, glaciers and soil (Leach et al., 2019). For businesses to locate potential interface with surface water sources, the Global Surface Water Explorer provides a resource of freely available data for almost 4 decades at 30-metre resolution, that tracks surface water using 300 million Landsat images (Pekel et al., 2016). This historical data record, provides an opportunity to track points of potential past and present interaction with and impact on water sources. The data tool has been incorporated by the United Nations Environmental Programme to officially track SDG target 6.6.1 for all 192 member countries (UNEP).

Earth Observation measurements can also be used for assessing potential risk that water sources can put on resources or infrastructure utilised by businesses, including due to increased rain fall, floods and tsunamis. The Global Flood Monitoring System (GFMS) by NASA, provides real time information on the possible occurrence of floods within a 12km grid point, and is supported through hydrological data from the Global Precipitation Measurement mission, an international constellation of satellites (Wu et al., 2014). These missions can prove to be especially useful for organisations like Floodbase, that use satellite tracked flood risk information to inform and increase the coverage of flood insurance in vulnerable areas. The firm uses a mix of public and private satellite images to achieve a resolution of 10-250 m, and intervals ranging from 1 day to two weeks (Floodbase; Tellman et al., 2021). Among upcoming initiatives using earth observation to assess risk; the CEO Water Mandate, established by the UNGC and the Pacific Institute, has collaborated with the European Space Agency to monitor 100 most stressed water basins in the world for the 455 endorsed businesses that have signed on to their mandate.

Products

Data tool	Nature component	Dependency / Impact	Satellite data used	Source
Global Surface Water Explorer	Surface water extent and change	To track interface with Water	Landsat	Pekel et al., 2016
Hydrological Modeling and Analysis Platform (HyMAP)	River discharge and basin hydrology	Dependency - supports water resource planning and identifies water stress risks	TRMM, GPM, MODIS, SRTM	Getirana et al., 2012
Global Flood Monitoring System (GFMS)	Flood	Impact - informs flood response, disaster mitigation, and insurance	TRMM, GPM, MODIS	Wu et al., 2014
Global Flood Awareness System (GLOFAS)	Flood	Dependency - supports infrastructure resilience and disaster preparedness	SMOS, Sentinel-1 (for validation); model-based forecasts	Alfieri et al., 2013; Copernicus EMS

Data tool	Nature component	Dependency / Impact	Satellite data used	Source
SeaWiFS Data Analysis System (SeaDAS)	Ocean colour, chlorophyll, turbidity	Dependency - supports fisheries, coastal health monitoring Impact - tracks water quality	SeaWiFS, MODIS-Aqua, VIIRS	NASA OBPG
BlueDot Observatory	Surface water anomalies	Dependency - monitors seasonal water availability and anomalies for health and agriculture	GRACE, MODIS, Sentinel-2	BlueDot Observatory
Global Land Water Storage (GLWS)	Total terrestrial water storage	Dependency - monitors freshwater Impact - tracks groundwater depletion	GRACE, GRACE-FO	Gerdener et al., 2023; (GRACE-FO); NASA JPL

Table 4.6: Example 'water' products utilising EO data

Best practice scoring

Table 4.7 shows the best practice scoring for relevant atmosphere products.

	High quality satellite data	Transparent about the algorithms used	Develop and publish code	Experimental dataset - EO derived output	Quantifiably validated	FAIR principles	Total Score
Global Surface Water Explorer	1	1	1	1	1	1	6
Hydrological Modeling and Analysis Platform (HyMAP)	1	1	0	1	1	0	4
Global Flood Monitoring System (GFMS)	1	1	0	1	1	0	4
Global Flood Awareness System (GLOFAS)	1	1	1	1	1	1	6
SeaWiFS Data Analysis	1	1	1	1	1	1	6

	High quality satellite data	Transparent about the algorithms used	Develop and publish code	Experimental dataset - EO derived output	Quantifiably validated	FAIR principles	Total Score
System (SeaDAS)							
BlueDot Observatory	1	0	0	1	0	0	2
Global Land Water Storage (GLWS)	1	1	1	1	1	1	6

Table 4.7: Water products - Best practice score

BlueDot Observatory is the lowest scoring product largely due to its experimental nature. Other lower scoring products indicate constraints on transparency or the absence of adhering to FAIR principles.

4.5. Alignment to market needs and best practice – example of TNFD LEAP

The definition and application of EO best practices does not of itself lead to outcomes, products, information, etc. that are necessarily fit for purpose for the market. A good understanding and mapping of client expectations for those outputs is critical to achieving success, not only in terms of data validity, integrity and ease of use, but also in promoting quality assurance, client confidence, uptake pathways and eventually market development for EO based services that support nature finance.

Additional work is required to fully appreciate and define those client best practices that will influence the design and utilisation of (best practice) EO based services and products to fulfil those expectations. This will be an important element of the LEON project and any other activity seeking to promote EO in the Nature Finance sector, especially as both the Space and Finance domains both appear to becoming more aware of and engaged in collaborative activities and prospects of mutual interest and potential benefit.

The TNFD offers important guidance on the characteristics of decision useful data – important in establishing best practices for EO – in their discussion paper on data and analytics (TNFD 2022). The paper also provides an overview and non-exhaustive mapping of a number of data platforms and sources to identify where they can support different phases and steps in a LEAP assessment.

TNFD's discussion paper notes that "from automation to traceability and remote sensing to eDNA sampling, improving computable data holds the promise to help businesses better understand baseline values, and predict, mitigate and monitor nature-related risks". Developments in asset and sector specific geospatial analysis sits at the heart of this technological emergent trend but, whilst the rate of development and increased demand is appreciated, greater transparency of process and methodology is something to addressed at the same time.

TNFD envisage developments bringing gains in efficiencies by greatly reducing the amount of time necessary to gather nature-related data and perform impact and dependency analysis, enabling users of the TNFD framework to respond to nature-related risks and opportunities in a much more meaningful time frame.

The CFRF also identifies EO as an important source of science-based and independent geospatial data in their 2024 technical guidance on data for risk assessment by financial institutions (CFRF 2024). The guide presents helpful advice on the data landscape available to Financial Institutions and describes some examples of instruments of relevance, The guide also illustrates a few of the metrics and services provided by a selection of entities providing EO related services and products in the context of applying principles in action to address TNFD financial disclosures that could meaningfully improve outcomes for biodiversity.

It is clear that a significant volume of nature-related metrics and data already exists. However, challenges remain around standardisation of methods and definitions, maintenance and connectivity of data sets, and accessibility.

The TNFD response to this was to launch the Nature-related Data Catalyst, working to address the need for high-quality, trusted decision useful data on nature-related risks and opportunities. It brought together a range of actors to reduce the identified data challenges and gaps. Their 2023 scoping study assessed the viability of a global public data utility for nature-related data in recognition of the fact that companies, governments and financial institutions would require robust benchmarks to set targets in response to the Global Biodiversity Framework. The overarching conclusion was that demand for nature-related data is growing quickly, and a global nature-related public data facility could provide a solution helping to scale the availability, quality, and maintenance of nature-related data. This would be a complementary resource to the Net Zero Public Data Utility that was announced in 2022 (TNFD 2023a).

Key outcomes on market requirements concerning the criteria for selecting data platforms and tools included:

- Relevance
- Resolution and scalability
- Temporality
- Frequency of update
- Geographic coverage
- Accessibility
- Comparability
- Thematic coverage
- Authoritativeness, including traceability

Three significant challenges were identified: variance in measurement approaches, relevance to market decision making, and the comprehensiveness of data coverage. Notably, a lack of data was not the top concern.

In addition to considering the technical requirements of data and analytics, TNFD provide helpful guidance on some key approaches and typologies to ecosystem characterisation and related efforts at standardisation - relevant to considering when, where and how EO could best be applied (TNFD 2023b).

They point out that some typologies, such as that of the Align project , use a simpler classification with a focus on only the living components of the ecosystem:

- Structure: both at a location (e.g. canopy height) and relating to the broader landscape or seascape (e.g. patch size and connectivity)
- Composition (e.g. the species present and their abundance) and
- Function and physical, chemical and biological processes (e.g. primary productivity or detritus formation)

However, TNFD recommends that their LEAP approach should not only address those topics but also measure non-living components, such as water quality, soil structure and air pollutant concentrations, where they are relevant to impacts and dependencies. The indicators in a component that should be measured will depend on the ecosystem in question.

They define ecosystem integrity as the degree to which an ecosystem's composition, structure and function resemble those characteristics of its natural range of variation. Ecosystem integrity and ecosystem condition are often used interchangeably, but for a LEAP assessment, it is useful to distinguish between them based on scale:

- Ecosystem integrity refers to an ecosystem type (that could be at any level within a hierarchical ecosystem typology);
- Ecosystem condition refers to a defined spatial unit within an ecosystem type (equivalent to the SEEA's 'ecosystem asset').

Within the TNFD LEAP approach:

- Ecosystem integrity (of broad ecosystem types) is most relevant in the Locate phase for determining the context of the nature interface (L3) and sensitive location identification (L3) and
- Ecosystem condition (of defined spatial units) is most relevant for the Evaluate, Assess and Prepare phases, focused on particular assessment locations.

Ecosystem condition is an important complementary measure to ecosystem extent. While impact measures based on changes in ecosystem extent, such as the area of a vegetation type converted or restored, are relatively simple to assess, and can be achieved using EO approaches, measuring ecosystem extent alone can give an incomplete picture that does not account for changes in the quality of ecosystems at different stages of degradation or restoration.

Summary

The LEON project presents an opportunity to create a framework that aligns EO capabilities with the evolving requirements of the Nature Finance sector. As Nature Finance increasingly becomes a central instrument for addressing global environmental challenges, the role of EO data and methods must be held to scientific rigour, transparency, and interoperability. These ensures that EO-derived products can serve as credible, actionable evidence in financial instruments tied to environmental outcomes.

The summary analysis in Table 4.8 provides an overview of the maturity of the exemplar EO products in this context for the domains of biodiversity, atmosphere and water. It provides an indication of how example current products relevant to LEON are using EO and adhere to current best practice in EO science and workflows. It is not intended as a definitive list of products and services that will necessarily be applied in all of the Pilots. This approach does however support the process of assessing whether these products, or any other candidate dataset nominated for inclusion, could potentially be applied in the Pilots depending on their relative merits and correspondence to the EO best practice framework.

Among the 22 datasets reviewed, most are based on robust satellite data and frequently include experimental datasets and metadata. Encouragingly, 18 of the products are quantifiably validated, with transparency around the data generation process. However, the review also reveals significant inconsistencies: only 14 datasets are published according to FAIR principles, and only 15 provide open access to their source code.

As is well-established, this shows how there remain multiple good practice proxies available for biodiversity, but no direct measurements that can be applied in financial workflows and decision chains. In addition there are emerging foundation models that the LEON team is now looking into, and the development of private sector initiatives (such as e.g. the Planet Labs Centinela project).

This variability of information sources clearly poses a risk to the credibility and comparability of EO products for routine uptake within financial contexts and emphasises the need to promote consistent application of EO best practices. These findings thus highlight both a challenge and an opportunity. On one hand, the foundations for using EO to support credible Nature Finance applications is clearly in place. On the other, without a stronger commitment to standardisation and openness across the community, EO risks falling short of the transparency and reproducibility expectations required by financial actors e.g. investors, regulators, and market actors. Whilst this analysis focused on published datasets, similar variation likely exists across the wider ecosystem of operational, unpublished, or commercial EO products.

To address these gaps, EO applications must be built upon validated, peer-reviewed methodologies. This includes the adoption of standards established by global initiatives such as CEOS, GEO, and the QA4EO framework. An important reference point in promoting EO best practices for biodiversity monitoring is GEO BON since it provides a science-based framework for biodiversity observations through its EBVs, which guide the collection, analysis, and reporting of biodiversity data. By aligning EO-based indicators and monitoring systems with the GEO BON framework, Nature Finance initiatives could ensure that the biodiversity data they rely on are methodologically standardised.

Additionally, transparent documentation, version control, open-source code, and uncertainty quantification must become the norm. Interoperability and transparency are key for scaling Nature Finance across geographies and different type of asset. EO datasets must be machine-readable and well-documented, with clear provenance tracking to ensure trust and auditability. Initiatives such as the TNFD will increasingly require such high-integrity data as input into assessments of risk, dependency, and impact.

In summary, variability in EO data practices remains a key barrier to credible Nature Finance. LEON is well placed to address this by formalising best practices across its pilots and partners, using the framework described, thus providing a foundation to promote EO uptake in finance for a nature-positive future.

	High quality satellite data	Transparent about the algorithms used	Develop and publish code	Experimental dataset - EO derived output	Quantifiably validated	Fair principles	Total Score
Copernicus Global Land Service / CLMS	1	1	1	1	1	1	6
Biodiversity Intactness Index (BII)	1	1	1	1	1	0	5
Global Forest Watch – Biodiversity	1	1	1	1	1	1	6
Global Mangrove Watch	1	1	1	1	1	1	6
Carbon Monitor Cities	1	1	1	1	1	1	6
NASA Carbon Monitoring System (CMS)	1	1	1	1	1	1	6
Climate TRACE	1	0	0	0	1	0	3
Global Forest Watch - Carbon Flux maps	1	1	1	1	1	1	6
Carbon Mapper	1	1	1	1	1	1	6
Open GHG	1	1	1	1	1	1	6
Blue Carbon Explorer	1	1	1	1	0	1	3
METER-ML (Stanford ML Group)	1	1	1	1	1	0	5
Methane Alert and Response System (MARS)	1	1	0	1	1	0	4
Global Surface Water Explorer	1	1	1	1	1	1	6
Hydrological Modeling	1	1	0	1	1	0	4

	High quality satellite data	**Transparent about the algorithms used**	**Develop and publish code**	**Experimental dataset - EO derived output**	**Quantifiably validated**	**Fair principles**	**Total Score**
and Analysis Platform (HyMAP)							
Global Flood Monitoring System (GFMS)	1	1	0	1	1	0	4
Global Flood Awareness System (GLOFAS)	1	1	1	1	1	1	6
SeaWiFS Data Analysis System (SeaDAS)	1	1	1	1	1	1	6
BlueDot Observatory	1	0	0	1	0	0	2
Global Land Water Storage (GLWS)	1	1	1	1	1	1	6
	19	**18**	**15**	**19**	**18**	**12**	

Table 4.8: Summary of best practice scores. The scoring is based on a simple presence or absence criterion, codified as 1 or 0 respectively and then totalled.

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Appendix A: Tables used to support biodiversity metrics analysis

Habitat-level metrics

ID	EBV category	Metrics (id) see *	Literature
1	Above-ground biomass	18.above-ground_biomass 22.deforestation_rates 22.aboveground_biomass 26.above-ground_biomass 25.biomass 21.carbon_stocks	- (Guo et al., 2023) Maps of forest composition and vertical structure, including canopy height, which serve as proxies for inferring biomass - (Holcomb et al., 2024) Biomass predictions at 30-m resolution by combing GEDI and Sentinel-derived metrics.
2	Below-ground biomass	26.belowground_biomass	Remote sensing applications to directly measure below-ground biomass remain relatively unexplored. Below-ground biomass estimates have been produced by predicting soil carbon properties, based land cover characterisation and in-situ measurements (e.g. thorough established relationships between remotely sensed above-ground and below-ground estimates), or by predicting variations in soil organic components from remotely-sensed plant functional traits combined with in-situ estimates.
3	Ecosystem fragmentation	2.fragmentation 18.forest_disturbance	- (Wagner et al., 2019) - (Dalagnol et al., 2023) - (Dixon et al., 2023) - (McNicol et al., 2018)
4	Terrestrial ecosystem structural variance (plant structure)	25.plant_apical 25.plant_diametric 25.plant_indicator	- (Turubanova et al., 2023) Modelled changes in tree canopy height across Europe from 2001 to 2021 using historical Landsat imagery, combined with ALS and GEDI. - (Becker et al., 2023) Country-wide retrieval of forest structure from optical and SAR satellite imagery and UAVs with deep ensembles.
5	Forest species and age class	25.plant_mortality 26.tree_density	- (Dixon et al., 2023) - (Tolan et al., 2024) 1 m resolution map by using very high resolution RGB images from Maxar satellites and ALS data.
6	Land cover (vegetation type) Ecosystem distribution	4.land_cover 20.ecosystems_distribution 10.vegetation_distribution 23.cpland_index 26.forest_area 10.vegetation_extent	Well-established, widely studied in the literature
7	Marine Ecosystem Vertical Profile	23.rugosity_(marine) 27.coral_reef	Due to the spectral interference of water, most remote sensing approaches using aerial or satellite imagery have been limited to mapping broad benthic classes in shallow waters (Hedley et al., 2016; Zeng et al., 2023). Few studies, (e.g., Doo et al., 2017), combined drone imagery and satellite imagery with in situ data collection to derive reef-scape level biomass estimates. (Lutzenkirchen et al., 2024) demonstrates a proof-of-concept for integrating in-situ and remote sensing methods in coral reef mapping to predict ecosystem conditions over larger scales. Of the few crediting systems examined that incorporate the marine realm, they all requested measurements of

ID	EBV category	Metrics (id) see *	Literature
			rugosity as an indicator of habitat complexity to predict marine biota, however, the reliability of this rugosity as an indicator of ecosystem condition remains uncertain (Pygas et al., 2020). - (Doo et al., 2017)
8	Terrestrial Ecosystem Vertical Profile	26.vegetation_vertical	- (Potapov et al., 2021) Available as the Global Forest Canopy Height 2019 data layer, derived by combining GEDI, ALS and Landsat (though saturates at 25m) - (Lang et al., 2023) Available as a 10m resolution map for the year 2020, using GEDI and Sentinel 2. Does not show agreement with (Potapov et al., 2021) - (Turubanova et al., 2023) Approach to derive temporal changes in canopy height and extent at 10 mts resolution. - (S. Li et al., 2023) Demonstrates an approach to map location, crown size, and height of trees from aerial images as 20 cm res. Flags limitations with deep learning for estimating biomass change from crown detection, as biomass increases are not always directly linked to changes in the crown area.
9	Marine live cover fraction (habitat structure)	9.kelp_biomass 27.volume_occupied 9.kelp_canopy	Data collected with autonomous underwater vehicles (AUVs) combined with DL has been recently trialed for providing simplified kelp species identification and deriving biomass estimates (Mahmood et al., 2020; Overrein et al., 2024) - (Fraiola et al., 2023) High resolution habitat maps of benthic systems using commercial high-resolution satellite imagery. - (Marquez et al., 2022) Giant kelp forest mapping using Landsat Thematic Mapper
10	Terrestrial live cover fraction (habitat structure)	21.forest_integrity 18.extent_of 26.tree_canopy 27.canopy_cover	**Tropical forests** - (Vancutsem et al., 2021) - (Grantham et al., 2020) Forest Landscape Integrity Index, involving tropical forests for the year 2019 provided AT 300 meters resolution. **Grasslands** - (J. Wang et al., 2019) - (Muro et al., 2022) - (Díaz-Ireland et al., 2024) Involve the use of Sentinel 2 data and deep learning to detect and map habitats and dominant species **Wetlands** - (Muro et al., 2020)
11	Soil organic carbon (non EVB)	26.soil_organic 25.soil_organic 26.leaf_litter	Case studies demonstrating the viability of mapping soil organic carbon from openly accessible sensors (Sentinel and Landsat) have been trialed in recent years. - (Xiao et al., 2024) Soil organic carbon mapped using Landsat TM5 - (Cui et al., 2025) Trailed an approach for deriving SOC estimate sin Southern China by combing Sentinel 1 and Sentinel 2 time-series data.
12	Net primary productivity	26.net_primary 23.ndvi	Well established, widely studied in the literature (e.g. NDVI is widely used as a proxy for productivity)

Table 7.1 Habitat-level metrics

Species-level metrics

ID	EBV category	Metrics (id) see *	Literature
13	Kelp Community Composition (Density of juvenile kelp plants)	9.density_of	see 16
16	Kelp sp abundance	9.occurrence_of	Kelp extent mapping can be influenced by tides and currents, due to the buoyancy of the kelp structures and species-level morphology, requiring high spatial (centimeters) and temporal (minutes) resolutions that are not currently possible with satellites for accurate abundance detection (Timmer et al., 2024).
14	Coral sp abundance	9.occurrence_of	- (Lutzenkirchen et al., 2024) - (Lyons et al., 2024)
15	Mangrove sp abundance	9.occurrence_of	Multiple approaches for mangrove species detection have been trialed in the last decade, including applications involving very high resolution (e.g. <3 m) and sub-meter level spaceborne sensors (e.g.; SPOT, RapidEye, GeoEye, WorldView)(Wu et al., 2025) - (Jiang et al., 2021) This includes approaches fusing high-resolution imagery (WorldView-2) with UAV LiDAR to classify mangrove species, as well as
17	Vascular plants sp abundance	19.species_abundance 23.species_diversity 27.abundance_of 27.species_richness 23.species_richness 25.plant_species	Recent advances have been focusing on the problem of detecting tree crowns and estimating biomass using RGB data alone, whether from airborne or satellite sources, to delineate crowns and identify individual trees both within forested areas (Ball et al., 2023) and outside forested sites (Liu et al., 2023). Some papers are advancing the question of mapping and identifying tree species, which is currently being explored with UAVs (Zhang et al., 2021) and, to some extent, being tested with very high resolution images, complemented with lidar sensors (H. Li et al., 2021). - (Ball et al., 2023) - (H. Li et al., 2021) - (Zhang et al., 2021)
18	birds sp diversity	23.species_diversity 23.species_richness 10.bird_richness 25.increase_and/or 25.decrease_in	- (Boucher & Davies, 2023)
19	mammals sp diversity	25.increase_and/or 25.decrease_in	- Inconclusive (TBD)
20	Herpetofauna	25.increase_and/or 25.decrease_in	NA
21	benthic plant sp diversity	23.species_diversity 23.species_richness	see 14, 15, 16
22	sessile invertebrates sp diversity	23.species_diversity 23.species_richness	NA
23	fish sp diversity	23.species_diversity 23.species_richness	NA
24	bats sp abundance	25.index_of	NA

Table 7.2 Species-level metrics

Generic indicators

The following correspond to unspecified 'generic' species indicators.

ID	EBV category	Metrics (id) see *	Literature
25	Species diversity	24.indicator_species 26.abundance_of 4.species_richness 26.effective_population 2.species_richness 10.species_richness 10.threatened_species 20.species_presence/absence 26.specie_richness 26.occurrence_of	**Grasslands** - (Fauvel et al., 2020) Tested Sentinel optical and radar data for predicting taxonomic and functional diversity at 10 m. resolution. - (R. Wang et al., 2018) Vegetatio species detection based on spectral information, using hyper-spectral imagery **Tropical forests** Many applications are being developed purely for high-resolution UAVs for tree-level species detection based on AI/DL, e.g. (Almeida et al., 2021; Ferreira et al., 2020). Other approaches are being trailed that combine non-satellite with satellite-based sensors and AI. - (Wagner et al., 2020) Employed U-net and very high-resolution multispectral images (0.5 m) from GeoEye satellite to identify canopy palms across the Amazon - (Picard et al., 2024) DL approaches have been used to identify vegetation classes in tropical forests in Congo from high-resolution imagery, with classes correlating with ecosystem function and composition metrics
26	Taxonomic diversity	26.taxonomic_diversity	see 25
27	Phylogenetic diversity	26.phylogenetic_diversity	- (Schuman et al., 2024) Developed an approach to estimate genetic diversity indicators based on effective population size theory, inferred from habitat size and the potential number of mature individuals of a species living in such habitats.
28	Functional diversity	26.functional_trait	see 25

Table 7.3: Generic indicators

Appendix B: Best practices scoring – justification

Biodiversity

	High quality satellite data	Transparent about the algorithms used	Develop and publish code	Experimental dataset - EO derived output	Quantifiably validated	Fair principles	Total Score
Copernicus Global Land Service / CLMS	Satellite data from Copernicus missions	Methods mentioned within publications	Code provided within publications	Can be reproduced	Quality control methods mentioned within publications	Free and accessible	6
Biodiversity Intactness Index (BII)	Satellite data from ESA	Methods mentioned on website	Code published on website	Can be reproduced	Quality control methods mentioned	Access to the recent dataset is not free	5
Global Forest Watch	Data from Landsat, MODIS	Methods mentioned on website	Code published on website	Can be reproduced	Quality control methods mentioned	Free and accessible	6
Global Mangrove Watch	Data from ALOS PALSAR, Sentinel-1, Landsat	Methods mentioned within publication	Code published on github	Can be reproduced	Quality control methods mentioned within publication	Free and accessible	6

Table 8.1: Biodiversity scoring

Atmosphere

	High quality satellite data	Transparent about the algorithms used	Develop and publish code	Experimental dataset - EO derived output	Quantifiably validated	FAIR principles	Total Score
Carbon Monitor Cities	TROPOspheric Monitoring Instrument (TROPOMI) - Sentinel 5	Mentioned in detail in Huo et al., 2021	Published on Github	Can be reproduced	Validated against existing datasets	Free and accessible	6
NASA Carbon Monitoring System (CMS)	Satellite data from NASA missions	Methods derived are in related publications	Publishes different methodologies for different uses	Can be reproduced	Validation tests detailed in publications	Free and accessible	6
ClimateTRACE	High quality satellite data is mentioned but not specified	Mention use of ML and AI to improve emission monitoring from satellite imagery - but do not specify algorithms used	No published code	Mentions the emissions datasets used, but cannot be reproduced without additional data	The datasets used are quantifiably validated	Free and accessible	3
Global Forest Watch - Carbon Flux maps	Satellite data from NASA and Planet	Mentioned in Hansen et al., 2013	Code and methods published within website	Can be reproduced	Validated against existing datasets	Free and accessible	6
Carbon Mapper	Satellite data from NASA	Methods published	Code and methods published within website	Can be reproduced	Quality control guide is published	Free for non commercial purposes	6
OpenGHG	Can retrieve data from different satellite data sources	Methods published	Code published on github	Can be reproduced	Quality control methods are published	Free and accessible, with tutorials and guides	6
Blue Carbon Explorer	Satellite data from Planet	Methods published	Code published on github	Can be reproduced	Quality control methods are published	Free and accessible on Google Earth Engine	6

	High quality satellite data	**Transparent about the algorithms used**	**Develop and publish code**	**Experimental dataset - EO derived output**	**Quantifiably validated**	**FAIR principles**	**Total Score**
METER-ML (Stanford ML Group)	Satellite data from Sentinel missions	Methods published	Code published on github	Can be reproduced	Quality control methods are published	Only available for the US	5
Methane Alert and Response System (MARS)	Satellite data from Sentinel missions	Methods published	Code not published	Can be reproduced	Quality control methods are published	Only companies part of OGMP 2.0 are notified, companies cannot access the data on their own	4

Table 8.2: Atmospheric scoring

Water

	High quality satellite data	Transparent about the algorithms used	Develop and publish code	Experimental dataset - EO derived output	Quantifiably validated	FAIR principles	Total Score
Global Surface Water Explorer	Satellite data from ESA missions	Methods mentioned in the publication	Published on their own website	Can be reproduced	Quality control methods are published	Free and accessible	6
Hydrological Modeling and Analysis Platform (HyMAP)	Satellite data from NASA missions	Methods mentioned in the publication	Code not published	Can be reproduced	Quality control methods are published	Free and accessible use of the tool, but cannot be reused without code	4
Global Flood Monitoring System (GFMS)	NASA's TRMM and GPM data	Methods mentioned in the publication	Code not published	Can be reproduced	Quality control methods are published	Free and accessible use of the tool, but cannot be reused without code	4
Global Flood Awareness System (GLOFAS)	Data from Copernicus missions	Methods mentioned in the publication	Code published	Can be reproduced	Quality control methods are published	Free and accessible	6
SeaWiFS Data Analysis System (SeaDAS)	Data from NASA and ESA missions	Methods published on the website	Code published on the website	Can be reproduced	Quality control methods are published	Free and accessible, provision of tutorials as well	6
BlueDot Observatory	Data from copernicus missions	Methods not published	Code published on github	Cannot be reproduced	Quality control methods are not currently published	Site not functioning for free access	2
Global Land Water Storage (GLWS)	Data from GRACE	Methods explained within publication	Code published on the website	Can be reproduced	Quality control methods published, validated with GNSS	Free and accessible	6

Table 8.3 Water scoring

Appendix C: Summary Recommendations

- Pilot 1 **MI**ning supply chains (water quality): **MI**
- Pilot 2 **AG**rifood supply chains (land conversion): **AG**
- Pilot 3 Nature-related financial **RI**sks & opportunities (physical & transition risks): **RI**
- Pilot 4 **BI**odiversity metrics (biodiversity credits): **BI**
- Pilot 5 Biodiversity metrics for use in **N**atural **C**apital accounting: **NC**
- Pilot 6 **S**overeign **F**inance, debt-for-nature swaps and sustainability-linked bonds: **SF**

5.1.1. Summary general recommendations per pilot

Pilot	ID	User Requirement	Justification or comment	Priority	Scope
1	MI-UR-01	Generate geospatially explicit freshwater quality indicators near mining sites	Provide time-series maps and indicators (turbidity, chlorophyll-a, TSS, colour change) at watershed scale to enable FIs to identify and monitor water-related risks from mining.	**M**	**I**
1	MI-UR-02	Provide attribution or links to pollution signals to mining activities.	Develop methods to distinguish mining-related pollution signals from other land-use or natural sources.	**S**	**CI**
1	MI-UR-03	Enable temporal trend analysis of mining-related impacts	Detect whether water quality is improving or deteriorating near mines over time to support monitoring of mitigation commitments and long-term exposure of financed assets.	**S**	**I**
1	MI-UR-04	Explore integration of water use and solid waste metrics	Assess feasibility of including water use intensity and solid waste pollution where relevant.	**W**	**NI**
2	AG-UR-01	Generate asset-level indicators for key environmental impacts (deforestation, water quality) and dependencies (carbon stock, fire risk).	This is the core objective of the pilot: to move beyond high-level assessments to quantify real, asset-level performance for use by financial institutions.	**M**	**I**
2	AG-UR-02	Provide temporal analysis of the indicators to track changes and trends since a 2020 baseline.	Users require trend analysis to assess whether a company's performance is improving or declining over time, which is essential for engagement and risk assessment.	**M**	**I**
2	AG-UR-03	Enable the integration of EO-derived metrics with non-EO data sources, such as RSPO certification status from supplier lists.	Contextualising the EO data with business information (e.g., certification) is needed to create a holistic environmental performance assessment.	**M**	**I**
2	AG-UR-04	Deliver outputs (maps and quantified data) in a format that is easily interpretable and suitable for financial risk	The primary user (BNP Paribas) needs the outputs to be directly actionable and integrable into	**M**	**I**

Pilot	ID	User Requirement	Justification or comment	Priority	Scope
		models and corporate engagement.	their existing workflows for risk analysis and decision-making.		
2	AG-UR-05	Allow for the spatial disaggregation of data to the supply shed level (25km radius around a mill).	This is the defined unit of analysis for the pilot and is essential for the asset-level assessment required by the user.	**M**	**I**
2	AG-UR-06	Identify and track indicators of regenerative agriculture practices where sufficient data is available.	This addresses the exploratory, "nature-positive" goal of the pilot, which is of interest to the user for developing new financial products.	**W**	**CI**
2	AG-UR-07	Generate early warnings for significant fire events or rapid deforestation in commodity sourcing areas.	This supports proactive risk mitigation and timely engagement with companies on acute environmental events.	**S**	**CI**
3	RI-UR-01	Generate geospatially explicit indicators of soil-related impacts on agricultural output relevant to FI decisions	Supports end-to-end supply chain traceability and environmental performance assessment.	**M**	**I**
3	RI-UR-02	Quantify temporal trends in soil degradation	Supports end-to-end supply chain traceability and environmental performance assessment.	**M**	**I**
3	RI-UR-03	Link soil degradation to financial exposure metrics	Translate soil degradation indicators into financial exposure metrics (e.g., yield loss, revenue reduction, insurance claims, credit risk).	**S**	**I**
4	BI-UR-01	The approaches developed should be suitable for helping financiers assess the ecological robustness of biodiversity gains	A key user requirement for financial organisations interested in biodiversity credits, to avoid the risks of greenwashing and inadequate ecological outcomes.	**M**	**I**
4	BI-UR-02	Approaches should be able to provide timely updates of progress (e.g., annual at minimum)	To identify risks in a timely fashion, approaches need to be able to regularly show progress.	**M**	**I**
4	BI-UR-03	The approach should be applicable to the emerging/potential EU biodiversity credit market, as well as emerging voluntary and regulatory reporting frameworks (e.g., TNFD, NPI, GRI).	The interest in credits is partially driven by the regulatory market, as well as the want to make financial investments in biodiversity. Integrating with these frameworks is important for helping companies and financiers disclose the impacts of their operations or investments on nature, and linking in with existing efforts.	**M**	**I**
4	BI-UR-04	To ensure robustness, the approach should be compatible / able to be integrated with approaches for assessing	Measuring biodiversity is a challenge, but assessing outcomes and impact requires wider considerations explored in	**M**	**I**

Pilot	ID	User Requirement	Justification or comment	Priority	Scope
		counterfactual impacts, leakage and additionality.	the biodiversity and carbon offsetting literature. This is important to ensure robustness of the markets.		
4	BI-UR-05	CS2: The approach should be able to measure outcomes, but also provide early warnings where credits may not be delivering promised goals.	Early warnings are important for helping to address issues before they become major risks.	**M**	**I**
4	BI-UR-06	CS1: Provide an approach that can measure biodiversity uplifts in agricultural landscapes.	Agricultural landscapes are widespread across Europe and likely a target of many actors interested in generating biodiversity uplift. However, this area is poorly covered at the moment in terms of feasible and robust measures for measuring biodiversity uplift.	**M**	**I**
4	BI-UR-07	Approaches should be able to utilise, or be able to integrate at a later data, field collected data.	Integration of different data sources is key to verify the outcomes of the assessment	**M**	**I**
4	BI-UR-08	CS1: Assess the suitability of existing indicators for providing robust estimates of biodiversity change.	A key component of Case Study 1 is to help assess the robustness of different indicators to assess species-level changes – a key component of credit markets and often a gap in remote sensing datasets.	**M**	**I**
4	BI-UR-09	Approaches should be scalable – applicable to both local sites, but also to portfolios of investments or crediting projects.	Financial organisations will need to be able to aggregate measures to look at the performance of individual sites, and across their portfolio.	**M**	**I**
5	NC-UR-01	Assess EO-based GNNI indicators against existing national accounting data (e.g., SEEA, Eurostat) and biodiversity inventories.	Ensures credibility, alignment with statistical standards, and comparability with official economic metrics	**M**	**I**
5	NC-UR-02	Provide uncertainty estimates for all indicators. Quantify and communicate uncertainty ranges in EO-derived biodiversity and economic valuation metrics.	Essential for decision-makers to interpret reliability of outputs and avoid misuse in policy or finance.	**M**	**I**
6	SF-UR-01	Assess the value added of a list of forest relevant EO data within historical transactions	Using a historical benchmark of current practices allows to assess the validity of EO data here	**M**	**I**
6	SF-UR-02	Analyse the potential options of indices over single forest relevant metrics	This element would be vital to assess if the simplicity of a single metric would be preferable over a	**M**	**I**

Pilot	ID	User Requirement	Justification or comment	Priority	Scope
			combined metric which might be more robust to biases in any one given layer		
6	SF-UR-03	Assess which variables are most suitable for a temporal monitoring system	This would be support the design of further outcome payments which require the detection of temporal changes in target variables	**M**	**I**
6	SF-UR-04	Provide a workflow that takes a location data as an input and provides location specific data as an output	Relevant for project level assessments	**M**	**I**
6	SF-UR-05	Provide a workflow that that provides national level forest relevant metrics and maps	Relevant to assess overall national level dynamics	**M**	**I**
6	SF-UR-06	Provide a dashboard that allows for a user-friendly option for the two prior outlined user requirements	Improves accessibility and usability of forest metrics.	**W**	**CI**
6	SF-UR-07	Explore the value added of AI based systems for prediction and monitoring of forest relevant variables	Tests potential efficiency gains in monitoring.	**C**	**CI**
6	SF-UR-08	Trial out the development of inclusion of spatial socio-economic metrics in the context forest linked financial transactions	Adds context to forest–finance linkages.	**C**	**CI**
All	RB-01	Adopt our definition of 'nature finance', and test that it is consistent with any definition being used by Early Adopters and other organisations on the project			
All	RB-02	Consider all pilots in relation to the twin aspects of financing green and greening finance (some address one, others address both)			
All	RB-03	Develop tools and/or methodologies that are reasonably ambivalent to the specifics of current policies, given the rapidly changing policy landscape i.e. futureproof			
All	RB-04	Design tools not only for robustness in monitoring biodiversity, but also to allay concerns from investors (e.g. applying counterfactual thinking to confirm genuine impact)			
All	RB-05	Seek methods for addressing data gaps in EO (through inclusion of open empirical data, extrapolation based on emerging foundation models, etc.)			

***Table 10.2**. Collation of user requirements*

ID	Description	Justification or comment	Priority	Scope	User Requirement ID
TR-001	System shall generate EO-based freshwater quality indicators and time-series for mining regions	Enables monitoring of water-related environmental risks near mining operations	**M**	**I**	MI-UR-01, MI-UR-03
TR-002	System shall implement attribution methods to associate water quality changes with mining activity	Supports distinguishing mining signals from other land-use impacts	**S**	**CI**	MI-UR-02

ID	Description	Justification or comment	Priority	Scope	User Requirement ID
TR-003	System shall provide asset-level EO indicators for land-use change, deforestation, and environmental dependencies	Core functionality for agrifood and forestry use cases requiring supply chain transparency	**M**	**I**	AG-UR-01, AG-UR-05, SF-UR-04
TR-004	System shall support temporal tracking of indicators from at least 2020 onward	Enables trend analysis for performance monitoring and compliance	**M**	**I**	AG-UR-02, RI-UR-02, SF-UR-03
TR-005	System shall enable integration of EO metrics with external datasets (e.g., certification, financial data)	Supports contextualisation with supply chain or finance-related data	**M**	**I**	AG-UR-03, RI-UR-03, BI-UR-07
TR-006	System shall deliver outputs in accessible formats (e.g., maps, CSV, GeoTIFF) suitable for modelling and reporting	Ensures interoperability with financial systems and usability by analysts	**M**	**I**	AG-UR-04, SF-UR-06
TR-007	System shall support alerts for rapid environmental changes such as deforestation or fire	Enables proactive risk mitigation and engagement	**S**	**CI**	AG-UR-07, BI-UR-05
TR-008	System shall generate soil-related indicators (e.g., soil moisture, erosion risk) for agricultural regions	Supports risk analysis of agricultural productivity and degradation	**M**	**I**	RI-UR-01, RI-UR-02
TR-009	System shall compute financial risk proxies from environmental degradation indicators	Translates EO signals into business-relevant metrics	**S**	**I**	RI-UR-03
TR-010	System shall enable assessment of ecological robustness, additionality, and leakage for biodiversity projects	Supports credit market integrity and avoids greenwashing	**S**	**CI**	BI-UR-01, BI-UR-04
TR-011	System shall generate biodiversity metrics that are compatible with EU and global reporting frameworks (e.g. TNFD, NPI)	Ensures usability of outputs in regulatory and voluntary disclosures	**M**	**I**	BI-UR-03
TR-012	System shall support scalable biodiversity assessments from field to portfolio level scale	Supports local validation and portfolio-wide financial analysis	**M**	**I**	BI-UR-02, BI-UR-06, BI-UR-07, BI-UR-08, BI-UR-09
TR-013	System shall assess EO-derived biodiversity indicators against national and statistical datasets	Ensures compatibility with national accounts and credibility with policymakers	**M**	**I**	NC-UR-01
TR-014	System shall include uncertainty estimates with all derived indicators	Supports responsible interpretation and decision-making in finance and policy	**M**	**I**	NC-UR-02
TR-015	System shall support evaluation of EO metrics for past forest-related financial transactions	Supports benchmarking of EO added value in sovereign finance	**M**	**I**	SF-UR-01
TR-016	System shall support generation and comparison of composite indices and single-metric indicators	Enables assessment of robustness and simplicity trade-offs	**M**	**I**	SF-UR-02
TR-017	System shall provide both location-specific and national-level EO workflows for forest monitoring	Supports project-level and sovereign-level assessments	**M**	**I**	SF-UR-04, SF-UR-05

ID	Description	Justification or comment	Priority	Scope	User Requirement ID
TR-018	System shall include basic AI/ML infrastructure to enable predictive analytics and future expansion	Supports long-term scalability and exploration of advanced capabilities	**C**	**CI**	SF-UR-07
TR-019	System shall include optional integration of socio-economic spatial data layers	Adds context to EO indicators for financial analysis	**C**	**CI**	SF-UR-08

Table 10.2. *Collation of technical requirements*