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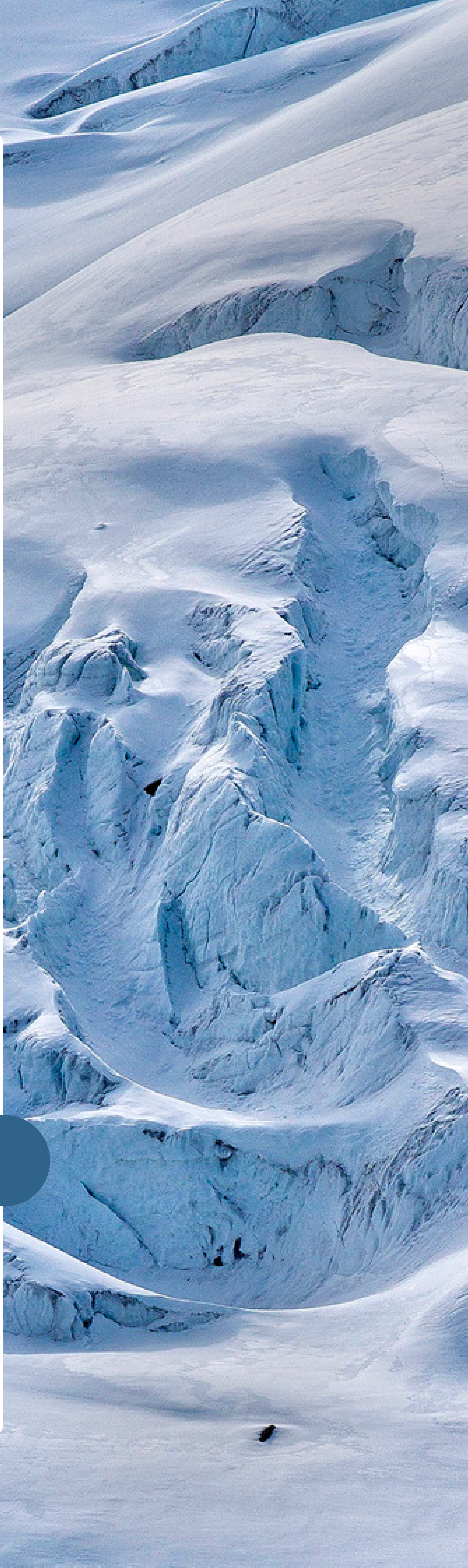
Assessing the Ecological Debt, A Key Lever for Biodiversity Risks Integration



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Executive Summary.

While some progress has been made in assessing and integrating climate risks – both physical and transition - into our economies, biodiversity risks remain far less addressed, in part because of their complexity.

At Candriam, as a responsible investor, our efforts to understand and assess biodiversity risks started a few years ago and resulted in the release of a proprietary model and the publication of our **Biodiversity Strategy** – a process to integrate biodiversity risks in our investment strategies. But one piece was still missing: financial quantification – in other terms, **how to quantify a company's biodiversity impact in financial terms, and take another step toward a more accurate and thorough sustainability analysis of companies in investors' portfolios?**

We have the conviction that international "no net loss" strategies – environmental policies aiming to counterbalance the negative impacts on the environment – are likely to translate into transition risks for corporates and materialise into financial results. We propose **a methodological framework for integrating biodiversity costs into corporate financial analysis.** Through analysis of companies' impact induced by physical flows, restoration cost in different countries and regional ecological impact assessments, **we develop indicators that quantify biodiversity footprints in monetary terms.**

A test of our methodology on a selection of five major textile companies reveals that the cost of restoring the biodiversity they have destroyed in a year is equivalent to 2% of their annual revenues on average —and up to 4% for the most exposed—, with a potential negative impact of 46% on net income for the most exposed companies.

Beyond providing a monetary indicator for biodiversity transition risk assessment, the footprint indicators that we develop enable the identification of actionable levers for impact reduction. This framework can thus serve to build **trajectories for biodiversity footprint reduction,** with specific action levers and long-term objectives, supporting both risk assessment and strategic environmental management.

1. Introduction.

The Urgency of Biodiversity Finance

While the COP 16 Biodiversity Summit introduced new conservation funding mechanisms, current financial tools remain far from sufficient to meet the $200 billion mobilisation target[1]. Reducing harmful subsidies is a policy priority, but complementary private investment in nature preservation and restoration is essential.

At present, public-sector funding dominates nature restoration financing, while the private sector still struggles to develop viable economic models for biodiversity protection. Unlike economic debt, which can grow without constituting immediate existential threats to states, ecological debt follows a different logic. The accumulation of environmental damage can lead to systemic breakdowns and irreversible catastrophes, especially for enterprises whose viability depends directly on the health of their operational environment. Holding companies responsible for their biodiversity impacts is a matter of environmental justice, in alignment with the polluter-pays principle.

Drawing on climate finance precedents, biodiversity-related transition risks can be incorporated into **financial mechanisms that require companies to limit environmental impacts and compensate for unavoidable negative environmental externalities.**

The fundamental question that we raise is: **Who should pay how much, and to whom?** This question extends beyond technical refinements of methods and indicators into the broader debate over about the "financialisation of nature" and its ethical acceptability.

1-Target 19 of the Kumming Montreal agreement ratified in 2022 requires to mobilise $200 billion per year for biodiversity from all sources, including $30 billion through international finance.

The Challenges of Integrating Nature into Economics

The integration of nature into economic models has been a longstanding challenge, with neoclassical theories historically marginalising natural systems to focus on capital and labour.

Recent efforts in the 1970s have sought to reintroduce nature into economic discussions through the concept of "natural capital", but **nature's integration into economic models remains partial and contested.** The complexity of ecological systems, methodological challenges, and epistemological debates continue to impede the development of a comprehensive, universally accepted framework **Biodiversity valuation needs to address key challenges** linked to the very nature of biodiversity.

- **Its spatial dimension**— the localisation criterion —is central to evaluating ecological functions and biodiversity services. Although recent tools such as Impact World+[2] incorporate impact localisation, **there is still no widely accepted, rigorous method for conducting Life Cycle Assessments (LCA) that is truly applicable to biodiversity.**
- **Its multiple functions, goods, and services** complicate valuation. A common comparison contrasts wetlands with wastewater treatment plants: both can filter water, but wetlands simultaneously provide a wide range of ecological and social benefits that artificial systems cannot replicate.
- **The limitations of current methods** explain the persistent lack of consensus on how to measure biodiversity and, by extension, how to quantify the impacts of human activities on biodiversity.

While our approach translates biodiversity impacts into monetary terms to estimate companies' biodiversity-related "debt", this monetary valuation does not imply that financial investment in offsetting this debt is the most effective or appropriate path to sustainability. On the contrary, **any measures aimed at reducing this "debt" should be implemented in strict alignment with the AR3T hierarchy (Avoid, Reduce, Restore, Regenerate, and Transform)** promoted by the Science-Based Targets Network. In other terms, biodiversity financing should occur only after all measures to avoid and reduce impacts have been implemented.

2-IMPACT World+ is a globally regionalised method for life cycle impact assessment (LCIA). It characterises thousands of substances which impacts have been spatially and temporally differentiated when relevant. IMPACT World+ is developed by the International Reference Center for Life Cycle Assessment and Sustainable Transition (CIRAIG) and the Technical University of Denmark (DTU).

Economic Valuation Methods for Biodiversity

There have been attempts to quantify ecological functions using monetary tools, in the aim to incorporate them into political and economic decision-making.

- **The substitution or replacement cost method** estimates the value of ecosystem service by **calculating the cost of artificial goods or services that could replace them.** Such evaluations rely on the assumption of functional equivalence between natural systems and human infrastructure—an assumption that presents clear limitations, particularly when dealing with multiple or hard-to-substitute ecological functions.
- The **avoided damage costs approach** values ecosystem services by **estimating the costs of preventing negative impacts.** For example, the value of mangrove protection can be estimated through the economic losses avoided during storms or tsunamis. While this method highlights nature's protective role, it depends on counterfactual scenarios that can be challenging to model with precision.
- The **Payment for Ecosystem Services** (PES): it is a market-based conservation mechanism in which **beneficiaries compensate providers who protect, enhance, or restore ecosystem services.** Since the 1992 Rio Conference, PES has emerged as one of the most promising innovations in biodiversity conservation. However, existing programs face criticism for their potential inefficiencies, including lack of additionality, leakage, and inaccurate payments.
- The **repair or restoration costs** method estimates ecosystem value based on the **expenditure required to rehabilitate it after degradation.** It is particularly used in contexts of ecological compensation or environmental liability (for example the cost of rehabilitating a wetland or watercourse following industrial damage). However, restoration is not always technically feasible. This valuation method is used in our research to assess transition risk and the “nature debt” of companies held in our portfolios.

Yet, economic valuation has "scarcely been applied in practice and has therefore not yielded tangible conservation outcomes"[3].

While these methods are useful for integrating environmental considerations into economic calculations, they have several limitations.

- **Commoditisation risk** - They reduce nature to market value, overlooking its symbolic, cultural, and ethical dimension.
- **Simplifying assumptions** - They tend to rely on oversimplified hypotheses, such as perfect substitutability, homogeneity of ecological functions, or full reversibility of degradation.
- **Cost-efficiency bias** - They can favour approaches that implicitly justify certain levels of destruction, provided compensation appears economically viable.
- **Geographic disparities** - They risk undervaluing the necessary investment in some regions, as restoration costs vary greatly, potentially deepening geographic inequalities in biodiversity preservation financing.

Caveat: Although this paper aims to provide both a monetary and an impact indicator, this should not be seen as an attempt to assign a definitive value to nature— something that remains impossible in any objective or absolute sense. No indicator, however scientifically robust, should be used to justify the destruction of living systems under the pretext of compensation or offsetting.

3-Valuing Nature to Save It? The Centrality of Valuation in the New Spirit of Conservation, Maechler, 2024

Objective and Scope of our Research

This study proposes a biodiversity impact assessment method based on restoration costs, applying a general approach to cover portfolios comprising a potentially high number of issuers.

We recognise that beyond the general challenges of assessing biodiversity impacts through aggregated indicators, economic valuation based on restoration costs faces fundamental limitations.

- **Ethical Concerns**

The method implies an equivalence between destruction and repair, potentially legitimising biodiversity destruction acceptability by suggesting it can be offset through restoration. Therefore, it is crucial to strictly follow the Avoid/Reduce/Restore framework, reserving compensation or restoration as a last resort. This method is primarily developed as a means of evaluating enterprise participation in biodiversity financing objectives and comparing restoration claims against companies' "nature debt".

- **Restoration Efficacy Assumptions**

The approach may rest on overly optimistic assumptions about the effectiveness of restoration projects. Biodiversity and its ecological conditions remain poorly understood, and projects deemed successful may have limited real impact - or even unintended negative consequences. Restoration plans have highly varying success rates depending on the countries[4]. Restoration costs are also affected by factors such as labour costs, market access, and power dynamics among stakeholders within countries.

While the approach proposed in this study results in a straightforward monetary indicator, such a measure on its own cannot capture the complex, multidimensional nature of biodiversity. Monetary indicators should therefore be applied only within well-defined, context-specific boundaries.

Despite its limitations, we believe this method can play a valuable role in evaluating enterprises' negative contributions to biodiversity.

4-*The cost and feasibility of marine coastal restoration,* Elisa Bayraktarov et al.2016

2 . The How – Our Methodology.

This study develops a comprehensive methodology to estimate restoration costs linked to corporate biodiversity impacts across value chains. Our approach facilitates portfolio-level assessment of biodiversity transition risks while delivering actionable indicators to guide impact reduction strategies.

The methodology employs three similar but distinct indicator-based metrics for impact monetisation, **m²-eq, PDF.m².year** and **MSA.km²**. The framework is structured along five sequential steps detailed hereafter.

Step 1 – Input Data Collection, and Geographical Allocation

Corporate production activities are geographically allocated as precisely as possible depending on data availability:

1. When data are available, production is **directly allocated to the company's physical assets and their precise geographic coordinates.** Production amounts can be estimated using proxies such as water consumption, carbon emissions or on-site workforce data.
2. Where specific asset locations are unavailable but production countries are known, allocation is made at the **sub-regional level** using national production databases.
3. When the origin of production is unknown, **global average production** data are applied.

Production is evaluated per amount of commodity produced by the company. Commodity refers to a good or a service produced by the company.

For data sources, we primarily use corporate annual reports, sustainability disclosures, and integrated reporting documents to quantify material flows. When comprehensive data are unavailable, inputs are estimated using business segment revenue allocations combined with industry-specific material intensity factors.

Our methodology is also tailored by commodity type to reflect distinct production patterns and data availability (see examples in our Case Study).

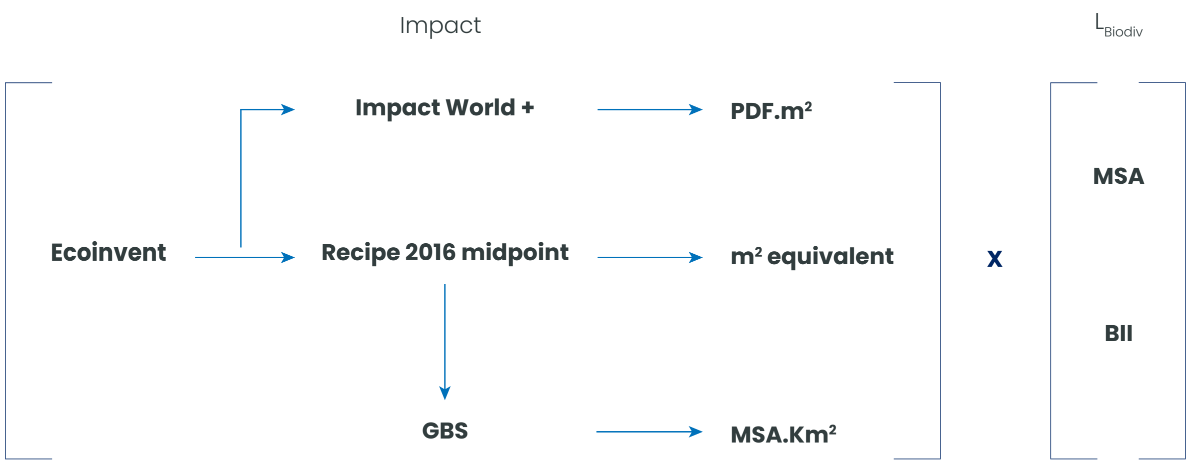
At the end of step 1, we have a mapping of the company's production per region and per commodity.

Step 2 – Biodiversity Impact Assessment at Commodity Level

For each company, the environmental impact is evaluated commodity by commodity, using life cycle assessment methodologies, with two primary impact assessment methods - **ReCiPe 2016 H** and **Impact World + v2.0.1.** In addition, a third biodiversity impact is quantified using the Global Biodiversity Score (GBS) model, through the **OpenGBS** tool developed by CDC Biodiversité.

The life cycle inventory data are sourced from the **Ecoinvent v3.10 cut-off system process** database.

Figure 1: Multi-indicator assessment framework



Source: Candriam

The result of this step is a map of the company's biodiversity impact (for the whole supply chain), by commodity and by region/ sub-region.

Step 3 – Quantification of Local Biodiversity Loss

Local biodiversity loss (L_{biodiv}) is quantified using two distinct biodiversity metrics derived from two different biodiversity models.

- The **Biodiversity Intactness Index (BII)** quantifies the relative intactness of local species composition. The index is calibrated relative to 2005 conditions and ranges from 0 (complete absence of all original species populations) to 1 (intactness equivalent to 2005 levels) and potentially exceeding 1 (indicating compositional states closer to undisturbed conditions than observed in 2005)[5] .
- **Mean Species Abundance (MSA)** is a quantitative indicator of local terrestrial biodiversity intactness. This metric is derived from empirical data documenting compositional changes in biological communities under varying anthropogenic pressure regimes. MSA values are calculated by determining the ratio of species abundance under specific pressure conditions to abundance in corresponding undisturbed reference states within individual studies, with a maximum at 1.

The biodiversity loss function is expressed as $\mathbf{L_{biodiv}(country,t)}$ where t=1 represents the temporal parameter for annualised impact assessment.

This step results in a quantification of Biodiversity Loss (L_{biodiv}) per country using two metrics (BII and MSA).

5-*Has land use pushed terrestrial biodiversity beyond the planetary boundary? A global assessment*, Tim Newbold et al. 2016

Step 4 – Assessment of Restoration Costs

Restoration costs are integrated using a layered approach reflecting geographic data availability. We primarily use direct regional restoration cost data from peer-reviewed studies and governmental databases. When direct data are lacking, we alternatively use regional extrapolation using biogeographic similarity indices and economic development indicators. In case of total lack of regional data, we use global average restoration costs adjusted for regional economic conditions.

Assessing the cost of ecosystem restoration by relying on country-level restoration expenditure data faces several methodological limitations. First, this approach requires aggregating highly heterogeneous elements, including diverse restoration methods, working conditions, and financing mechanisms, which vary significantly across countries. Consequently, substantial differences arise between countries that promote community-based restoration approaches - such as Brazil -, and those that rely on more centralised or state-led models - such as China or the United States of America. Furthermore, restoration costs are influenced by numerous factors unrelated to the ecological characteristics of the ecosystems themselves, including labour costs or inequal access to the global market.

At the end of step 4, we have an estimation of restoration cost for each country where the company operates.

Step 5 – Monetary Valuation of Biodiversity Loss

The final monetary valuation **(L_{fin})** is calculated in euros to allow integration into portfolio-level financial analysis:

Individual Company Assessment:

$$L_{fin} = \Sigma(\text{Impact} \times \text{Lbiodiv} \times \text{Regional\_Restoration\_Cost})$$

Impact: Quantified impact metric from step 2, expressed in Impact.m²

Lbiodiv: Biodiversity loss coefficient from step 3, ratio ranging from 0 to 1

Restoration cost: Unit restoration expenditure calculated in Step 4, denominated in €/m²

Formally, the terminal result L_{fin} (financial value of Biodiversity Loss caused by the company) is expressed in Impact.€ units (MSA.€ or PDF.€). Given the constraints inherent in restoration impact quantification, the simplifying assumption is adopted that 1 Impact.€ ≈ 1€.

3 . Case Study: Application to the Textile Sector.

Why Textile?

We use the textile sector as a case study to illustrate our biodiversity impact assessment methodology. Its key characteristics make it a fitting example of complex, globally distributed value chains:

- **Supply Chain Complexity:** The textile industry operates through extensive multi-tier value chains, with biodiversity impacts concentrated primarily in upstream processes (raw material production and processing), while maintaining enough transparency to support detailed analysis.
- **Data Availability:** Many textile companies exhibit high supply chain transparency, with leading firms disclosing supplier information down to Tier 4 (raw material extraction). This enables precise geographic attribution of impacts – a level of detail often lacking in other sectors.
- **Representative Impact Patterns:** Textile production involves a wide range of biodiversity pressures — such as agricultural land use change (cotton, natural fibers), chemical processing (dyeing, finishing), and manufacturing (apparel assembly)—making it representative of broader industrial impact patterns.
- **Financial Materiality:** The sector's significant environmental footprint, coupled with growing regulatory pressure and consumer awareness, creates substantial transition risks, making it highly relevant for portfolio-level biodiversity risk assessments.

Step 1 - Input Data Collection, and Geographical Allocation

We collected textile company input data using our hierarchical approach depending on data availability.

Given the practical constraints of collecting comprehensive supply chain data across portfolio companies, we focus on the most representative materials contributing to aggregate biodiversity impact.

- **For raw materials:** we prioritise commodities linked to deforestation risks: cotton, leather, natural rubber, wood-based packaging
- **For manufacturing processes:** the assessment is based on corporate reporting, typically broken down by business segment: footwear production, textile apparel production, textile accessories production

Textile equipment production data are allocated directly to corresponding company facilities, using employee headcount as a proxy for production capacity. Employee data are sourced from corporate disclosures, regulatory filings, and facility-specific reports where available.

Our sub-regional allocation methodology is tailored by commodity type, for agricultural commodities on one side and livestock product on the other, to reflect distinct production patterns and data availability.

Our multi-indicator assessment framework, displayed in Figure 1, generates biodiversity impact estimates in **three different units, MSA·km², PDF·m²·year, and m² equivalent,** with spatial resolution at the sub-regional level and material resolution by commodity type.

Our main working assumptions:

- **Leather Origin:** All leather inputs derive from bovine sources, neglecting contributions from ovine, caprine, and exotic leather sources (estimated <5% of global leather production)
- **Manufacturing Allocation:** Employee headcount serves as reliable proxy for production capacity across facilities within individual companies
- **Temporal Consistency:** Production and sourcing patterns remain sufficiently stable over the analysis timeframe (typically 1-3 years of corporate data)

Despite several limitations, this analytical step makes it possible to **identify the key geographic regions where textile sector companies exert their greatest impacts,** along with the specific commodities driving this impact in each location, as illustrated in Figure 2.

Step 2 - Biodiversity Impact Assessment at Commodity Level

The environmental impact of textile sector company production is modelled using life cycle assessment (LCA) tools applied to two distinct analytical frameworks: (1) commodities identified as having deforestation risk potential, and (2) end products categorised by business segment. This dual methodological approach accounts for the heterogeneous levels of data transparency observed across the textile supply chain.

The commodity-focused analysis takes advantage of the relatively high transparency of raw material consumption data for high-risk commodities associated with deforestation pressures. In contrast, the business-segment analysis compensates for the limited transparency of environmental data at the consumer-product level, where disaggregated production information remains insufficient for detailed impact quantification.

Commodities where impacts are assessed include the following:

- **Footwear manufacturing:** Based on assumption, it has been estimated that an average footwear item (two shoes of 400g each) was composed of 20% PU foam, 25% rubber, 25% polyester textile and 25% polypropylene textile. **Cotton, leather and natural rubber are not allocated to the shoes production but to the raw material extraction.**

- **Textile apparel manufacturing:** the textile apparel business segment was modelised using a default value for a Medium size, unisex, 140 gram athletic T-shirt , using synthetic fibers only, based on the fact that the impact of cotton production was already taken into account in the raw material consumption.

  The T-shirt is made of 75% polyester (89.25g), 15% Elastane (17.85g) and 10% polyamide (11.90g)[6]. A total manufacturing yield of 75% is used[7].

6-*Recycling of Blended Fabrics for a Circular Economy of Textiles: Separation of Cotton, Polyester, and Elastane Fibers,* Choudhury, K et al 2024
7-*Recent advances in recycling technologies for waste textile fabrics: A review,* Baloyi R. et al 2023
8-*A global study on the Life Cycle Assessment (LCA) of the modern cow leather industry,* Brugnoli 2025

- **Textile accessories manufacturing:** Textile accessories encompass caps and beanies, based on an average weight of 150 grams. Consistent with the methodology applied to all manufactured products, specific commodities with particularly high deforestation exposure, such as leather - which is prevalent in the accessories sector - are analysed separately. The textile accessory is assumed to comprise 55% polyester, 15% elastane, 10% rigid plastic (TPU type), 5% dye, and 5% foam.
- **Cotton - global average consumption:** covers the field activity for the production of 1 kg of seed-cotton for the main cotton variety known as American Cotton (Gossypium hirsutum). The production of seed cotton involves inputs of land tillage, irrigation, seeds, mineral fertilisers, pesticides, growth hormones (mepiquat chloride and nitrobenzene) and culminates in harvesting of seed-cotton.
- **Cotton from India - consumption:** covers the field activity for the production of 1kg seed-cotton in the Gujarat state in India in 2016-17. Total yield is 1'750 kg/ha. The production of seed cotton involved inputs of land tillage (ridge tillage), irrigation, seeds, mineral fertilisers (urea, ammonium phosphate), pesticides and compost.
- **Leather consumption:** Leather production has a massive impact on biodiversity due to its upstream process, which is beef cattle[8]. Data on leather impact are derived from the LCA of beef for slaughterhouse production.
- **Natural rubber consumption:** The impact of rubber production is approximated. Included are white spirit and the required transportation by rail and road, land surface occupation, and hydrocarbon emissions to air. The dataset does not include any energy consumption during the production phase.

Source: Candriam modelised in QGIS

Based on the results evaluation, **the countries experiencing the highest aggregate biodiversity impacts across the textile production value chain are India, Argentina, the United States of America, China, Vietnam and Indonesia.** This geographic distribution reflects the concentration of both raw material production (particularly cotton cultivation and livestock systems) and manufacturing processes within these major textile-producing nations.

Step 3 – Quantification of biodiversity loss

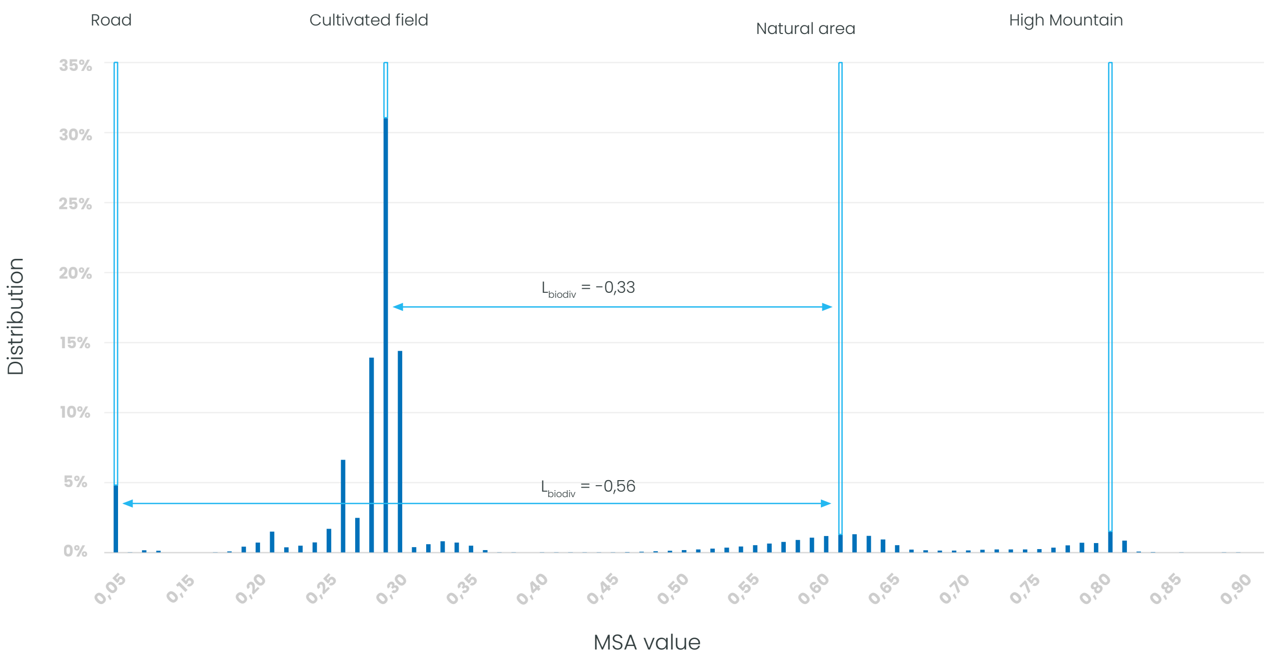
For each country where the majority of the biodiversity impact occurs, we measure the L_{Biodiv} depending on the asset type between agricultural field or factory in urban area.

Two estimations of LBiodiv are done using two indicators: the Biodiversity Intactness Index (BII) and the Mean Species Abundance (MSA).

- ### Mean species Abundance (MSA)

The spatial assessment of Mean Species Abundance (MSA) is conducted using the GLOBIO model framework. Mean Species Abundance distribution by country allows us to estimate the biodiversity impacts of land conversion by economic activity by country and then deduct L_{biodiv} coefficient.

Figure 3: Mean Species Abundance grid in India



Source: Candriam

Using the MSA metric, biodiversity loss when converting a natural area to an urban area is estimated at -0.33, while it is -0.56 from a natural area to a cultivated field.

A satellite view shows the geographical distribution of MSA in India (figure 4).

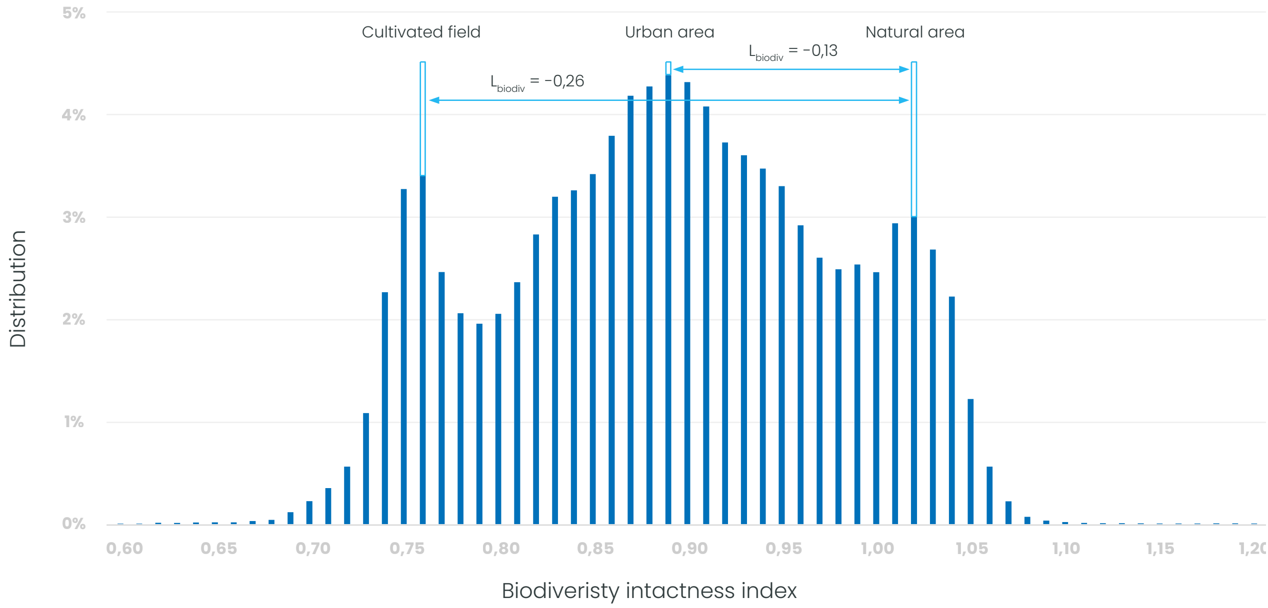
Figure 4: Mean Species Abundance distribution in India - Satellite view

Source: Candriam

- ## Biodiversity intactness index (BII)

Similarly, the distribution of Biodiversity Intactness by country allows us to estimate the biodiversity impacts of land conversion by economic activities, by country, and then to deduce the L_{biodiv} coefficient.

Figure 5: Biodiversity intactness index cell repartition in India (BII metric)



Source: Candriam

In this example, we see that converting a natural area into an urban area results in an average biodiversity loss of -0.13, while the loss is -0.26 when converting a natural area into a cultivated field.

- **Results**

L_{biodiv} is quantified based on country-specific Biodiversity Intactness Index (BII) and Mean Species Abundance (MSA) values. The associated uncertainties in these measurements are primarily attributed to spatial heterogeneity in land use patterns within individual countries, which results in variable biodiversity loss estimates.

Table 1: L_{Biodiv} for most impacted countries (sample companies)

Country	L_{biodiv} BII	L_{biodiv} MSA
India	-0.2 ± 0.1	-0.45 ± 0.12
United States of America	-0.29 ± 0.075	-0.53 ± 0.02
China	-0.3 ± 0.1	-0.61 ± 0.035
Vietnam	-0.25 ± 0.05	-0.35 ± 0.05
Brazil	-0.2 ± 0.1	-0.45 ± 0.05
Indonesia	-0.25 ± 0.05	-0.36 ± 0.05
Argentina	-0.25 ± 0.05	-0.56 ± 0.02

Source: Candriam

Step 4 - Assessment of Restoration Costs

Table 2 summarises our estimations of restoration costs in the various regions, used as input data in our model. Details on restoration policies of the individual countries can be found in the Appendix.

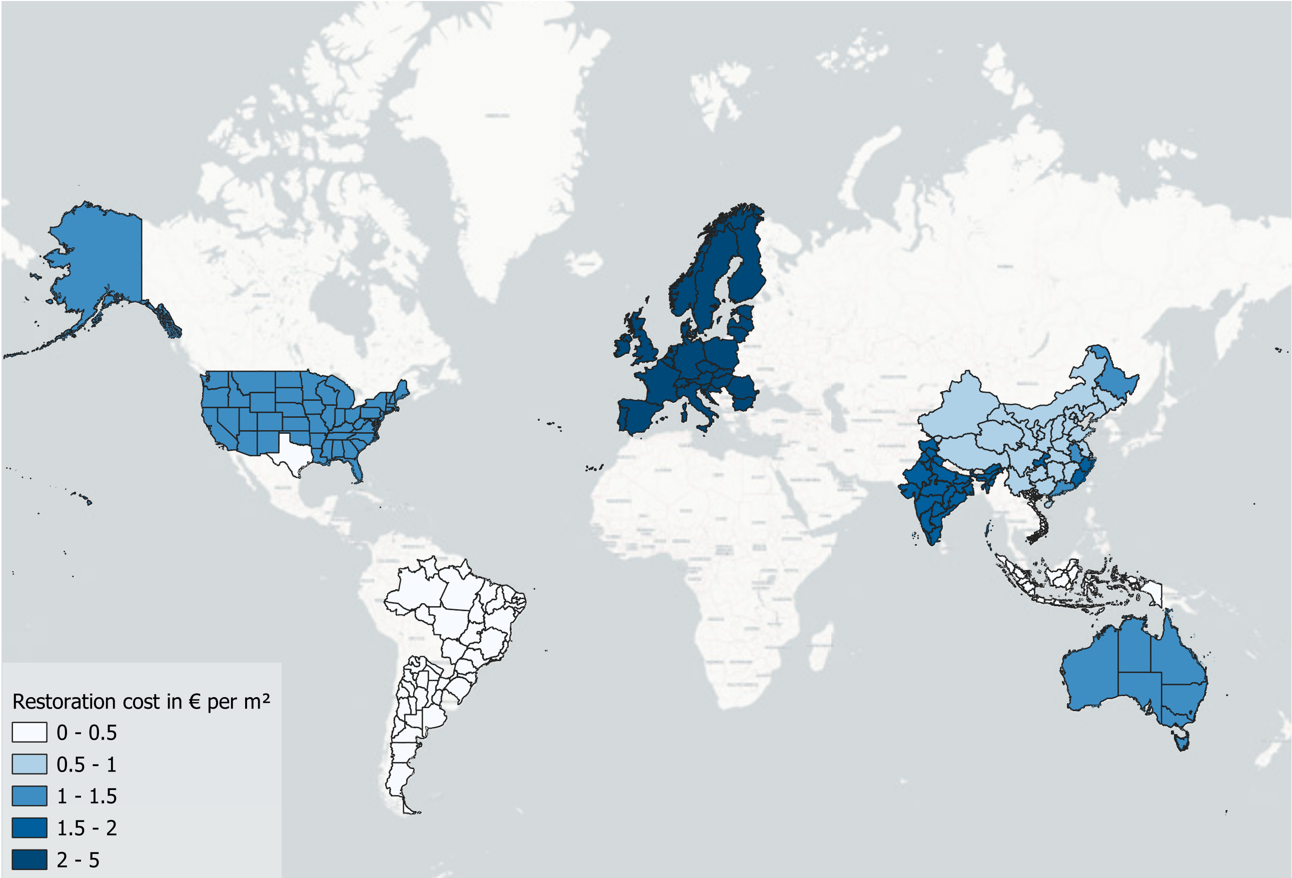
Table 2: Restoration costs estimates (Candriam)

Country / Region	Restoration cost estimates
Australia	€ 1.2 /m²
U.S.A.	€ 1.15 /m²
China	€ [1-2] /m²
Brazil	€ 0.085 /m²
Argentina	€ 0.03 /m²
Vietnam	€ 0.3 /m²
India	€ 1.6 /m²
Indonesia	€ 0.35 /m²
Europe	€ 5 / m²

Source: Candriam

A marked variation is observed between countries regarding **the potential restoration cost per square meter, ranging from $0.03 to $5** depending on the region. This discrepancy is primarily attributed to differences in labour costs, which can account for up to 50% of total restoration expenses. Furthermore, restoration projects often lack adherence to standardised strategies, leading to significant cost variability between afforestation initiatives and conservation efforts. While we report indicative prices based on country-level feedback and case studies, it is important to note that the vast majority of impact assessment authors agree that these amounts are generally insufficient to ensure effective ecological restoration. However, no consensus has yet been reached on appropriate cost benchmarks.

Figure 6: Restoration cost map for sample companies



Source: Candriam modelised in QGIS

The figures presented in our table appear to be underestimated in comparison with other studies.

For example, Potsch et al. report a cost of **€8.7 per m²** for the restoration of a coal mine in Germany[9].

Brander et al. (2024) conducted a study estimating the economic values of ecosystem services, ranging **from 0.06 to 7.7 €/m²/year[10].**

9-*Biodiversity value-at-risk: Challenges and opportunities in quantification*, Potsch et al. 2024
10-*Economic values for ecosystem services: A global synthesis and way forward*, Brander et al. 2024

Step 5 – Monetary Valuation of Biodiversity Loss

The final step in calculating restoration costs for biodiversity impacts consists in integrating all previously collected data to estimate the cost of a hypothetical restoration scenario, in which a textile company seeks to restore biodiversity to the full extent of the deterioration caused, factoring in the geographic location of each impact. As shown in Table 3, this exercise reveals a significant effect on the company's revenue.

$$L_{fin} = \Sigma Lbiodiv(country) \times I(x,y) \times \text{Restoration cost}(region)$$

Table 3: L_{fin} values for a selection of corporates within the Textile sector

Company	L_{fin}	% Revenues ($-L_{fin}$/revenue)
Company A	€688 Mn ±372 Mn	-2.8% ±1.5%
Company B	€34 Mn ±16 Mn	-0.8% ±0.4%
Company C	€150 Mn ±67 Mn	-1.7% ±0.8%
Company D	€1,782 Mn ±574 Mn	-4.5% ±1.4%
Company E	€42 Mn ± 35 Mn	-0.5% ±0.4%
Sample average	€539 Mn ±213 Mn	-1.9% ±0.9%

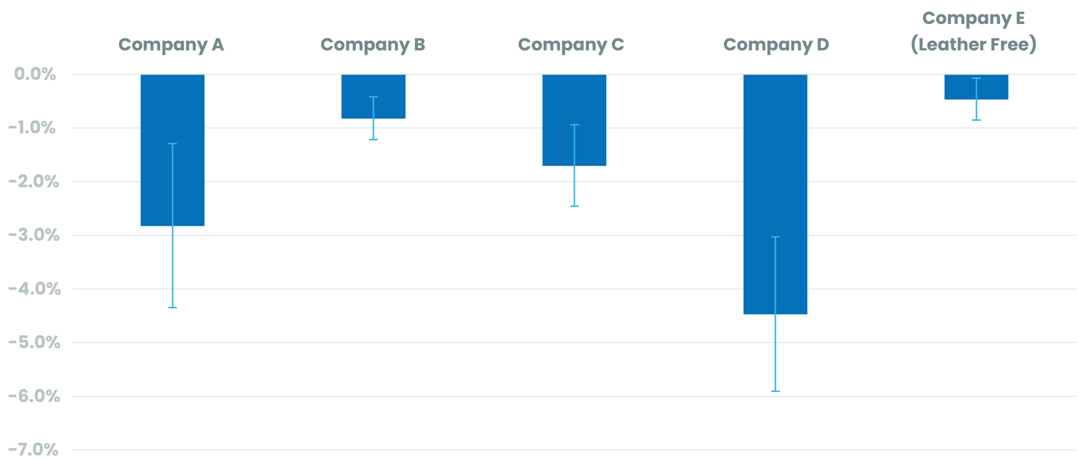
Source: Candriam

Results show significant disparities among companies within the textile sector, some companies showing higher transparency and commitment to sustainability; for example, one company committed to leather free production seems less impacted by a potential transition risk.

Overall, the potential cost of restoration for companies in the chosen sample is high, representing on average more than **2% of annual revenues** (and more than 4% for company D). In the P&L, this could represent for some companies a **46% decrease in net income.** This result is obtained by considering the biodiversity loss compensation as an additional operating expense, while other variables remain unchanged, through the formula:

$$\text{Impact on net income} = -\text{Biodiversity cost} \times (1 - \text{effective tax rate})$$

Figure 7: Average expected revenue loss in a comprehensive compensation scenario



Source: Candriam

In contrast, a leather-free textile company with a sustainability focus, such as **Company E, would bear a restoration cost equivalent to 0.5% of its annual revenue.** If considered as an additional operating expense, **this cost would negatively impact the company's net income by 1.8%.** This example illustrates the **financial advantage of prioritising the prevention of negative impacts over compensating for them.**

Results

4 . Results and Implementation.

Quantifying Potential Transition Risks Linked to Biodiversity Restoration

Who should pay how much, and to whom?

The analysis reveals that, **on average, companies in the textile sector could experience a 2% cut in revenue under a biodiversity transition scenario in which all the company's negative biodiversity impacts need to be restored.** However, this figure masks significant disparities among players within the sector, largely explained by differences in raw material consumption—notably leather and cotton, which represent a substantial share of the overall biodiversity impact.

This method has several limitations, notably in quantifying impacts, assessing data on local biodiversity loss, evaluating restoration feasibility, and attributing monetary value. Therefore, the resulting monetary estimate should not serve as a direct measure of impact, but rather as **a way to relate biodiversity pressures to corporate revenues.** At present, the likelihood of a transition risk scenario in which companies are required to compensate fully or partially for their residual biodiversity impacts remains low.

Despite these limitations, **this method advances the integration of biodiversity considerations into transition risk assessment strategies.** It provides an impact measurement framework that accounts for the geographic distribution of corporate assets, associated production, and supply chains, considering various levels of issuer transparency.

20-The SFDR DNSH principle refers to the consideration of Principal Adverse Impacts (PAI).

Implementation into Candriam Strategies

Our tool will be first **rolled out within our sustainable fund range, with a particular emphasis on our thematic strategies such as climate, circular economy, water and nutrition** - areas where biodiversity risks are central to achieving our sustainability mandate.

In a broader sense, by demonstrating the influence of stock selection strategies in reducing environmental footprints, our methodology empowers portfolio managers to mitigate biodiversity impact beyond conventional sectoral reallocation approaches.

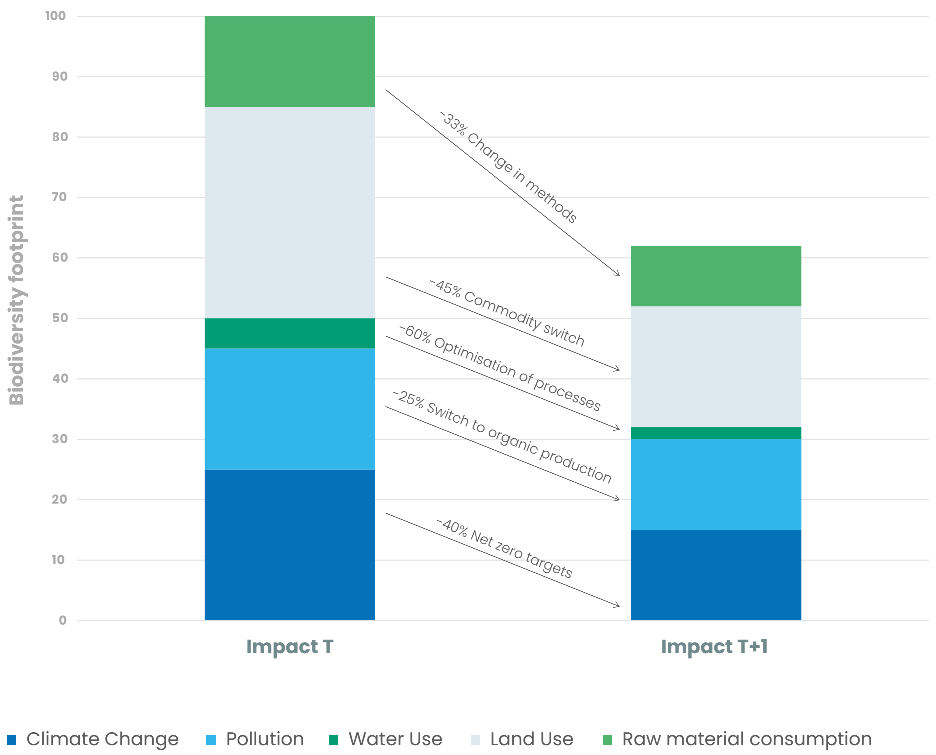
A lever for Outcome-oriented Shareholder Engagement

Our methodology supports the formulation of quantified biodiversity targets and trajectories that will enrich our shareholder engagement efforts. Equipped with insights on actionable levers for impact reduction, we will be able to **develop more outcome-oriented shareholder engagement on biodiversity,** a key lever to further accelerate biodiversity action.

Disclosing impact trajectories, quantitative targets, and specific action mechanisms at the portfolio level will also advance transparency in biodiversity disclosures.

Figure 8 shows an example of a potential biodiversity trajectory developed at the issuer or portfolio level, in the context of building a biodiversity strategy.

Figure 8: Example of a potential biodiversity trajectory built for a portfolio, based on our methodology



Source: Candriam

Conclusion: A Further Step Towards the Integration of Biodiversity in Investments.

We believe our method marks **an important step in more precisely integrating biodiversity considerations into investment portfolios.**

We believe that the financial quantification of biodiversity-related risks will soon become essential for anticipating emerging transition risks and for safeguarding our clients' investments. Our priority is thus to **initiate the integration of biodiversity-related indicators into asset managers' analytical framework and engagement practices with investee companies.** Our approach will be instrumental in setting quantitative biodiversity targets and defining nature-related trajectories, contributing to the development of comprehensive nature strategies that go beyond the sole focus on climate issues.

Besides, it underscores the **critical role of biodiversity in transition risk assessments and introduces the concept of a company's annual "ecological debt".**

While our initiative is not an end point, it is an important milestone in a process that we will continue to refine, guided by scientific progress and evolving reporting standards.

Appendix.

Restoration Policies Country Insights

Australia

Australia has created the world's first legislated national voluntary biodiversity market through the **Nature Repair Act 2023.** The market, administered by the Clean Energy Regulator, became operational in 2024 with sophisticated design features including standardised assessment instruments, independent oversight, and public transparency registers.

Australia's restoration sector is undergoing major structural reform with the Department of Climate Change, Energy, the Environment and Water (DCCEEW) leading national coordination. The government is establishing two new agencies in 2024, Environment Protection Australia (EPA), as an independent national regulator, and Environment Information Australia (EIA), for authoritative data provision.

Reside et al. (2024) have established that maximizing threatened species recovery in Australia varied from 0 to 12,626$ ha depending on the species. In the upper assumption, that's equivalent to **1.26 $/m² ≈ 1.2€** , which is in line with restoration cost in the US and China. This upper assumption is retained because it corresponds mainly to land use by, and for, human activities.

United States of America

The US are often considered as the country of emergence of biodiversity offset policy and practice, with the adoption in 1969 of the **National Environmental Protection Act.**

The US demonstrate strong multi-agency coordination with EPA, NOAA, US Fish and Wildlife Service, USDA Forest Service, and Army Corps of Engineers leading restoration efforts. The Estuary Habitat Restoration Council coordinates five federal agencies, while *the America the Beautiful* Initiative manages the implementation of 30x30 conservation.

The US operate a highly mature restoration market valued at $6.5 billion for mitigation banking alone, projected to reach $16.1 billion by 2030 with a 14.7% annual growth. Over 1,200 approved mitigation banks operate nationwide with 750,000 credits approved so far. We focus here on Habitat conservation plans (HCPs) to assess the restoration cost in the US.

HCPs are planning documents designed to accommodate economic development while authorizing the limited and unintentional take of listed species, with plans designed to provide long-term benefits to species and their habitats. Authorised under Section 10 of the federal Endangered Species Act (ESA), HCPs allow for limited "take" of listed species in exchange for certain measures to protect and restore habitat

Through HCPs mechanism, conservation fees are designed to internalise the costs of biodiversity impacts by requiring developers to contribute financially to the conservation, restoration, and management of habitats and species affected by their activities. Under the Endangered Species Act (ESA), any activity that might result in the incidental take of a listed species requires an Incidental Take Permit (ITP), which must be supported by a Habitat Conservation Plan (HCP).

An HCP outlines: Anticipated impacts on species/habitats, Measures to avoid, minimise, and mitigate those impacts, Long-term conservation strategies and Funding mechanisms, including impact fees.

HCP fees are charged to landowners, developers, or municipalities to offset their share of the conservation costs associated with impacting habitat covered by the HCP.

HCP fees=Land Acquisition cost+Restoration cost+administration cost+monitoring cost+Endowment contribution

Restoration costs vary a lot depending on the state, ranging from $2,000 per acre (€0.5 per m²) in Texas to $8,000 per acre (€1.8 per m²) in California. The cost retained at country level is €1.15 per m².

The efficiency of restoration programs in the US is criticised. Sonter et al 2019 established that many compensation programs in California have failed to reach a positive outcome and may have in some cases prevented biodiversity gains.

China

Since the enactment of the first **Forestry Law** in 1998, the Chinese government has implemented numerous projects within the framework of its ecological restoration policy. China currently operates several biodiversity-related payment systems, with compensation for contemporary development impacts representing the closest approximation to ecological compensation mechanisms. This framework encompasses various compensation instruments, including the Forestry Vegetation Restoration Fee (FVRF), Grassland Vegetation Restoration Fee (GVRF), and Wetland Restoration Fee (WRF). Currently, compensation projects are limited to development activities resulting in land artificialization and do not include pollution or other operational impacts.

Unlike the compensatory schemes implemented in the United States and Australia, Chinese developers are not required to negotiate prices directly with compensation providers. Compensation fees paid to the government are not calculated on a case-by-case basis unless developers elect to implement compensation measures independently. Consequently, developers remit standardised fees to the government based on initial Environmental Impact Assessments (EIA), with provisions for reimbursement if final impacts prove lower than projected. The government assumes responsibility for financing compensation projects.

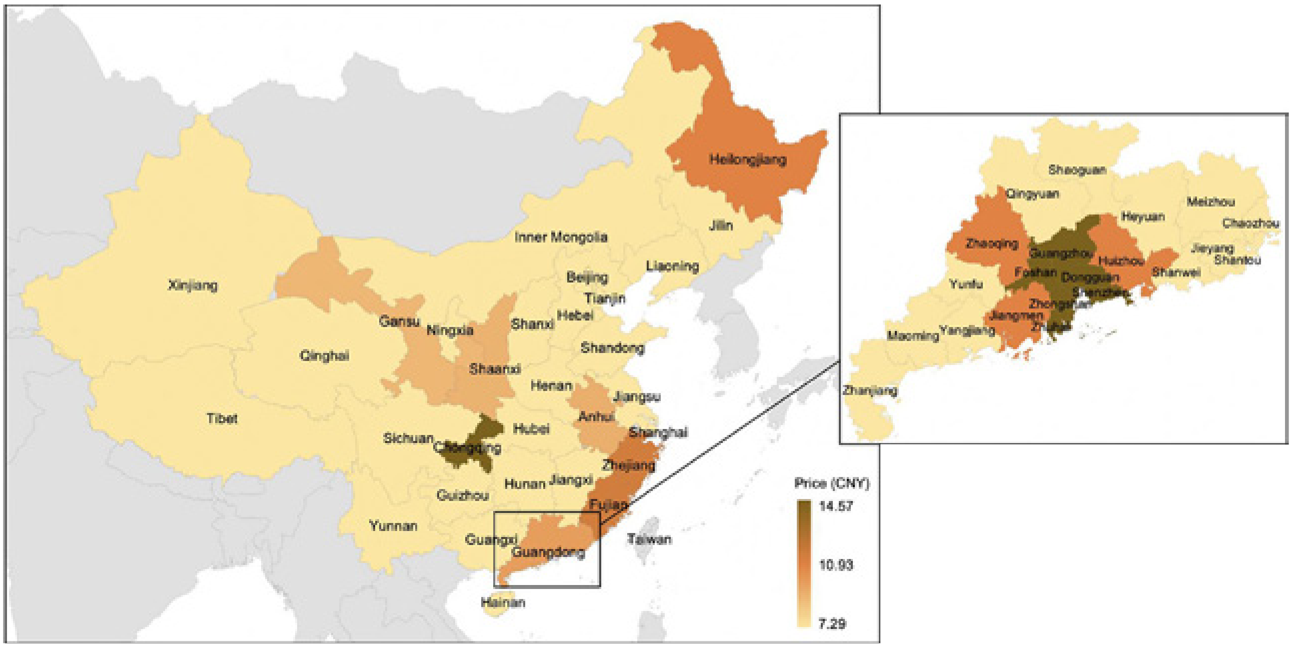
Within China's compensation system, current policies lack sufficient data to draw definitive conclusions regarding outcomes and implementation strategies for achieving compensation objectives. Accordingly, efficacy studies focus predominantly on the FVRF, the oldest system, revealing substantial regional disparities across administrative provinces.

Compensation rates range from a maximum of CNY 16/m² in Chongqing Province to a minimum of CNY 7.29/m², corresponding to an interval of €1-2 per restored square meter. Research indicates that these investment levels are substantially undervalued, failing to reflect the financial requirements for effective restoration.

Several studies have identified significant deficiencies in Chinese compensation projects, particularly the notable absence of quantitative indicators[11] (Gao et al., 2023). Furthermore, China's compensation strategy focuses primarily on habitat areas without consideration of habitat quality or associated ecological functions.

Additionally, China adopts a weak substitutability principle that allows the replacement of one natural resource with another, thereby allowing compensation for wetland impacts through forest plantation.

Figure 8: Example of a potential biodiversity trajectory built for a portfolio, based on our methodology



11-*Analyzing the outcomes of China's ecological compensation scheme for development-related biodiversity loss* Gao et al, 2023

Brazil

Brazil operates through a decentralised yet coordinated system with the Ministry of Environment and Climate Change (MMA) leading policy through the newly launched Planaveg 2.0, targeting the restoration of 12 million hectares of degraded land by 2030. The Brazilian Institute of Environment (IBAMA) manages enforcement with a $241 million annual budget, while ICMBio oversees restoration within 34 million hectares of protected areas.

Brazil has established an ecological compensation policy framework through the **Native Vegetation Protection Law,** commonly known as the **New Forest Code**[12]**.** This legislation defines regulations governing the maintenance of Permanent Preservation Areas (Áreas de Preservação Permanente - APPs) and legal reserves on properties that must maintain native vegetation coverage ranging from 20% to 80%, depending on the biome. Properties exhibiting native vegetation deficits must implement compensatory measures on ecologically equivalent sites (Declaratory Action of Constitutionality 42 – Judgment, February 28, 2018). Recent legislative developments have demonstrated inconsistency in establishing clear ecological equivalence frameworks, with systematic ecological equivalence concepts being introduced in 2023[13] but subsequently removed in 2024[14].

Brazil has implemented the **National Plan for Native Vegetation Recovery** (Plano Nacional de Recuperação da Vegetação Nativa - PLANAVEG), which establishes an objective to restore 12 million hectares by 2030. Additionally, Brazil operates a tax redistribution system known as the Ecological ICMS (Imposto sobre Circulação de Mercadorias e Serviços Ecológico), which redistributes taxes at the local level based on value-added indicators for environmental conservation. Several states incorporate biodiversity conservation indicators, including protected area metrics, within these redistribution criteria.

Cost assessments of restoration projects in Brazil reveal significantly lower expenses compared to international standards. Systematic analysis indicates restoration costs of approximately **€850 per hectare** (equivalent to **€0.085 per m²**), substantially lower than comparable international restoration programs[15]. This is explained by Brazil's preferred restoration approach, which relies on actions led by local communities.

12-Law No. 12,651 ; May 25, 2012
13-Lopes et al., 2023
14-Lopes et al., 2024
15-Brancalion et al., 2019

Argentina

Argentina's restoration sector experienced major disruption in December 2023 when President Javier Milei dissolved the Ministry of Environment and Sustainable Development (MAyDS), downgrading environmental functions to sub-secretary level under the Secretary of Sport, Tourism and Environment. The National Parks Administration (APN) continues as a decentralised agency, while COFEMA (Federal Council for the Environment) maintains federal-provincial coordination, though with reduced national-level support.

Despite political backlash, initiatives remain. The **ForestAR 2030 platform** targets 2 million hectares of reforestation, including 300,000 hectares of native forest restoration. However, enforcement remains challenging while illegal deforestation continued with 722,782 hectares lost in Argentine Dry Chaco between 2008 and 2017[16].

Argentina's restorations funding relies heavily on international funding through World bank programs and the UNDP BIOFIN initiative.

Argentina shows relatively low costs for restoration projects, with **Atlantic Forest restoration at €54-93 per hectare** based on Fundación Vida Silvestre projects, **native forest/Chaco ecosystem restoration at €30-50 per hectare** for large-scale projects, and **Pampas grasslands ranging from €50-200 per hectare** for natural regeneration to €200-500 per hectare for active restoration with seeding. **Retained value is €0.03 per m².** Similarly to Brazil, though with less political commitment, the cost of restoration in Argentina remains very low due to a restoration approach that prioritises community-led and passive interventions, combined with underinvestment by the state and the absence of performance indicators.

16-M. Vallejos et al. 2021

Vietnam

Vietnam operates through a highly centralised approach with the Ministry of Agriculture and Rural Development (MARD) as the primary authority for forest restoration, working alongside the Ministry of Natural Resources and Environment (MONRE). The Vietnam Administration of Forestry (VNFOREST) manages forest resources while Provincial Forest Protection and Development Funds coordinate the world's first national Payment for Forest Ecosystem Services (PFES) program.

Vietnam has not yet established a fully developed and standardised biodiversity compensation or offset system comparable to those implemented in countries such as Australia or the United States. However, recent legislative developments indicate that the country is progressively advancing toward formalizing biodiversity offsets within its environmental policy framework. The **2020 Law on Environmental Protection** introduced provisions for "compensation for biodiversity losses" and "restoration obligations" for developers whose activities cause biodiversity degradation. Nevertheless, this regulatory framework remains under development, precluding the establishment of standardised restoration costs based on existing projects and implementation mechanisms.

According to assessments conducted by the International Rice Research Institute, Vietnam requires $15.583 billion for ecosystem restoration by 2050, covering approximately 4.4 million hectares. This corresponds to **$3,541 per hectare,** equivalent to **€0.3 per m²** of required restoration investment.

India

Development projects involving deforestation, officially designated as "diversion of forest land for non-forest purposes," are regulated under India's **Forest Conservation Act** (FCA) of 1980. This legislation establishes the regulatory foundation for compensatory afforestation, representing a national-level offsetting mechanism. The FCA mandates that developers (designated as "user agencies") remit various compensatory levies as a precondition for project approval (termed "forest clearance"). These levies encompass costs for compensatory afforestation, additional compensatory afforestation, penal compensatory afforestation, and catchment area treatment[17].

The Indian compensatory afforestation policy has received significant criticism from researchers[18] due to its failure to account for ecosystem-specific requirements, employing standardised afforestation strategies such as planting 1,000 trees per hectare regardless of ecological context. Additionally, the policy does not incorporate local community participation in implementation processes.

Cost assessment analysis has been conducted by Narain and Maron (2018), examining economic implications and perverse incentives within India's biodiversity offsetting framework. Current restoration cost in India are established to be around **€1.6 per m².**

17-MOEF, 2004; Sridhar, 2011
18-Tambe et al., 2022

Indonesia

Indonesia underwent institutional restructuring in October 2024, splitting the Ministry of Environment and Forestry into separate entities: the Ministry of Forestry under Raja Juli Antoni, and a new Ministry of Environment. This split creates specialised focus areas, with the Ministry of Forestry specifically handling forest restoration programs, while a newly established Environmental Control Agency (BPLH) manages broader environmental control and climate change. The Peatland and Mangrove Restoration Agency (BRGM) continues overseeing restoration of 1.2 million hectares of peatlands and 600,000 hectares of mangroves, though achieving only 25% of peatland targets and 6% of mangrove targets by 2021.

Indonesia operates a mature restoration market, leveraging its position in global voluntary carbon markets. The government plans to raise **$65 billion by 2028** from forest and peatland restoration carbon credits, with East Kalimantan committing to reduce 86.3 mtCO2e over 2020-2024 at $5/tCO2e. The **Roundtable on Sustainable Palm Oil** (RSPO) also plays a role in biodiversity conservation within the country with 2.12 million hectares certified (13% of total palm oil area) by 2019, complemented by the government-backed Indonesian Sustainable Palm Oil (ISPO) system.

In this context, Indonesia presents a comprehensive restoration strategy with restoration costs considered high in this area. **Restoration cost for mangroves can represent €0.35 per m²** including infrastructure and community training[19]. This is in line with average restoration value in the South-East Asia region. In addition, forecast restoration scenarios estimate the restoration cost of peatlands and mangroves at **€0.43-0.65 per m²,** these values could be integrated in future work to assess transition risk in the future.

19-Van Zanten et al. 2025

Europe

At the European Union level, the **Biodiversity Strategy 2030** establishes a comprehensive financial framework requiring **€20 billion annually for biodiversity restoration initiatives**[20]. This program operates under the regulatory framework of the **Nature Restoration Law** of 18 August 2024, providing the necessary legal foundation for ecosystem restoration across member states.

The Nature Restoration Law establishes quantitative restoration targets whereby Member States must implement restoration measures across at least 20% of the EU's terrestrial areas and 20% of marine areas by 2030. The legislation adopts a progressive approach, extending these requirements to encompass all degraded ecosystems requiring restoration by 2050.

The financial architecture supporting restoration activities relies on agricultural policy mechanisms. The Common Agricultural Policy constitutes the predominant funding source, contributing €64.4 billion (on the €112 billion required between 2021 and 2027) through the European Agricultural Guarantee Fund **EAGF** (€37.9 billion) and the European Agricultural Fund for Rural Development **EAFRD** (€26.5 billion).

The assessment of European restoration effectiveness faces substantial standardization deficiencies, including the absence of unified monitoring protocols across restoration projects and considerable variation in field methodologies and measurement approaches. While the EU Biodiversity Strategy Dashboard incorporates 16 targets with corresponding indicators, the Nature Restoration Law proposes six specific indicators for forest restoration assessment. **Geographic bias remains pronounced in monitoring approaches, with Germany and Spain accounting for 40% of efficiency studies** - while temporal data gaps limit the availability of long-term datasets for most restoration sites.

Restoration costs demonstrate significant variation across ecosystem types, with Terrestrial ecosystems around €2-3 per m², Wetland systems around €2-4 per m², and Marine ecosystems around €8-160 per m². With an allocation based on effective restoration activities (70% for terrestrial, 20% for wetlands and 10% for marine areas), **the estimated restoration cost for Europe** in the study **is €5 per m².**

Countries close to the European Union and that present similar biodiversity strategies and similar socio-economic conditions **are also estimated with a restoration cost of €5 per m²** for the study (United Kingdom and Norway for example).

20-IEEP, 2022

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