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Assessing economic exposure to nature-related risks

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Assessing economic exposure to nature-related risks

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Résumé
La dégradation accélérée de la biodiversité expose les activités économiques et financières à des risques systémiques comparables à ceux liés au changement climatique.

Nous proposons une méthode qui permet d'évaluer l'exposition socio-économique aussi bien aux risques physiques que de transitions de la plupart des pays du monde en recourant à des bases de données ouvertes et gratuites. Un exemple d'application d'évaluation de l'exposition de l'économie de l'Afrique du Sud est fourni. Cette méthode est perfectible. Elle ne suffit pas à réaliser des notations de risque pays ou des prises de décision d'allocation de capitaux ou de financement, mais elle fournit une évaluation préliminaire qui peut guider des diligences plus poussées et des prises de décisions plus éclairées de financement.

Elle peut aider un large éventail de parties prenantes, de décideurs publics, de régulateurs de marché, d'entreprises et d'institutions financières à atteindre les objectifs d'amélioration du suivi, de l'évaluation et de la divulgation transparente des risques, des dépendances et des impacts sur la biodiversité des acteurs économiques. Elle peut ainsi contribuer à la réalisation de la cible 15 du Cadre mondial pour la biodiversité de Kunming-Montréal, ou à la mise en œuvre des recommandations de la Task-Force on Nature-related Financial Disclosure (TNFD) ou de la directive européenne relative à l'information sur le développement durable des entreprises (CSRD).

Abstract
The accelerated degradation of biodiversity exposes economic and financial activities to systemic risks comparable to those associated with climate change.

We propose a method for assessing the socio-economic exposure of most of the world's countries to both physical and transition risks, using free, open databases. An example of application to assess the exposure of the South African economy is provided. There is room for improvement in this method. It is not sufficient for country risk ratings or capital allocation or financing decisions, but it provides a preliminary assessment that can guide further due diligence and more informed financing decisions.

It can help a wide range of stakeholders, public decision-makers, market regulators, companies and financial institutions to meet the objectives of improving the monitoring, evaluation and transparent disclosure of the risks, dependencies and impacts on biodiversity of economic players. In this way, it can contribute to achieving Target 15 of the Kunming-Montreal Global Biodiversity Framework, or to implementing the recommendations of the Task-Force on Nature-related Financial Disclosure (TNFD) or the European Corporate Sustainability Reporting Directive (CSRD).

Keywords
Nature-related risk, Biodiversity, Ecosystem service, Physical risk, Transition Risk, GBF Target 15, TNFD, CSRD

JEL classifications Q01 (Sustainable Development), Q56 (Environment and Development • Environment and Trade • Sustainability • Environmental Accounts and Accounting • Environmental Equity • Population Growth), Q57 (Ecological Economics: Ecosystem Services • Biodiversity Conservation • Bioeconomics • Industrial Ecology)

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1. INTRODUCTION

Human activities are accelerating biodiversity loss at an unprecedented rate, leading to what scientists call the "sixth mass extinction". The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) reports that one million species face extinction, and vast portions of terrestrial and marine ecosystems have been altered. Key drivers of this crisis include land use changes, resource extraction, climate change, pollution, and invasive species, exacerbated by socio-economic factors. As ecosystems degrade, essential services—such as food, water, and climate regulation— diminish, threatening economic stability.

Biodiversity loss poses systemic financial risks comparable to climate change. While climate change dominates discussions on human-environment interactions, biodiversity loss may have equally severe consequences, often amplifying climate impacts (IPBES & IPCC, 2021). The World Economic Forum ranks biodiversity loss and ecosystem collapse as the third most significant global threat in the next decade (WEF, 2024). Moreover, biodiversity-related financial risks may materialize faster than climate risks, increasing the urgency for systemic valuation of nature in financial decision-making.

Global biodiversity governance began with the 1992 Rio Earth Summit and the Convention on Biological Diversity (CBD). Despite initiatives like the Aichi Targets, progress has been slow. The 2022 Kunming-Montreal Global Biodiversity Framework introduced 23 new targets to halt biodiversity loss by 2030, urging governments and financial sectors to integrate biodiversity considerations into policies and investments.

The term "nature" is used in this document to encompass the risks associated with the degradation of biotic and abiotic elements of biodiversity, and therefore the role of biodiversity in mitigating climate change.

Nature risks are categorized as **physical risks**, which stem from ecosystem service declines (e.g. reduced pollination affecting agriculture), and **transition risks**, arising from policy changes or shifting market dynamics. Sectors indirectly exposed through supply chains may face compounded risks. Assessing these risks remains complex but is crucial for sustainable economic stability.

This document presents a detailed methodology to assess socio-economic exposure to nature-related risks (NNRs) worldwide. The approach serves as a screening tool to identify the main potential physical and transition risks, drawing on publicly available data sources. It is not intended for direct decision-making, but rather to guide efforts towards gathering data that are more accurate and engaging local stakeholders to validate the main risks identified through this approach.

The NRR assessment methodology can contribute to the major issues detailed in Table 1, and can therefore be used by a wide range of economic actors working with national or sectoral data.

This methodology builds upon two previous AFD research:

Hadji-Lazaro et al. (2024) on the biodiversity related-financial risks of French financial institutions. We used the same methodological framework and background.

Hadji-Lazaro et al. (2025) on the risks and opportunities related to nature in South Africa. We replicated parts of the methodology to analyze the dependencies and impacts of economic sectors worldwide on nature and constructed two additional indicators on the state of ecosystem services and the contribution of sectors to species extinction risk.

WHAT IS NRR ASSESSMENT CONTRIBUTION?	FOR WHICH ACTOR?	WHY? (examples)
Targeting public policies	Ministry of the Environment / Biodiversity Agency	Target the most effective conservation policies according to the pressures exerted by sectors on biodiversity.
	Ministry of Finance	Locate sectors and regions where biodiversity loss could affect GDP, employment and taxation. Identify the economic and budgetary impacts (both in terms of lost revenue and increased expenditure) of conservation or ecological transition policies.
	Financial supervisors and regulators	Identify regulatory reporting levers based on existing quantitative tools.
Mapping nature-related risks for better protection	Private industrial	Anticipate supply chain disruptions due to ecosystem degradation. Assess the impact of new regulations. Avoid reputational risks and innovate to meet environmental standards.
	Central banks and financial institutions	Identify the financial institutions and assets most at risk from the disruption caused by the degradation of ecosystem services. Anticipate the prudential policies required in the face of new environmental policies, sustainability innovations and changing consumer preferences.
	States	Prevent socio-economic instabilities linked to biodiversity degradation and associated international regulations.
Meeting regulatory challenges	Private industrial	Meeting ESG reporting obligations to identify impact and dependencies on nature.
	Financial institutions	Improve the ability of financial institutions to identify and declare their financial risks, in particular to meet the demands of financial regulators
Meeting international commitments	States	Targeting sectoral public policies to reduce anthropogenic pressures on the GBF, identify critical ecosystem services to maintain and tackle GBF's targets.
Financing the ecological transition	Commercial banks/private equity fund	Map the investments most exposed to nature-related risks, to redirect portfolios towards resilient assets. Identify investment opportunities in innovative companies aligned with sustainability or transition objectives.
	Development banks	Target the most vulnerable economic players to better support them in their transition, and redirect subsidy, technical assistance or capital flows accordingly.

WHAT IS NRR ASSESSMENT CONTRIBUTION?	FOR WHICH ACTOR?	WHY? (examples)
Create synergies between the various actors	Multi-actor	Find the best public policy trade-offs.

Table 1. The main objectives of NRR assessment methodology and its users.

2. EXPOSURE TO PHYSICAL RISKS

This section outlines a methodological approach **to identify the economic sectors most exposed to physical risks, as well as their relative weight in key socio-economic aggregates at the national level.**

Physical risks arise when the degradation of nature and the loss of ecosystem services affect economic activity. These risks may be chronic or acute, and their effects can manifest at local or global scales. The approach presented here estimates countries' socio-economic exposure to such risks by analyzing the dependence of economic sectors on ecosystem services.

Indeed, economic sectors rely extensively on ecosystem services—defined as the ecological characteristics, functions, or processes that directly or indirectly support human well-being (Costanza et al., 1997; Millennium Ecosystem Assessment, 2005). Anthropogenic or non-anthropogenic degradation of these services can consequently weaken the capacity of economic sectors to generate goods and services (i.e. physical shocks). Economic sectors are therefore likely to be exposed to nature-related physical risks. Indeed, if a sector production process is highly dependent on an ecosystem service, and if this service is not delivered in sufficient quantities by ecosystems, the sector could be threatened. However, reducing exposure does not have to mean reducing dependence. If some processes artificialization can happen sometimes, at the end of the day, the economy is embedded in nature (Dasgupta, 2021) and some dependencies on nature cannot be avoided at affordable economic costs. Rather, the challenge is to strengthen ecosystem resilience and anticipate the potential economic disruption associated with their degradation.

Sometimes sectors exposed to physical shocks can make a significant contribution to a country's main macroeconomic aggregates, exposing it directly to NRRs.

The methodology to address physical risks can be broken down into three main stages as follows (Figure 1):

1-/ We identify globally a set of exposed sectors to nature-related physical risks based on their dependence on ecosystem services (Section 2.1);

2-/ We compute the share of main socio-economic indicators generated by these exposed sectors to evaluate countries' exposure to physical shocks (Section 2.2);

3-/ We add qualitative information about the capacity of ecosystems to provide ecosystem services on a national scale (Section 2.3).

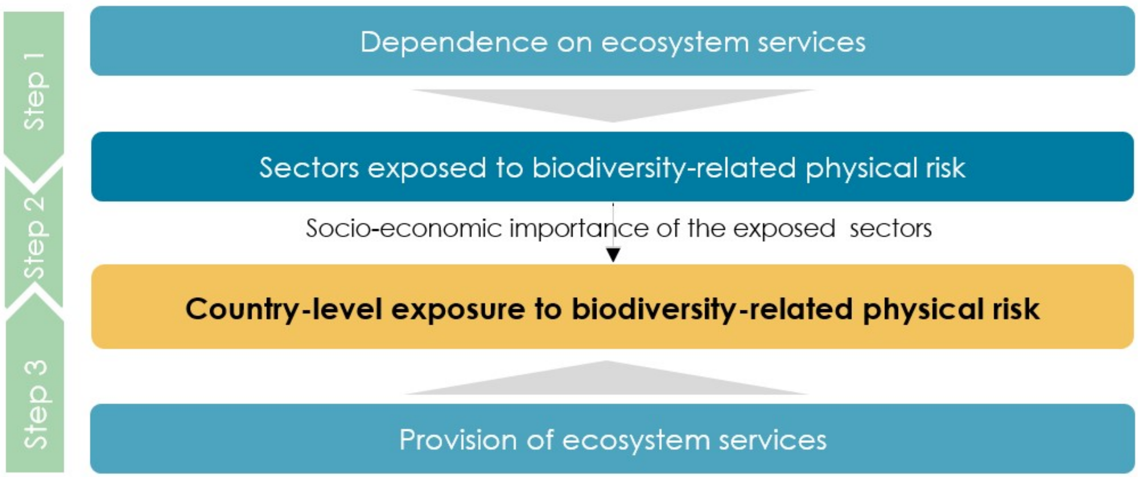

Figure 1. Overview of the assessment of country-level nature-related physical risks.

2.1. Identification of exposed sectors

2.1.1. Sector dependence on ecosystem services

The first step in the assessment of a country's socio-economic exposure is to identify the sectors most exposed to physical risks. In this context, exposure is defined by an economic sector's high dependence on ecosystem services.

Sectoral dependence on ecosystem services is quantified using the 2024 version of the **Exploring Natural Capital Opportunities, Risks and Exposure (ENCORE) tool**[1] (see Appendix 6.1.1 for database details), which classifies sector–ecosystem service relationships into five levels of dependency materiality across 25 ecosystem services (Table 2).

Among the 25 ecosystem services listed in ENCORE, only 17 are included in our analysis, based on the following selection criteria:

- Recreation, visual amenity, education, scientific and research and spiritual, artistic and symbolic services (4) are not included in the assessment because we believe that ENCORE overestimates the ability of cultural ecosystem services to disrupt economic processes[2]. This choice is also aligned with the methodological approach proposed by Garel et al. (2025);

[1] ENCORE Partners (Global Canopy, UNEP FI, and UNEP-WCMC) (2025). ENCORE: Exploring Natural Capital Opportunities, Risks and Exposure. [On-line], Cambridge, UK: the ENCORE Partners. Available at: https://encorenature.org.

[2] Either the economic sectors show no dependence on these services in the ENCORE tool, or they are very heavily dependent on them, risking production incapacity if these services were to disappear. Between 53 and 91 NACE economic sectors are concerned by these very strong dependencies depending on the cultural service considered. For example, the higher education sector is very heavily dependent on the visual amenity service provided by ecosystems, which could put it in serious difficulty if this service were to disappear. However, this situation seems unlikely. In the absence of a published methodology that would explain these extreme levels of dependence, we have chosen not to include cultural services in our analysis.

- Noise attenuation, mediation of sensory impacts other than noise, animal-based energy, and dilution by atmosphere and ecosystems (4) are excluded because no sector is heavily dependent on them (Section 2.1.2).

To identify the economic sectors exposed to physical risks and their role in a country's socio-economic stability, we used the GLORIA EE-MRIO table (Appendix 6.1.2).

A correspondence between NACE (as provided by the ENCORE tool) and GLORIA's sector nomenclature was necessary for the subsequent steps of the analysis (Section 2.2). To achieve this, we utilized an official correspondence table between NACE and EXIOBASE nomenclatures, and a correspondence between EXIOBASE and GLORIA. However, manual corrections to the resulting table were required because the extensive matching process tended to suggest sub-sectors that were not significant for certain economic sectors. The resulting correspondence table between NACE and GLORIA is available on request.

In the correspondence table, GLORIA's 120 economic sectors can be linked to more than one NACE sector, and thus to several levels of dependence for the same ecosystem service. In order to obtain a single score for each pair of economic sectors and ecosystem services, we calculated the average dependency score per economic sector (sensitivity assessment using minimum and maximum scores instead of averages is available in Appendix 6.3). An extract of the final matching is shown in Figure 2. As we have averaged the dependency scores by sector, a continuous scale (from 0 to 5) represents the level of dependency on ecosystem services. It can be seen that sectors do not depend on the same ecosystem services, and that the degree of dependence varies. For example, most sectors have a low dependency on the ecosystem service of solid waste remediation. Nevertheless, many sectors are highly dependent on the water purification service, including the agricultural and manufacturing sectors linked to crops and livestock.

Rating	Description
Very high materiality	The production process is extremely vulnerable to disruption. The degree of protection offered by the ecosystem service is critical and irreplaceable for the production process.
High materiality	The production process can take place with some disruption of the ecosystem service, but the high quantity of the ecosystem service required for the production process makes this a high risk.
Medium materiality	Although less practical, the production process can take place without the ecosystem service due to availability of substitutes.
Low materiality	Most of the time the production process can take place even with partial disruption of the ecosystem service.
Very low materiality	Most of the time the production process can take place even with full disruption of the ecosystem service.

Table 2. Classification of materiality of potential dependencies from the ENCORE tool[3].

[3] Natural Capital Finance Alliance; ENCORE. Exploring Natural Capital Opportunities, Risks and Exposure; Natural Capital Finance Alliance (Global Canopy, UNEP FI and UNEP-WCMC): Oxford, UK, 2022.

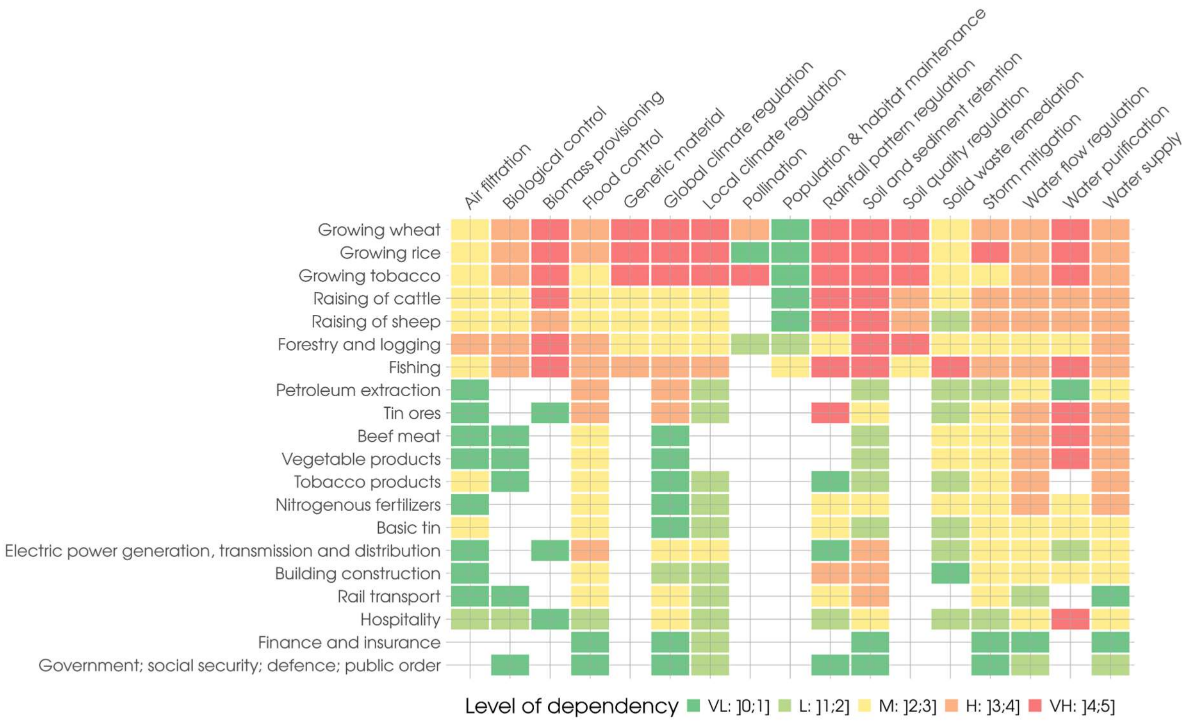

Figure 2. Sample of ecosystem services dependency scores for some GLORIA economic sectors.VL= Very Low, L = Low, M = Medium, H = High, VH = Very High. No color implies no dependency.

2.1.2. Threshold for considering a sector as potentially exposed

The next sub-step involves identifying which sectors can be considered exposed to physical risks. As shown in Table 2, a "high" or "very high" materiality score indicates that the ecosystem service is critical and irreplaceable for production processes. In contrast, lower scores suggest that production might still continue, albeit potentially at a reduced capacity or efficiency. Therefore, we have chosen to consider a sector as exposed to physical risk only if it exhibits a high dependency on an ecosystem service, meaning if the dependency score is strictly higher than 3.

Figure 3 shows the distribution of sectors exposed to physical risks. The agricultural sector is highly exposed to physical risks because it relies on production processes that are directly strongly dependent on ecosystem services (e.g. pollination, biomass provisioning, soil quality, biological control). The mining sector could also be exposed to shocks related to water and climate services. As for the fishing sector, it is the only one heavily dependent on the maintenance of nursery habitats service, and it is highly sensitive to solid waste remediation. Moreover, only the forestry and logging sector is highly dependent on air filtration.

Moreover, no economic sector is strongly or very strongly dependent on the ecosystem services of noise attenuation, mediation of sensory impacts other than noise, dilution by atmosphere and ecosystems and animal-based energy, although they are necessary for human quality of life.

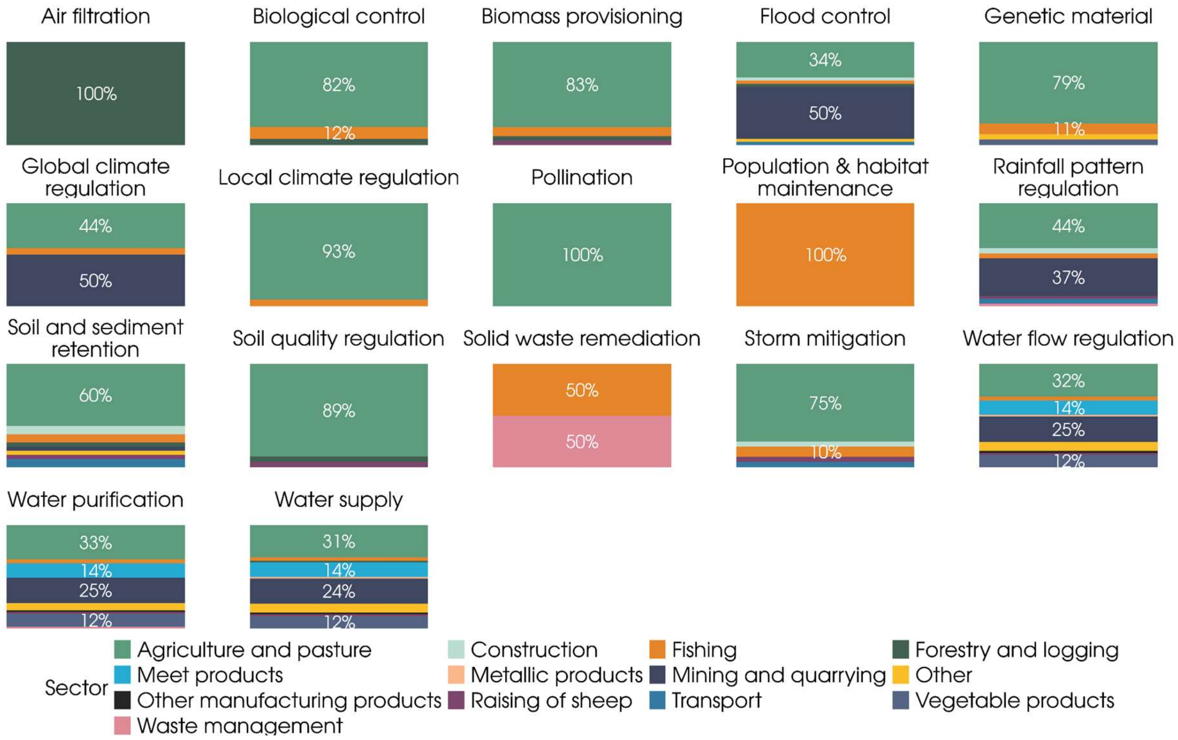

Figure 3. Distribution of sectors with high and very high dependence on ecosystem services.

2.2. Socio-economic indicators

The second step consists in evaluating the socio-economic significance of sectors exposed to physical risks, in order to assess the country's overall exposure.

To analyze the socio-economic impacts of physical or transition shocks, it is essential to employ multidimensional indicators. While traditional measures focus on fiscal health, external balance, and economic performance (e.g. GDP or GDP growth), this methodology emphasizes the inclusion of social dimensions.

We propose six socio-economic indicators, inspired by Magacho et al. (2023), which highlight various sources of instability: employment, wage, and final demand for social dimensions; net taxes for fiscal aspects; net exports for external factors; and production for economic activity (Table 3). These indicators are derived from the GLORIA MRIO-EE table (see Appendix 6.1.2).

Socio-economic indicator	Nature of instability	Description
Net exports	Economic and External	**Share of net exports within countries.** Exports net of imports needed to produce these goods and services. Net exports come from both intermediate consumption (goods and services used in production) and final demand (goods and services directly consumed or invested). Sectors with a negative trade balance are constrained to 0 to ensure the calculation of a meaningful share of net exports. This way, the variable captures the share of net exports only from sectors with a positive trade

		balance, focusing on those that contribute positively rather than those that rely more on imports than they generate in exports.
Net taxes	Economic and Fiscal	**Share of net taxes within countries.** Taxes on products and production, after subtracting subsidies on products and production, along with estimates of income taxes where available (including taxes on profits, wages, and social contributions), as detailed in the Appendix 6.4. Sectors with negative net taxes are constrained to 0 to ensure a meaningful calculation of the share of net taxes. This approach ensures that the variable reflects only the contribution of sectors that generate more tax revenue than they receive in subsidies, rather than those that are net beneficiaries of subsidies.
Wages	Social	**Share of wages within countries.** It refers to the compensation of employees (D.1) as recorded in the value-added (VA) matrix.
Employment	Social	**Share of jobs within countries.** It represents male and female employment, as derived from the satellite matrix (Q).
Production	Economic	**Share of production within countries.** It refers to the vector x, which includes the total production derived from all transactions at basic prices.
Final demand	Social and Economic	**Share of final household consumption within countries.** It represents the total final demand by sector. It is calculated by summing the components of final demand (FD), which include household final consumption (P.3h), non-profit institutions serving households (P.3n), government final consumption (P.3g), gross fixed capital formation (P.51), changes in inventories (P.52), and acquisitions less disposals of valuables (P.53).

Table 3. Socio-economic indicators studied.

2.3. Likelihood of physical shocks

The final step involves assessing the likelihood of a physical shock by using an indicator referred to as the **"capacity of the country's ecosystems to provide ecosystem services".**

With support from the consulting firm Biotope, we conducted a literature review of existing techniques for assessing changes in ecosystem services across various countries. In the absence of an established method, we developed the first indicator of the potential capacity of national ecosystems to deliver the ecosystem services listed in ENCORE. The steps involved in creating this indicator are detailed below and maps showing the results by country are available in Figure 4.

Comment: The tool was developed based on the ecosystem services of the 2018-2023 version of the ENCORE tool. We therefore had to adapt it to the ecosystem services of the 2024 version of ENCORE to obtain SEEA-EA ecosystem service provision capacity scores. These changes are detailed in Appendix 6.5.

2.3.1. Construction of the capacity to provide ecosystem services indicator

2.3.1.1. STAGE 1: Capacity matrix

To the best of our knowledge, there is currently no database for assessing the provision of ecosystem services by a country's ecosystems. In response to this finding, we developed an approach based on a capability matrix.

A capability matrix is a correspondence table linking land cover (i.e. ecosystem types and/or land use/occupation patterns) to ecosystem services. The capability matrix approach was introduced by Burkhard et al. (2009). Since then, the use of a semi-quantitative rating of ecosystem service capacity has been developed and applied in numerous studies (Kroll et al., 2012; Vihervaara et al., 2010), in many countries (e.g. Austria and Hungary by Hermann et al. (2014); China by Cai et al. (2017); USA by Cotillon (2013); Thailand by Kaiser et al. (2013)) and at different scales (e.g. local scale in Nedkov et al. (2014); national scale in Depellegrin et al. (2016); and European scale in Stoll et al. (2015)).

The matrix shows land cover in columns and ecosystem services in rows. **A score from 0 to 5 is assigned to each land cover, expressing the capacity of ecosystems (assumed to be in good condition) to provide ecosystem services: a score of 5 means that the land cover has a high potential to produce the service, while a score of 0 indicates a low potential.** The scores were established by the project team (Biotope/AFD), then revised and validated by several international ecology experts. The capacity matrix is identical for the whole world, and is therefore an approximation of the natural processes involved. An extract from the matrix is shown in Table 4, while the full matrix is available on request.

Service	Tree cover	Inland water	Cropland	Wetland	Sparse vegetation	Grass-land	Shrubland	Artificial surfaces	Bare area
Solid waste re-mediation	4	4	2	5	3	3	3	0	0
Global climate regulation	5	3	2	4	2	3	2	0	0
Local climate regulation	5	3	2	4	2	3	2	0	0
Biological control	5	5	2	5	5	5	5	0	5
Biomass provi-sioning	5	5	4	5	2	2	3	0	0
Storm mitiga-tion	5	0	1	3	2	4	2	0	0
Flood control	4	5	1	5	1	3	1	0	0

Table 4. Extract from the ecosystem/ecosystem services matrix (from Agence française de développement with the support of the consulting firm Biotope).

The land cover/ecosystem service capacity scores (from 0 to 5) are then weighted by the surface area of each land cover[4] present in the country, and averaged by ecosystem service as shown below.

$$Average\ ecosystem\ service\ score_i = \frac{\sum_j \quad (Score_j^i \times Surface_j)}{Total\ surface\ area\ of\ habitats}$$

$$with\ j\ the\ habitat\ and\ i\ the\ ecosystem\ service$$

2.3.1.2. STAGE 2: State of biodiversity

In addition, for each ecosystem service, an analysis of the natural assets on which the provision of this service depends (habitat, species or both) has been carried out, i.e. a physical entity with specific biodiversity characteristics. This enables us to modulate the potential capacity score according to the state of the country's biodiversity. Indeed, a country whose ecosystems are severely degraded will not have the same capacity to produce a range of ecosystem services as a country whose ecosystems are in good condition.

The metrics selected for this stage are based on a literature review comparing available metrics of biodiversity and ecosystem services. The three metrics presented in Table 5 were chosen for their quality, their ability to be updated and their geographical coverage. They were then converted to a discrete scale from 1 to 4 as described in Appendix 6.6.

Indicator	Database	Description
Species integrity *(Species asset)*	**Biodiversity intactness Index (BII)**[5]	• Indicator of the general state of biodiversity in a given area, by synthesizing data on land use, ecosystem extent, species richness and population abundance • Score between 0 and 1 • Global scale • 2022 data
Habitat integrity *(Habitat asset)*	**Ecoregions and conservation status**[6]	• Geographically distinct assemblages of biodiversity whose boundaries encompass the space required to support key ecological processes • Ecoregion threat status rankings (Stable/Intact, Vulnerable, Endangered or Critical) • Global scale • 2017 data

[4] Copernicus Climate Change Service, Climate Data Store, (2019): *Land cover classification gridded maps from 1992 to present derived from satellite observation*. Copernicus Climate Change Service (C3S) Climate Data Store (CDS). DOI: https://doi.org/10.24381/cds.006f2c9a.

[5] Helen Phillips; Adriana De Palma; Ricardo E Gonzalez; Sara Contu et al. (2021). *long_data.csv* (from *The Biodiversity Intactness Index - country, region and global-level summaries for the year 1970 to 2050 under various scenarios*) [Data set resource]. Natural History Museum. https://data.nhm.ac.uk/dataset/bii-bte/resource/2876792f-98d9-4a8d-beee-7dc3e572e2b1

[6] Olson, D. M., Dinerstein, E., Wikramanayake, E. D., Burgess, N. D., Powell, G. V. N., Underwood, E. C., D'Amico, J. A., Itoua, I., Strand, H. E., Morrison, J. C., Loucks, C. J., Allnutt, T. F., Ricketts, T. H., Kura, Y., Lamoreux, J. F., Wettengel, W. W., Hedao, P., Kassem, K. R. 2001. Terrestrial ecoregions of the world: a new map of life on Earth. Bioscience 51(11):933-938. Terrestrial Ecoregions of the World | Publications | WWF

Connectivity of protected areas *(Habitat asset)*	Protected Area Connectedness Index[7]	• Index reflecting the connectivity between protected terrestrial areas and areas containing natural habitats in the surrounding unprotected landscape. It integrates information from remote sensing datasets on forest change and land use, as well as a global database on protected areas • Score between 0 and 1 • Global scale • 2019 data

Table 5. Indicators selected to compute the country's state of biodiversity indicator.

The potential capacity of ecosystems to provide ecosystem services, obtained in stage 1, are then modulated by the state of biodiversity (scores from 1 to 4), depending on the asset responsible for providing the service. Appendix 6.7 provides the link between ENCORE ecosystem services and natural assets.

Thus, if the service is provided solely by the species asset, the previous score will be modulated by the species asset score (i.e. BII); if the service is provided only by the habitat asset, then the service will be modulated by the average habitat asset score (i.e. average of the BII and the Protected Area Connectedness Index). Finally, if species/habitat assets provide the service, then the average score of the three-biodiversity indicators will modulate the score. The abatement percentages implemented are available in Appendix 6.8.

[7] Harwood, Tom; Ware, Chris; Hoskins, Andrew; Ferrier, Simon; Bush, Alex; Golebiewski, Maciej; Ota, Noboru; Perry, Justin; & Williams, Kristen (2022): PARC: Protected Area Representativeness Index: 30s global time series. v2. CSIRO. Data Collection. https://doi.org/10.25919/e3jp-jh25

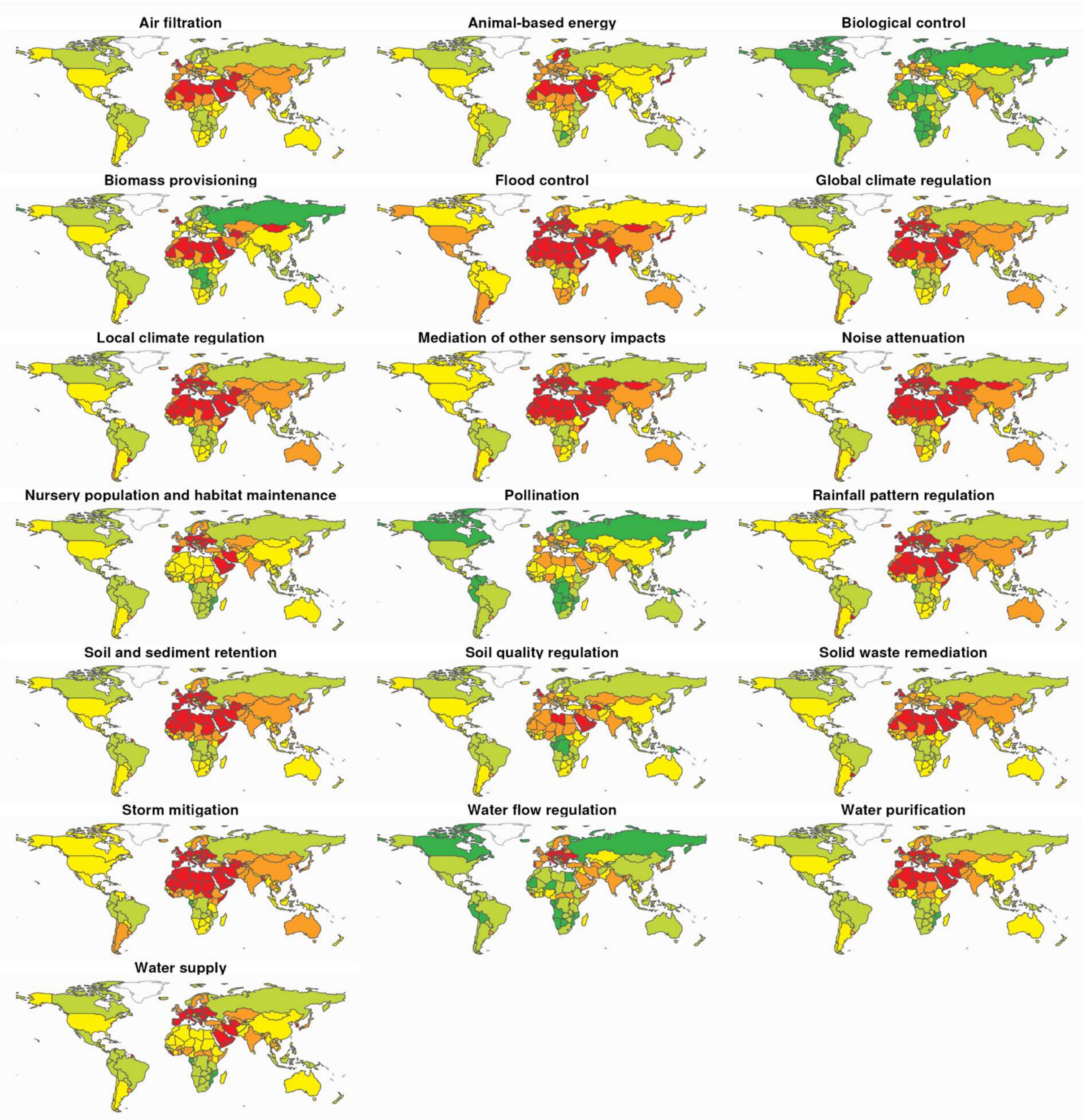

Figure 4. Score of countries' capacity to provide ecosystem services.

2.3.2. Limits

The score of countries' potential capacity to provide ecosystem services is a static indicator, which means that it does not change in line with trends in biodiversity degradation, even if these affect the capacity of ecosystems to provide ecosystem services. The only parameter in its calculation that takes into account the level of biodiversity (through natural capital assets) is based on indicators with data from 2017 to 2022. It therefore does not take into account the projected degradation of biodiversity and the speed of this degradation.

The ecosystem service of dilution by the atmosphere and ecosystems has not been analyzed, as the ecosystem/ecosystem service matrix does not provide us with a level of ecosystem capacity to provide this service. In fact, this service depends on the oceans and the atmosphere and not on the land cover of countries.

Box 1. Example: Physical risk methodology application to South Africa

The application of this nature physical risk assessment methodology to South Africa shows that 57% of the country's net exports are generated by industries highly dependent on at least one ecosystem service and 41% by sectors relying heavily on four or more ecosystem services. In addition, industries highly dependent on at least one ecosystem service drive 35% of production, 34% of net taxes and final demand, as well as about 30% of employment and wages (Fig E1).

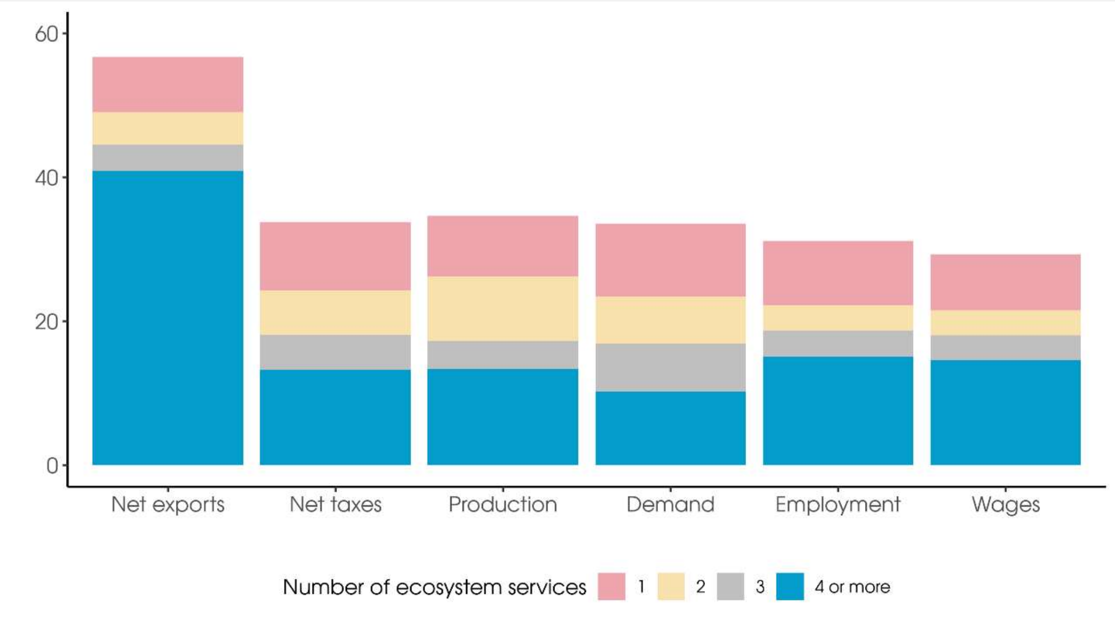

Fig E1. Share of socio-economic indicators generated by exposed sectors in South Africa.

The country appear particularly exposed to physical shocks concerning the decline of water- related ecosystem services and global climate regulation. Indeed, between 39% and 48% of the country's net exports are generated by industries heavily dependent on at least one of these ecosystem services, and between 3% and 19% for other socio-economic indicators. Of all the ecosystem services, the least well provided seems to be flood control. Consequently, it is important for the country to monitor industries most dependent on this service, both to ensure that they have the capacity to mitigate the risk and that the ecosystem services they need most to produce are provided locally in sufficient quantity (Fig E2).

A

	Net exports	Net taxes	Production	Demand	Employment	Wages
Water supply	47.15	15.51	17.85	12.89	15.04	14.74
Water purification	47.63	19.34	18.89	18.26	18.65	18.01
Water flow regulation	46.91	15.53	17.82	12.89	14.96	14.69
Storm mitigation	3.87	6.63	5.53	7.54	7.81	5.81
Solid waste remediation	0.76	0.62	0.47	0.86	1.29	0.56
Soil quality regulation	3.36	2.95	2.76	3.04	3.52	2.04
Soil and sediment retention	9.25	15.21	14.18	16.38	13.77	11.72
Rainfall pattern regulation	39.92	14.94	15.54	12.84	15.48	15.04
Pollination	2.99	2.38	1.73	2.63	3.02	1.75
Nursery population and habitat maintenance	0.03	0.03	0.01	0.01	0.15	0.06
Local climate regulation	3.08	2.61	1.88	2.81	3.13	1.84
Global climate regulation	38.85	7.68	8.43	3.07	9.91	10.12
Genetic material	5.55	4.51	3.43	5.24	4.18	2.82
Flood control	39.58	13.37	13.44	9.11	15.98	16.02
Biomass provisioning	3.71	3.12	2.92	3.19	3.9	2.25
Biological control	3.15	2.66	1.94	2.83	3.33	1.93
Air filtration	0.03	0.02	0.05	0.01	0.05	0.03

B

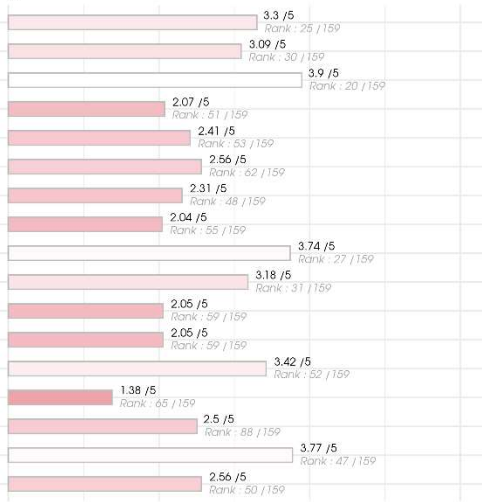

Fig E2. (A) Share of socio-economic indicators generated by economic sectors highly dependent on a given ecosystem service in South Africa. (B) Approximated capacity of South Africa to provide ecosystem services.

The economic sector that exposes the country most is mining and quarrying, which explains South Africa's high exposure to water-related services and global climate regulation (36%). Additionally, the manufacturing sector generates 10% of the exposure related to final demand, 6% to jobs and wages, 10% to production and 9% to tax revenues (Fig E3).

	Net exports	Net taxes	Production	Demand	Employment	Wages
Water supply; sewerage, waste management and remediation activities	0.63 %	0.54 %	0.4 %	0.82 %	1.05 %	0.42 %
Transportation and storage	3.48 %	4.43 %	3.77 %	4.11 %	3.73 %	3.62 %
Mining and quarrying	35.81 %	5.21 %	6.79 %	0.27 %	6.88 %	8.5 %
Manufacturing	10.12 %	8.72 %	9.9 %	10.11 %	5.85 %	5.53 %
Human health and social work activities	0.15 %	2.53 %	2.22 %	3.63 %	1.93 %	1.91 %
Electricity, gas, steam and air conditioning supply	0.33 %	2.14 %	2.27 %	1.64 %	2.14 %	2.3 %
Construction	0.38 %	5.85 %	5.35 %	8.18 %	4.45 %	3.94 %
Agriculture, forestry and fishing	3.71 %	3.12 %	2.92 %	3.19 %	3.9 %	2.25 %
Accommodation and food service activities	2.15 %	1.25 %	1.03 %	1.61 %	1.21 %	0.86 %
Total	56.75 %	33.79 %	34.66 %	33.56 %	31.13 %	29.34 %

Fig E3. Distribution of physical risk exposure across the South Africa's economic sectors. In other words, the share of socio-economic indicators originating from economic sectors that rely heavily on at least one ecosystem service.

3. EXPOSURE TO TRANSITION RISKS

This section presents a methodological framework for **determining which economic sectors are most exposed to transition risks and evaluating their significance within key national socio-economic indicators.**

Over 195 countries have signed up to the United Nations Convention on Biological Diversity and are committed to the Kunming-Montreal Global Biodiversity Framework, which was adopted in December 2022 (CBD, 2022). As such, signatory countries will have to draw up new national trajectories for sustainable development and the protection of living organisms by applying sectorial policies to reduce anthropic pressures on biodiversity. This approach is consistent with the current narrative that claims that first, national policies should support biodiversity conservation in order to reduce ecological degradation on a global scale.

Countries are likely to encourage sectors that are harmful to biodiversity to change their practices through regulatory, fiscal or trade-related reforms and/or the adoption of environmentally related instruments with an aim to protect nature. These policy interventions may adversely affect the sectors that exert the most pressure on biodiversity or threaten the most species with extinction. They can also face mounting pressures to innovate and meet the voluntary commitments of competing companies engaged in CSR/ESG strategies or risk an erosion of their attractiveness for investors. Changes in consumer habits can exacerbate this, as consumers lose interest in these industries and contribute to environmental protection. These shocks can occur locally—such as changes in subsidies—or globally, for example through trade reforms addressing biodiversity loss.

The methodology to assess exposure to transition risks can be broken down into two main stages as follows:

1-/ We identify in EE-MRIO GLORIA table at the country level a set of exposed sectors to a transition based on the pressures they exert on biodiversity and on their contribution to species' risk of extinction (Section 3.1);

2-/ We compute the share of main socio-economic indicators generated by these sectors (Section 3.2) to evaluate countries' exposure to the transition.

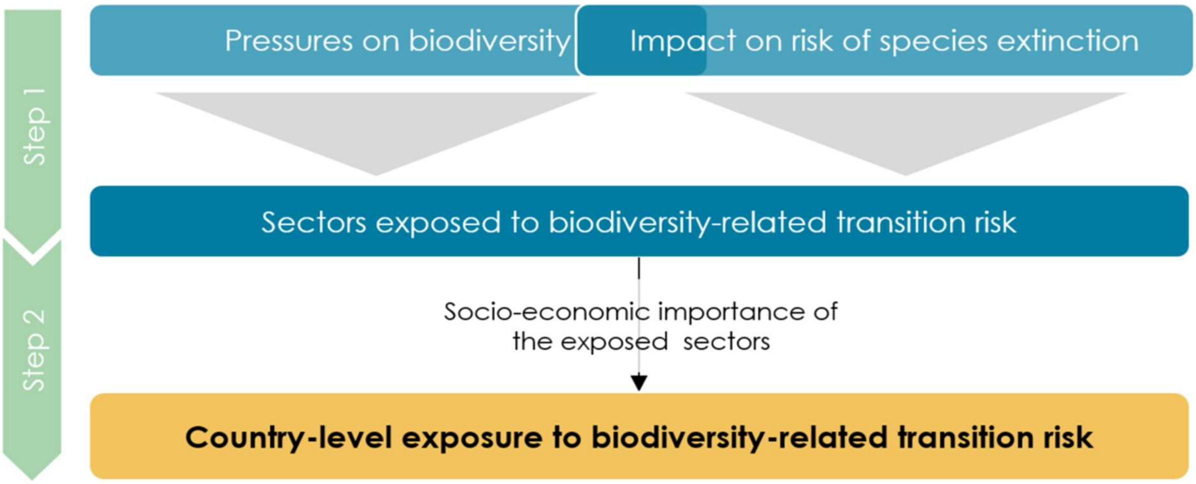

Figure 5. Overview of the assessment of country-level nature-related transition risks.

3.1. Identification of exposed sectors

To identify the most exposed sectors to a nature-related transition, we identify the economic sectors that have the greatest impact on biodiversity.

Numerous biodiversity indicators are available, but there is no consensus on which ones are the most effective for reporting the total impact of sectors on biodiversity. Indeed, each of these indicators focuses on a subset of biodiversity and is not sufficient on its own to measure all the impacts of human activities on changes in biodiversity.

Biodiversity is complex and its dynamics are non-linear, meaning that a change in pressure is not necessarily proportional to change in biodiversity. Ecosystems can sometimes collapse completely due to human pressures with no way of recovering their initial state, forever disrupting the diversity of living organisms present (e.g. rainforests becoming savanna or farmland) (Lenton, 2013). Identifying and anticipating the tipping point of these ecosystem changes is very difficult and not available with current science on a global scale (Maurin et al., 2022).

As a result, biodiversity cannot be summed up in a single indicator. We have therefore decided to use two types of approach: an approach based on pressures exerted by sectors on biodiversity and an approach based on sectoral contribution to the risk of species extinction. This methodology tries to approximate impact on ecosystem integrity and species diversity and implicitly ignores genetic diversity. However, it can be complemented as new indicators and connections with sectors are constructed.

Thus, to identify exposed sectors at the country level, we apply a two-layered filter based on these two approaches:

- A pressure-based approach to identify sectors that generate most pressures on biodiversity (Section 3.1.1);

- A STAR approach to identify sectors that contribute to endangered species risk of extinction (Section 3.1.2).

The **pressure-based approach** alone is insufficient to identify exposed sectors to nature-related transition risks, as many pressures on biodiversity are not included in the analysis (e.g. invasive species, biomass extraction, artificialization of non-agricultural land). Furthermore, the damage function describing the relationship between pressures exerted by economic sectors (e.g. GHG emissions, land use) and resulting impacts on biodiversity (e.g. ecosystem fragmentation, decline in species populations) is unknown, although IPBES establishes a direct link between these pressures and biodiversity decline (IPBES, 2019). This method avoids discriminating between types of biodiversity. It has a more global scope, focusing on the underlying sources of biodiversity loss rather than its consequences.

The **STAR approach**, which is based on the Red List database, is also an incomplete metric, as it does not include all aspects of biodiversity (e.g. genetic diversity, ecosystem diversity, the dynamics surrounding all its components) and not all species are referenced (e.g. soil diversity, plants) or known. Moreover, we can only analyze a small subset of the Red List database due to missing data or methodological choices (Box 2 in Section 3.1.2). However, this **approach allows us to estimate the damage function, which gives us a better representation of the possible effective loss of biodiversity induced by economic sectors for the species under consideration.**

The combination of these two frameworks enables us to overcome some of the limits underlying each of them, and increases our chances of better identifying the sectors with the greatest impact on biodiversity. **Nevertheless, the methodology users must be cautious when interpreting the results, as the method do not quantify all the impacts that economic activities exert on biodiversity (e.g. including for marine ecosystems and other numerous pressures on biodiversity).**

3.1.1. Pressures exerted by sectors on biodiversity

The first approach used to identify exposed sectors to a transition is to calculate the share of pressures generated by economic sectors on biodiversity in a given country.

We measure these pressures using the GLORIA EE-MRIO (Multi-Regional Input-Output Environmentally Extended) table (see Appendix 6.1.2).

GLORIA satellite accounts include some pressures known to significantly affect biodiversity. These pressures, selected to assess transition exposure, are listed in Table 6 and will be quantified for GLORIA sectors and countries (Table 7 and Figure 6 provides summary statistics on these pressures). As the "number of sectors directly concerned" column shows, not all sectors generate each of the pressures studied. For example, by definition only 20 agricultural/forestry sectors are concerned by the "agricultural land use" pressure.

Nevertheless, as stated above, many key pressures on biodiversity cannot be analyzed with GLORIA, such as invasive species, biomass extraction, non-agricultural land-use change or numerous pollutants, as they are not part of the pressures listed in the database. Moreover, pressures are calculated by major sectors of activity and do not take into account the specific production methods of each company, which can have a major impact on the interpretation of results. Sectors exerting the most pressure will be identified, but the ones with the most harmful production practices locally will not. This is where the methodology stops, and helps identify sectors that require ad hoc research to verify the materiality of the risk identified through this approach.

We then calculate the share of a specific pressure (p) exerted by a given sector (s) in a given country (c) as follows (e.g. share of GHG emissions generated by the "raising of cattle" sector in Brazil in relation to the country's total GHG emissions).

$$Share\ of\ pressure_{c,s}^{p} = \frac{Amount\ of\ pressure_{c,s}^{p}}{\sum_{s=1}^{S} \quad Amount\ of\ pressure_{c,s}^{p}}$$

Figure 7 illustrates the average sectoral distribution of these pressures. On average, agriculture is responsible for the largest share of pressures on biodiversity, particularly in terms of blue water consumption, land use, and NH_3 emissions, as well as a significant share of GHG and NO_X emissions. The mining and quarrying sector also contributes the largest share of SO_2 emissions and a substantial share of NO_X and GHG emissions. The transportation and storage sector is a major contributor to NO_X emissions, and the manufacturing sector contributes to all types of pressures except land use.

<u>Comment:</u> The tool does not identify the most "biodiversity-damaging" sectors on a global scale. However, it does help identify those that have the largest local impact in a given country and therefore are most likely to be exposed to nature-related policies.

IPBES Driver of change	Pressure	Unit	Type of pressure	Number of sectors directly concerned (among the 120 sectors)
Climate change	**GHG emission**	kt CO_2eq	Global	118
Direct exploitation	**Blue water consumption**[8]	million m³ H_2Oeq	Local	120
Land-use change	**Agricultural land use**[9]	1000 ha	Local	20
Pollution	**NO_X emission**	kt	Local	118
	NH_3 emission	kt	Local	118
	SO_2 emission	kt	Local	117

Table 6. Pressures on biodiversity analyzed. The column "Pressure" shows the pressures extracted from GLORIA to approximate four of the fifth main biodiversity "drivers of

[8] **Blue water** refers to water that swiftly traverses rivers, lakes, and groundwater, distinct from green water, which is retained within the soil and biomass.

[9] **Agricultural land use pressure** does not exactly align with land use change pressure, as it does not account for the biodiversity loss associated with land conversion. It solely refers to the area dedicated to agriculture or forestry, without considering the impacts of land-use changes that may destroy ecosystems during conversion.

change" identified by IPBES. No pressure was found in GLORIA to approximate the fifth missing IPBES driver of change, namely "Invasive species dissemination"[10].

Variable	Mean	Min	Max	Median	CV
Blue Water	7391.7226	0.5151921	320158.38	821.0119	447.2584
GHG	285762.5765	1140.192003 1	13570085.08	44945.8942	420.8351
Land use	38508.3894	4.5780070	874029.55	6435.0262	298.9777
NH3	508.5693	0.6824871	13143.21	118.0589	297.8830
NOX	506.3228	3.6802637	19091.46	99.2037	358.2287
SO2	547.2141	0.6864596	27598.92	57.0804	453.6180

Table 7. Summary of biodiversity pressure statistics analyzed in this methodology.

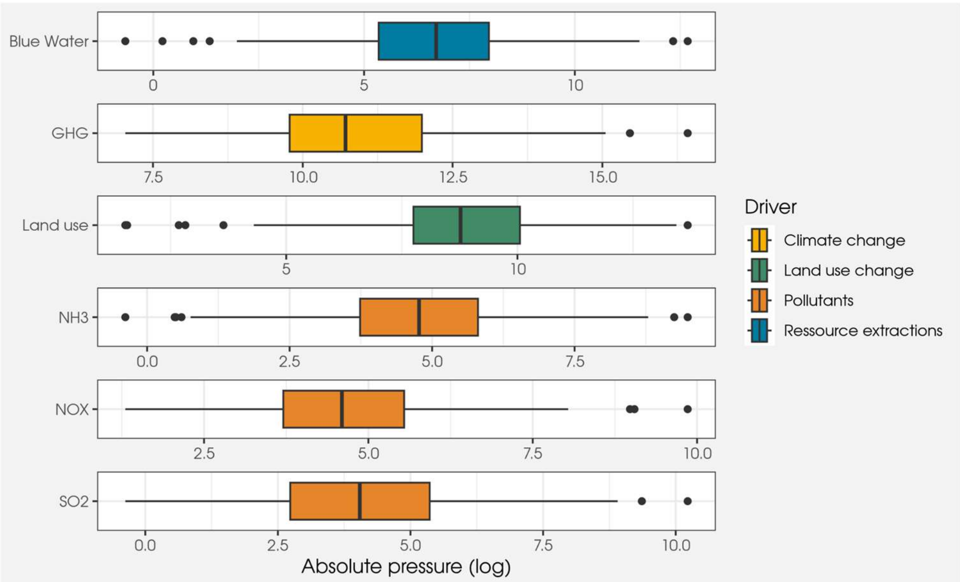

Figure 6. Distribution of national pressure values across the 159 countries studied.

[10] **Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES)**, drivers of change are all the factors that, directly or indirectly, cause changes in nature, anthropogenic assets, nature's contributions to people and a good quality of life. See : Brondízio, E. S., Settele, J., Diaz, S., & Ngo, H. T. (2019). Global assessment report of the intergovernmental science-policy platform on biodiversity and ecosystem services. IPBES.

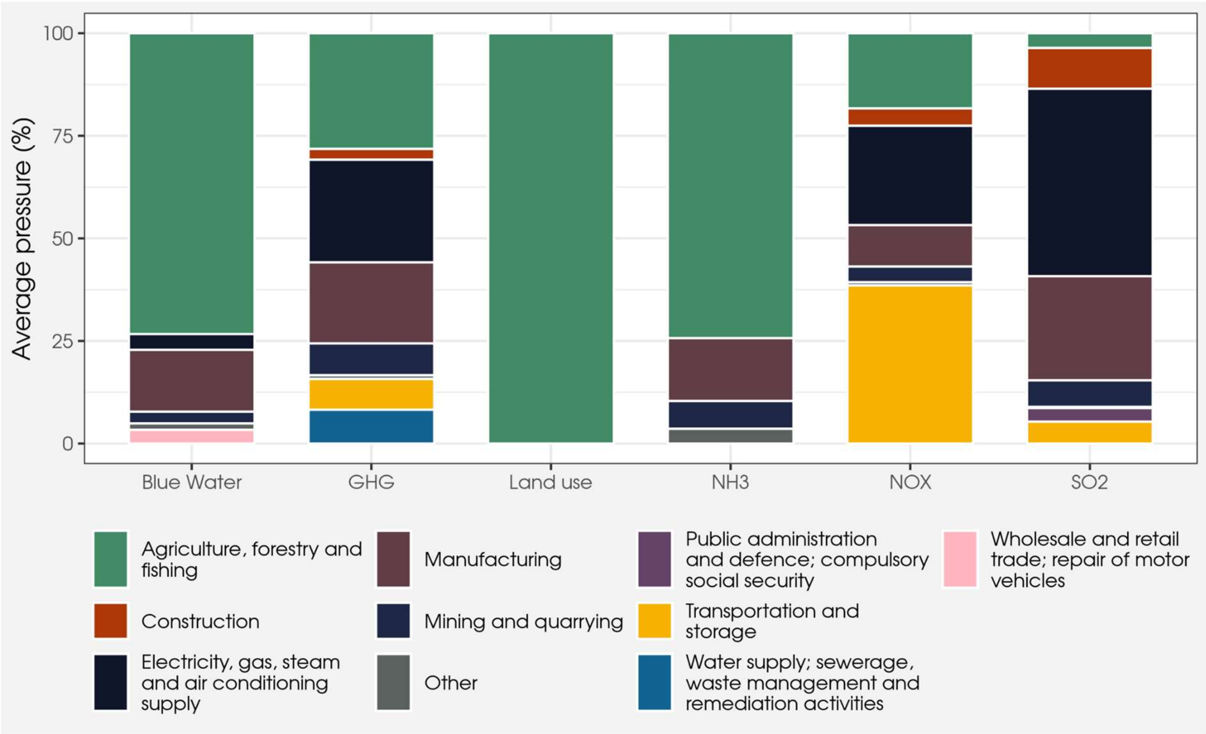

Figure 7. Average share of pressure generated by economic sectors across countries worldwide

<u>Comment:</u> Some countries have missing pressures on biodiversity in GLORIA's satellite accounts. Table 8 lists the countries concerned. South Sudan is the only country with no documented pressures except agricultural land use, while Palestine and Serbia have only the pressure linked to water consumption and agricultural land use recorded.

Country	ISO	Water	GHG	NH3	NOX	SO2	Land use
Bahamas	**BHS**	X	✓	✓	✓	✓	✓
Equatorial Guinea	**GNQ**	X	✓	✓	✓	✓	✓
Hong Kong	**HKG**	X	✓	✓	✓	✓	✓
Palestine	**PSE**	✓	X	X	X	X	✓
South Sudan	**SDS**	X	X	X	X	X	✓
Serbia	**SRB**	✓	X	X	X	X	✓

Table 8. Countries with missing data on biodiversity pressures

3.1.2. Contribution of sectors to the risk of species extinction

Our second approach consists in identifying exposed sectors to a nature-related transition using an adapted version of the Species Threat Abatement and Recovery (STAR) metric developed by the International Union for Conservation of Nature (IUCN)[11]. This metric is based

[11] IUCN. 2023. The IUCN Red List of Threatened Species. Version 2023. https://www.iucnredlist.org. Accessed in December 2023.

on global Red List threat and geolocalized species range data, but does not initially distinguish between the economic sectors responsible for threats.

The final aim of this approach based on the STAR metric is to quantify the contribution of economic sectors to the extinction risk of species available in the Red List database. We will first apply the same STAR calculation as in the Irwin et al. (2022) methodology, then make methodological adaptations (differentiation of global and local pressures) and distribute it among the economic sectors according to the pressures they exert on biodiversity.

Figure 8 illustrates the data linkage required to create this in-house STAR metric. We used the methodology from Irwin et al. (2022) to link the range of species by country and their level of criticality (Red List) for each of the threats they face. We also linked IUCN Red Lists threats to species to the pressures available in the GLORIA EE-MRIO table in order to distribute STAR scores according to the level of pressure that sectors generate on biodiversity.

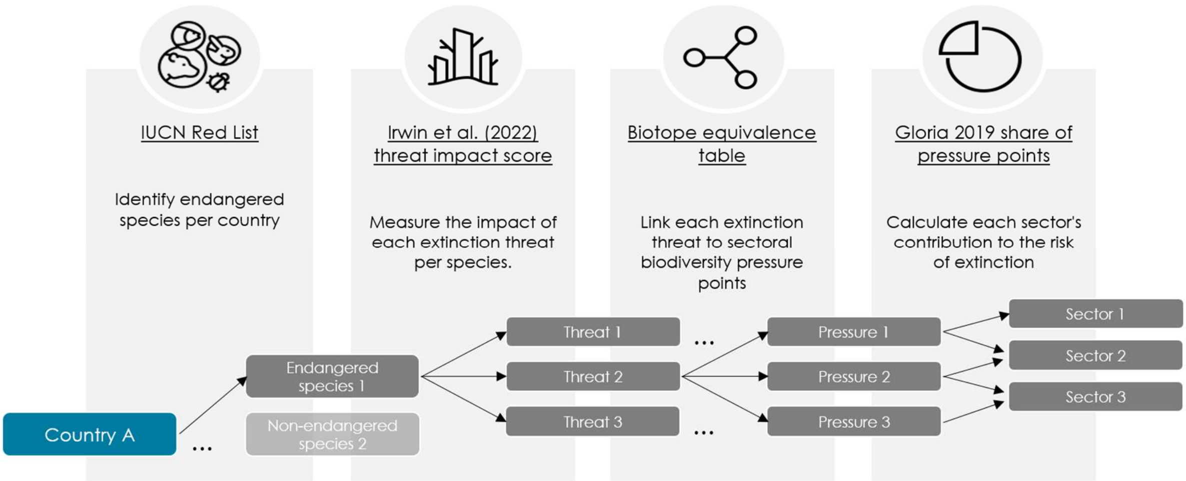

Figure 8. Data linkage to create the in-house STAR metric.

All the analytical steps involved in calculating a STAR score by sector/country, are detailed below (see Appendix 6.9 for more details on the STAR metric and a comparison with the Potentially Disappeared Fraction (PDF) metric available in GLORIA database).

1-/ STAR PER THREAT: RED LIST & IRWIN ET AL. (2022)

The IUCN Red List of Threatened Species[12] is a comprehensive database of the global conservation status of more than 150,300 species of plant and animal species maintained by the International Union for Conservation of Nature (IUCN). The Red List assesses the extinction risk of various species and provides information about their distribution, population size, habitat, and the threats they face. The assessments are global and based on scientific data, field surveys, and expert evaluations.

[12] IUCN. 2023. The IUCN Red List of Threatened Species. Version 2023. https://www.iucnredlist.org. Accessed in December 2023.

Species are categorized into different extinction risk categories (*W*), which include Least Concern (LC); Near Threatened (NT); Vulnerable (VU); Endangered (EN); Critically Endangered (CR); Extinct in the Wild (EW); Extinct (EX). Only the following categories have been retained and converted into numeric values: NT=1; VU=2; EN=3; CR=4 to avoid taking into account species that are already extinct (i.e. no longer threatened by economic sectors), species that are no longer in the wild (i.e. not included in the scope of biodiversity conservation policies) and those that are not expected to become extinct in the near future (i.e. least concern species).

We classify threats according to their **severity** and **scope**. Severity corresponds to the extent and speed of the decline, and is broken down into 6 categories (e.g. causing of likely to cause rapid declines: 20-30% over 10 years of three generations) and scope corresponds to the size of the population affected by the threat (e.g. affects the majority (50-90%) of the population).

According to Irwin et al. (2022) and based on Garnett et al. (2019), the combination of these two pieces of information can result in a threat impact score ($TS^{e,t}$) for each threat (t) acting on a species (e):

		Severity of threat			
		Causing or likely to cause negligible declines OR No decline	Causing or likely to cause relatively slow, but significant declines OR Causing or likely to cause fluctuations	Causing or likely to cause rapid declines (20-30% over 10 years or three generations)	Causing or likely to cause very rapid declines (>30% over 10 years or three generations)
Scope of threat	Affects the minority (<50%) of the population	0	5	7	24
	Affects the majority (50-90%) of the population	0	9	18	52
	Affects the whole (>90%) population	1	10	24	63

Table 9. Threat impact score (TS) correspondence table (Irwin et al. (2022)).

We calculate the Species Threat Abatement and Restoration (*STAR*) metric for each species-threat (*e*,*t*) combination by multiplying the value representing the species' extinction risk category (W^e) by the threat Impact score ($TS^{e,t}$), following Irwin et al.(2022).

$$STAR^{e,t} = W^e * TS^{e,t}$$

<u>Example:</u> Let's take a simple example of a frog species that is considered vulnerable (W=VU=2) with only one threat: the airborne pollutants. This threat is likely to affect the majority of the population and it is causing rapid declines (TS=18). In this case, the STAR for this species and this threat will be equal to: $STAR^{frog,pollutants} = W^{frog} * TS^{frog,pollutants} = 2 * 18 = 36$.

2-/ STAR PER PRESSURE: THREAT TO PRESSURE CORRESPONDENCE TABLE

As the final objective of this approach is to assign STAR scores to economic sectors according to the GLORIA pressures they exert on Red List species, we need to establish the equivalence between IUCN threats and GLORIA pressures.

We produced, with the help of the Biotope consulting firm, an equivalence table between the 99 IUCN threats and the 159 GLORIA pressures available in its satellite accounts v057. It is filled with binary links between the IUCN threat classification system and GLORIA pressures: if a link exists, the resulting correspondence is 1; if no link appears, the correspondence is 0. An extract from the matrix is shown in Table 10, while the full matrix is available on request.

In addition, as some IUCN threats are sector-specific, we have added this information to the equivalence table. Therefore, for example, only agricultural sectors can be responsible for the shifting agriculture threat.

			IUCN Threats				
			Shifting Agriculture	Mining & quarrying	Logging and wood harvesting	Smog	...
GLORIA Sectors/ Pressures	Growing fruits and nuts	NH3	1			1	...
		Coal and peat	0			0	...
		...	...			...	...
	Forestry and log-ging	NH3			0	1	
		Coal and peat			0	0	
		...			...	...	
	Basic iron and steel	NH3		0		1	...
		Coal and peat		1		0	...
		...		...		...	...
	...	...	...	...	...	...	...

Table 10. Illustration of the equivalence table between IUCN threats and GLORIA v057 pressures.

Thanks to the correspondence table, the STAR metric can be recalculated as a function of pressure (p) rather than threat (t) as follows:

$$STAR^{e,p} = \sum_{t=1}^{T} STAR^{e,t} * \frac{1}{number\ of\ pressures^{t}}$$

<u>Comment:</u> We distribute the STAR scores across all pressures evenly given the difficulty in measuring the impact of each pressure on threats to endangered species. Therefore, the more pressures there are, the lower the impact of each pressure on a threat.

<u>Example:</u> For instance, let's take again the example of the frog species, which had a STAR= 36 linked to only one threat: the airborne pollutants. Imagine that in the correspondence table,

two pressures (GHG and NH₃) are linked to this threat. The STAR score of the frog species for the GHG pressure is as follows:

$$STAR^{frog,GHG} = STAR^{frog,pollutants} * \frac{1}{number\ of\ pressures^{pollutants}} = 36 * \frac{1}{2} = 18$$

In addition, the STAR score related to NH_3 pressure is therefore calculated in an equivalent way such as: $STAR^{frog,NH3} = 18$.

3-/ STAR PER COUNTRY (IUCN RED LIST + BIRDLIFE SPECIES RANGES)

As the Red List is global, we need to know the geographic range of species to distribute STAR scores across countries (*c*).

The IUCN provides ranges for most of the Red List species, and BirdLife provides spatial bird data[13]. By adding country boundaries to the layers, we can calculate the share of species range present in different countries around the world.

Among the 159 GLORIA's (v057) pressures, we have decided to distinguish two types of pressure for which we have calculated a different STAR score according to their characteristics.

Global pressures:

Greenhouse gases are a global pressure on species, because they threaten species no matter where they are emitted. This means that if a species is endangered due to the pressure of GHG emissions, even a country that does not have the species in its territory contributes to the risk of extinction of that species through the GHG emissions of its sectors. Thus the STAR metric will not depend on the species' range within a country *c*, such that $STAR_c^{e,p} = STAR^{e,p}$.

Local pressures:

We consider all other pressures, such as land use, water consumption and pollution, to be local because they threaten species close to where they occur. The STAR scores for each country must therefore be distributed according to the surface area occupied by the species in a given country. Thus, if a country does not host a species threatened by local pressures, it cannot be held responsible for the threats the species faces. On the other hand, if it does host a species, its responsibility at the global level will depend on how representative the species is in the country, such that:

$$STAR_c^{e,p} = STAR^{e,p} * \frac{range_c^e}{\sum_{c=1}^{C} \quad range_c^e} \quad with \quad \sum_{c=1}^{C} \left(\frac{range_c^e}{\sum_{c=1}^{C} \quad range_c^e} \right) = 1$$

Where *range* represents the range of a species (*e*) in a country (*c*) in km².

[13] Access to shapefiles https://www.iucnredlist.org/resources/spatial-data-download

Comment: *The above calculation has a significant limitation. It assumes that the local pressures exerted by economic sectors on species do not extend beyond a country's borders, which is not necessarily true. For example, an industry located close to the border of a neighboring country and emitting high levels of pollutants is likely to impact species in the neighboring country through its emissions. However, this limitation is insurmountable as we are unable to pinpoint the location of sectors in the world, or the area actually impacted by their pressures. Spatially explicit assessment is not covered here but technically feasible with proper datasets as shown in Hadji-Lazaro et al. (2025).*

Comment: *The Red List database is global in scope and does not distinguish between countries. As a result, it does not provide information on where the most threatened specimens of a species are actually located. This means that we may be attributing threats to countries where, in reality, those threats do not exist. However, as long as the Red List remains global, this limitation cannot be addressed.*

Example: *In our previous example, only two pressures were threatening the frog species: GHG, which is a global pressure, and NH_3, which is a local pressure (remember the frog is threatened only by the airborne pollutants, which is caused by GHG and NH_3). Moreover, imagine that the frog species has a distribution area of 10km² in Gabon and 5km² in Rwanda. The STAR score linked to GHG pressure in Gabon will therefore be the same as before:* $STAR_{Gabon}^{frog,GHG} = 18$. *On the other hand, the STAR score linked to NH_3 pressure in Gabon will be equal to:*

$$STAR_{Gabon}^{frog,NH3} = STAR^{frog,NH3} * \frac{range_{Gabon}^{frog}}{\sum_{c=1}^{C} range_{c}^{frog}} = 18 * \frac{10}{10+5} = 12.$$

Box 2. Number of species in the scope of the analysis

Of the 153,732 species in the Red List, our analysis is limited to only 4,146 (i.e. 2,622 amphibians; 1,421 mammals; and 103 birds) for the following reasons:

- only mammals, amphibians and birds are kept, as these are the species best represented in the Red List [25,102 species conserved]
- only species with a threat category equal to Near Threatened (NT), Vulnerable (VU), Endangered (EN) or Critically Endangered (CR) are included [7,374 species]
- only "On-going" of "Future" threats are retained [7,340 species]
- only species having geographic range are kept [4,590 species]
- only threats with clear links to sectoral pressures are analyzed [4,146 species]

4-/ STAR PER SECTOR: GLORIA PRESSURES

The final step of the analysis consists in distributing STAR scores between sectors proportionally to the share of pressure they generate.

As explained in Appendix 6.1.2, the GLORIA EE-MRIO allows us to know the quantity of pressures (*p*) generated by sectors (*s*) for a given year (i.e. 2019 in this analysis).

STAR scores for a given sector can be recalculated as follows:

Where *press* represents the amount of pressure *p* generated by the sector *s* in the country *c* that threaten species *e* in absolute value.

Global pressures: $STAR_{c,s}^{e,p} = STAR^{e,p} * \frac{press_{c,s}^{e,p}}{\sum_{c,s=1}^{C,S} press_{c,s}^{e,p}}$ with $\sum_{c=1,s=1}^{C,S} \cdot \left(\frac{press_{c,s}^{e,p}}{\sum_{c,s=1}^{C,S} press_{c,s}^{e,p}}\right) = 1$

In the case of <u>global</u> pressures, the pressure share of a given sector is measured as a function of <u>total global</u> pressures, to express the fact that all sectors in the world generating the global pressure are responsible for the risk to the species.

Local pressures: $STAR_{c,s}^{e,p} = STAR_{c}^{e,p} * \frac{pres_{c,s}^{e,p}}{\sum_{s=1}^{S} press_{c,s}^{e,p}}$ with $\sum_{s=1}^{S} \cdot (\frac{press_{c,s}^{e,p}}{\sum_{s=1}^{S} press_{c,s}^{e,p}}) = 1$

In the case of <u>local</u> pressures, a given sector's share of pressure is measured as a function of the <u>country's total</u> pressures, to express the fact that the country is solely responsible for the pressure threatening the species inside.

<u>Comment:</u> In the case of local pressures, a country's responsibility is determined solely by the spatial distribution of the species within its territory. The distribution of pressures across economic sectors is considered only in a subsequent step. Consequently, if two countries host an equivalent area of habitat for the same species, they will be attributed equal responsibility for the associated pressures—even if, in absolute terms, one country exerts significantly more pressure than the other.

<u>Comment:</u> With regard to local pressures, it is entirely possible that contributions to extinction risk are attributed to economic sectors that are not, in fact, responsible. For example, an economic sector may be located far from the range of a threatened species and, even if it generates the type of pressure that could affect that species, it may not be the actual cause of the threat. In the absence of spatially explicit data on the location of economic activities—and ideally, on the extent of their impact zones—this limitation cannot be corrected in the current analysis.

<u>Example:</u> Let's go back to our previous example. Let's imagine that the growing fruits sector in Gabon emits 3 kt of NH_3 and 20 kt of GHG, knowing that the total NH_3 emissions of the country's sectors are 14 kt and that sectors worldwide emit 300,000 kt of GHG. The growing fruits sector's STAR scores for GHG and NH_3 pressures can be calculated as follows:

$$STAR_{Gabon,fruits}^{frog,GHG} = STAR^{frog,GHG} * \frac{press_{Gabon,fruits}^{frog,GHG}}{\sum_{c,s=1}^{C,S} press_{c,s}^{frog,GHG}} = 18 * \frac{20}{300000} = 0.0012$$

$$STAR_{Gabon,fruits}^{frog,NH3} = STAR_{Gabon}^{frog,NH3} * \frac{press_{Gabon,fruits}^{frog,NH3}}{\sum_{s=1}^{S} press_{Gabon,s}^{frog,NH3}} = 12 * \frac{3}{14} = 2.57$$

To obtain a single score for each sector corresponding to its contribution to total species risk of extinction in each country, we sum species/pressures scores as follows:

$$STAR_{c,s} = \sum_{e=1}^{E} \cdot \sum_{p=1}^{P} STAR_{c,s}^{e,p}$$

Example: *Let's imagine, for the sake of simplicity, that there is only one species in Gabon, the frog mentioned above. In this case, we can measure the contribution of the growing fruit sector to the total extinction risk as follows:*

$$STAR_{Gabon,fruits} = \sum_{e=1}^{E=1} \cdot \sum_{p=1}^{P=2} STAR_{Gabon,fruits}^{e,p} = STAR_{Gabon,fruits}^{frog,NH3} + STAR_{Gabon,fruits}^{frog,GHG} = 0.0012 + 2.57 = 2.5712$$

Once we have calculated the STAR scores for each sector, we can measure the share of STAR generated by a sector in a given country as follows (as in the pressure-based approach):

$$Share\ of\ STAR_{c,s} = \frac{STAR_{c,s}}{\sum_{s=1}^{S} STAR_{c,s}}$$

Comment: *The tool does not enable us to identify the most "biodiversity-damaging" sectors on a global scale. However, it does identify those that have the largest national impact and are thus most exposed to nature-related policies implemented at the country level.*

3.1.3. Threshold for considering a sector as potentially exposed

Once we have calculated the contribution of sectors to the pressures on biodiversity generated in the country (Section 3.1.1) and to the risk of species extinction (Section 3.1.2), we determine which of them are likely to be impacted by policies in favor of biodiversity.

As explained in the introduction, we consider that the sectors that have the greatest impact on biodiversity will be most exposed to an ecological transition. In our context, this means determining a pressure threshold and a STAR threshold at which sectors are considered to be exposed.

There are no widely accepted guidelines concerning the most relevant thresholds to adopt to identify the sectors that generate the greatest pressures on biodiversity and the greatest threats to species extinction. Consequently, the choice of thresholds is necessarily arbitrary. Nevertheless, the aim is to find the most relevant threshold according to the share of total pressures and total threats captured by the set of exposed sectors, while limiting their number to avoid overestimating countries' exposure.

After multiple sensitivity tests, varying both thresholds, we chose to implement a threshold of 5% for the share of threat on species and 10% for the share of each pressure on biodiversity (see Appendix 6.10 for sensitivity assessments). In other words, to be considered exposed, a sector must meet at least one of the following conditions:

- Either it generates at least 10% of a total given pressure on biodiversity in the country;
- Or it exerts at least 5% of the country's total species risk of extinction (STAR).

We opted for a more restrictive extinction risk threshold than the pressure threshold, because the STAR metric enables us to more directly represent the impact of an industry on biodiversity. Conversely, it is very difficult to ascertain to what extent and in which ways a given pressure will actually affect biodiversity in the end.

3.2. Socio-economic indicators

Cf. Section 2.2.

Box 3. Example: Transition risk methodology application to South Africa

When applied to South Africa, the method to assess nature related transition risk shows that the electric power generation, transmission, and distribution sector is a major source of environmental emissions, accounting for 67% of SO_2 emissions, 43% of NO_X emissions, and 43% of GHG emissions. Additionally, the land use pressure in the country is primarily driven by three key sectors: Raising sheep and goats (61%), forestry and logging (23%) and cattle ranching (10%). The growing fruits and nuts sector is the main contributor to NH_3 emissions, generating 40% of this particular pressure. Furthermore, the growing leguminous crops and oilseeds generate 20% of the total water consumption pressure (Fig E4).

	GHG	Land use	NH3	NOX	SO2	STAR	Water
Raising of sheep and goats	0.63	61.37	1.09	0.24	0.01	4.22	5.07
Raising of cattle	4.01	10.6	0.83	0.03	0	4.29	0.87
Materials recovery	0.98	0	0.1	0.01	0.01	5.1	0
Hard coal	6.1	0	8.28	10.33	10.45	9.37	0
Growing sugar beet and cane	0.01	0.29	0.32	0.02	0	0.81	11.7
Growing leguminous crops and oil seeds	0.05	0.37	1.44	0.08	0	2.11	20.26
Growing fruits and nuts	1.24	0.43	40.44	2.28	0.06	7.86	6.03
Growing crops n.e.c.	0.02	0	0.46	0.03	0	1.95	13.87
Forestry and logging	0.07	23.64	0.3	0.04	0.01	14.53	0
Electric power generation, transmission and distribution	43.68	0	0.03	43.44	67.69	3.4	7.27
Civil engineering construction	1.57	0	0.36	1.28	1.64	6.49	0
Air transport	0.82	0	3.02	22.11	0.06	0.15	0
TOTAL	59.18	96.7	56.65	79.89	79.94	60.27	65.07

Fig E4. Share of pressures generated by sectors in South Africa.

South Africa is moderately exposed to an ecological transition across all the socio-economic indicators considered in this assessment, indeed industries with the highest pressures on biodiversity generate 12% of net exports, 11% of employment, 9% of wages, 9% of wages, and 8% of net taxes and production (Fig E5).

Moreover, a transition targeting a reduction in SO_2 and NH_3 emissions, as well as the contribution of sectors to the risk of species extinction would expose South Africa's economy the most (Fig E5). The hard coal sector is by far exposing the country the most, accounting for 8% of net exports. This sector contribute to a large portion of NO_X, SO_2 and STAR pressures. It is therefore crucial for the country to assess whether this sector can adapt to an ecological transition or explore opportunities for diversifying its tax revenue sources and export industries. Moreover, some sectors, such as raising sheep and goats, growing fruits and nuts, or air transport, for example, exert significant pressure on biodiversity but do not contribute substantially to the country's key socio-economic aggregates. If more detailed subnational analyses confirm this observation, it could be beneficial to prioritize the pressure reduction of these sectors in order to minimize the country's economic impact while slowing down biodiversity loss (Fig E5).

	Net exports	Net taxes	Production	Demand	Employment	Wages	
Raising of sheep and goats	0.27	0.18	0.64	0.01	0.32	0.19	Land use
Raising of cattle	0.01	0.15	0.24	0.2	0.04	0.02	Land use
Materials recovery	0.62	0.12	0.08	0.15	0.89	0.27	STAR
Hard coal	7.58	1.12	1.39	0.02	1.27	1.58	STAR, NOX, SO2
Growing sugar beet and cane	0	0.04	0.05	0.06	0.01	0.01	Water
Growing leguminous crops and oil seeds	0.02	0.07	0.05	0.08	0.06	0.03	Water
Growing fruits and nuts	1.86	0.48	0.36	0.56	1.75	0.92	STAR, NH3
Growing crops n.e.c.	0	0.02	0.03	0	0.02	0.01	Water
Forestry and logging	0.03	0.02	0.05	0.01	0.05	0.03	STAR, Land use
Electric power generation, transmission and distribution	0.33	2.14	2.27	1.64	2.14	2.3	GHG, NOX, SO2
Civil engineering construction	0.32	3.54	2.71	4.44	4.05	3.59	STAR
Air transport	1.21	0.54	0.5	0.55	0.48	0.52	NOX
TOTAL	12.25	8.42	8.36	7.72	11.07	9.48	

Fig E5. Share of socio-economic indicators generated by sectors exposed to an ecological transition in South Africa (with the corresponding source of pressure responsible for the exposure listed in the right-hand column).

4. CONCLUSION

This method enables a preliminary assessment of nature-related country risk based on the principle of double materiality, in alignment with the recommendations of the European Corporate Sustainability Reporting Directive (CSRD), the Taskforce on Nature related

Financial Disclosure (TNFD) reporting framework and the 2024 Network for Greening the Financial System (NGFS) conceptual framework to guide Action by Central Banks and Supervisors.

While the method has limitations — notably the omission of certain pressures (such as resource exploitation, invasive species, and specific forms of pollution) and the exclusion of some ecosystem services (particularly cultural and well-being services) — these gaps stem from the current lack of robust, dedicated, and open-access data sources.

Nevertheless, in the face of the accelerating biodiversity crisis, this approach provides a pragmatic basis for immediate action. It enables to identify the economic sectors in which we should conduct more in-depth risk analysis by gathering ad-hoc information relating to the environment, economic sectors and environmental or transition policies of the countries concerned. This is a valuable tool for informing nature-related risk analysis, though it should not be considered a comprehensive or sufficient method for risk scoring on its own.

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6. APPENDIX

6.1. Databases

6.1.1. ENCORE

The Exploring Natural Capital Opportunities, Risks And Exposure (ENCORE)[14] tool version 2024[15] was developed by Global Canopy, the UN Environment Programme Finance Initiative (UNEP-FI), and the UN Environment Programme World Conservation Monitoring Centre (UNEP-WCMC). It offers a range of datasets to support financial institutions and companies in assessing both their dependencies on nature and their environmental impacts. In terms of dependencies, links between economic sectors and ecosystem services were established through an extensive literature review of each ecosystem service and relevant production processes, supplemented by interviews with sector-specific experts. ENCORE assigns five levels of materiality to the potential dependencies[16] of 615 NACE sectors on 25 ecosystem services, thereby helping assess the extent to which production processes could be disrupted by the degradation of these services (see Table A1 for a description of the ecosystem services included).

While the database has not undergone scientific peer review and its methodology is not fully transparent on the ENCORE website[17], it remains the only comprehensive data source currently available that covers dependencies across all economic sectors. However, the list of ecosystem services is not exhaustive, and the tool is not geographically specific—meaning it applies uniform dependency assessments globally, despite variations in production processes and ecosystem reliance across regions. Furthermore, ENCORE does not account for cross-dependency effects between ecosystem services. As such, the tool is intended for preliminary screening only and should be complemented with spatially explicit, sector-specific analyses for more robust decision-making.

Ecosystem service	Definition	Analyzed in this tool
Biomass provisioning	Ecosystem's contributions to the production of organic matter usable by humans. They include the growth of crops, forage, trees and other natural or cultivated biomass for various uses such as food, fiber and energy.	✓
Water supply	Contributions of ecosystems to flow regulation, water purification and other processes, providing water of appropriate quality for a variety of uses, including household consumption.	✓

14 ENCORE Partners (Global Canopy, UNEP FI, and UNEP-WCMC) (2025). ENCORE: Exploring Natural Capital Opportunities, Risks and Exposure. [On-line], Cambridge, UK: the ENCORE Partners. Available at: https://encorenature.org . DOI: https://doi.org/10.34892/dz3x-y059.

15 The link between ecosystem services in the 2018-2023 and 2024 versions is explained in Appendix 6.2.

16 For the sake of simplicity, and because we do not know to what extent sectors can adapt to a physical shock, we are going to talk about ‘dependency’ instead of ‘materiality of potential dependency’.

17 See ENCORE’s Explanatory note, FAQ and Knowledge base: https://encorenature.org/en/data-and-methodology/methodology

Global climate regulation	Contributions of ecosystems to regulating the chemical composition of the atmosphere and oceans, thereby influencing global climate through the accumulation and retention of carbon and other greenhouse gases (GHGs) such as methane. These services also include the capacity of ecosystems to remove (sequester) carbon from the atmosphere.	✓
Local climate regulation	Contributions of ecosystems to the regulation of ambient atmospheric conditions, including micro-scale and meso-scale climates, through the presence of vegetation that improves people's living conditions and supports economic production. For example, urban trees (“green spaces”) provide cooling through evapotranspiration, while urban water bodies (“blue spaces”) play a crucial role in regulating local climatic conditions.	✓
Rainfall pattern regulation	Ecosystem contributions of vegetation, particularly forests, to the maintenance of precipitation regimes by evapotranspiration on a sub-continental scale. Forests and other vegetation recycle atmospheric moisture, making it available for precipitation generation. Precipitation in the interior parts of continents is largely dependent on this recycling.	✓
Soil quality regulation	Contributions made by ecosystems to the decomposition of organic and inorganic matter, as well as to soil fertility and characteristics, promoting biomass production, for example.	✓
Soil and sediment retention	Ability of vegetation and other natural elements to reduce soil and sediment loss, limiting erosion and supporting various human activities such as agriculture. In addition, this stabilization helps to mitigate potential landslides, which also protects buildings, infrastructure and people from damage associated with mass movements of soil, rock and snow.	✓
Solid waste remediation	Ecosystem's contributions to the transformation of organic or inorganic substances, through the action of micro-organisms, algae, plants and animals that mitigate their harmful effects.	✓
Water purification	Contribution of ecosystems to restoring and maintaining the chemical quality of surface water and groundwater. These processes include the decomposition of nutrients and other pollutants by living organisms, as well as other mechanisms that reduce contaminant levels. These actions protect human health and support aquatic biodiversity.	✓
Water flow regulation	Ecosystem services by which ecosystems contribute to moderating and stabilizing river, groundwater and lake flows. This results from their capacity to absorb, store and gradually release water, thus regulating flows during dry or evapotranspiration periods, and attenuating flow peaks during periods of intense precipitation. These services are essential for maintaining a regular flow of water and reducing the risks associated with flooding and other extreme hydrological events.	✓
Flood control	Ecosystem services provided by riparian vegetation and other natural elements that act as physical structures and natural barriers against high water levels. These services reduce the impacts of flooding by limiting the speed and volume of water, thus protecting local communities from damage caused by flash or prolonged flooding.	✓

Storm mitigation	Contributions of vegetation, including linear features (such as hedgerows, woodland strips, or rows of trees planted along roadsides), in mitigating the impacts of wind, sand and other storms (excluding water-related events) on local communities.	✓
Pollination	Contributions of wild pollinators to crop fertilization, maintaining or increasing the abundance and diversity of species used or valued by economic units.	✓
Biological control	Services provided by ecosystems to reduce the presence of pest species, helping to prevent or reduce the effects of pests on biomass production and other economic activities, as well as on human health.	✓
Nursery population and habitat maintenance	Ecosystem contributions needed to maintain species populations that economic units come to use or value, either by maintaining habitats (e.g. for breeding or migration), or by protecting natural gene pools.	✓
Genetic material	Ecosystem contributions from all biota (including seed, spore or gamete production) that are used by economic units, for example (i) to develop new animal and plant breeds; (ii) in gene synthesis; or (iii) in product development directly using genetic material.	✓
Air filtration	Contributions of ecosystems to the filtering of atmospheric pollutants through the deposition, absorption, fixation and storage of pollutants by ecosystem components, particularly plants, which mitigate the harmful effects of pollutants.	✓
Mediation of sensory impacts other than noise	Vegetation is the main natural barrier used to reduce light pollution and other sensory impacts, thus limiting their impact on human health and the environment.	X
Noise attenuation	Ecosystem's contribution to reducing the impact of noise on people, thereby reducing the harmful or stressful effects of environmental noise. Vegetation is the main natural barrier used to reduce light pollution and other sensory impacts, thus limiting their impact on human health and the environment.	X
Animal-based energy	Physical labor is provided by domestic or commercial species, such as oxen, horses, donkeys, goats and elephants. These animals can be grouped into three categories: draught animals, pack animals and mounts.	X
Dilution by atmosphere and ecosystems	Water, both fresh and saline, and the atmosphere can dilute the gases, fluids and solid waste produced by human activity.	X
Recreation	Ecosystem contributions, in particular through the biophysical characteristics and qualities of ecosystems, that enable people to use and enjoy the environment through direct, in-situ, physical and experiential interactions with the environment. This includes services to both locals and non-locals (i.e. visitors, including tourists). Recreation-related services may also be supplied to those undertaking recreational fishing and hunting.	X
Visual amenity	Ecosystem contributions to local living conditions, in particular through the biophysical characteristics and qualities of ecosystems	X

	that provide sensory benefits, especially visual. This service combines with other ecosystem services, including recreation-related services and noise attenuation services to underpin amenity values.	
Education, scientific and research	Ecosystem contributions, in particular through the biophysical characteristics and qualities of ecosystems, that enable people to use the environment through intellectual interactions with the environment.	X
Spiritual, artistic and symbolic	Spiritual artistic and symbolic services are the ecosystem contributions, in particular through the biophysical characteristics and qualities of ecosystems, that are recognised by people for their cultural, historical, aesthetic, sacred or religious significance. These services may underpin people's cultural identity and may inspire people to express themselves through various artistic media. This is a final ecosystem service.	X

Table A1. Description of ecosystem services in ENCORE.

6.1.2. GLORIA

Global Resource Input-Output Assessment (GLORIA) is a Multi-Regional Input-Output Environmentally Extended (EE-MRIO) database developed using the IELab infrastructure by the University of Sydney, commissioned by the UN International Resource Panel (UN IRP)[18]. GLORIA was originally created to support the update of material footprint accounts, which form a key part of the UN IRP Material Flows Database. To maximize synergies among various United Nations Environment Programme (UNEP) initiatives, GLORIA was also adopted as the underlying MRIO framework for the Sustainable Consumption and Production Hotspots Analysis Tool (SCP-HAT).

An MRIO table compiles national input-output data from multiple countries and regions into a coherent global matrix, representing the economic transactions and intersectoral dependencies across borders. It captures how goods and services produced in one sector or country are used as inputs in others, allowing for the tracing of value chains and the mapping of global economic interconnections. The environmentally extended framework integrates satellite accounts that complement the economic data with social and environmental dimensions. On the social side, satellite accounts include information on employment—such as the number of jobs, hours worked, and, in some cases, disaggregation by gender, education level, or income group. On the environmental side, they cover biophysical resource inputs (e.g. energy, water, land use) and outputs such as emissions and waste (e.g. greenhouse gases, air and water pollutants).

Our analysis is based on the 2019 edition (v059a) of the GLORIA database, which includes 120 sectors, 164 countries and 6130 satellite indicators. Although more recent years exist, they are currently considered unsuitable due to the profound disruptions caused by the COVID-19 pandemic, which significantly altered national and international economic patterns. However, as more recent years of the GLORIA database become available, they can be

[18] https://ielab.info/resources/gloria/about

incorporated into this methodology. Likewise, our approach can be adapted for retrospective analyses using the earlier release of GLORIA.

The methodology could also be easily replicated using other EE-MRIO tables, such as EXIOBASE—which offers greater sectoral detail but covers fewer countries, making it particularly suitable for analyzing middle- and high-income economies—or EORA, which includes more countries but features fewer sectors. This methodology is presented using the GLORIA database, which has been selected due to its broader country coverage, better meeting the evaluation needs of a wider range of potential users.

Moreover, although GLORIA harmonizes national statistics, inherent disparities in data quality, reporting standards, and estimation methodologies across countries may introduce systematic biases. Several environmental pressure indicators are derived from generalized estimates rather than direct measurements, potentially affecting their reliability. Furthermore, the technical documentation[19] concerning the satellite accounts lacks full transparency, particularly with regard to the construction of environmental pressure indicators and the methods used for sectoral downscaling, which are not comprehensively explained.

6.2. Correspondence between ecosystem services in the ENCORE 2018-2023 and the 2024 version

ENCORE 2018-2023 version (21 services)	ENCORE 2024 version (25 services)
CICES V4.3 (2013) classification	UN SEEA-EA (2021) classification
Animal-based energy	Animal-based energy
Fibres and other materials	Biomass provisioning
Bio-remediation	Solid waste remediation
Buffering and attenuation of mass flows	Soil and sediment retention
Mass stabilisation and erosion control	
Water quality	Water purification
Soil quality	Soil quality regulation
Dilution by atmosphere and ecosystems	Dilution by atmosphere and ecosystems
Disease control	Biological control
Pest control	
Filtration	Water purification
	Air Filtration
Ventilation	
Flood and storm protection	Flood control
	Storm mitigation
Genetic material	Genetic material
Climate regulation	Global climate regulation
	Local climate regulation

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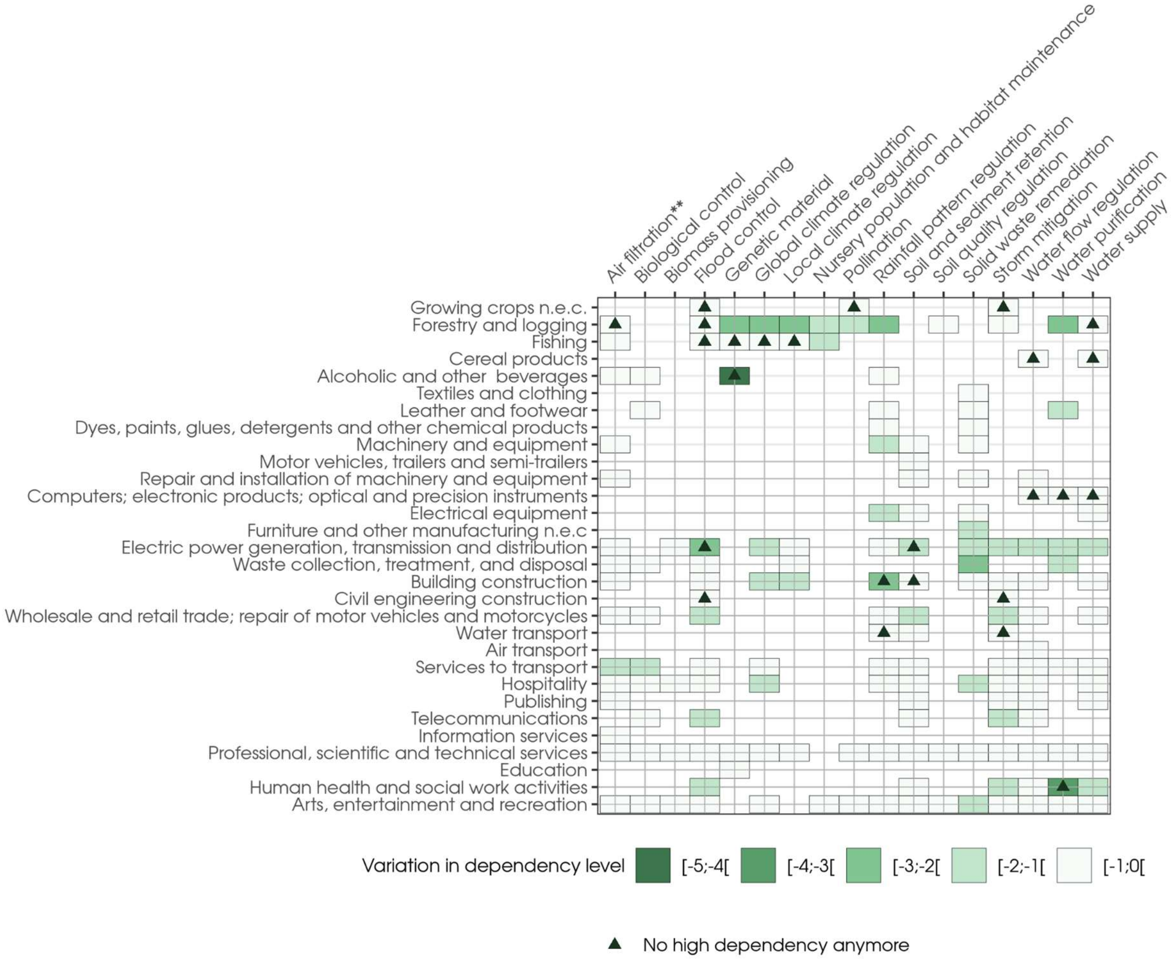
Surface water	Water supply
Ground water	
Nursery population and habitat maintenance	Nursery population and habitat maintenance
Mediation of sensory impacts	Noise attenuation
	Mediation of sensory impacts (other than noise)
Pollination	Pollination
Water flow regulation	Water flow regulation
	Rainfall pattern regulation
	Recreation related services
	Visual amenity services
	Education, scientific and research services
	Spiritual, artistic and symbolic services

6.3. Construction of an alternative matrix of dependencies on ecosystem services

The dependency of GLORIA sectors on ecosystem services is calculated using the average of the dependencies of the NACE sectors that best characterize them. In this section, two alternative calculation methods are tested: the minimum and the maximum dependency.

As a result, 25 dependencies are no longer considered very high (i.e. score > 3) in the analysis using the method of minimum values rather than the method of averages (Figure A1). In addition, the forestry and logging sector was the only one relying heavily on the ecosystem service of air filtration: it is no longer the case with the minimum method, meaning that this ecosystem service will no longer be a source of exposure. Alternatively, when we use the maximum values method, 28 dependency links become very strong (i.e. score > 3) compared to the averages method (Figure A2). For example, the forestry and logging sector become highly reliant on genetic material and climate regulation with this method.

However, these two methods do not significantly alter the number of strong dependency links attributed to sectors in the analysis. Out of the 433 strong dependency links identified using the average method, the minimum and maximum methods result in only about twenty more or fewer links, respectively. That said, the overall share of socio-economic indicators generated by industries highly exposed to a physical shock does vary across the three methods (Figure A3). The minimum method tends to underestimate countries' exposure through final demand, production, and taxes (with the median increasing by 10 percentage points compared to the average method). In contrast, the maximum method tends to overestimate exposure, particularly in terms of wages and employment (with the median increasing by 1 and 17 percentage points, respectively, compared to the average method).



** No economic sector is highly dependent on this ecosystem service using the minimum dependency method.

Figure A1. Using the minimum ecosystem service dependency method to aggregate GLORIA's economic sector dependency levels. The graph highlights the sectors where dependency levels differ from the mean method, with color intensity indicating the degree of variation. Triangles represent sectors where dependency, previously x>3 with the mean method, has dropped below x≤3 using the minimum dependency method.

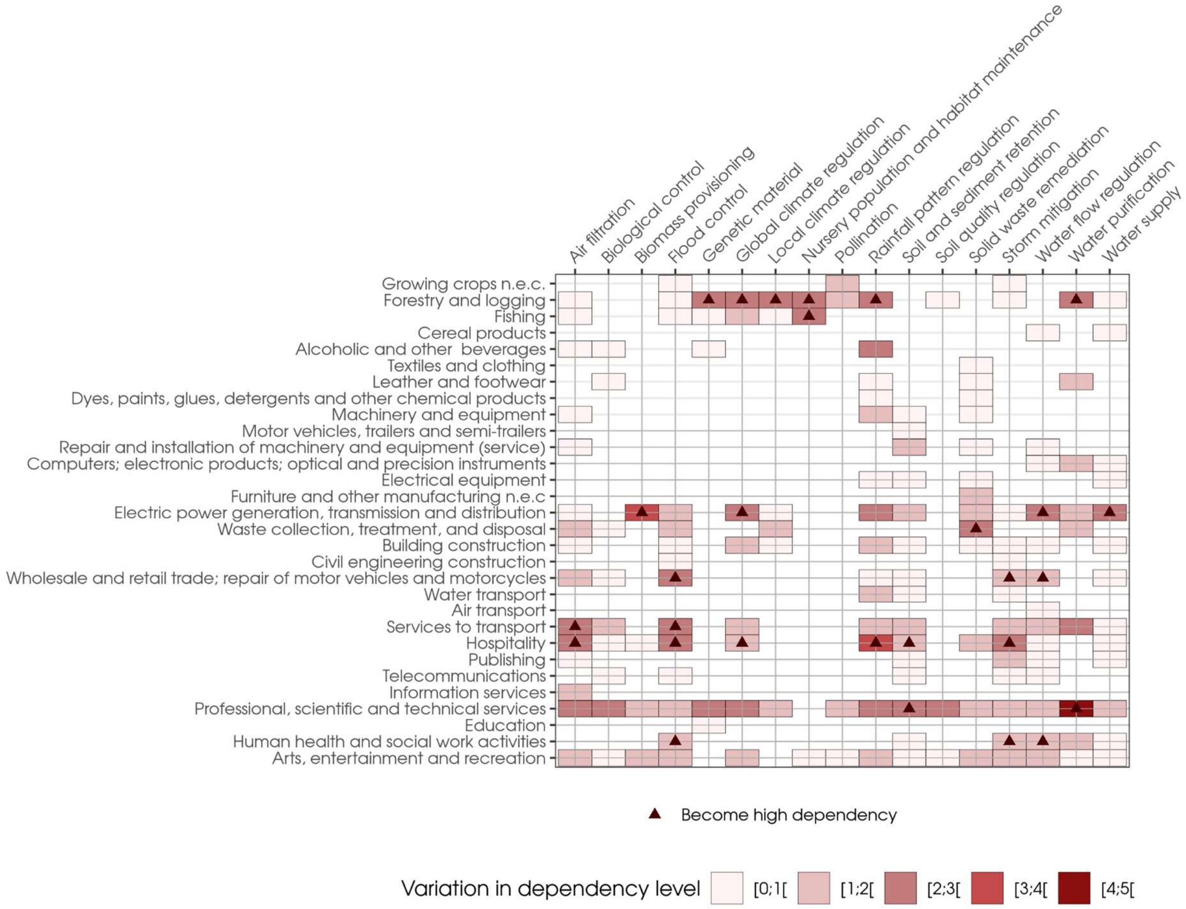


Figure A2. Using the maximum ecosystem service dependency method to aggregate GLORIA's economic sector dependency levels. The graph highlights the sectors where dependency levels differ from the mean method, with color intensity indicating the degree of variation. Triangles represent sectors where dependency, previously x≤3 with the mean method, has increased to at least x>3 using the minimum dependency method.

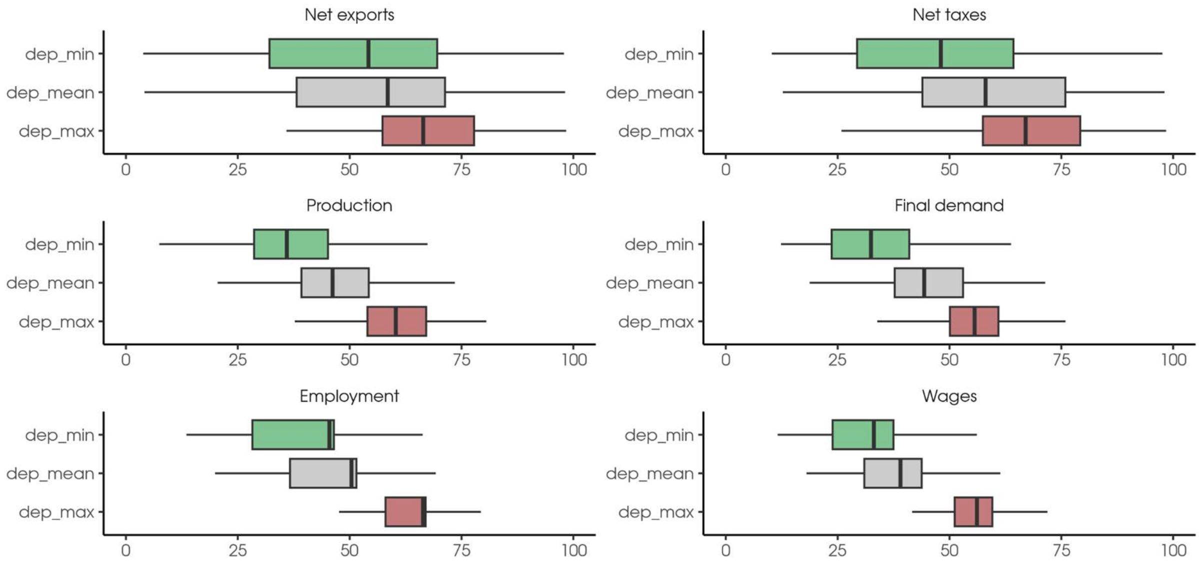


Figure A3. Share of socio-economic indicators generated by sectors with at least a high dependency on an ecosystem service, according to the three methods.

6.4. Estimation of income taxes

In the GLORIA EE-MRIO database, it is possible to directly obtain taxes and subsidies on production from the value-added (VA) matrix. These taxes represent all taxes that sectors incur as a result of engaging in production, regardless of the quantity or value of the goods and services produced or sold. Taxes and subsidies on products can be calculated from the transaction matrix (T) and the final demand matrix (FD) using GLORIA's valuations Markup_004 and Markup_005. These taxes are levied per unit of a good or service produced or transacted. They may be a fixed amount per unit or calculated ad valorem as a specified percentage of the price or value of the goods and services produced or transacted, and they include, notably, value-added taxes (VAT).

In addition to products and production taxes, some sectors may contribute more to a country's total revenue than others, depending on the varying tax rates on profits and wages. However, for most countries considered, sector-specific data on taxes levied on profits and wages are unavailable. To address this, we adopt the method outlined in Magacho et al. (2023), which assumes that taxes on profits and wages are uniform across sectors within each country. This approach includes both taxes on profits and taxes on wages, which also encompass social contributions. Based on the Government Finance

Statistics (GFS/IMF)[20], we estimate the sectoral tax contributions on profits and wages using the following formula:

$$Income\ taxes_s \quad = \frac{ProfTaxes}{Profits} * Profits_s + \frac{WageTaxes}{Wages} * Wages_s$$

Where *s* represents a specific sector, *ProfTaxes* and *WageTaxes* refer to the taxes on profits and wages (plus social contribution), respectively (from the GFS/IMF database), and *Profits* and *Wages* are the total profits[21] and total wages[22], respectively.

Taxes from the GFS/IMF are provided either in local currency or as a percentage of GDP. To avoid discrepancies due to exchange rates with the GLORIA EE-MRIO database, which are expressed in 1,000 USD, we have chosen to work with the GDP share unit. To convert the taxes in percentage of GDP into 1,000 USD, we multiplied it by the GDP[23] calculated with GLORIA.

By summing the taxes on production, products and income, we can then determine the sectoral direct contribution to net taxes.

However, for some countries, taxes on profits, wages, or social contributions are not recorded in the GFS/IMF database. The number of countries covered by our method is detailed in Figure A.4. Specifically, 123 out of 164 countries have reported data on profit taxes and 121 out of 164 countries have reported data on wage taxes, enabling us to estimate the share of specific taxes paid by their sectors. For the 96 countries with complete data on social contributions, these contributions were added to the wage taxes.

Moreover, since our study is based on economic data from 2019, we have also used tax data from the GFS/IMF for that year. However, for countries where data for 2019 was unavailable, we relied on data from a slightly earlier or later year to maximize the number of countries analyzed. The countries affected are listed in Table A.2. It is important to note that our tool does not compare countries directly but instead applies a screening method within each country. Therefore, the lack of comparability across countries is not an issue. However, it remains essential to understand the composition of the net taxes for each country in order to interpret it accurately.

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20 International Monetary Fund. 2024. *Government Finance Statistics (GFS), Revenue*. Accessed April 2, 2025. https://data.imf.org/?sk=774B4DC8-18E8-49F3-9F37-3A67EF9A9F62.

21 Profits are calculated by summing three components from the value-added (VA) matrix: net operating surplus (B.2n), net mixed income (B.3n), and consumption of fixed capital (K.1). The exact nature of mixed income is open to discussion. It is mostly related to self-employed workers which can have a "wage" component and a "profit" component (related to the owning of capital). In many countries it is also connected to informal revenues, which can be again of both nature (wage or profits). For the sake of simplicity we allocate all of mixed income to profits.

22 It refers to the compensation of employees (D.1) as recorded in the value-added (VA) matrix.

23 The GDP is calculated by summing all the components of the value-added (VA) matrix, which includes: net operating surplus (B.2n), net mixed income (B.3n), consumption of fixed capital (K.1), compensation of employees (D.1), taxes on production (D.29), and subsidies on production (D.39).

ISO	Country	Year used to calculate taxes on profits	Year used to calculate taxes on wages	Year used to calculate social contributions
AFG	Afghanistan	2017	2017	2017
ARM	Armenia	2019	2019	2015
BLZ	Belize	2019	2019	2016
EGY	Egypt	2015	2015	2019
GIN	Guinea	2023	2023	2019
GMB	Gambia	2018	2018	2019
IND	India	2018	2018	2018
PAN	Panama	2019	2019	2018
PHL	Philippines	2019	2019	2017
SAU	Saudi Arabia	2019	2017	2019
SLE	Sierra Leone	2018	2018	2019
SOM	Somalia	2019	2019	2023
TJK	Tajikistan	2022	2022	2022
ZWE	Zimbabwe	2018	2018	2018

Table A.2. Time series datasets used to approximate income taxes.

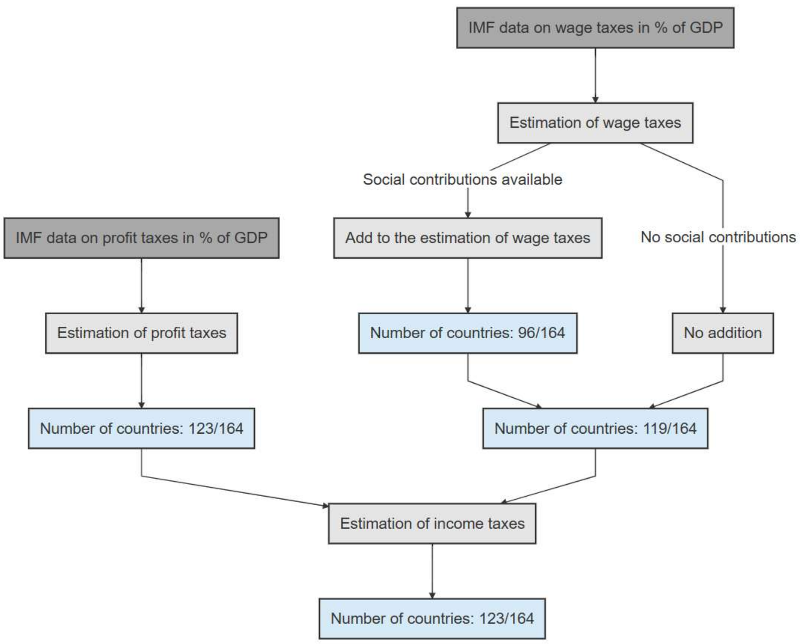


Figure A4. Diagram illustrating the approach used to estimate income taxes paid by corporations and individuals.

6.5. Updating the capacity matrix with the SEEA-EA ecosystem services

Initially designed to analyze capacity of land covers to provide the ecosystem services of the 2018-2023 version of ENCORE, the tool developed with Biotope had to be adapted to match the 2024 version of ENCORE, which uses the SEEA-EA classification of services. The changes adopted concern the scores of the land-cover and ecosystem service capacity matrix, and the table below presents our modifications for each ecosystem service.

Ecosystem services	Changes implemented
Animal-based energy	No change. Scores have already been established for the ecosystem service of animal-based energy.
Biomass provisioning	Use of the scores originally implemented for the ecosystem service of fibers and other materials, given the similarity between these two services.
Solid waste remediation	Use of bio-remediation scores determined in the first version of the tool.
Soil and sediment retention	Average of the scores for the ecosystem services of mass stabilization and erosion control and the buffering and attenuation of mass flows, since soil and sediment retention is a fusion of these two services.
Water purification	Use of previously established water quality scores.
Soil quality regulation	No changes. Scores have already been established for the ecosystem service of soil quality.
Dilution by atmosphere and ecosystems*	No changes. Scores have already been established for the ecosystem service of dilution by the atmosphere and ecosystems.
Biological control	Given that the scores for disease control and pest control were the same, and that the biological control service is a fusion of these two services, we have retained the scores initially established.
Air filtration	Use of scores linked to the filtration service initially established, since in both cases it involves the filtering, sequestration and storage of pollutants by ecosystem components.
Flood control	Scores for the capacity to provide the ecosystem service of flood and storm protection have been proposed. We have adapted these scores to correspond more closely to flood protection, by reducing the vegetation-related scores.
Storm mitigation	Scores for the capacity to provide the ecosystem service of flood and storm protection have been proposed. We have adapted these scores to correspond more closely to storm protection, reducing the scores for inland waters and slightly for wetlands.
Genetic material*	No modifications. Scores have already been established for the ecosystem service of genetic materials.
Global climate regulation	Use of the climate regulation scores previously established.
Local climate regulation	Use of the climate regulation scores previously established.

Water supply	Average of surface water[24] (which in turn is the average of groundwater, water flow and water quality) and groundwater scores initially established.
Nursery population and habitat maintenance	No change. Scores have already been established for the ecosystem service of nursery population and habitat maintenance.
Noise attenuation	Use of mediation of sensory impacts scores determined in the first version of the tool.
Mediation of sensory impacts other than noise	Use of mediation of sensory impacts scores determined in the first version of the tool.
Pollination	No changes. Scores have already been established for the ecosystem service of pollination.
Water flow regulation	No changes. Scores have already been established for the ecosystem service of water flow regulation.
Rainfall pattern regulation	Creation of new scores based on the service definition. These scores are similar to those for the climate regulation service and storm and flood protection, and enhance the value of areas linked to the presence of vegetation.
Recreation	Cultural services could not be integrated into the tool, as their provision depends more on local and cultural characteristics than on land cover.
Visual amenity	
Education, scientific and research	
Spiritual, artistic and symbolic	

24 The methodology initially developed with Biotope was inadequate for analyzing the **surface water ecosystem service**. Given that this service is only provided by wetlands and inland waters, and that these land covers are very limited on a national scale, surface water scores were extremely low for all countries. On the basis of a literature review carried out by Biotope experts, we decided to modify the surface water score by averaging the scores of the ecosystem services that help deliver this service, namely the water flow regulation service, the groundwater service and the water purification service.

6.6. Calibration of biodiversity indicators

The three biodiversity metrics were converted to a discrete scale from 1 to 4 using Jenks optimization method (Table A3). Also known as Jenks natural breaks classification, this method is a data clustering technique designed to determine the optimal arrangement of values into different classes. It does so by minimizing the average deviation within each class while maximizing the differences between class means. In other words, the method aims to reduce variance within classes and maximize variance between them.

BIODIVERSITY INTACTNESS INDEX		
	Score	**Interpretation**
[0,856;1]	1	Good condition
[0,707;0,856[	2	Average condition
[0,545;0,707[	3	Poor condition
[0;0,545[	4	Very poor condition
ECOREGIONS		
	Score	**Interpretation**
Stable/Intact	1	Good condition
VU OU (Stable/Intact + G200)	2	Average condition
VU + G200	3	Poor condition
CR/EN OU CR/EN + G200	4	Very poor condition
PROTECTED AREA CONNECTEDNESS INDEX		
	Score	**Interpretation**
[0,583;1]	1	Good condition
[0,413;0,583[	2	Average condition
[0,174;0,413[	3	Poor condition
[0;0,174[	4	Very poor condition

Table A3. Discretization of biodiversity indicators.

6.7. Ecosystem services and natural assets

Service	Assets
Animal-based energy	Habitats
Solid waste remediation	Habitats/Species
Global climate regulation	Habitats
Local climate regulation	Habitats
Dilution by atmosphere and ecosystems	Habitats
Biological control	Habitats/Species
Biomass provisioning	Habitats/Species
Storm mitigation	Habitats
Flood control	Habitats
Genetic material	Species
Water supply	Habitats
Nursery population and habitat maintenance	Habitats

Soil and sediment retention	Habitats
Mediation of sensory impacts other than noise	Habitats
Noise attenuation	Habitats
Pollination	Habitats/Species
Soil quality regulation	Habitats/Species
Air filtration	Habitats/Species
Rainfall pattern regulation	Habitats
Water flow regulation	Habitats
Water purification	Habitats

Table A4. Natural assets that enable the provision of ecosystem services.

6.8. Abatement technique

We perform an exponential abatement technique to modulate the capacity of the ecosystems to provide services as shown in Figure A.5.

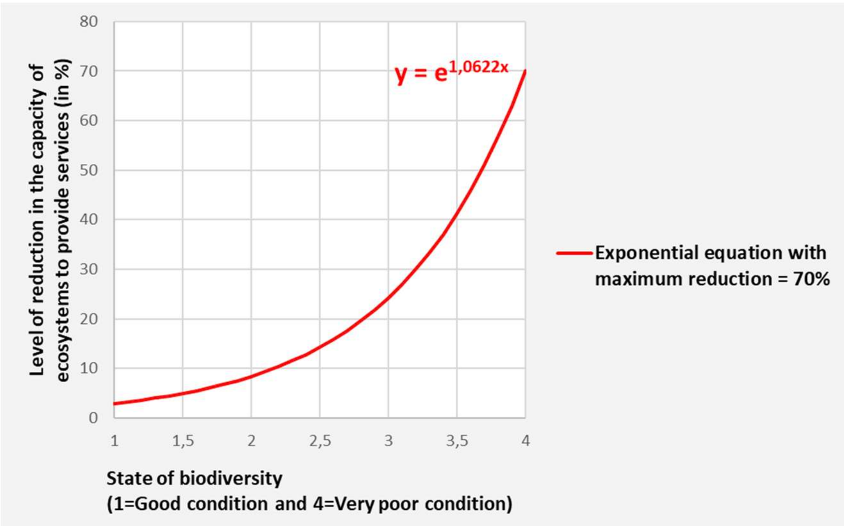
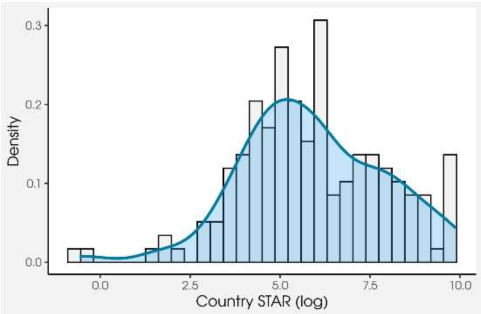


Figure A.5. Abatement method chosen to reduce scores for country capacity to provide ecosystem services.

6.9. STAR vs. PDF

The Species Threat Abatement and Restoration (STAR) metric is a unit-less indicator based on data from the IUCN Red List of Threatened Species. With the refinements applied in our analysis, STAR can be used to assess the extent to which economic sectors are likely to impact species in a given country.

At the national level, STAR values range from 0.57 (in Malta) to 19,502.78 (in Madagascar), with an average of 1,930.36 (see Figure A.6). The countries with the highest STAR scores are Madagascar, Ecuador, Mexico, and Colombia. However, it is important to note that the indicator does not account for species that have already gone extinct. Consequently, a country that has lost most of its native biodiversity may record a very low STAR score. Yet, in such cases, protecting the remaining species is even more critical—making it relevant to examine the relative share of STAR within countries. The more threatened species a country hosts, the higher its STAR value tends to be (unless many of them are categorized as Least Concern). It is also essential to interpret STAR with caution, as the IUCN Red List is not yet fully comprehensive. Several life groups remain underrepresented. In particular, marine species, reptiles, and trees are expected to be more systematically included in upcoming updates of the Red List, which will enhance the robustness and scope of the STAR metric in future analyses.



Mean	Median	Min	Max	CV
1 930.36	313.04	0.57	19 502.78	206.67

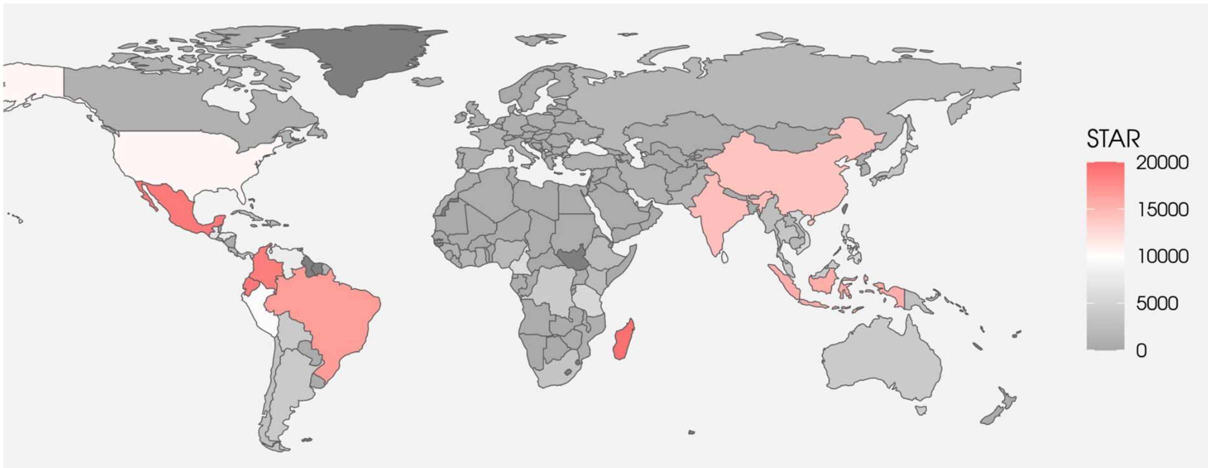
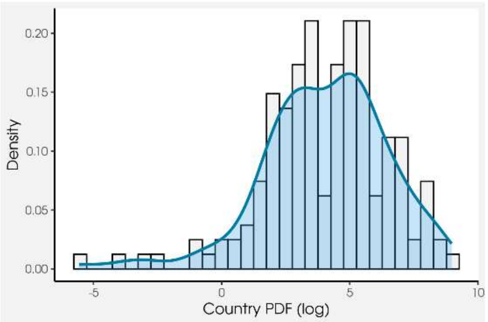


Figure A.6. STAR values at the country level.

Another commonly used biodiversity impact metric in sectoral analyses is the Potentially Disappeared Fraction of Species (PDF) (Verones et al., 2017). In the GLORIA framework, the PDF metric estimates the potential loss of species over a specific time horizon due to land use-driven habitat loss or degradation. Although we prefer to use the STAR metric, which is grounded in expert-based assessments rather than more theoretical estimates, the limited availability of comprehensive global biodiversity metrics means that none should be overlooked. For this reason, we have chosen to include a comparison between the two indicators in this section. Among all countries, Brazil has by far the highest PDF score (PDF = 7890.101), while the Kingdom of Bahrain has the lowest (PDF = 0.0044) (Figure A7). The global average PDF score is 430.449. Similar to the STAR results, the highest PDF values are concentrated in the Americas and parts of Asia and Oceania.



Mean	Median	Min	Max	CV
430.449	74.079	0.004	7890.101	1047.957

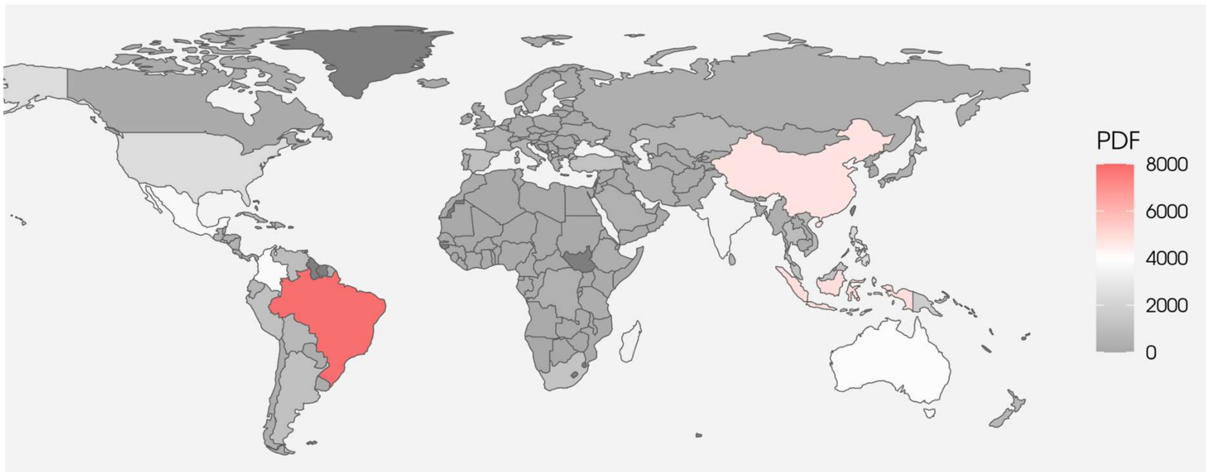
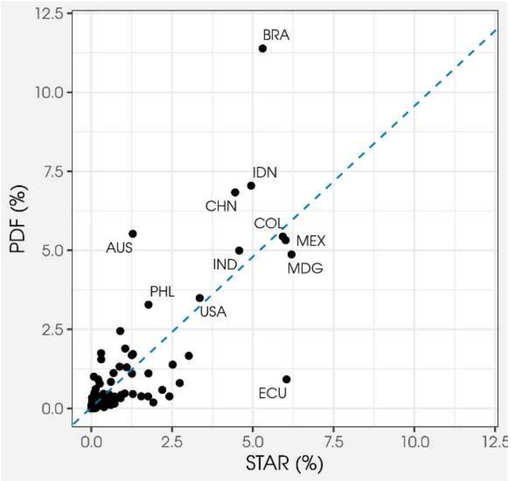


Figure A7. STAR values at the country level (express in micro-PDF*year).

When plotting STAR and PDF scores, we observe a strong correlation between the two metrics at the country level (Figure A8), despite the fact that PDF focuses exclusively on the agricultural sector, whereas STAR encompasses the full range of economic activities. This highlights the substantial role agriculture plays in driving biodiversity loss globally. To go beyond visual comparison, we conducted a Pearson correlation test to assess the statistical relationship between the two metrics. The results confirm a strong and significant correlation between PDF and STAR at the national level.



Statistique	Valeur
r de Pearson	0,804
t	17,136
p-value	< 2,2e-16
IC 95 %	[0,742 ; 0,852]

Figure A8. (Left) Correlation between STAR and PDF scores at the country level, expressed as the share of biodiversity impact generated by each country relative to the global total. (Right) Results of the Pearson correlation test between the two metrics.

According to the STAR metric, the economic sectors contributing most to extinction risk are primarily agricultural, but other sectors are also represented, including water treatment, machinery, electricity, and road transport (Figure A9). The sectors with the highest STAR impacts include forestry and logging, growing fruits and nuts, and civil engineering construction. In contrast, the PDF metric in GLORIA is limited to agricultural sectors. Its impacts are predominantly attributed to raising cattle and forestry and logging. Overall, aside from civil engineering construction, which has a high STAR impact but no associated PDF score, the sectors contributing most to biodiversity loss are broadly consistent across the two metrics.

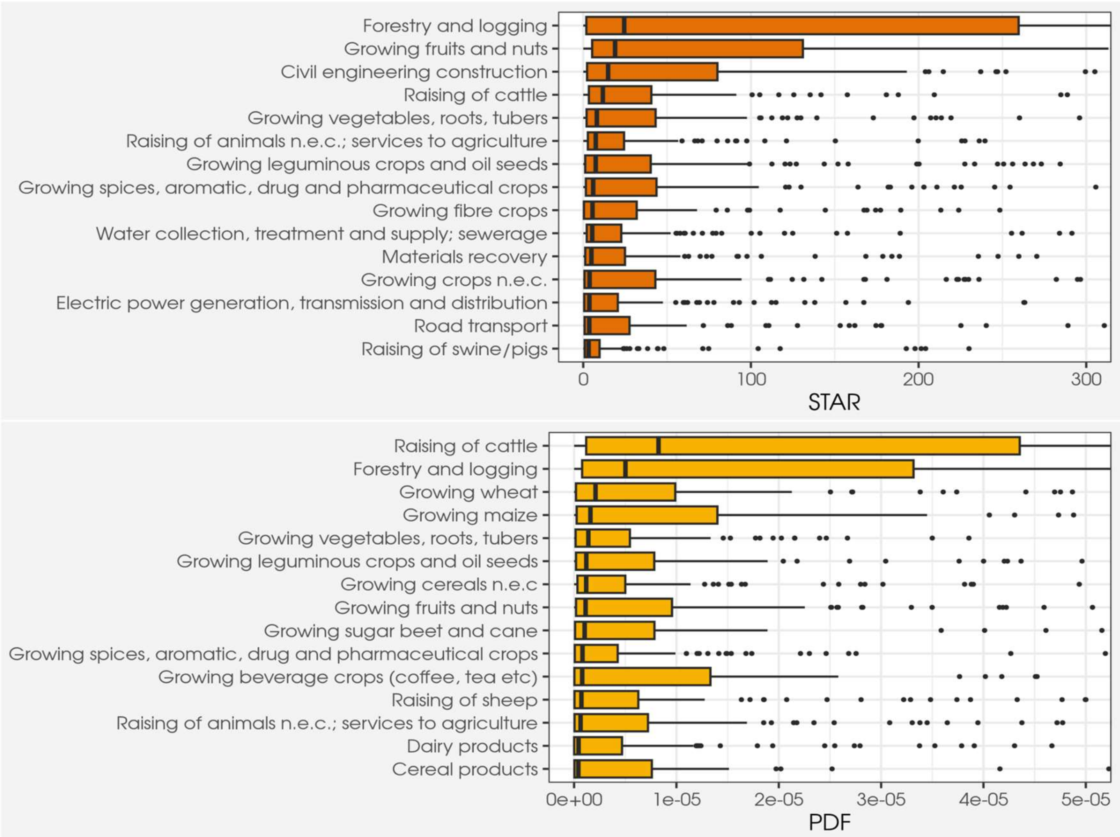


Figure A9. Distribution of STAR and PDF scores across economic sectors (boxplots).

On average, when PDF is included in the analysis of countries' exposure to transition risks, only 0.84 additional sectors per country are considered exposed to PDF, whereas they were not identified as such based on the other variables used so far (STAR and pressures). On average, the share of socio-economic indicators generated by exposed sectors increases by no more than 2%, although country-level variation can be significant—particularly for net taxes, where this share can range from 0% to around 27% depending on the country (Table A5). The country for which the inclusion of PDF alters the results the most is Mali, where the "growing of cereals" sector—responsible for a large share of net taxes—is exposed to PDF but not to the other indicators considered.

	Mean	Min	Max	Median	CV
Final demand	0.76	0	6.51	0.18	155.96
Employment	0.52	0	2.92	0.35	115.42
Net exports	0.28	0	2.98	0.09	166.94
Production	0.94	0	7.85	0.38	137.81
Net taxes	2.06	0	26.96	0.31	202.43
Wages	0.36	0	2.50	0.17	134.35

Table A5. Statistics on the share of socio-economic indicators generated by sectors that are exposed to PDF but not to other pressures (using a 5% threshold for PDF exposure).

6.10. Thresholds for transition risk exposure

In our methodology, transition risks capture national public policy changes in favor of biodiversity, as well as technological shifts and behavioral changes that may affect economic sectors responsible for the highest pressures on biodiversity. To estimate sectoral exposure to such shocks, we need to identify which sectors are likely to be affected. However, despite countries having signed international agreements aimed at reducing sectoral pressures, it remains difficult—if not impossible—to predict how these policies will be implemented at the national level.

As a simplification, we assume that sectors generating the highest pressures (as measured by available tools) at the country level are the most likely to face transition shocks. This assumption requires a clear definition of what constitutes "the highest pressures." Inevitably, an arbitrary choice must be made to filter and select the most relevant sectors.

To this end, we chose two criteria we consider relevant for identifying these sectors: (i) maximizing the total share of pressure captured by exposed sectors in a country, and (ii) minimizing the number of exposed sectors. These criteria led us to adopt a threshold of 10% for pressures and 5% for impacts on threatened species (i.e. STAR). On average, these thresholds allow us to capture, on average, 61.45% of the total pressure/impact while limiting the number of exposed sectors to 11.79 per country (Figure A10).

Regarding environmental pressures, the interquartile range (Q1–Q3) of the average share of total national pressure captured exceeds 50% for land use, NH_3, NO_X, SO_2, and water consumption (Figure A11). This level of coverage would not have been achieved with a higher threshold—even as low as 11%. In contrast, greenhouse gas (GHG) emissions are distributed across a wide range of sectors. As a result, in many countries, the list of exposed sectors fails to capture more than 50% of total GHG pressure, regardless of the threshold applied.

For the STAR indicator, using a 5% threshold allows for capturing a median share of STAR pressure above 50%, while also keeping the number of exposed sectors relatively low (Figure A12). With this threshold, the median number of exposed sectors per country is limited to five.

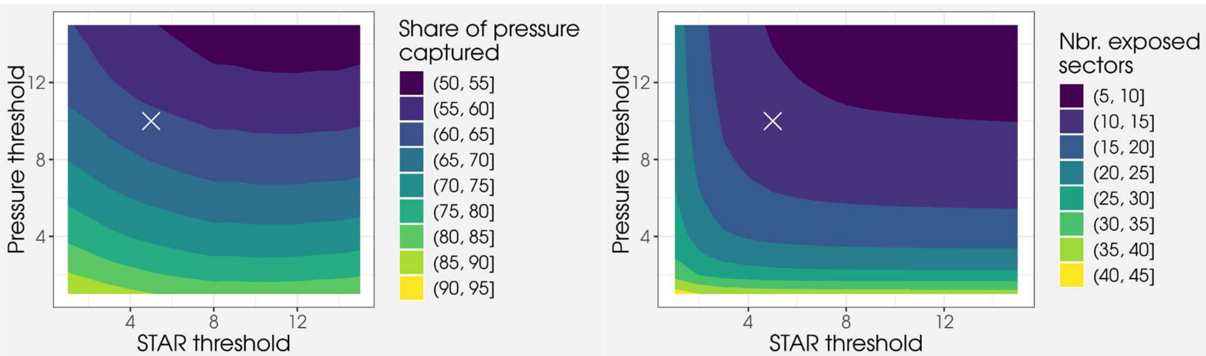


Figure A10. (Left) Average share of total pressure captured by country, given the pressure and STAR thresholds. (Right) Average number of exposed sectors per country as a

function of pressure and STAR thresholds. The white cross indicates the threshold values used in this study.

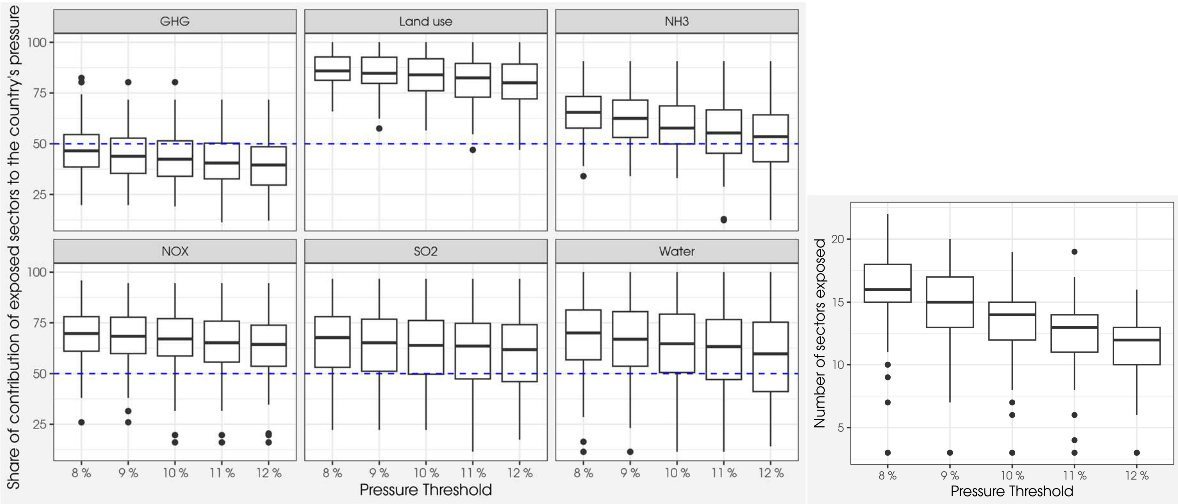


Figure A11. Variation in pressure thresholds: (Left) effect on the share of pressure captured at the country level; (Right) effect on the number of sectors exposed to transition risks.

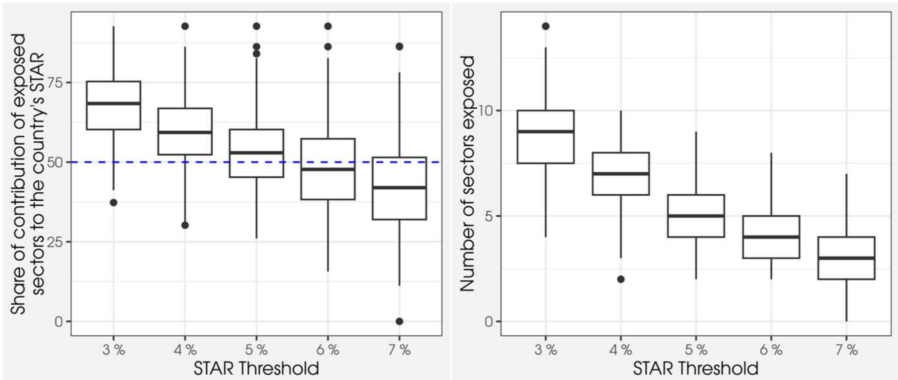


Figure A12. Variation in STAR threshold: (Left) effect on the share of pressure captured at the country level; (Right) effect on the number of sectors exposed to transition risks.

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