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Andrej Ceglar, Simone Boldrini, Chiara Lelli,
Laura Parisi, Irene Heemskerk

The impact of the euro area economy and banks on biodiversity

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Abstract

Biodiversity – the variety of life on Earth – is essential for sustaining the healthy ecosystems that our economy and banks depend on. Despite the clear benefits of a healthy natural world for people and the economy, humanity is putting immense pressure on nature and biodiversity. Economic activities that rely on healthy nature are often responsible for generating environmental pressures. It is important to assess the impact that firms and financial institutions have on nature degradation, in order to reveal their exposure to transition risk and highlight the need to move towards an economic system that values nature, rather than putting it at risk. This study analyses the contribution of euro area economic activities – and the bank loans provided to enable them – to biodiversity loss by estimating biodiversity footprints. The datasets we use account for approximately €4.3 trillion in corporate loans to around 4.2 million companies located in the euro area, issued by more than 2,500 unique consolidated euro area banks. Considering two primary drivers of biodiversity loss (land-use change and climate change), the results show that the economy has had a significant impact on biodiversity, equivalent to the loss of 582 million hectares of "pristine" natural areas worldwide. Even though the impact on biodiversity is highest in Europe, the supply chains of companies are important determinants of their indirect biodiversity footprint worldwide. Asia and Africa have the largest areas impacted by activities that take place in company supply chains. Additionally, financing of economic activities with a high global impact on nature is concentrated: the ten banks with the highest financing share are responsible for financing around 40% of the total global impact of euro area firms. To avoid risk underestimation, this study highlights the importance of considering both climate change and nature loss when developing risk assessment frameworks, because they are inextricably intertwined.

Keywords: biodiversity loss, nature degradation, input-output table, materiality score, economy, impact, climate-nature nexus.

JEL codes: C55, G21, G38, Q5.

Executive summary

Our economy and the financial system, as an enabler of the economy, are highly dependent on nature and the ecosystem services it provides. Biodiversity – the variety of life on Earth – is essential for sustaining the healthy ecosystems that our economy and banks depend on. Despite the clear benefits of a healthy natural world for people and the economy, humanity is putting immense pressure on nature. Human activity has led to significant alterations in three-quarters of the land-based environment and two-thirds of the marine environment.

Greenhouse gas (GHG) emissions that lead to climate change, unsustainable land use, overexploitation of natural resources, pollution, invasive species and nitrogen deposition are among the major pressures resulting in our planet's current biodiversity loss. Economic activities that rely on healthy nature are often responsible for generating these environmental pressures. It is important to assess the impact of firms and financial institutions on nature degradation, in order to reveal their exposure to reputational and transition risk and highlight the need to move towards an economic system that values nature, rather than putting it at risk.

The scope of this study is to raise awareness of nature-related risks by assessing the impact of the euro area economy – and the bank loans that enable economic activity – on biodiversity. We quantify the extent to which the euro area economy and financial sector are contributing to nature degradation by estimating their biodiversity footprints. As climate change is a primary driver of biodiversity loss, this study also explores the climate-nature nexus and demonstrates the importance of taking an integrated view to fully capture the nature-related risk profile.

Nature affects firms and banks through two main channels: physical risks and transition risks. This study focuses on transition risk. Governments are stepping up their efforts to protect the environment: the UN Convention on Biological Diversity[1] set global targets in 2022, including the conservation of at least 30% of the world's lands, inland waters, coastal areas and oceans. Such measures could lead to changes in regulation and policy to limit the exploitation of natural resources or ban certain products that trigger degradation. Technological innovation, new business models and changes in consumer or investor sentiment could also result in transition risks and costs as firms are forced to adapt.

Nature loss can therefore amplify transition risks for banks and their borrowers. Considering climate change and land-use change as two primary drivers of biodiversity loss, the combined impact of euro area firms on nature is equivalent to the loss of 582 million hectares of "pristine" habitats worldwide. This is comparable to 60% of the European land area. Domestically, euro area firms generate an impact equivalent to the loss of 398 million hectares of pristine nature. German firms have the largest impact, while French banks finance the largest share of the total biodiversity footprint. The local impact of non-financial corporations (NFCs) is allocated according to the location of their headquarters, while bank footprints are computed by dividing borrowers' footprints according to banks' share of their total

[1] https://www.cbd.int/

indebtedness. We find that financing of firms with a high global impact on nature is concentrated: the ten banks with the highest financing share are responsible for financing around 40% of the total global impact caused by euro area firms. This share is around 90% if we consider the 100 banks with the highest financing share (out of more than 2,500 banks included in our assessment).

Climate change and nature loss are inextricably intertwined. It is essential to identify the interdependencies and reinforcing mechanisms between the climate system, environmental pressures and biodiversity in order to fully capture the nature-related risk profile. For the first time, we investigate the combined physical risk of firms and banks due to their vulnerability to nature degradation and climate change. We analyse the dependency of economic sectors on surface water provision, which can compound with high drought risk and have an amplified impact on banks. We find that the highest compound impact amplification exists in the agricultural, manufacturing and electricity production sectors, especially in Spain, France and Italy. In terms of increased flood risk due to climate change and the capability of ecosystems to protect companies against floods, the highest compound impact amplification on the financial system materialises in Latvia, Lithuania and Slovenia. The impact of biodiversity loss and climate change on financial systems, as well as the interplay between them, is highly complex and likely to be characterised by non-linearity and irreversibility due to tipping points being reached.

This is the first time that we have assessed the exposure of euro area NFCs and banks to the potential compound effect of climate change and nature loss. Further work is required to deepen our understanding and address the challenges of modelling the climate-nature nexus. Better understanding of compound effects will further inform policymaking aimed at supporting both climate mitigation and nature preservation and avoiding their misalignment. To date, there has been less progress in measuring and understanding nature-related risks than in analysing those stemming from climate change. There is a gap to be filled in disclosure and quantitative risk modelling frameworks, and a need to identify and quantify the key transmission channels. This should be a co-development process that involves policymakers, researchers and civil society organisations. Timely recognition, assessment and action to address these challenges are essential to prevent or mitigate economic downturns in the future.

In order to mitigate future financial risks, policymakers will need not only to quantify the materiality of climate change and biodiversity loss for the financial system, but also to measure and reduce the financial system’s negative impact on the climate and environment.

1 Introduction

Our economy and the financial system, as an enabler of the economy, are highly dependent on nature and the ecosystem services it provides (Boldrini et al., 2023). Physical risk due to loss of biodiversity and the degradation of natural ecosystems poses a significant threat to the broader economy and financial stability that central banks and financial supervisors cannot ignore. Boldrini et al. (2023) find that 72% of euro area NFCs are highly dependent on ecosystem services, and would therefore experience critical economic problems as a result of ecosystem degradation. 75% of all corporate loans in the euro area are granted to NFCs with a high dependency on at least one of the ecosystem services that nature provides. Loan portfolios may be significantly affected if environmental degradation continues to follow current trends, with stronger vulnerabilities concentrated in certain regions and economic sectors.

Biodiversity – the variety of life on Earth – is essential for sustaining the healthy ecosystems that our economy and banks depend on. A breathable atmosphere, food provision, climate regulation through carbon sequestration and storage are just some of the benefits that would not exist without biodiversity. More than 50% of the global economy relies directly on our planet's natural and biological resources (EU Biodiversity Strategy for 2030[2]; World Economic Forum, 2020). More than half of the global population depends on biodiversity for their livelihoods, with 70% of the world's poor and vulnerable directly depending on it for their survival and wellbeing.[3]

Despite the clear benefits of a healthy natural world for people and economy, humanity is putting immense pressure on nature. Six of the nine planetary boundaries have been transgressed, which significantly increases the risk of generating large-scale abrupt or irreversible environmental changes (Richardson et al., 2023). The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) has provided evidence on the unprecedented worldwide decline in nature that has seen species extinction rates accelerating (Díaz et al., 2019). The ominous picture painted by this assessment shows overwhelming evidence that the health of ecosystems is deteriorating more rapidly than ever. Global per-capita consumption of materials has increased by 15% since 1980; nearly 60 billion tonnes of renewable and non-renewable resources are extracted globally each year. Over one-third of global land and almost three-quarters of freshwater resources are currently devoted to crop or livestock production. More than 85% of wetlands that were present in 1700 had disappeared by 2000, a loss three times faster than that of forests. These are just a few examples of human activity that has resulted in a significant alteration of three-quarters of the land-based environment and two-thirds of the marine environment.

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[2] European Commission, Directorate-General for Environment (2021).

[3] https://unctad.org/isar/topic/trade-and-environment/biotrade/kunming-montreal-global-biodiversity-framework

GHG emissions leading to climate change, unsustainable land use, overexploitation of natural resources, pollution, invasive species and nitrogen deposition are among the most important pressures leading to the current pace of biodiversity loss, which is unprecedented in human history. Current global trends point to a further increase in the risk of extinction and biodiversity loss in the future. Europe is no exception here: European nature is declining at an alarming rate, with more than 80% of habitats in a poor condition.[4] Nature protection and restoration actions are essential for reversing biodiversity loss globally. For this reason, the Kunming-Montreal Global Biodiversity Framework, which was adopted at the 15th Conference of Parties to the UN Convention on Biological Diversity in December 2022, sets out a new and ambitious framework aimed at halting and reversing biodiversity loss by 2030.[5] Under the umbrella of the European Green Deal, the EU is taking action through targeted policies and legislation, such as the EU Biodiversity Strategy for 2030, the EU Birds[6] and Habitats[7] Directives, and the EU Pollinators Initiative.[8] Within the EU, an agreement was reached in June 2023 on a proposal for a Nature Restoration Law[9], the first continent-wide law of its kind.

European demand for ecological goods and services strongly exceeds the supply capacity of its ecosystems to produce biological products and absorb carbon emissions.[10] Economic activities that rely on these ecosystems often also generate environmental pressures and reduce the capacity of ecosystems to provide essential services. This can amplify the physical risk for companies and banks lending to them, as discussed in an assessment of the European economy's exposure to nature degradation (Boldrini et al., 2023). NFCs that have a strong impact on nature might also face significant **reputational** and **transition risks** due to changes in regulation and policy, for example limiting the exploitation of natural resources or banning certain products that trigger degradation. Technological or business model innovation and consumer or investor sentiment could also lead to transition risks and costs as NFCs are forced to adapt.

Given its central role in the economy, the financial system can either support nature protection or contribute to its degradation. On the one hand, financing of activities that contribute to nature degradation, including biodiversity loss, is very likely to contribute to both physical and transition risks. On the other hand, the **financial system** can also **promote nature conservation**, **sustainable use of natural resources** and **nature restoration**. Promoting and investing in a nature-positive and net-zero economy results in healthier and more biodiverse ecosystems, with beneficial effects for climate change mitigation, disaster prevention, water quality, clean air, healthier soils and overall wellbeing. It is worth remembering that nature restoration does not imply stopping economic activity in restored ecosystems but is primarily about living and producing in a sustainable way (Nature Restoration

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[4] https://www.eea.europa.eu/ims/conservation-status-of-habitats-under

[5] https://www.unep.org/resources/kunming-montreal-global-biodiversity-framework

[6] https://environment.ec.europa.eu/topics/nature-and-biodiversity/birds-directive_en

[7] https://environment.ec.europa.eu/topics/nature-and-biodiversity/habitats-directive_en

[8] https://environment.ec.europa.eu/topics/nature-and-biodiversity/pollinators_en

[9] https://environment.ec.europa.eu/topics/nature-and-biodiversity/nature-restoration-law_en

[10] https://www.eea.europa.eu/ims/ecological-footprint-of-european-countries

Law). According to the World Economic Forum (2020), nature-positive solutions have the potential to create €10 trillion in annual business opportunities and more than 390 million new jobs by 2030.

Assessing the impact of firms and financial institutions on nature degradation can reveal their exposure to transition risk. This study quantifies the contribution of current economic activities in the euro area to various environmental pressures and the resulting impact on biodiversity. Furthermore, by measuring the biodiversity footprint this study analyses the contribution of euro area banks' loans to economic activities with a high biodiversity footprint; this measure is essential in order to better understand the potential implications for transition risk. Our results also highlight the need to move towards an economic system that values nature, rather than putting it at risk.

Since climate change and nature loss are inextricably intertwined, it is important to identify the interdependencies and reinforcing mechanisms (feedback loops) between the climate system, environmental pressures and biodiversity in order to fully capture the nature-related risk profile. Although climate change and nature-related risks have different features, they may amplify or mitigate each other (Pörtner et al., 2023). Policy-related actions in the climate space are likely to have an impact on nature and vice versa. This study therefore investigates the climate-nature nexus to better understand the exposure of the euro area economy to climate and nature-related risks.

2 Project overview

2.1 Aim of our analysis

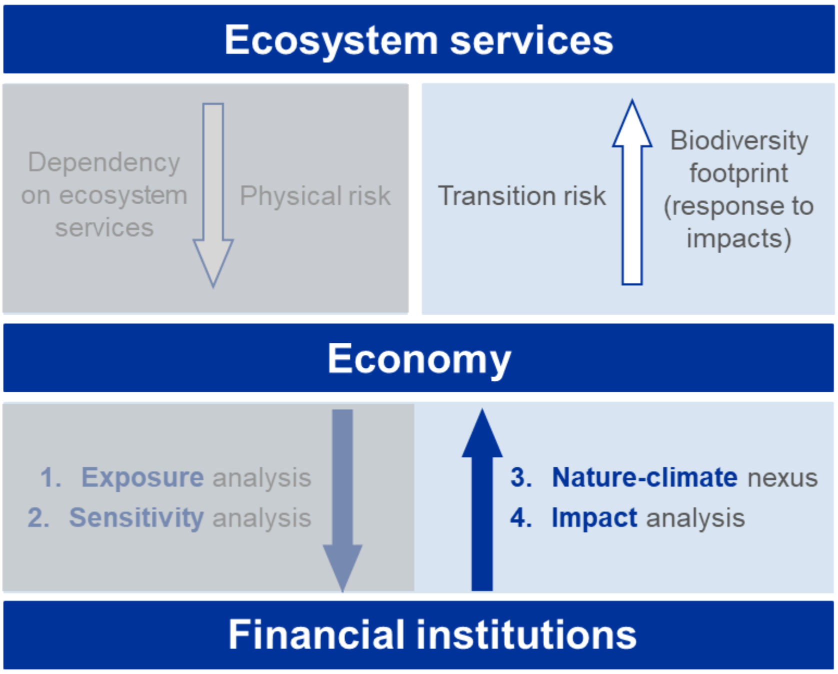
This study builds on the previous work on exposure assessment and physical risk (Boldrini et al., 2023) and extends it to investigate transition risk for NFCs and banks in the euro area. By looking into the impact of NFCs and banks on nature degradation, this study completes the assessment of nature-related risks (Chart 1) and complements previous work by focusing on two main aspects.

First, this study quantifies how much the euro area economy and financial sector are contributing to nature degradation by estimating their biodiversity footprint. The biodiversity footprint measures the contribution of an economic activity to the drivers of biodiversity loss. Compared with the carbon footprint, the biodiversity footprint depends on a much broader set of environmental impacts. Selecting the biodiversity loss metric, localising the impact on biodiversity and collecting granular data on sources of pressure (such as land-use change and climate change) are some of the challenges that differentiate the biodiversity footprint from the carbon one. Our calculations provide us with a general overview of the pressures from various sectoral activities financed by financial institutions, and therefore ultimately show the extent to which financial institutions contribute to biodiversity loss via their loan investments.

Second, the study investigates the integrated climate-nature risk assessment. We combine previous insights into the impact of climate on financial stability to assess the interdependence between climate and nature-related risks. In this preliminary step, we demonstrate and discuss the potential amplification between the two risk categories. While a comprehensive quantitative climate-nature nexus assessment is beyond the scope of this study, our analysis provides important initial insights into sectoral exposure to both climate and nature-related risks and paves the way towards a more comprehensive conceptual framework in the future.

Chart 1

Main elements of the nature-related risk assessment. This study focuses on the impact of NFCs and banks on biodiversity, by analysing biodiversity footprints. It also highlights the importance of the climate-nature nexus framework.



Source: ECB.
Notes: High-level description of the project on nature-related risk.

This paper is organised as follows. Chapter 3 analyses the impact of euro area economic activities – and the bank loans provided to enable those activities – on biodiversity loss (i.e. the biodiversity footprint). In Chapter 4, we introduce an initial assessment of the integrated climate-nature nexus by looking at the physical and transition risks arising from nature and climate-related hazards. We conclude the paper by discussing the limitation of our approaches and the possible policy implications of this study.

3 Biodiversity footprint

While exposure assessment and the sensitivity analysis performed to date can be used to gauge physical risk, transition risk can be assessed by analysing the impact of euro area NFCs and banks on biodiversity loss (the biodiversity footprint). This footprint measures the contribution of an economic activity to the drivers of biodiversity loss or gain. In this section we aim to quantify the biodiversity footprint of NFCs, defined as the contribution of an economic activity to the drivers of biodiversity loss, and map these impacts to the banks that finance the NFCs.

Our sample relies on the AnaCredit dataset, a confidential dataset containing detailed information on individual bank loans in the euro area. The sample is based on December 2021 and covers approximately €4.3 trillion in corporate loans to around 4.2 million NFCs issued by more than 2,500 unique consolidated banks. Importantly, a biodiversity footprint calculation requires data on the revenue of the NFC borrowers. This is sourced either from AnaCredit itself, augmented using Orbis and iBACH.

3.1 Pressures considered

The methodology used to assess the euro area NFC biodiversity footprint is based on the GLOBIO model.[11] The GLOBIO model is used to compute biodiversity intactness, expressed by the mean species abundance (MSA[12]) indicator, as a function of multiple anthropogenic pressures such as land use, climate change, development of roads, fragmentation (division of habitats into smaller and more isolated fragments), hunting and atmospheric nitrogen deposition (Schipper et al., 2019; Alkemade et al., 2009). These pressures are a normal by-product of economic activities and are important factors in determining losses in a region's MSA. The GLOBIO model output consists of local MSA loss values (in MSA-loss·ha) for each pressure. Country-specific aggregated MSA loss values are then used to derive biodiversity loss factors for each land-based pressure in each country (Wilting et al., 2021). These factors are assumed to be the same for all regions in each country, which makes them a suitable input for our country and sector-specific footprint model. More information on the GLOBIO model is provided in Boldrini et al. (2023).

11 The GLOBIO model is a global model of biodiversity intactness, expressed by the MSA metric, as a function of multiple anthropogenic pressures on the environment (Schipper et al., 2020; Alkemade et al., 2009).

12 MSA is an indicator of local biodiversity intactness. It ranges from 0 to 1, where 1 means that the species assemblage is fully intact, and 0 means that all original species are extirpated (locally extinct). MSA is calculated based on the abundance of individual species under the influence of a given pressure, compared with their abundance in an undisturbed situation (natural situation/reference). Source: https://www.globio.info/

In our study we consider two highly significant pressures currently contributing to biodiversity loss on a global level: land use and climate change (Díaz et al., 2019). These are generally considered to be the main pressures leading to MSA losses for plants and warm-blooded vertebrates (Schipper et al., 2019). Land use has a direct impact on biodiversity due to the eradication of natural habitats and an indirect impact due to habitat fragmentation and human encroachment (Wilting et al., 2017). GHG emissions contribute to future global climate change and therefore affect biodiversity by causing changes in species distribution and abundance. Other pressures such as hunting, nitrogen deposition and road disturbance can also contribute significantly to MSA loss. However, due to data availability issues, these pressures are not considered in our analysis, which means that the overall biodiversity footprint is underestimated.

The determinants of these pressures are taken from EXIOBASE. EXIOBASE is an Environmentally Extended Multi-Regional Supply-Use Table (MR-SUT) and Input-Output Table (MR-IOT) that contains inter-industry relationships within an economy and the rest of the world. These economic flows are then extended with environmental pressures and emissions.[13] Specifically, for climate change, EXIOBASE provides data on industry-specific air emissions for 27 pollutants (Stadler et al., 2018). These emissions are obtained by combining activity data with consolidated emission factors. To characterise land use, EXIOBASE uses statistical data, taken mainly from the Food and Agriculture Organization of the United Nations (FAO) and the Statistics Division of the FAO (FAOSTAT). EXIOBASE considers three land use categories (cropland, grazing land and forest), which are in turn allocated to 16 sectors of biomass extraction (Stadler et al., 2018). Cropland categorises harvested areas for 178 crops. Pastures are used for grazing cattle, grazing meat animals and grazing animals to produce raw milk. Finally, forestry use refers to managed forest, that is areas used for forestry operations (e.g. logging). Another land use-related pressure are settlement areas, which refer to all developed land, including transportation and settlement infrastructure. However, due to data unavailability these are not considered in our analysis.

The impact of climate change on biodiversity is quantified using GHG emissions figures taken from EXIOBASE. Specifically, we consider emissions of carbon dioxide (CO_2), nitrous oxide (N_2O), fossil and biogenic methane (CH_4) and sulphur hexafluoride (SF_6). All GHG emissions are expressed in terms of CO_2-equivalents, a measure that compares GHG emissions on the basis of global warming potential (GWP; IPCC, 2007). More details of the calculation procedure can be found in Appendix A.

For land-use pressures we utilise the cropland, grazing land and forest areas provided by EXIOBASE. These areas include areas for subsistence farming and forestry. The country-specific biodiversity loss factors are taken from Wilting et al. (2021), who calculated these factors by translating habitat replacement due to land use into gridded MSA loss values using the GLOBIO model. The gridded outcomes are aggregated to country-specific loss factors for each pressure, which are used here to quantify the impact of land use. Please note that biodiversity loss due to

[13] More detailed information of possible EXIOBASE use cases can be found in Boldrini et al., 2023.

urban areas and fragmentation of natural habitats due to cropland and roads are not considered in our study.

3.2 Biodiversity footprint calculation

The first step in quantifying the biodiversity footprint is to compute the impact of a single NFC using EXIOBASE. The latter is used to calculate not only the direct impact generated by production of the good or service locally, but also the global impact of its intermediate input production due to supply chain flows. This ultimately allows us to compute how euro area NFCs impact biodiversity in euro area countries, and how much they contribute to global species degradation abroad due to the outsourcing of intermediate goods production.

An impact coefficient is computed using EXIOBASE (for more detailed information, please refer to Appendix A). Specifically, this involves computing the quantity of emitted GHGs and the amount of land used to produce a unit of a good in a given sector of a country, not only locally but also globally through the import of intermediate goods. Using the coefficients provided by the GLOBIO model, it is then possible to convert these physical impacts into the MSA loss. In this way, we can determine how much biodiversity is lost both locally and worldwide when producing one unit of output in each sector.

The second step consists of weighing the NFCs' impact coefficients with their revenues, to obtain their local and worldwide impact in terms of MSA loss. As described in Appendix A, these coefficients are country/sector-specific, and they are assigned to a given borrower according to its economic sector (NACE statistical classification of economic activities in the European Community) and headquarters.[14] The term "local" signifies the country in which the borrower's headquarters are based. Particularly in the case of large multinational corporations, the headquarters are not necessarily in the same place as the production location. Nevertheless, this assumption is more reasonable for small and medium enterprises, which represent a significant share of the euro area economy in our sample.

Consider the example of a manufacturing NFC in Italy that requires an intermediate good from Germany to produce its final product. The NFC in Italy will have an impact on biodiversity in Italy when it produces its final product and sells it to a final consumer; similarly, its supplier in Germany has an impact on biodiversity in Germany by producing the intermediate goods. By importing an intermediate good from Germany, the Italian NFC is therefore having an impact on biodiversity in Germany. The impact of the Italian NFC is thus redistributed geographically to the location where the intermediate economic activity is performed and therefore where emissions are produced and land is used. For a more detailed description of the approach used, please refer to Appendix A.

Finally, we associate the impact of NFCs with the banks financing them. Specifically, we attribute the impact of a given NFC to the banks financing it. We look

[14] Information obtained from AnaCredit.

at all the banks lending to a given NFC and split its local and global footprint between them, according to their share of the total indebtedness. Consider the example of an NFC borrowing from two banks, one accounting for 30% of the NFC's total indebtedness and the other for the remaining 70%. Our method attributes 30% of the NFC footprint (both local and global) to the first bank and the remaining 70% to the second bank. In this way, it is possible to attribute the economy (local and global) impact to the financial sector.

3.3 Results

In total, euro area NFCs generate an impact on nature comparable to the loss of 582 million hectares of "pristine" natural areas worldwide. This is the equivalent of 60% of the European land area. These are the findings of an accumulated biodiversity footprint assessment, based on impacts that remain over time. This measure integrates the loss of biodiversity as a consequence of already observed land conversion with potential biodiversity loss in the next 100 years due to the GWP of GHG emissions in 2021. For comparison, Wilting et al. (2017) estimated the total biodiversity loss caused by human consumption in Europe to be higher than 800 million hectares worldwide. The higher impact determined in their study is due to their focus on the whole of Europe (rather than only the euro area), as well as a consumption-oriented narrative. Svartzman et al. (2021) calculated that the accumulated terrestrial biodiversity footprint of French securities alone is comparable to a loss of "pristine" nature corresponding to the complete artificialisation of 24% of the area of metropolitan France.

The biodiversity footprint generated by NFCs is mostly concentrated in Europe. Specifically, euro area NFCs generate an impact equivalent to the loss of around 398 million hectares in Europe and 365 million hectares in the euro area alone. This is equivalent to a complete artificialisation of around 37% of the European land area. Nevertheless, this highly significant impact also takes on a global dimension because of the supply chain dependency.

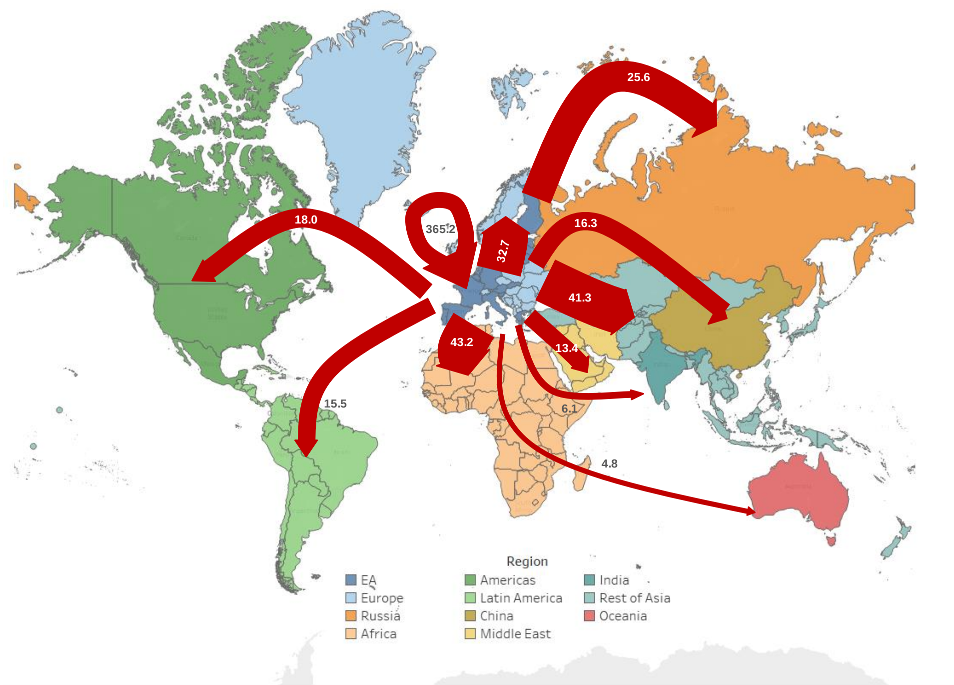
Indirectly, the European economy has a significant biodiversity footprint in all continents (except Antarctica, which is not analysed here). The largest impacted areas can be observed in Asia (including Russia) and Africa (Chart 2). Analysed NFCs are observed to have slightly lower impacts in both Americas and the lowest impact in Australia. The biggest impacts in Asia and Africa can be attributed to the high dependency of NFCs on the supply chain of agricultural, mining and manufacturing products in these continents. Bigger impacts in these two continents with respect to other regions can, to an extent, also be attributed to less efficient production processes; for example, more land is needed under rain-fed and nutrient-limited conditions to produce the same amount of output as under irrigated agriculture. Overall, our analysis shows that the footprint of euro area NFCs cannot be isolated to the euro area alone but extends well beyond its borders.

Chart 2

Euro area NFCs' total biodiversity footprint

Map of euro area NFCs' total biodiversity footprint. A footprint in other countries is assigned to euro area NFCs when they import intermediate goods. These MSA loss values integrate the loss of biodiversity as a consequence of already observed land conversion and potential biodiversity loss in the next 100 years due to the GWP of GHG emissions in 2021.

(December 2021, million MSA-loss·ha·yr)

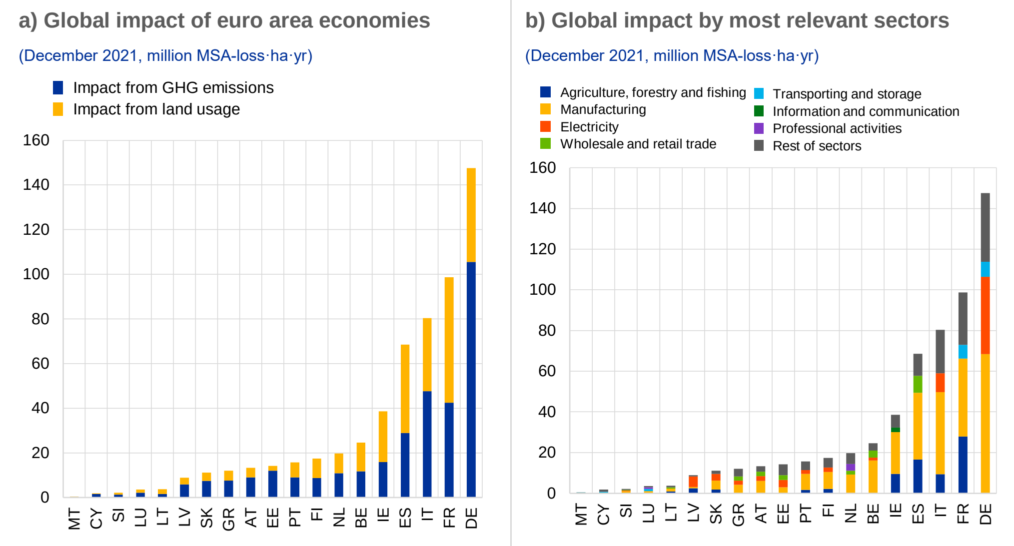


Sources: AnaCredit, EXIOBASE, Orbis, iBACH, Schipper et al., 2019.
Notes: Local and global biodiversity loss caused by euro area NFCs. Global biodiversity loss is allocated to euro area NFCs to the extent that they require intermediate inputs outsourced abroad. MSA losses are computed taking into account GHG emissions and the area of land used in the production of goods.

The biggest economies in the euro area contribute the most to the overall impact on nature. The concentration of larger NFCs with headquarters in Germany, France and Italy explains the greater impact of these economies. We can see that the contribution of the GHG emissions-related and land use-related impact on biodiversity are heterogeneous across countries. NFCs located in Spain and France generate most of their impact on biodiversity through land use (Chart 3a), while NFCs located in countries such as Germany and Italy have more impact on biodiversity through their GHG emissions. In terms of sectors, manufacturing is the most impactful sector across the euro area (Chart 3b). This sector is particularly relevant in Germany and Italy, and to a lesser extent also in Spain and France. Agriculture, forestry and fishing make up a second group of impactful sectors. These sectors in Spain, France and Italy have a relatively bigger impact on biodiversity compared with other euro area economies.

Chart 3

Total biodiversity footprint of NFCs in euro area countries and sectors



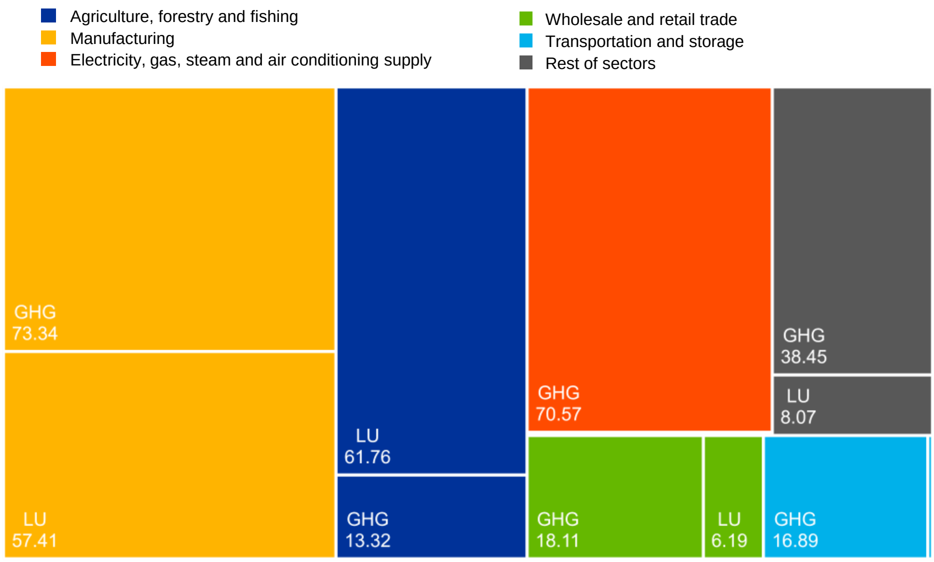
Sources: AnaCredit, EXIOBASE, Orbis, iBACH, Schipper et al., 2019.
Notes: Total impact of euro area NFCs on biodiversity losses globally. The MSA losses are computed taking into account GHG emissions and the area of land used in the production of goods and are grouped by the country in which the NFC is based (Panel A). For each economy, we show the three most impactful sector and a residual “rest of sector” bucket (Panel B).

Domestically, euro area NFCs generate an impact on biodiversity equivalent to the loss of 398 million hectares of pristine nature. The sectoral representation of losses shows that manufacturing is the most impactful sector, accounting for around 36% of the damage to euro area natural habitats or the equivalent of around 130 million hectares (Chart 4). Manufacturing impacts biodiversity through both GHG emissions and land use. Agriculture is responsible for the loss of around 75 million hectares, almost entirely through land use, while electricity production, which generates an impact of around 71 million hectares, impacts nature almost entirely through GHG emissions.

Chart 4

Domestic (euro area) impact of euro area NFCs on biodiversity loss through GHG emissions and land-use (LU) change

(December 2021, million MSA-loss·ha·yr)



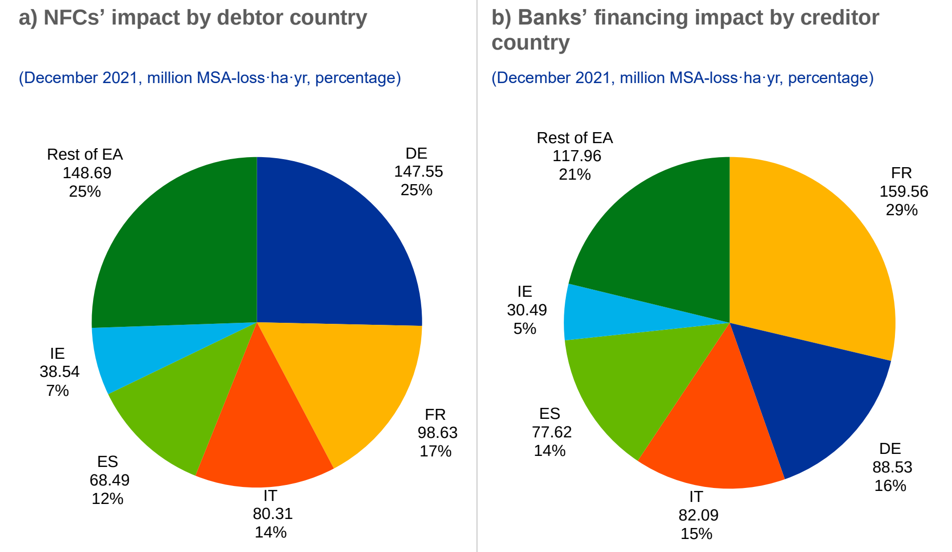
Sources: AnaCredit, EXIOBASE, Orbis, iBACH, Schipper et al., 2019.
Notes: Total impact of euro area NFCs on biodiversity loss limited to the euro area. MSA losses are computed taking into account GHG emissions and the area of land used in the production of goods and are grouped into the five most impactful sectors.

3.3.1 Financed impacts by euro area banks

Similarly to the exposure analysis (Boldrini et al., 2023), we associate the impact of NFCs with the banks financing them. Specifically, we attribute the impact of each NFC to all banks financing it. When multiple banks are lending to the same borrower, the overall impact of the NFC is attributed to the banks depending on their share of the total borrower indebtedness. In other words, if a bank accounts for 50% of all the mapped loans for a given NFC, we will attribute 50% of the NFC impact to that bank. This helps us to understand whether the impact is concentrated at certain banks or in the financial sectors of particular countries. The results show that NFCs with headquarters in Germany have the largest impact in the euro area, while banks headquartered in France finance the largest share of the total biodiversity footprint (Chart 5). One possible reason why French banks have the highest footprint in the euro area is their stronger international focus, especially when compared with German banks. France also has the largest banking system in the euro area in terms of consolidated banking assets and corporate loans in our sample. Interestingly, NFCs headquartered in Ireland are among the five biggest contributors to biodiversity loss at euro area level. This can be attributed to large and consolidated NFCs with their headquarters in Ireland, whose production activities are likely to take place abroad. Nevertheless, the impact is assigned to Irish NFCs and banks lending to them, which is likely to mean the results for this euro area country are overestimated.

Chart 5

Share of global NFCs' impact generated and financed in different euro area countries

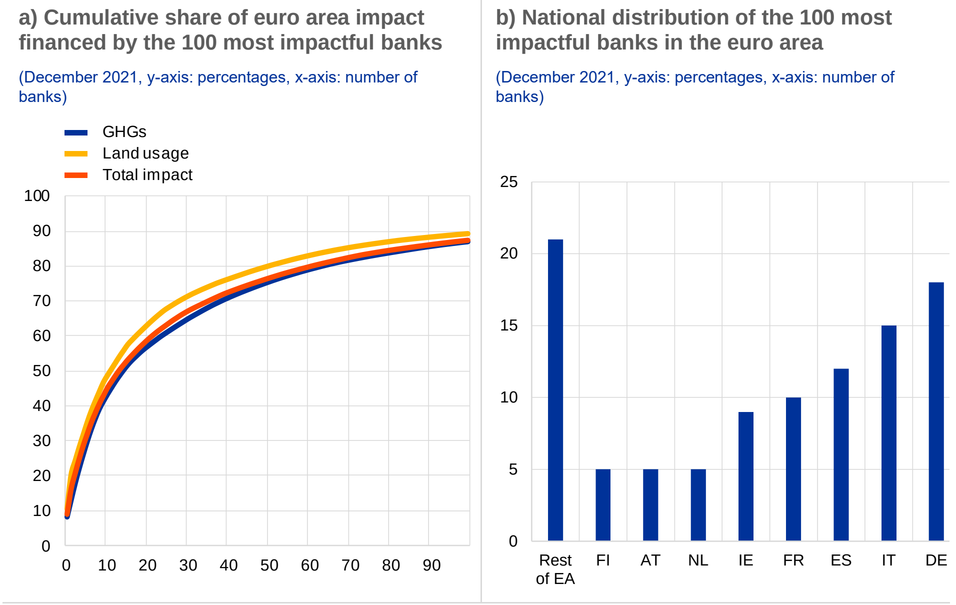


Sources: AnaCredit, EXIOBASE, Orbis, iBACH, Schipper et al., 2019.
Notes: Total global impact of euro area NFCs on biodiversity loss grouped by each country of origin (Panel A) or the country of the financing bank (Panel B). MSA losses are computed taking into account GHG emissions and the area of land used in the production of goods.

The impact on biodiversity loss financed by euro area banks is highly concentrated. The first ten banks ranked by the size of their impact on nature finance around 40% of the total global impact (Chart 6a). This share reaches around 90% when we consider the first 100 banks by the size of their impact, out of the total of 2,500 that are included in this exercise. This means that there is a high concentration of transition risk among certain credit institutions. This concentration is further highlighted by the steep increase among the first 20 banks. Of the 100 banks that finance the most biodiversity degradation, 18 are headquartered in Germany and 15 in Italy (Chart 6b).

Chart 6

Concentration of impact on biodiversity loss financed by euro area banks



Sources: AnaCredit, EXIOBASE, Orbis, iBACH, Schipper et al., 2019.
Notes: Concentration of euro area biodiversity impact financed by the 100 most impactful banks by type of pressure (Panel A) and the headquarters of these consolidated banks (Panel B). Impacts are attributed from the borrower to banks according to the bank's share of the borrower's total indebtedness. MSA losses are computed taking into account GHG emissions and the area of land used in the production of goods.

4 Climate-nature nexus

Climate change and nature loss are inextricably intertwined. It is necessary to identify the interdependencies and reinforcing mechanisms (feedback loops) between the climate system, environmental pressures and biodiversity in order to fully capture the nature-related risk profile. Although climate change and nature-related risks have different features, such as distinct time horizons, hazard dependencies and spatial properties, they are interrelated and, depending on possible future policy actions, may amplify or mitigate each other (Pörtner et al., 2023). Policy-related actions in the climate space are likely to have an impact on nature. Poorly planned policy actions can have degrading effects on the health of ecosystems and provision of their services, which humans and our economy ultimately depend on.

In the financial sector, the risks and financial implications of climate change and the degradation of nature are largely tackled as independent issues. However, it is highly likely that the most significant impact on our economy and financial system will materialise as a compound effect of both. Assessments based on univariate statistics may strongly underestimate risk if impacts depend on multiple dependent variables (Zscheischler and Seneviratne, 2017). Risk assessment must therefore go further and consider the dependence structure between climate and nature-related variables, since this can amplify the overall impact.

Physical risk in the climate-nature space is associated with NFCs' and banks' vulnerability to both nature degradation and climate change. Climate change and nature degradation share common drivers such as GHG emissions and land use, and are highly interconnected. For example, well-functioning terrestrial and marine ecosystems can take up and store large amounts of carbon, reducing CO_2 levels in the atmosphere. However, climate change alters these ecosystems, causing species losses and ecosystem service decline. This means that loss of biodiversity not only disrupts the ecosystem services that our economy depends on, but also triggers a series of cascading effects such as reduced capacity for atmospheric CO_2 uptake, which in turn amplifies climate change effects.

We apply the integrated approach to two cases of related physical climate and nature risks (water stress/surface water provision and flood risk/flood and storm protection) and for the nexus of climate and nature transition risk. Our analysis starts by classifying NFCs into a two-dimensional high-low risk space, with the two dimensions corresponding to climate and nature risk. Among other data sources, we use the thresholds defined in the economy-wide climate stress test of Alogoskoufis et al. (2021). In the first part of the analysis, we investigate the ensuing classification of NFCs specifically for the above two cases of combined physical risks. As a second step, we investigate the combined transition risk, whereby both GHG emissions and land use are examined separately as drivers of transition risk. The analysis is carried out by aggregating the classified NFC dataset across the sector/country/risk dimensions.

To demonstrate the relevance of an integrated approach, we leverage the work of the economy-wide climate stress test (Alogoskoufis et al., 2021) which investigates climate-related physical and transition risks. Their study shows that for the corporates and banks most exposed to climate risks, the impact of climate change can be very significant, especially in the absence of mitigation and adaptation policies. To assess and discuss the interdependency between climate and nature-related risks for different sectors in the euro area economy, we introduce a multivariate perspective, in which NFCs are split into four categories based on their level of exposure to both climate and nature-related risks, as shown in Table 1. In particular:

- NFCs exposed to low levels of both risks are assigned to the "Low-Low" (or LL) category;
- NFCs exposed to low levels of climate risk and high levels of nature risk are assigned to the "Low-High" (or LH) category;
- NFCs exposed to high levels of climate risk, but low levels of nature risk are assigned to the "High-Low" (or HL) category;
- NFCs exposed to high levels of both risks are assigned to the "High-High" (or HH) category.

Table 1
NFC classification matrix in the climate and nature space

	Low nature risk	High nature risk
Low climate risk	Low-Low (LL)	Low-High (LH)
High climate risk	High-Low (HL)	High-High (HH)

Source: ECB.

This classification is performed for both physical and transition risk. For transition risk classification, NFCs are classified on the climate side based on their Scope 1, 2, and 3 GHG emission intensities[15] (Urgentem) and the brownness of their energy mix[16], and on the nature side based on their impact on MSA loss.

To assign a level of physical climate risk to each NFC, we use the thresholds defined in the economy-wide climate stress test of Alogoskoufis et al. (2021). According to this, for instance, an NFC is exposed to high water stress if its score is above 65, and it is exposed to high flood risk if its score is above 50. An NFC is deemed to be highly dependent on an ecosystem service if its dependency score is

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[15] A firm's Scope 1, 2, and 3 GHG emission intensity is defined as its GHG emissions in tonnes of CO_2-equivalent normalised by its revenues in EUR millions (Urgentem).

[16] The brownness of a firm's energy mix is determined by the share of brown energy sources in its energy mix, defined as: $share\ of\ brown\ sources = \frac{total\ energy\ consumption\ from\ brown\ sources\ [MWh]}{total\ energy\ consumption\ [MWh]}$

In this exercise, brown energy sources comprise oil, gas and coal.

higher than or equal to 0.5. A summary of the variables considered in the classification of NFCs is provided in Table 2.

Table 2
Summary of variables considered in the classification of NFCs

	Physical risk	Transition risk
Climate-related risk	Exposure to extreme weather events	Scope 1, 2, and 3 GHG emissions Brownness of energy mix
Nature-related risk	Dependency on ecosystem services	MSA loss due to GHG MSA loss due to land use

Source: ECB.

Starting with the physical risk, we focus on a few combinations: we compare water stress (drought) with surface water provision, and flood risk with dependency on flood and storm protection and mass stabilisation and erosion. A complete assessment considering the entire set of climate physical risks and dependencies on ecosystem services is beyond the scope of this paper.

First, we consider the climate risk of water stress and the related ecosystem service of surface water provision (nature-related hazard). Clean surface water is provided through freshwater resources from collected precipitation and water flow from natural sources. Freshwater provision depends not only on precipitation, but also on factors such as healthy aquatic ecosystems. For example, forests help to clean and filter water, prevent soil erosion and mitigate the risks of landslides and floods, and are important for recharging underground water reservoirs. They are therefore essential to the provision of a downstream water supply. In terms of consumption, crops and livestock are important users of freshwater resources.

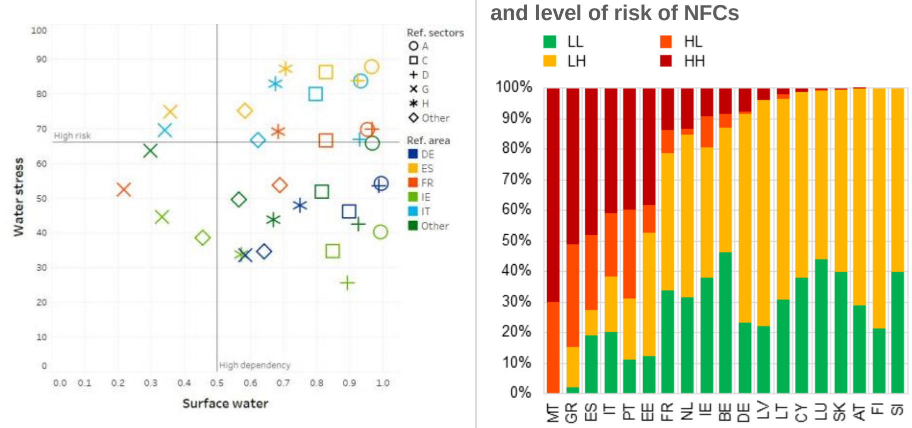
Chart 7a shows aggregated country-sector combinations of sectoral dependency on water provision and sectoral exposure to drought risk. Higher dependency of an economic sector on surface water provision can compound with high drought risk, which may result in an amplified impact on NFCs in those sectors and on the banks who lend to them. The upper right quadrant (HH), characterising high drought risk and dependency on water provision, mainly contains the agricultural, manufacturing and electricity production sectors in Spain, France and Italy. The wholesale and retail trade sector in these countries is exposed to relatively high drought risk, but dependency on surface water provision is significantly lower. Country-sector combinations in the upper right quadrant (HH) are of the highest concern for economic and financial risk management. This is particularly relevant in Mediterranean countries, in which the highest proportion of loans are given to NFCs operating in sectors of the upper right quadrant (Chart 7b).

Chart 7

Physical risk from climate and nature space – example of drought risk (water stress) and dependency on surface water provision

a) Average level of risk by country-sector

b) Share of loans by country of residence and level of risk of NFCs

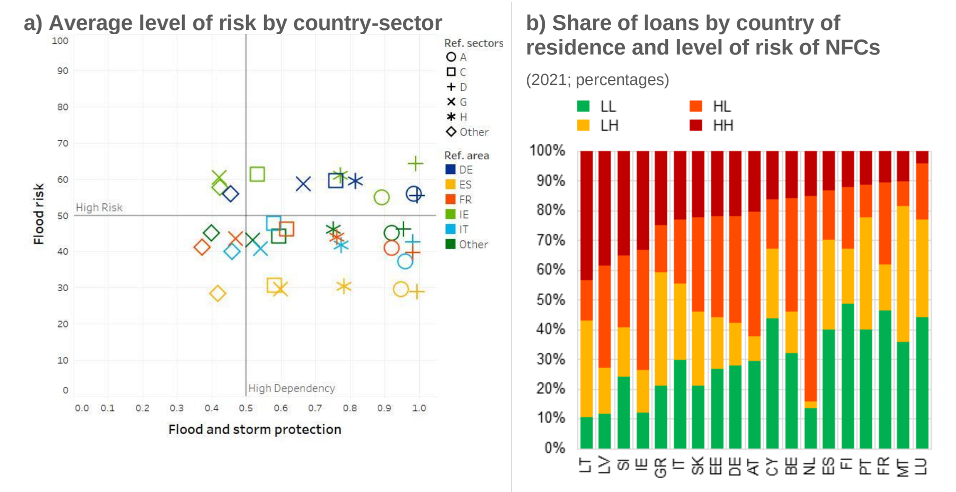


Sources: AnaCredit, EXIOBASE, Orbis, iBACH, Alogoskoufis et al. (2021).
Notes: Panel A shows the average level of water stress risk for 2031-2040 (y-axis) and the average dependency score on surface water (x-axis) by country-sector (NACE level), with the following level of granularity: DE, ES, FR, IE, IT and Other for the reference areas; A (Agriculture, Forestry and Fishing), C (Manufacturing), D (Electricity supply), G (Wholesale and retail trade), H (Transport and storage) and Other for the reference sectors. The water stress score measures the projected changes in drought-like patterns over time. Panel B illustrates, for each euro area country, the share of loans to euro area NFCs based on their combined climate and nature risk levels: Low climate risk – Low nature risk (LL), Low climate risk – High nature risk (LH), High climate risk – Low nature risk (HL), and High climate risk – High nature risk (HH).

Second, we assess the nexus of flood risk caused by climate change and the degradation of the related ecosystem service of flood and storm protection (i.e. sheltering, buffering and attenuating effects of natural and planted vegetation). Economic sectors in the euro area that are highly vulnerable to degradation of the flood and storm protection ecosystem service are mostly exposed to higher flood risk levels in central, western and northern Europe (Chart 8). The country-sector combinations in the upper right quadrant (HH) are also of the highest concern for economic and financial risk management. The highest share of loans given to those NFCs can be seen in Latvia, Lithuania and Slovenia, where they constitute around 38% of the total amount of loans granted to NFCs. Nevertheless, other euro area countries also have a relatively high share of loans to NFCs where a compound effect of increased flood risk and future nature degradation might significantly amplify the impact on their businesses.

Chart 8

Physical risk from climate and nature space – example of flood risk and dependency on flood and storm protection



Sources: AnaCredit, EXIOBASE, Orbis, iBACH, Alogoskoufis et al. (2021).
Notes: Panel A shows the average level of flood risk for 2031-2040 (y-axis) and the average dependency score on flood and storm protection by country-sector (NACE level), with the following level of granularity: DE, ES, FR, IE, IT and Other for the reference areas; A (Agriculture, Forestry and Fishing), C (Manufacturing), D (Electricity supply), G (Wholesale and retail trade), H (Transport and storage) and Other for the reference sectors. Flood risk measures the severity and frequency of historical floods, the frequency of future heavy rainfall events, and the intensity of prolonged periods of heavy rainfall. Panel B illustrates, for each euro area country, the share of loans to euro area NFCs based on their combined climate and nature risk levels: Low climate risk – Low nature risk (LL), Low climate risk – High nature risk (LH), High climate risk – Low nature risk (HL), and High climate risk – High nature risk (HH).

For the transition risk assessment, we use the NFC-level GHG emissions, the energy mix, and the total MSA loss linked to climate change and land use. The economy-wide climate stress test has shown that higher GHG emissions lead to a higher transition risk. However, those same NFCs may also impact biodiversity through GHG emissions and land-use change, either through their direct activities (such as agriculture) or indirectly through the supply chain. An NFC could be impacted by policies put in place to limit climate change by reducing GHG emissions and by policies to halt biodiversity loss by, for example, limiting nitrogen use and pesticides. Chart 9 represents both climate transition risk due to GHG emissions and nature-related transition risk due to GHG emissions and land use.

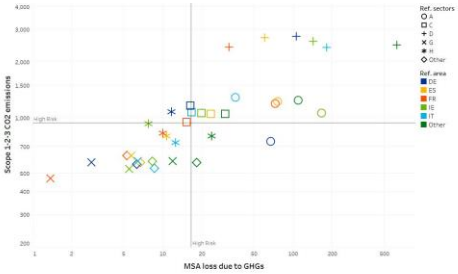
Agriculture and electricity production are clearly the sectors in the euro area that are most exposed to transition risk and the potential amplification effect due to interconnectedness. The amplification mechanism may materialise through the effect of future policies and regulations focusing on both climate change mitigation and nature preservation. Understanding their compound effect is essential to enable a timely policy agenda that supports both climate mitigation and nature preservation and avoids their misalignment.

Chart 9

Transition risk from the climate and nature space

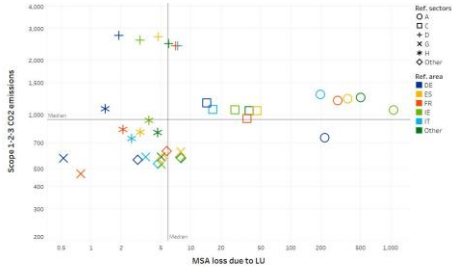
a) Comparison of emissions (GHGs) and MSA loss caused by climate change, both normalised by sectoral revenues

(2021; percentages)



b) Comparison of emissions (GHG) and MSA loss caused by LU, both normalised by sectoral revenues

(2021; percentages)



Sources: AnaCredit, EXIOBASE, Orbis, iBACH, Urgentem, Eurostat, Alogoskoufis et al. (2021).
Notes: Panel A shows the average level of CO_2 emissions intensity [tonnes/EUR millions] (y-axis) and the average MSA loss due to GHG emissions normalised by revenues (EUR millions) by country-sector (NACE level), with the following level of granularity: DE, ES, FR, IE, IT, and Other for the reference areas; A (Agriculture, Forestry and Fishing), C (Manufacturing), D (Electricity supply), G (Wholesale and retail trade), H (Transport and storage) and Other for the sectors. Panel B shows the average level of CO_2 emissions intensity [tonnes/EUR millions] (y-axis) and the average MSA loss due to land use normalised by revenues (EUR millions) by country-sector (NACE level), with the following level of granularity: DE, ES, FR, IE, IT, and Other for the reference areas; A (Agriculture, Forestry and Fishing), C (Manufacturing), D (Electricity supply), G (Wholesale and retail trade), H (Transport and storage) and Other for the reference sectors.

5 Limitations of our study and future research needs

Research in the complex area of nature-related transition risk for financial stability is still at an early stage, and therefore comes with limitations. However, it also highlights topics for further investigation. The limitations of this study are directly related to those discussed in the nature-related physical risk assessment (Boldrini et al., 2023). The current analysis focuses on corporate loans and adopts a static view of the supply chain. Nevertheless, when focusing on the impact assessment and relations between climate and nature, different factors should be taken into account.

The biodiversity footprint assessment is based on NFC biodiversity impacts that are assumed to reflect the footprints of existing businesses and their emissions, as recorded in 2021. A dynamic approach to footprint assessment would integrate the changes in biodiversity levels over time as a consequence of changes in consumption patterns and restoration or conservation of nature (Svartzman, 2021). As we have highlighted, this study only considers two drivers of biodiversity loss: climate change and land use. Other pressures, such as atmospheric nitrogen deposition, overexploitation of natural resources, pollution and hunting, as well as aquatic pressures in marine and freshwater ecosystems, are not considered here. Not accounting for dynamics and an entire set of biodiversity loss drivers makes it very likely that our figures on the biodiversity footprint are an underestimation of the real value.

The impact calculation is based entirely on goods production and does not consider consumption. When computing the MSA impact of firms we used their total revenues. Nevertheless, the location where goods are consumed can impact the composition of a firm's effective biodiversity footprint. Obtaining granular data for the geographical breakdown of firms' downstream revenue could help to understand who is consuming and ultimately fuelling the impact on biodiversity.

Our exercise on the relationship between climate and nature is just a first step towards better understanding the climate-nature nexus. We have limited our analysis to portraying the factual correlation between climate and nature physical and transition risks, without modelling possible interactions. Nevertheless, this unconditional correlation is quite useful and informative, and highlights the importance of continuing to work in this direction.

A risk assessment framework such as the one used in the economy-wide climate stress test (Alogoskoufis et al., 2021; Emambakhsh et al., 2023) requires systematic development of integrated climate-nature scenario narratives and quantification of the economic and financial impacts of key nature-related risk transmission channels. Physical and transition risk evaluation relies on integrated nature and climate scenarios; positive and/or negative synergies between climate change mitigation and nature restoration and preservation can only be addressed through a carefully designed integrated scenario framework that leverages the existing Network for Greening the Financial System climate scenarios. By integrating key nature-economy transmission channels into economic modelling frameworks, we will be able to better quantify the magnitude of nature shocks and their cascading effects on the global macroeconomy. As our knowledge of nature-related risks evolves, we will be able to identify and map the main types of location/region-specific hazards arising from degradation of biodiversity (and the related ecosystems service) that could impact different countries and sectors. This will reduce the likelihood of avoiding systemically important blind spots.

6 Policy implications

The economy is inevitably impacting nature and its ecosystem services, which has far-reaching consequences on the ability of the economic system to keep producing. It is crucially important to understand our impact on nature and how this can, in turn, affect us. Measuring the biodiversity footprint of economic activities and the banks financing them is an important step towards assessing the potential effects of the nature preservation regulatory environment on transition risk. The biodiversity footprint can also shed light on how the economy is contributing to the problem of nature depletion.

Policymakers, governments and parliaments are the main players in protecting the environment, putting regulatory requirements in place to preserve nature, discouraging activities that harm biodiversity and removing subsidies that incentivise nature loss and harm the environment. Governments are increasing their efforts to protect the environment: the UN Convention on Biological Diversity set global targets in 2022, including the conservation of at least 30% of the world's lands, inland waters, coastal areas and oceans. Within the EU, an agreement was reached in June 2023 on a proposal for a Nature Restoration Law.[17] The proposal aims to put in place recovery measures that will cover at least 20% of the EU's land and 20% of sea areas by 2030, and all ecosystems in need of restoration by 2050. It sets specific legally binding targets and obligations for nature restoration in each of the listed ecosystems – from agricultural land and forest to marine, freshwater and urban ecosystems.[18]

These regulations will succeed if they have an impact on firms' investment decisions and consumer preferences. The rationale behind them should be to move funds away from the most impactful sectors and towards more nature-positive activities. Policymakers should not ignore the possible ripple effects on the economy and financial system, especially because a high proportion of impact is financed by certain banks.

Finally, the strong correlation between climate and nature risks means they should be considered two sides of the same coin. As climate and nature are intrinsically interdependent, so are the related risks. By accounting for interconnections between these two risk categories, we reduce the possibility of blind spots and risk underestimation, which could have adverse consequences for financial stability (Kedward et al., 2022). Biodiversity loss and climate change can lead to compounding risks that may significantly amplify the impact of individual shocks in terms of duration and severity (Ranger et al., 2021). In order to mitigate future financial risks, policymakers will need not only to quantify the materiality of climate change and biodiversity loss for the financial system, but also to measure

17 https://environment.ec.europa.eu/topics/nature-and-biodiversity/nature-restoration-law_en

18 https://www.consilium.europa.eu/en/press/press-releases/2023/06/20/council-reaches-agreement-on-the-nature-restoration-law/

and reduce the financial system's negative impact on the climate and environment (Adams et al., 2021).

7 Conclusions

The findings show that the economy has a significant impact on nature and biodiversity, equivalent to the loss of 582 million hectares of "pristine" natural areas worldwide. Together with the results in Boldrini et al. (2023), this accumulated biodiversity footprint shows that the economy not only depends on nature, but also contributes to its degradation. This means it is even more timely and important to focus on nature-related risk.

In total, euro area NFCs generate a local impact of around 398 million hectares in Europe. However, nature-related risks have a global reach with indirect dependency through the supply chain, which is particularly significant for certain sectors and countries. Supply chains also determine NFCs' indirect biodiversity footprint worldwide. Firms may reduce their local impact by outsourcing production of intermediate goods, but nature will be depleted elsewhere. The largest impacted areas due to NFCs' supply chains are Asia and Africa. The global scope of NFCs' dependency and impact means that countries should not act alone.

Our project highlights the importance of integrating climate change and nature loss when developing risk assessment frameworks, because they are inextricably intertwined. Both physical and transition risks stemming from climate change and nature degradation are strongly correlated. This means that interdependencies and reinforcing mechanisms may exist and there is therefore a risk of drastically underestimating climate and nature risk when they are seen in isolation.

Our actions today will clearly determine the impact of nature-related losses on the economy and financial systems, through both physical and transition risk. Timely recognition, assessment and action to address these challenges are essential to prevent future economic downturns. The complex interlinkages between biodiversity loss and climate change, and their potential economic and financial consequences, need to be holistically understood using a systemic risk approach. We must build a scientifically sound analytical framework to assess the complex interactions between nature, the macroeconomy and the financial system, as well as bridging the data gaps. This will enable us to better understand how nature-related risks are transmitted from the macroeconomy to the individual financial institutions and financial systems that the ECB oversees.

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Appendix A: Methodology

Impact assessment

To better understand how the biodiversity footprint is computed, we have provided a stylised numerical example to demonstrate the impact allocation among sectors and regions. Consider a world with two economies: the euro area and the rest of the world. For both, we will consider two separate sectors: agriculture and manufacturing. The world economy can be represented using a multi-region input-output (MRIO) table, as shown in Table 1A. Please note that the figures are not indicative, but rather randomly selected for demonstration purposes.

Table 1A

Example of MRIO table to demonstrate the impact allocation.

Illustrative money flow and resource usage in an MRIO table

(EUR monetary flows, CO_2 kg, and km^2)

		Euro area		RoW		Euro area	RoW	
		Ag	Ma	Ag	Ma	Final demand	Final demand	Output
Euro area	Ag	80	20	50	30	50	60	290
	Ma	10	120	30	60	80	100	400
RoW	Ag	80	100	175	100	150	120	725
	Ma	40	120	90	140	180	100	670
	VA	80	40	380	340			
	GHG	3,500 CO_2 kg	2,100 CO_2 kg	17,500 CO_2 kg	12,250 CO_2 kg			
	LU	420 km^2	175 km^2	980 km^2	385 km^2			

Source: ECB calculation.
Notes: Indicative input-output table for a two-region two-sector world containing the euro area and the rest of the world (RoW). The sectors considered are agriculture (Ag) and Manufacturing (Ma). In the main body of the table, the numbers represent indicative monetary flows within the euro area and the rest of the world. The environmental impacts associated with production activities are measured in CO_2-equivalents for GHG emissions and area of land used (LU).

An input-output table contains the yearly monetary transactions between the different sectors in the economy. Each column of the main square matrix contains information on the input and imports required by that sector to produce. Each row contains information on the output and exports of that particular economic activity. In our example, the agricultural sector in the euro area purchases EUR 10 worth of goods from the euro area manufacturing sector, while it imports EUR 80 of goods from the agricultural sector in the rest of the world and EUR 40 from the manufacturing sector in the rest of the world. The table is then completed by the column containing the final demand of households, non-profit organisations and gross fixed capital formation. For simplicity, the example depicts the summed values. The bottom row represents the value added generated by each sector.

EXIOBASE and other EE-MRIO tables extend this canonical input-output table with data on the direct environmental pressures generated by each sector. In this example, we consider two pressures: GHGs and land usage, measured in kg of CO_2 and km^2. This means that the agricultural sector in the euro area emitted the equivalent of 3,500 kg of CO_2 and used 420 km^2 of land in producing its output. Using this information, together with the total output, we can compute the direct intensity matrix F that contains the emissions and land usage associated with a single euro of output.

$$F_1 = \begin{bmatrix} 3500/290 & 2100/400 & 17500/725 & 12250/670 \\ 420/290 & 175/400 & 980/725 & 385/670 \end{bmatrix}$$
$$= \begin{bmatrix} 12.07 & 5.25 & 24.14 & 18.28 \\ 1.45 & 0.44 & 1.35 & 0.57 \end{bmatrix}$$

Nevertheless, these intensity factors do not consider intermediate sales between economic sectors. To consider these it is necessary to compute the inverse Leontief.

$$L = (I - A)^{-1} = \begin{bmatrix} 1.48 & 0.23 & 0.17 & 0.14 \\ 0.17 & 1.58 & 0.14 & 0.21 \\ 0.68 & 0.75 & 1.49 & 0.40 \\ 0.43 & 0.76 & 0.31 & 1.43 \end{bmatrix}$$

Using the inverse Leontief, it is possible to compute the total amount of emissions that occur anywhere in the whole economy to ultimately produce EUR 1 worth of goods in a given sector.

$$F_{tot} = F_1 \cdot L = F_1 \cdot (I - A)^{-1} = \begin{bmatrix} 43.04 & 43.07 & 44.43 & 38.81 \\ 3.39 & 2.47 & 2.50 & 1.67 \end{bmatrix}$$

However, since we are interested in understanding where the emissions take place, we can expand the previous matrix product and obtain the sector-wide impact as follows:

$$F_{tot}^{GHG} = L' \cdot diag(F_{1\cdot}) = \begin{bmatrix} 17.91 & 0.88 & 16.40 & 7.85 \\ 2.75 & 8.33 & 18.17 & 13.85 \\ 2.06 & 0.72 & 35.90 & 5.76 \\ 1.71 & 1.13 & 9.76 & 26.21 \end{bmatrix}$$

This matrix contains the total amount of emissions produced around the world and by the different sectors to produce EUR 1 worth of goods in a given sector. For example, if we consider the first row corresponding to the agricultural sector in the euro area, we can see that total local emissions are 18.79 kg of CO_2, with 17.91 kg stemming from the agricultural sector itself and 0.88 kg originating in the euro area manufacturing sector. Alternatively, the production of EUR 1 worth of goods in the euro area agricultural sector is responsible for emissions of 24.25 kg of CO_2 in the rest of the world. The same method can be applied with the data for land usage.

Using the coefficients provided by the GLOBIO model, it is possible to convert these physical impacts in terms of kg of CO_2 emitted and area of land used into the MSA loss factors. In this way, we can determine how much biodiversity is lost both locally and worldwide when producing one unit of output in each sector.

This value is then multiplied by the revenue of the NFCs in our sample to determine the overall impact generated by an NFC in terms of MSA hectares in 2021.

The impact of climate change on biodiversity is quantified using GHG emissions figures taken from EXIOBASE. Specifically, we consider emissions of carbon dioxide (CO_2), nitrous oxide (N_2O), fossil and biogenic methane (CH_4) and sulphur hexafluoride (SF_6). All GHG emissions are expressed in terms of CO_2-equivalents, a measure that compares emissions of various GHGs on the basis of GWP (IPCC, 2007). GWP describes the relative potency of a GHG, taking account of how long it remains active in the atmosphere. It is calculated over 100 years, and CO_2 is taken as the gas of reference (it is given a 100-year GWP of 1). For example, the GWP of N_2O is 310, indicating that emissions of 1 kg of N_2O are equivalent to emissions of 310 kg of CO_2.[19] The loss in MSA is then calculated based on the impact of temperature increases on MSA for 14 different terrestrial biomes (large geographic biotic units). Our study uses time and area-integrated loss in MSA per unit of CO_2 emissions for a time horizon of 100 years (consistent with IPCC, 2013): $4.37 \cdot 10^{-5}$ MSA-loss·ha·yr/kg. The time scale of integration is chosen to prioritise the impact of gases with a longer lifetime in the atmosphere (such as CO_2 and N_2O), considering the impacts that happen a century after the emissions occur (Joos et al., 2013).

Finally, in a similar way to the exposure, we can associate the impact of an NFC with the banks financing it. Specifically, we attribute the impact of an NFC to all banks financing it. When multiple banks are lending to the same borrower, the overall impact is attributed to all the banks depending on their share of the total borrower indebtedness.

[19] The GWPs of other GHGs considered here are as follows: 30 for CH_4, and 22,800 for SF_6.

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Andrej Ceglar
European Central Bank, Frankfurt am Main, Germany; email: andrej.ceglar@ecb.europa.eu

Simone Boldrini
European Central Bank, Frankfurt am Main, Germany; email: simone.boldrini@ecb.europa.eu

Chiara Lelli
European Central Bank, Frankfurt am Main, Germany; email: chiara.lelli@ecb.europa.eu

Laura Parisi
European Central Bank, Frankfurt am Main, Germany; email: laura.parisi@ecb.europa.eu

Irene Heemskerk
European Central Bank, Frankfurt am Main, Germany; email: irene.heemskerk@ecb.europa.eu

Postal address 60640 Frankfurt am Main, Germany
Telephone +49 69 1344 0
Website www.ecb.europa.eu

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