EUROPEAN CENTRAL BANK

EUROSYSTEM

Occasional Paper Series

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Living in a world of disappearing nature: physical risk and the implications for financial stability

No 333

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Abstract

The loss of biodiversity and the degradation of natural ecosystems pose a significant threat to the broader economy and financial stability that central banks and financial supervisors cannot ignore. To gain further insights into the implications of nature and ecosystem service degradation for financial stability, this study assesses the dependencies of euro area non-financial corporations and banks on different ecosystem services. The study then develops a method to capture banks' credit portfolio sensitivity to possible future changes in the provision of ecosystem services. Our results show that 75% of all corporate loan exposures in the euro area have a strong dependency on at least one ecosystem service. We also find that loan portfolios may be significantly affected if nature degradation continues its current trend, with greater vulnerabilities concentrated in certain regions and economic sectors.

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

JEL codes: C55, G21, G38, Q5.

Executive summary

A thriving nature provides many benefits that sustain human well-being and the global economy. Unfortunately, intensive land use, climate change, pollution, overexploitation and other human pressures are rapidly degrading our natural resources. This nature loss poses a serious risk to humanity as it threatens vital areas, such as the supply of food and medicines. Such threats are also existential for the economy and the financial system, as our economy cannot survive without nature.

The scope of this study is to raise awareness about nature-related risks by assessing the relationship between nature, our economy and euro area banks. To do so, we (1) assess the dependency of non-financial corporations (NFCs) financed by euro area banks on nature and study the magnitude and likelihood of shocks caused by nature depletion, and (2) discuss policy implications of our study for central banks.

Degradation of nature can impair production processes and consequently weaken the creditworthiness of many NFCs. Central banks and supervisors therefore need to understand how vulnerable the economy and the financial system are to this degradation. In this study we look at the dependency on nature of more than 4.2 million individual NFCs accounting for over €4.3 trillion in corporate loans in the euro area. We assess how dependent NFCs and banks are on the various benefits that humanity obtains from nature in the form of ecosystem services. Examples of such services are the products that we obtain from ecosystems, such as food, drinking water, timber and minerals; protection against natural hazards and local climate regulation; and carbon uptake and storage by vegetation.

There are two main channels via which nature affects NFCs and banks: physical risks and transition risks. Physical risks, which are the focus of this study, may be acute risks, such as increasingly severe natural disasters, or chronic risks, such as dwindling ecosystems. The effects can include falling crop yields owing to a decline in pollinating insects or the degradation of agricultural land, reduced capability of ecosystems to provide flood protection and freshwater resources due to deforestation, and decreased carbon uptake and storage in ecosystems due to unsustainable land management. Scarcity of nature's products can also lead to supply-side shocks for the pharmaceutical industry or to destinations becoming less attractive for tourism.

In the euro area, approximately 72% of NFCs (corresponding to around 3 million individual NFCs) are highly dependent on at least one ecosystem service. Degradation of the relevant ecosystem would translate into critical economic problems for such NFCs. We also find that almost 75% of corporate bank loans in the euro area are granted to NFCs with a high dependency on at least one ecosystem service. We observe only moderate differences between countries, as indirect supply chain dependencies offset smaller direct dependencies, especially in small and open economies. These dependencies could result in significant losses for banks, specifically if shocks are amplified by the large number of relevant ecosystem services.

The sensitivity analysis of the change in the expected losses of banks' credit portfolios due to possible biodiversity losses shows that euro area banks are vulnerable to future biodiversity losses. If the world follows its current emission pathway and continues to exert significant pressure on biodiversity, euro area banks' losses could be on average almost three times higher than under a Paris-aligned future scenario. The biggest losses (up to five times higher compared with a Paris-aligned future scenario) would be felt in countries such as Germany, Lithuania, Ireland and Belgium.

The loss of ecosystem services may have far-reaching consequences for the economy, including through the amplified effects of close interaction between biodiversity loss and climate change. Recognition of nature degradation and related biodiversity loss as a potential source of economic and financial risks is only a first step in the development of a response strategy to maintain financial and price stability. For capital markets to better consider the risks stemming from nature loss and limit their impact, gaps must be filled in disclosure and quantitative risk modelling frameworks.

1 Introduction

Healthy nature is essential for sustaining our well-being and supplies a multitude of benefits to society through ecosystem services (Dasgupta, 2021). We all depend on nature for our food, air, water, energy and raw materials. Beyond making our existence possible, nature and its biodiversity provide health and socio-economic benefits. Ecosystem services, such as food production, water purification and flood protection, are defined as the links between nature and the economy and represent the benefits that nature provides to sustain the economy. More than half of global gross domestic product (GDP) – some €40 trillion – depends on nature (EU Biodiversity Strategy for 2030, 2021; World Economic Forum, 2020), clearly indicating the magnitude of economic value derived from biodiversity. Pollination, for example, is required by about 75% of our food crops (Klein et al., 2007), with an estimated annual global economic value of €248 billion to €293 billion (IPBES, 2016). Beyond the above-mentioned benefits, ecosystem characteristics are frequently also incorporated into our cultural identity.

Despite scientific research showing evidence of high socio-economic benefits from nature, we are currently observing an unprecedent decline in natural ecosystems and their vital services. Human activities are responsible for driving the decline of natural capital and capacity to provide ecosystem services as well as loss of biodiversity (CISL, 2022). Climate change, invasive species, land use change, overexploitation of natural resources and pollution are among the direct drivers of nature loss. Out of an estimated 8 million animal and plant species on Earth, nearly 1 million are threatened by extinction due to habitat loss, urban expansion, agriculture and climate change (IPBES, 2019). In Europe alone, nearly a quarter of known species are currently threatened with extinction. Under increasing pressure from human activities, the world lost an estimated €3.5-18.5 trillion per year in ecosystem services from 1997 to 2011 (Costanza et al., 2014). These figures clearly demonstrate the immense economic and social costs of already observed biodiversity loss.

Nature-related risk encompasses biodiversity loss and ecosystem degradation and is very much interdependent with climate change. For example, biodiversity and ecosystem services play an essential role in climate regulation, as marine and terrestrial ecosystems currently absorb around 50% of man-made carbon emissions (Rockström et al., 2021). Thus, the loss of biodiversity will further accelerate climate change if ecosystems are not effectively protected. At the same time, climate change contributes to the loss of biodiversity and ecosystems. Anthropogenic climate change is projected to cause lasting ecological regime shifts and disrupt critical ecosystem services, potentially triggering irreversible effects (Meyer et al., 2022).

Recognising the value of natural capital would have considerable benefits for biodiversity and ecosystem services. The vast contribution of ecosystem services to the sustainable well-being of humans and the rest of nature should be at the centre of our efforts to reduce emissions and protect our nature (Costanza et al., 2017). Additionally, every euro invested in nature restoration creates between €8 and €38 in economic benefits (EU Nature Restoration Law, 2022).

1.1 What are nature-related risks and why are they important for central banks?

Nature-related risks are caused by loss of biodiversity and degradation of other natural ecosystems, leading to a substantial threat to financial stability and the broader economy via both physical and transition risk (CISL, 2021). Physical risk captures the threat to economic activities associated with nature degradation and can be acute, such as increasingly severe natural disasters, or chronic, such as dwindling ecosystems. Higher dependency of an economic sector on a specific ecosystem will result in a greater physical risk posed to that sector. The effects can include falling crop yields owing to a decline in pollinating insects or the degradation of agricultural land. Alternatively, scarcity of nature's products can lead to supply-side shocks for the pharmaceutical industry or to destinations becoming less attractive for tourism.

Nature loss can also lead to transition risks to non-financial corporations (NFCs) and to banks who lend to them. Economic sectors that are highly dependent on nature are often among those damaging it the most. Firms that have a substantial impact on nature could face important reputational and transition risks in the future. For example, governments have increased their efforts to protect nature. One instance of such regulation is the Kunming-Montreal Global Biodiversity Framework adopted at the 15th Conference of the Parties to the UN Convention on Biological Diversity in December 2022.[1] These measures could lead to changes in regulation and policy, for example by limiting the exploitation of natural resources or banning certain products that trigger degradation. Alternatively, technological or business model innovation and consumer or investor sentiment could lead to transition risks and transition costs as NFCs are forced to adapt. Some older business models could disappear, while others might become too expensive and lose market share.

In its seminal paper in 2020, De Nederlandsche Bank (DNB) and the Netherlands Environmental Assessment Agency assessed the extent to which the Dutch financial sector is exposed to risk because of nature degradation. Analysing data from Dutch banks, pension funds and insurers, they report that 36% of Dutch financial institutions' portfolios worldwide are exposed to NFCs with high or very high dependency on at least one ecosystem service (van Toor et al., 2020). Similarly, the study highlights that in 2019 Dutch financial institutions worldwide contributed €97 billion to finance NFCs involved in environmental controversies and which are thus vulnerable to transition risk.

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1 This framework sets global targets in terms of nature conservation. Specifically, it sets the target of preserving at least 30% of the world's lands, inland waters, coastal areas and oceans (Convention on Biological Diversity, 2022)

Similarly, the Banque de France (BdF) explored biodiversity and nature-related risks in France. Svartzman et al. (2021) found that 42% of securities in terms of value held by French financial institutions are issued by an NFC that is highly or very highly dependent on one or more ecosystem services. Moreover, they found that the total terrestrial biodiversity footprint associated with these securities can be compared to a loss of at least 13 million hectares of "pristine" nature. The Bank of England (BoE), using similar methodologies (BoE, 2022), found that 52% of UK GDP and 72% of UK lending are dependent on ecosystem services. Other exercises that utilise these methodologies have been conducted by the Central Bank of Malaysia (World Bank and Bank Negara Malaysia, 2022) and the Bank of Mexico (Martinez-Jaramillo et al., 2023).

The Network for Greening the Financial System (NGFS) has acknowledged that nature-related financial risk should be considered by central banks and supervisors in the fulfilment of their mandates. They should recognise nature as a potential source of economic and financial risk and need to assess the degree to which financial systems are exposed to nature. To this end, the NGFS launched a task force dedicated to biodiversity loss and nature-related risks and published a beta version of its conceptual framework for nature-related financial risks to help guide policies and action by central banks and financial supervisors (NGFS, 2023).[2] Likewise, the Taskforce on Nature-related Financial Disclosures (TNFD) has issued recommendations for a first integrated risk management and disclosure framework for nature-related issues (TNFD, 2022).

Nature-related risks could thus have important implications for the ECB's mandated objectives. Scientific evidence (e.g. CISL, 2021, and references therein; Svartzman, 2021) has highlighted that failure to mitigate and adapt to nature-related risks, including those related to biodiversity loss, could have significant macroeconomic as well as financial stability implications. From a macroeconomic perspective, these risks could hamper the real economy via effects on GDP, inflation, unemployment and/or long-term interest rates in response to changing policies or to physical climate shocks. From a financial stability perspective, the double materiality of nature-related risks – similarly to climate-related risks – emphasises the need to account not only for the exposures of financial institutions to those risks, but also to evaluate their contribution to them. Looking at the former, financial institutions can incur nature-related losses due to physical risks as well as transition risks driven by policy implementation, technological developments, market dynamics and reputational issues.

An increasing number of studies highlight the growing consensus among central banks and supervisors that nature-related risks could have significant macroeconomic implications and, if ignored, could lead to financial stability implications. Central banks can only pursue price stability if they are able to

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2 The aims of the task force are to (i) provide NGFS members with a common understanding of, and language and conceptual framework for, nature-related risks, including physical and transition risks related to biodiversity loss and ecosystem degradation; (ii) provide recommendations to NGFS workstreams on how to operationalise the integration of nature-related risks into their respective work programme; and (iii) identify potential needs for inputs from NGFS expert networks and for engagement with external initiatives.

understand and forecast how economic shocks and trends affect inflation and the effectiveness of monetary policy. Accordingly, apart from its scope and potential severity, the need to account for the climate and environmental crises could be considered urgent and comparable to accounting for globalisation, demographics or financial innovation. The fact that climate and environmental crises can lead to severe acute risks raises the urgency even more.

2 Project overview

2.1 Aim of our analysis

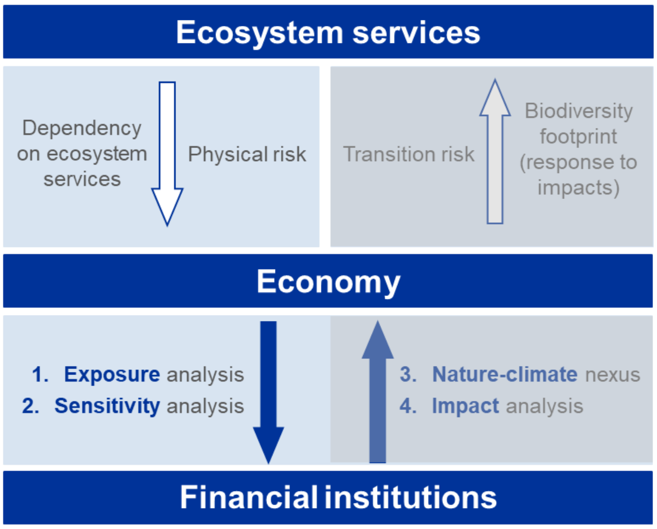
The primary objective of this study is to raise awareness about nature-related risks by assessing the relationship between nature, our economy and euro area banks. **The first section of the study quantifies the extent to which the euro area economy and financial sector are exposed to risks related to ecosystem services (Chart 1).** Ecosystem services can be defined as the benefits that nature provides to enable economic activities. To assess the physical risk, we evaluate the ecosystem service dependence of NFCs financed by euro area banks. The principal assumption behind the assessment of physical risk is that greater dependence on ecosystem services is likely to result in greater exposure to ecosystem degradation. This means that, in the future, if nature degradation continues, economic activities dependent on ecosystem services will be affected by issues such as supply chain disruption, reduced turnover or even inability to produce. This would result in large losses for any institutions lending to these NFCs, leading to financial stability concerns.

We also recognise that exposure is not enough when trying to conduct a risk assessment. The magnitude and likelihood of the shocks caused by nature depletion are important. With this in mind, we also assess the possible sensitivity of banks' credit portfolios to changes in biodiversity levels and the related financial viability of their borrowers. This assessment relies on scenarios of future biodiversity intactness loss caused by climate change and land use change (Schipper et al., 2020).

Quantifying the extent to which the euro area economy and financial sector contribute to nature degradation is an important indicator of transition risk. By estimating the biodiversity footprint, we can measure the contribution of an economic activity to the drivers of biodiversity loss. To this end, the formulation of an integrated framework on nature-climate risk assessment is essential to prevent underestimation of nature-related and climate-related financial risks. Both the biodiversity footprint and nature-climate nexus will be assessed in the follow-up study.

Chart 1

Main elements of the nature-related risk assessment. This study focuses on dependency on ecosystem services, performing exposure and sensitivity analyses. The follow-up study will focus on transition risk and will present the impact analysis and highlight the importance of the nature-climate nexus framework.



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

2.2 Key features and dataset of the study

This study is based on a comprehensive methodology for evaluating the dependency of euro area NFCs and euro area banks on nature as well as their impact on biodiversity loss. The approach builds on previous studies on nature-related exposure, such as those by DNB and BdF. However, the set-up of this project is unique and different from previous studies given that it considers the whole of the euro area. The results are based on unique and granular datasets comprising millions of NFCs in the euro area and abroad, mapping economic activities to ecosystem services and their impact on biodiversity loss. Specifically, our sample is based on the AnaCredit dataset for December 2021, which counts approximately €4.3 trillion in corporate loans to around 4.2 million NFCs. The loans are issued by more than 2,500 unique consolidated banks with headquarters in the euro area.[3] Further information on the sample is provided in Appendix A. This data is then enhanced with ENCORE[4] (Natural Capital Finance Alliance, 2022) and EXIOBASE[5]

3 The sample corresponds to all NFCs that fall within the scope of AnaCredit. This means that they have registered a loan with a value equal to or greater than €25,000 at the reporting reference date (December 2021).

4 ENCORE (Exploring Natural Capital Opportunities, Risks and Exposure) is a tool developed by Global Canopy, the UN Environment Programme Finance Initiative and the UN Environment Programme World Conservation Monitoring Centre to map the goods and services that nature provides to enable economic production.

5 EXIOBASE is a global, environmentally extended multiregional input-output (EE-MRIO) table (consisting of 44 countries, five rest-of-world regions, 163 industries and more than 1,000 emission categories and resource usages.

(Stadler et al., 2019) to determine the dependencies of NFCs on nature. GLOBIO[6] is used to determine location-specific shocks to biodiversity and how the latter is affected by the different NFCs. Finally, other data sources, such as Orbis, iBACH and FINREP/CONREP, are used to complement our analyses with financial information.[7]

The proposed framework considers physical risk, which is assessed through the dependency of NFCs on ecosystem services both directly and through their supply chain. These corporations are then linked to the financial institutions that lend to them to understand the share of banks' portfolios that is exposed to this kind of risk. Conversely, transition risk is measured using the impact that an NFC's economic activity has on nature, more specifically on biodiversity.

This paper is organised as follows. Section 3 introduces and describes the exposure of the euro area economy and financial system by assessing their dependencies on ecosystem services. Section 4 introduces a method for assessing financial system sensitivity to biodiversity loss and presents the results of sensitivity to different scenarios of biodiversity loss by 2050. We conclude this paper by discussing the policy implications of this study and the need for future research to move closer to risk-based assessment.

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

7 See Appendix A for further details of the datasets used.

3 Exposure assessment

3.1 The ENCORE dataset

The methodology used to assess euro area NFCs and financial institutions' exposure to ecosystem services is based on the ENCORE dataset. ENCORE (Exploring Natural Capital Opportunities, Risks and Exposure, Natural Capital Finance Alliance, 2022) is a tool to help users better understand and visualise the impact of environmental change, including biodiversity loss, on the economy. The database provides an assessment of industries' dependency on 21 ecosystem services such as flood and storm protection, carbon uptake and storage and soil erosion control. We complement ENCORE with the input-output table EXIOBASE to account for indirect dependencies on other ecosystem services through supply chains and assign to each borrower a total dependency score. Moving from the real economy to the financial sector, we then aggregate the dependencies of borrowers at the banks' portfolio level. Specifically, to compute lender-specific dependency scores we weight borrowers' dependency scores by the respective loan exposure. Further information on the ENCORE dataset is provided in Appendix A.

For each economic activity of euro area NFCs, ENCORE provides materiality scores on ecosystem services that range from "no dependency" to "very high dependency".[8] These scores consider how significant the loss of functionality in the production process could be if the ecosystem service is disrupted and how large the consequent financial loss would be. The higher the materiality score, the greater the dependency of the economic activity on that ecosystem service. The ENCORE scores therefore allow us to measure how much a certain ecosystem service supports a given economic activity.[9] It is important to note that most economic activities rely on multiple ecosystem services, highlighting the multidimensionality of nature-related risks.

Different economic sectors rely on different ecosystem services to different degrees (Chart 2). Importantly, ENCORE's industry classification is based on the Global Industry Classification Standard (GICS), while AnaCredit is based on the Statistical Classification of Economic Activities in the European Community (NACE). Because of this, a reclassification of ENCORE was performed.[10] As a result of the conversion, multiple GICS industries may be attributed to the same NACE code. In these situations, we considered the maximum dependency score across GICS industries for each ecosystem service. The rationale behind this decision is to be able to adopt a more conservative stance. Considering the maximum dependency score allows us to capture the worst-case scenario, thus avoiding the possible underestimation of exposures.

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8 To allow for analysis, we rescaled the ENCORE qualitative scale to a numeric one ranging from 0 (non-dependency) to 1 (very high dependency).

9 Further details on how ENCORE is constructed can be found in the Appendix A.

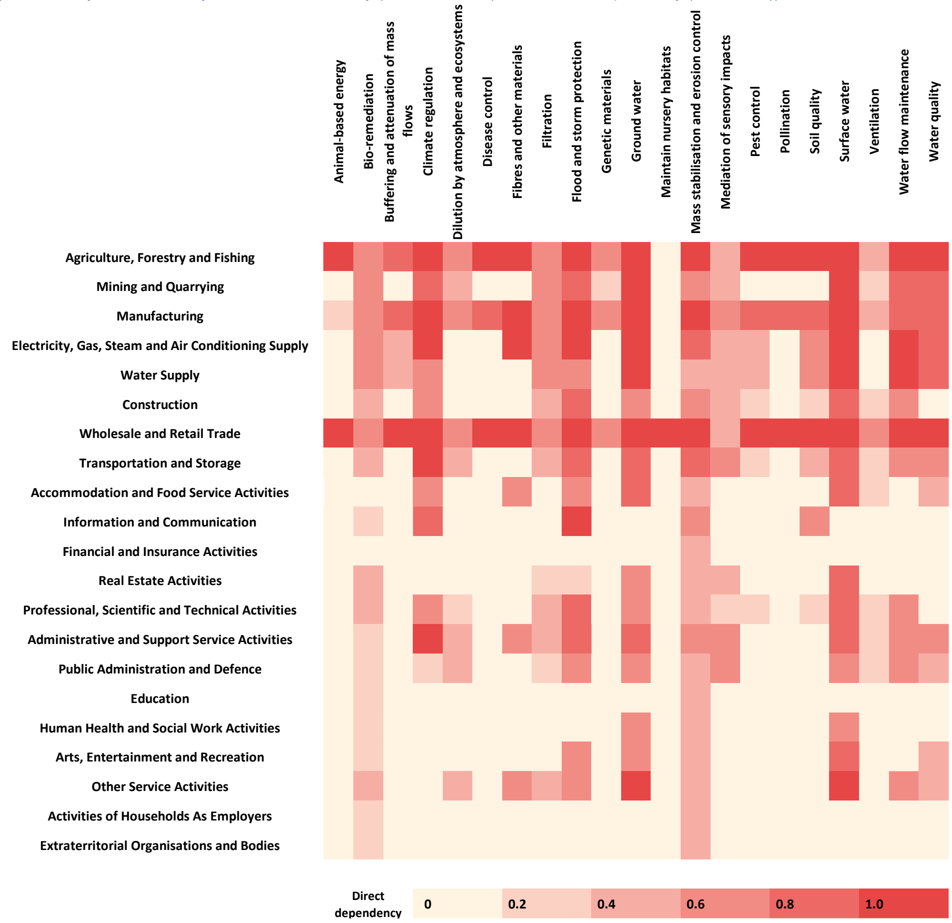
10 Specifically, we considered all four hierarchical levels of NACE (21 sections, 88 divisions, 272 groups and 615 classes) when reclassifying from GICS.

Chart 2

ENCORE materiality scores represent the significance of functionality loss in the production process if an ecosystem service is disrupted

ENCORE direct dependency scores aggregated at sectoral level

(x-axis: ecosystem services, y-axis: economic activity (NACE sections), value: direct dependency (from 0 to 1))



Source: ENCORE.
Notes: Direct dependency scores by NACE section. ENCORE production processes have been converted to NACE sections. Where multiple materiality scores for the same ecosystem service are attributed to the same NACE, the maximum value is considered.

Importantly, ENCORE does not distinguish across geography and excludes the value chain. This means that the dependency of a given economic sector on nature does not depend on the location, making the materiality scores provided by ENCORE sector-specific. Furthermore, ENCORE maps only direct potential dependencies, excluding dependencies through the supply chain. ENCORE thus represents only a first-order approximation. Nevertheless, given the lack of more granular data, this methodology has been extensively used in the literature and often combined with input-output tables to extend the dependency measure considering the supply chain (van Toor et al., 2020; Svartzman et al., 2021; World Bank and Bank Negara Malaysia, 2022). Finally, ENCORE is provided as a discrete metric, without specification of whether the relationships among the classes of materiality are linear or not. This means that the difference in potential economic damages caused by the materialisation of a “very high” and a “high” dependency might be greater than the one between “high” and “medium” ones. Due to limited data availability, it is currently not feasible to assess the presence or lack of a linear relationship between nature loss and economic damages.

3.2 Methodology

As a first step, we link banks' loan exposures to their counterparts, i.e. the NFCs that received the loan. AnaCredit is used as a main source of data to link banks' portfolios to their NFC counterparts. Our sample refers to December 2021 and considers €4.3 trillion in corporate loans granted by more than 2,500 different euro area consolidated banking groups. Overall, our sample maps 4.2 million unique NFCs located in the euro area and abroad. Orbis and iBach are then used to provide additional NFC-level financial data. In our sample, the biggest corporate sectors in terms of assets are located in Germany and France, followed by Italy and Spain. The distribution of NFCs in terms of size is quite asymmetric, suggesting a large overall number of small and medium-sized enterprises. Real estate and manufacturing are the sectors with the highest share in our sample, while some larger NFCs in Germany and France are concentrated in the sector of scientific and technical activities.

As a second step, we assess the dependency of each NFC on ecosystem services. As previously stated, for each borrower we compute two types of dependencies: direct dependency and indirect dependency through supply chain linkages. The direct dependency is provided by ENCORE, by using the dependency scores of NACE sectors in relation to ecosystem services. When converting from GICS to NACE, multiple GICS categories may be attributed to a single NACE sector. Therefore, multiple materiality scores for the same ecosystem service may be attributed to one NACE sector. In this case, the maximum materiality value is considered to avoid underestimating exposures (see Section 3.1).[11] The indirect dependency is computed using the supply chain data from EXIOBASE. EXIOBASE is an environmentally extended multiregional input-output (EE-MRIO) table that allows us to assess the input requirements, both direct and indirect, necessary to produce a given unit of output in a given sector of a country.[12] This information can thus be used to weigh the dependencies of all suppliers and obtain a measure of the indirect dependency of a given NFC (Chart 3). The overall indirect dependency relies on the shares of inputs in the value chain of the NFC, which in turn depend on the country where it is headquartered.[13] Hence, two NFCs with the same economic activities but operating in different regions will have the same direct dependency but different indirect ones. Further information on the EXIOBASE dataset is provided in Appendix A.

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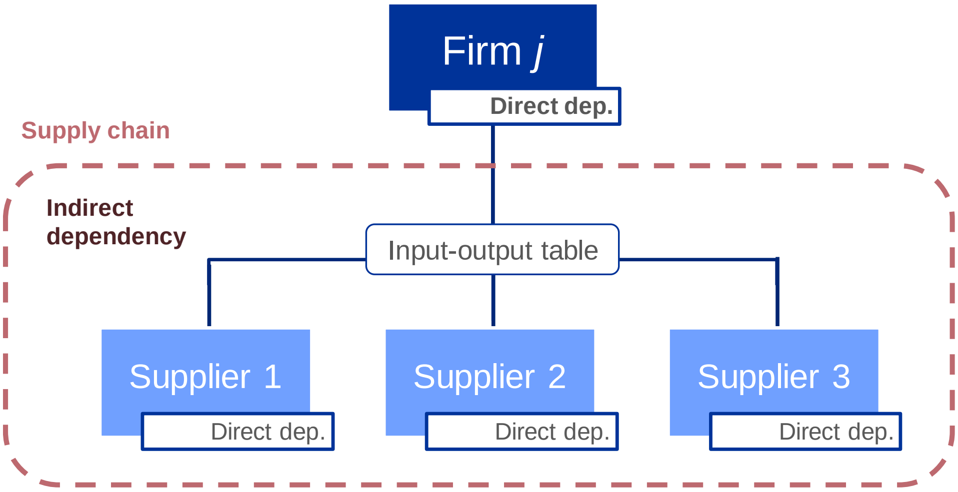
[11] This mostly occurs when aggregating at NACE levels 2 and 3. Nevertheless, in our AnaCredit sample, NACE level 4 represents 86% of our firms. Therefore, the choice of using the maximum as the aggregating function has a relatively small effect.

[12] Further details on EXIOBASE and how it is used in our analysis can be found in Appendix A.

[13] This assumes that each firm follows the aggregate production pattern and therefore may be an imperfect measure of the true supply chain characteristics of a firm. Nevertheless, existing datasets (such as FactSet Supply Chain Relationship), which map firm-level supply chain relationships between supplier and consumer, would provide a much smaller coverage compared with our sample.

Chart 3
Derivation of dependency scores at NFC level

Stylised representation of how an NFC exposure is assessed



Sources: ENCORE and EXIOBASE.
Note: Graphical representation of how direct and indirect dependency scores are computed.

The two measures of dependency, direct and indirect, are then aggregated as a total dependency score for each NFC. We assume that the indirect materiality score can be proxied as the share of unexplained dependency that can be attributed to suppliers. This allows us to combine direct and indirect dependency in a unique total dependency (DS_{tot}) for each borrower to facilitate the analysis[14]:

$$DS_{tot} = DS_{Direct} + (1 - DS_{Direct}) \times DS_{Indirect}$$

DS_{Direct} and $DS_{Indirect}$ are both continuous measures of dependency and can take values between 0 (no dependency) and 1 (very high dependency). In this aggregation, indirect dependency through the supply chain is only allowed to compensate for direct dependency. Once again, it is worth remembering that ENCORE, and thus the direct dependency score, do not consider the supply chain. We assume that the proposed method of aggregating the two scores minimises double-counting. Specifically, if the direct dependency is very high, then the overall impact of the supply chain component will be very limited even if the number itself is large. On the other hand, if the direct dependency is low, the total dependency could still be high due to supply chain considerations.

The total dependency can be seen as a weighted average, representing a unique indicator for each borrower that at the same time takes into consideration direct and indirect dependency. Nevertheless, we should note that this type of aggregation could generate an artificial "levelling" of dependencies. This effect could occur, for example, when an NFC with low direct dependency ultimately

[14] Other types of aggregation are possible, such as using the maximum or the average. Nevertheless, this type of aggregation is chosen to allow the indirect dependency linked to the supply chain to have an overall amplification effect on the total dependency. Indeed, based on our study, the results do not seem to be significantly sensitive to the aggregation method used, due to a high degree of correlation between direct and indirect dependency.

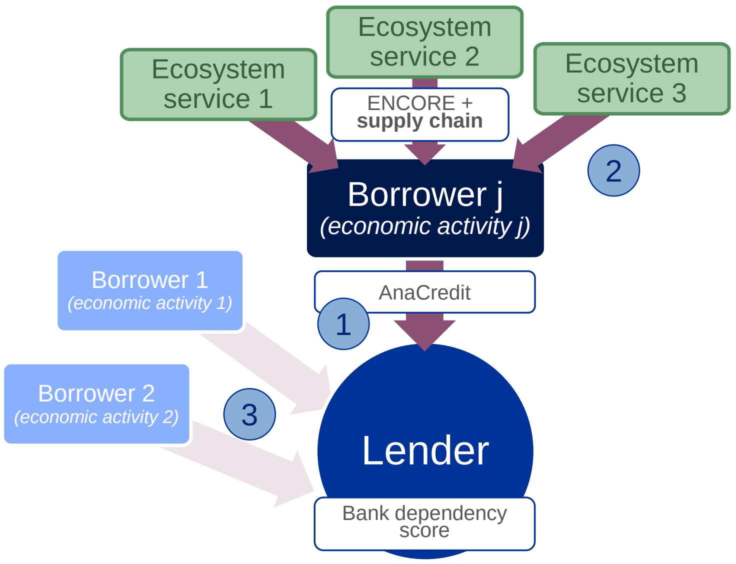
has a high total dependency exclusively through its supply chain exposure. In this case, the indirect dependency would level the low direct dependency upward. By contrast, for an NFC with an already large direct dependency, the indirect exposure will have a smaller impact. For comparison purposes, we show the results for all total as well as direct and indirect exposures.

Finally, as a third step we assign the dependencies of the borrower to the aggregate portfolio of euro area banks. The bank-level dependency score is calculated by weighting the dependency scores of different counterparts by their share in the portfolio. Additionally, banks' dependency scores are aggregated at country or euro area level, weighted by the respective loan amount. All three steps described above are summarised in Chart 4. Further details on the methodology can be found in Appendix B.

Chart 4

Framework for NFC and bank exposure assessment

Stylised representation of how bank exposure is assessed



Source: ECB.
Note: Graphical representation of how the assessment of exposure is performed.

3.3 Results

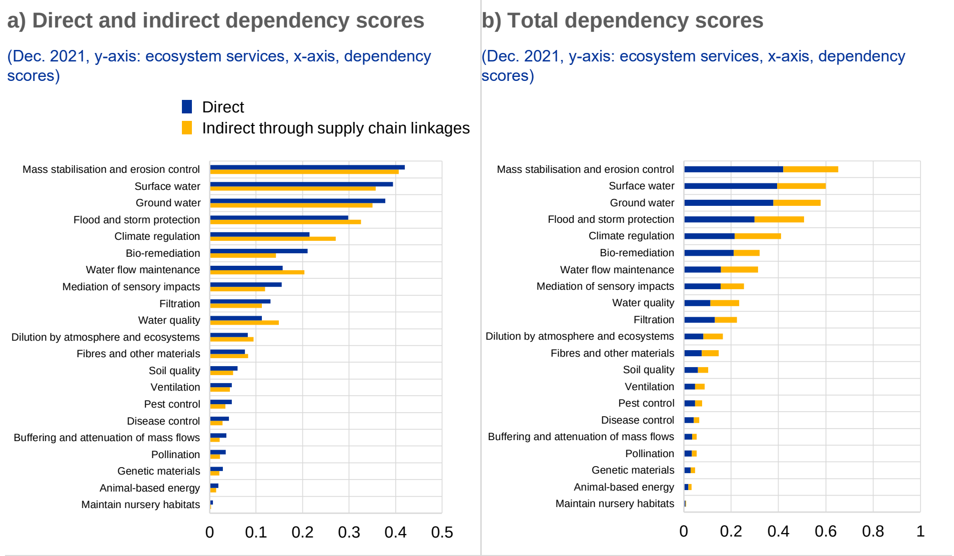
3.3.1 Dependency of euro area NFCs on ecosystem services

Our results show that euro area NFCs have a significant dependency on several ecosystem services, both directly and indirectly through supply chain linkages. All ecosystem services considered by ENCORE (Chart 2) appear to be relevant for economic production in the euro area. Should these ecosystem services become degraded, the dependent production process would be disrupted, and such disruption would be likely to directly affect the financial viability of the NFC.

Concretely, mass stabilisation and erosion, together with surface water and ground water provision, are the most relevant ecosystem services for euro area NFCs, followed by flood and storm protection, climate regulation, bioremediation and others (Chart 5). The majority of ecosystem services for which higher levels of dependency are recorded fall in the category of regulating ecosystem services. For example, vegetation cover, coastal wetlands and dunes provide mass stabilisation and erosion control. Additionally, vegetation on slopes also prevents avalanches and landslides, and mangroves, sea grass and macroalgae provide erosion protection for coasts and sediments. Similarly, natural and planted vegetation also provides flood and storm protection. Among provisioning services, freshwater provision is the most important.

Chart 5

Average dependency of euro area NFCs on ecosystem services



Sources: ENCORE, EXIOBASE and AnaCredit.
Notes: The euro area dependency score is computed as the average of the dependency scores of euro area NFCs and distinguishes between direct dependency and indirect dependency. The total dependency scores (panel b) are calculated by combining direct and indirect dependencies in a single metric.

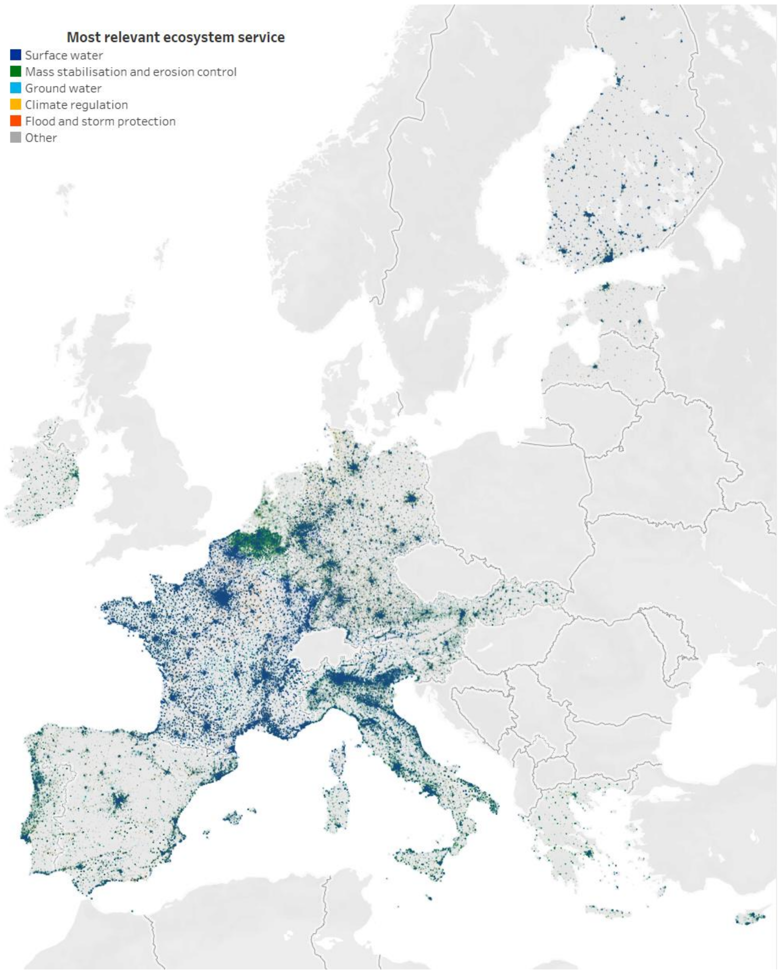
Geographical analysis of the 4.2 million NFCs indicates that the overall dependency of NFCs on ecosystem services is quite homogeneous across countries (Chart 6). In other words, there are no clear differences across countries when looking at the magnitude of the overall dependency. We can observe some minor clusters in France, the Netherlands and northern Italy, which represent some of the most populated and industrial areas. These clusters represent areas of higher magnitude in terms of total dependency compared with other regions.

On the other hand, it is possible to identity clusters of the most important ecosystem services for each NFC. For example, clusters of high dependency on surface water can be observed in France, the Netherlands, northern Italy and western Germany. This is the most relevant service for the largest share of NFCs in the euro area. NFCs are also highly dependent on mass stabilisation and erosion, with a particularly strong cluster in the Netherlands. Meanwhile, ground water, climate regulation and flood and storm protection are more evenly distributed across countries (Chart 6).

Chart 6

The most relevant ecosystem services for economic production across Europe

Geographical location of euro area NFCs considered. Each colour represents the most important ecosystem service for each NFC.



Sources: ENCORE, EXIOBASE and AnaCredit.
Notes: Each dot represents the location of the euro area borrowers considered in our sample. The colour represents the ecosystem service with the highest total dependency score for each NFC. Dots all have the same dimension; clusters are caused by the geographic proximity of the NFCs considered.

Overall, approximately 72% of NFCs (corresponding to around 3 million NFCs) are highly dependent on at least one ecosystem service (Chart 7). We label an NFC as highly dependent if its dependency score is equal to or greater than 0.7 on a scale of 0 to 1. This means that severe losses of functionality in the relevant ecosystem would translate into critical economic problems for such NFCs. This share is similar overall across countries with the exceptions of Latvia and Belgium, which have a significantly higher and lower share of highly dependent NFCs respectively. Differences in the contribution levels of the indirect component signal that reliance on and the overall composition of the supply chain vary across countries. If we consider only direct dependency, the share of euro area NFCs directly exposed to the risk of degradation of ecosystem services falls to 52%.

Similar results can be seen by looking at the share of total assets that are highly exposed to nature (Appendix C).

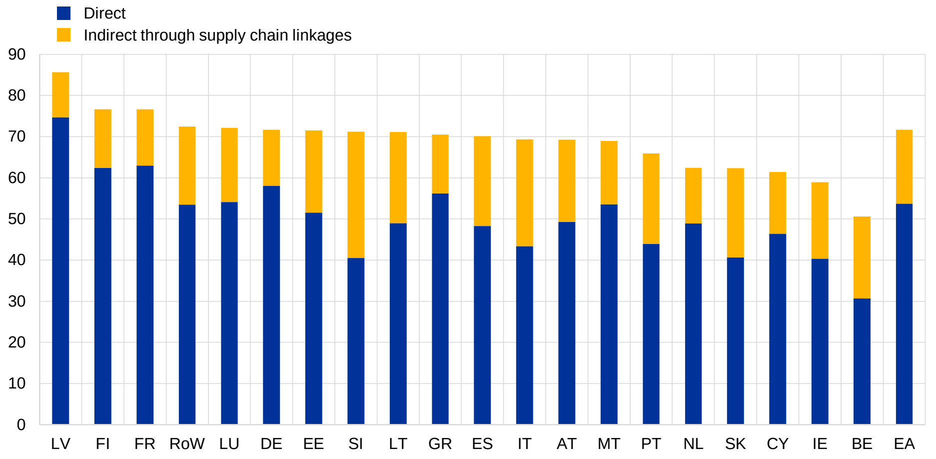
The threshold for delineating high dependency has been chosen in line with our mapping of the ENCORE materiality scores and considering what could be a reasonable loss of economic activity in case of ecosystem service disruptions. Specifically, the value 0.6 represents a medium dependency. In this case, the production process would still take place with disruptions of the ecosystem service but would be drastically impaired if the ecosystem service provision is fully blocked. The value of 0.8 represents a high dependency. In the latter case, the respective ecosystem service is critical and irreplaceable for the production process. Therefore, the chosen value of 0.7 aims at capturing the critical role of ecosystem services for production processes.

Chart 7

Dependency of euro area NFCs on ecosystem services

Share of NFCs with a high dependency score (greater than 0.7) for at least one ecosystem service. NFCs are allocated to the country where they are headquartered

(Dec. 2021, percentage points)

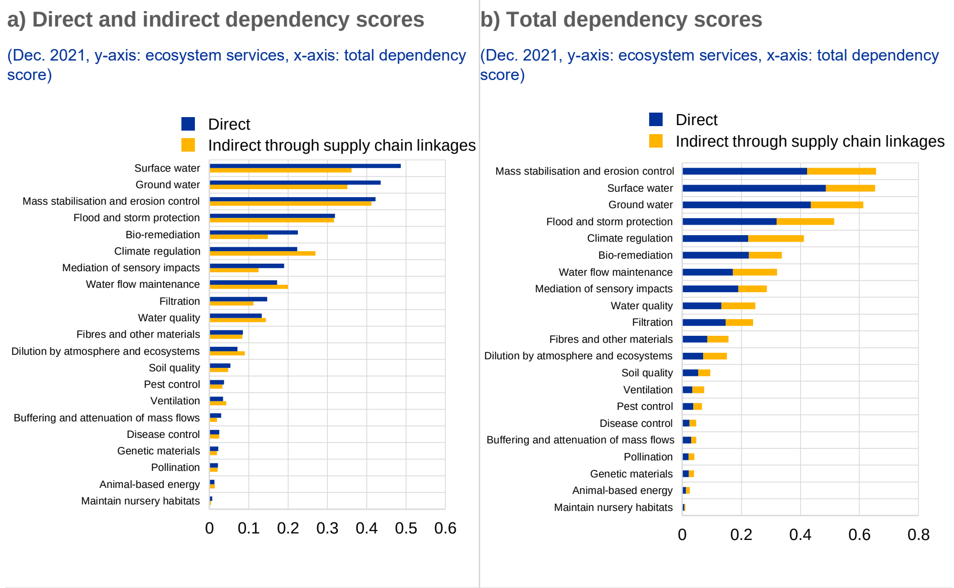


Sources: ENCORE, EXIOBASE and AnaCredit.
Notes: Share of NFCs with a high dependency score (greater than 0.7) for at least one ecosystem service. An NFC is labelled as highly dependent when it has a sufficiently high direct dependency score (blue bar) or sufficiently high dependency when also considering possible supply chain linkages (yellow bar).

Euro area banks' loan portfolios have significant exposure to several ecosystem services, similarly to the euro area economy (Chart 8). As expected, the most relevant ecosystem services are similar to those at NFC level. Specifically, surface and ground water, together with mass stabilisation and erosion, represent the most relevant ecosystem services, which makes banks vulnerable in case of degradation of ecosystem service provision through their borrowers. Nevertheless, there are some differences between NFC and loan portfolio exposures (Charts 5 and 8 respectively). This can be attributed to the different types of aggregation considered. In the case of NFCs, we compute a simple average across the dependency scores of NFCs, giving the same weight to small and large borrowers. By contrast, when computing lender-specific dependency scores, NFCs' dependency scores are weighted by their relative importance in the banks' overall corporate loan portfolio. As such, firms with more debt bring more weight to the final dependency score. In turn, the values expressed in Chart 8 are based on a weighted average of bank-specific dependency scores, with the weights defined as the banks' overall relative corporate loan portfolio sizes. This means that banks with a larger loan portfolio, which are exposed more to the real economy, contribute more to the overall dependency.

Chart 8

Weighted average dependency of euro area banks on ecosystem services via their loan portfolio



Sources: ENCORE, EXIOBASE and AnaCredit.
Notes: The average euro area bank dependency score is computed as the weighted average of the dependency scores of euro area banks using as weights the relative sizes of their loan portfolios. In turn, lender-level dependency scores are computed as weighted averages of borrower dependency scores with weights as the relative importance of the borrower in the bank's overall corporate loan portfolio. A distinction is made between direct dependency and indirect dependency through supply chain. The total dependency scores (panel b) are calculated using equation 1, combining direct and indirect dependencies in a single metric.

The composition of the financial system's dependency on ecosystem services is quite homogeneous across Europe (Chart 9). In most cases, banks' portfolio dependency on ecosystems is similar among euro area countries and reflects the dependency of NFCs in that country.[15] Surface and ground water, together with mass stabilisation and erosion, represent the major potential sources of physical risk for banks. High dependency can also be found on flood and storm protection, especially in Greece, Cyprus, Latvia, Lithuania and Slovenia.

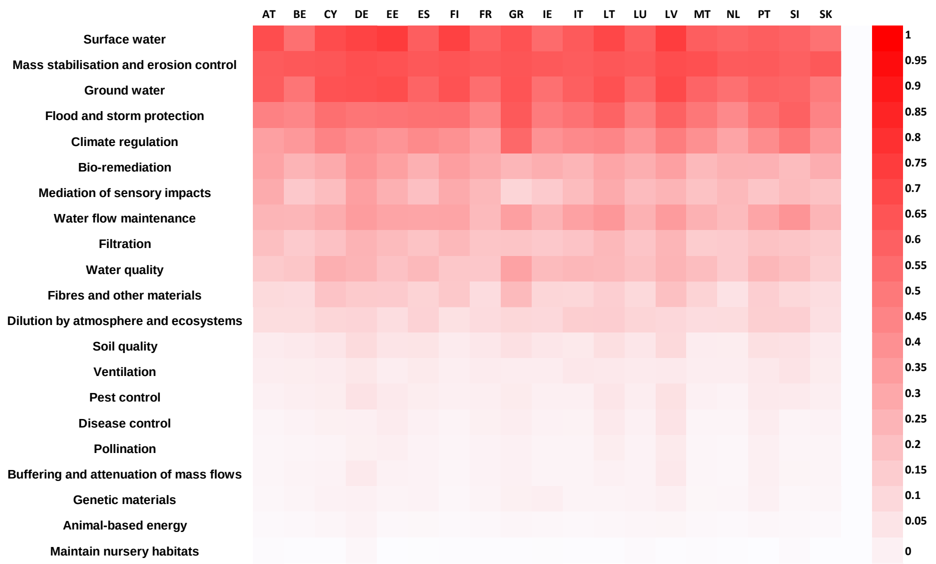
15 There is the possibility of inter-border lending in the sample, whereby an NFC in country A receives a loan from a bank in country B. However, this represents the minority in our sample. Specifically, the average share of intra-border lending in our sample is roughly 75%, meaning that NFCs in a given country tend to receive loans from their home country.

Chart 9

Dependency of euro area countries' financial systems on ecosystem services

Total dependency scores across ecosystem services in euro area countries' financial systems. The values are aggregated using consolidated banks headquartered in each country.

(Dec. 2021, total dependency score)



Sources: ENCORE, EXIOBASE and AnaCredit.
Notes: Country-level dependency scores are computed as weighted averages of the dependency scores of all the consolidated lending institutions headquartered in a given country. The weights represent the contribution of that institution to the overall lending stemming from that country.

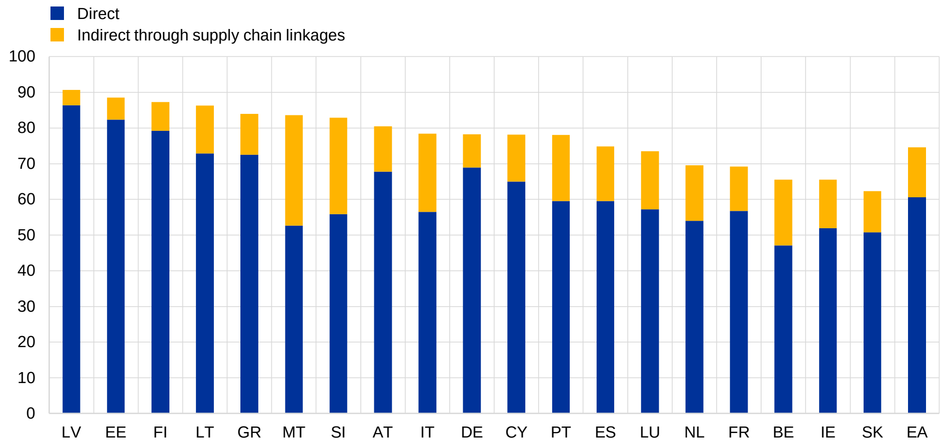
Overall, approximately 75% of euro area banks' corporate loans (nearly €3.24 trillion) to the 4.2 million euro area NFCs are highly dependent on at least one ecosystem service (Chart 10). Once again, a loan is labelled as highly dependent when the borrower NFC's dependency score is equal to or greater than 0.7. In this case, the economic losses for the borrower caused by the possible deterioration of the respective ecosystem service could lead to a worsening of its creditworthiness, with possible second-round effects on the performance of the bank's portfolio. The share of highly dependent loans is more heterogenous across countries than NFCs (Chart 7). It is also worth noting that the dependency values are generally higher. Given that in this case we are considering the share of loans, this result suggests that larger loans tend to be more dependent on ecosystem services. If we consider only the direct dependency, the overall share of euro area corporate loans highly dependent on at least one ecosystem service falls to approximately 61% instead of the 75% obtained when also factoring in supply chain exposure.

Chart 10

Dependency of euro area banks on ecosystem services

Share of corporate loans from banks to NFCs with a high dependency score (greater than 0.7) for at least one ecosystem service. Loans are allocated to the country where the headquarters of the bank are located

(Dec. 2021, y-axis: percentages; share of loans with high dependency)



Sources: EXIOBASE, ENCORE, AnaCredit and ECB calculations.
Notes: Share of loans with a high dependency score (greater than 0.7) for at least one ecosystem service. A loan is labelled as highly dependent when the borrowing NFC has a sufficiently high direct dependency score (blue bar) or sufficiently high dependency when also considering possible supply chain linkages (yellow bar).

This result is robust to changes in the threshold used to label the borrower as "highly dependent". As described above, the baseline threshold to label a borrower as highly dependent on at least one ecosystem service is 0.7. This choice of threshold is based on expert opinion and the literature recommendation; to make the assessment more robust, we assess the sensitivity of loan exposures to different thresholds. Intuitively, the share of loans is inversely related to the value considered. If we consider a lower threshold, the share of highly dependent loans will increase. Conversely, if we consider a higher threshold, only few borrowers will be flagged as highly dependent, and the share of highly dependent loans will fall. As shown in Chart 11, the share of highly exposed loans remains quite stable for threshold values between 0.65 and 0.8. It starts to decline quickly after 0.825, suggesting that more extreme dependencies are overall limited, yet still significant. The share of euro area corporate loans issued to borrowers with a total dependency score greater than 0.8[16] falls to 63 %. Finally, the share of corporate loans to borrowers with a dependency score greater than 0.9 is 23%, which, given the critical and irreplaceable nature of ecosystem services in the production process, can be considered relatively high.

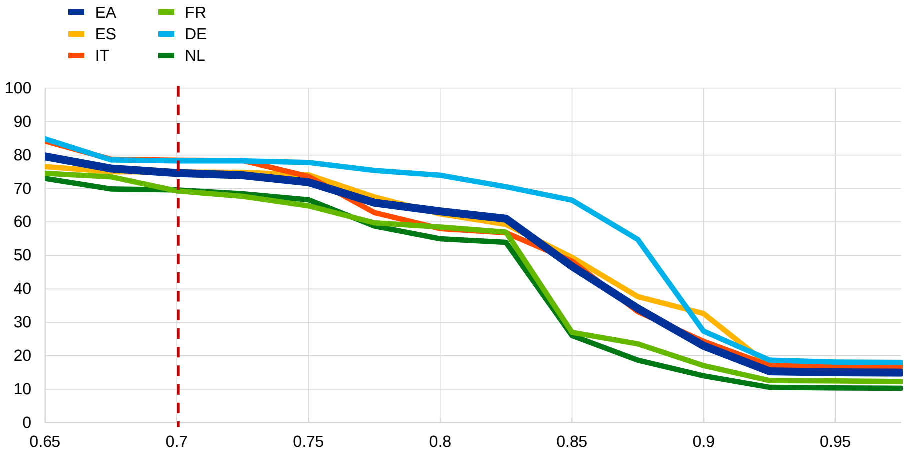
[16] A materiality score of 0.8 signals that the ecosystem service is critical and irreplaceable in the production process.

Chart 11

How the share of corporate loans from banks to NFCs with a high dependency score changes with the threshold considered

Share of euro area banks' corporate loans highly dependent on at least one ecosystem service as a function of the materiality threshold delineating high dependency. The share of the five largest countries by corporate loan amount considered are also shown.

(Dec. 2021, y-axis: percentages, x-axis: dependency score threshold)



Sources: EXIOBASE, ENCORE, AnaCredit and ECB calculations.
Notes: Share of loans with a determined dependency score for at least one ecosystem service. A loan is labelled as dependent when the borrowing NFC has a sufficiently high total dependency score. The share of loan is represented in the y-axis with the corresponding threshold in the x-axis.

In the euro area, almost 74% of the corporate loan amount considered, or around €3.21 trillion, has at least a medium dependency on multiple ecosystem services. While we have so far looked at ecosystem services in isolation, it is also important to capture the fact that NFCs depend on multiple ecosystem services. When considering the average exposure across all relevant ecosystem services for a borrower[17], it is possible to see that the medium level of dependency (between 0.4 and 0.6) represents the highest share in virtually all countries (Chart 12). Furthermore, it is possible to see how the exposure composition across different countries is quite heterogeneous, and in general we see that the dependency score falls from high to medium. Further analysis considering multiple ecosystem services can be found in Appendix C.

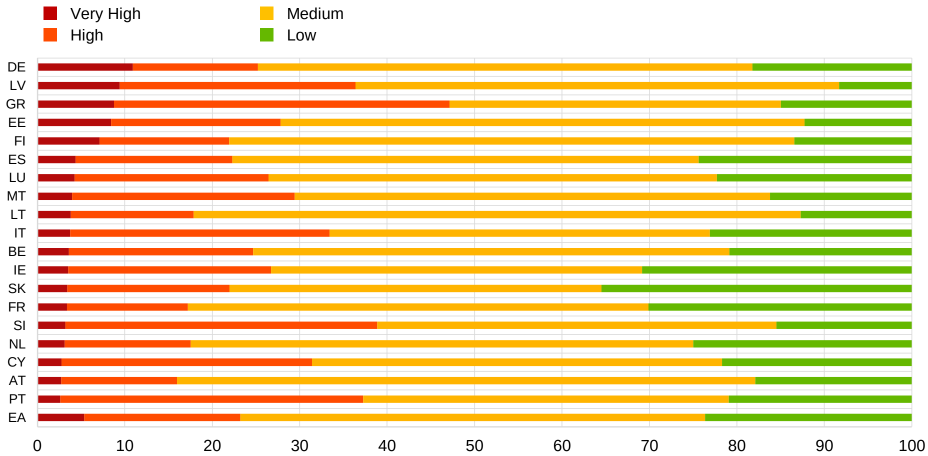
[17] A relevant ecosystem service for a given production process is one with a total dependency score greater than 0.2. This threshold corresponds to ENCORE's "very low" materiality rating, which means that even in the event of full disruption of the ecosystem service, the production process could still take place.

Chart 12

Total exposure of euro area banks' loan portfolios to nature-related risks

Share of loans exposed to multiple ecosystem services on a different degree of materiality

(Dec. 2021, x-axis: percentages; share of loans for level of exposure)



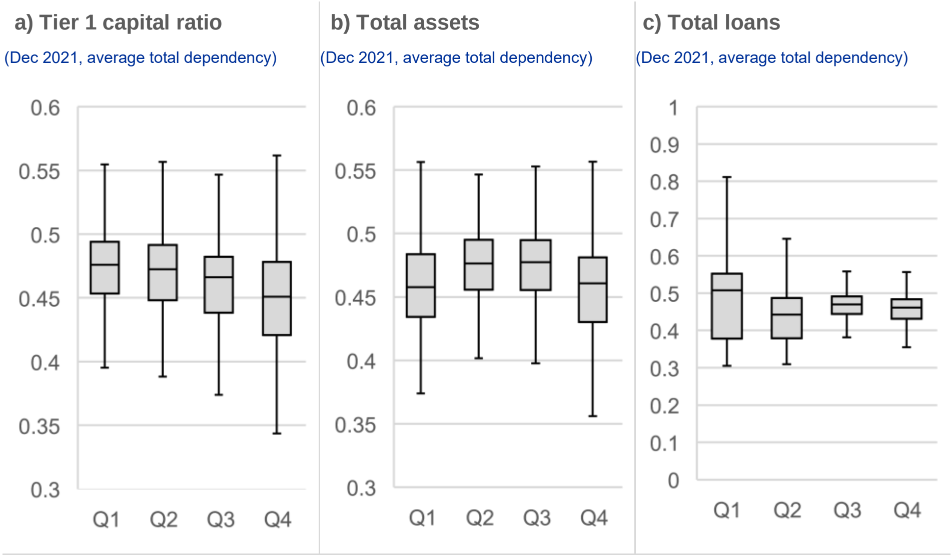
Sources: EXIOBASE, ENCORE, AnaCredit and ECB calculations.
Notes: Share of portfolio exposed to ecosystem services. The materiality scores considered are "low" (from 0.2 to 0.4), "medium" (0.4-0.6), "high" (0.6-0.8) and "very high" (0.8-1). This measure is calculated considering the average total dependency score across relevant ecosystem services. An ecosystem service is labelled "relevant" if it has a total dependency score greater than 0.2 (very low dependency).

Banks with lower Tier 1[18] capital ratios tend to have a slightly higher average total dependency (Chart 13, panel a). The median level of banks' dependency decreases when banks have larger capital ratios. This might signal a potential problem for less capitalised banks if the risk manifests. Conversely, both the overall size and the amount of loans granted to our sample do not seem to be a clear discriminant in terms of dependency on nature (Chart 13, panels b and c). Smaller banks' loans granted have a much wider distribution. This might be due to the fact that these banks tend to be more focused on specific regions and sectors when performing their lending.

18 Tier 1 capital includes common shares, retained earnings (Common Equity Tier 1) and all capital instruments which meet the criteria for Additional Tier 1. Tier 1 capital is set to provide loss absorption on a going-concern basis and thus represents a sort of first line of defence for banks. Tier 1 capital is then compared with the risk-weighted assets of a bank to compute the regulatory capital requirements.

Chart 13

Distribution of euro area banks' exposure to nature-related risks



Sources: ENCORE, EXIOBASE, AnaCredit, Orbis, FINREP/CONREP and iBach.
Notes: Distributions of bank-level average total dependency scores across relevant ecosystem services. An ecosystem service is labelled "relevant" if it has a total dependency score greater than 0.2 (very low dependency). The distributions are shown depending on the respective quantile of the bank in terms of Tier 1 capital (panel a), total assets (panel b) and total corporate loans granted to the sample (panel c).

4 Sensitivity analysis

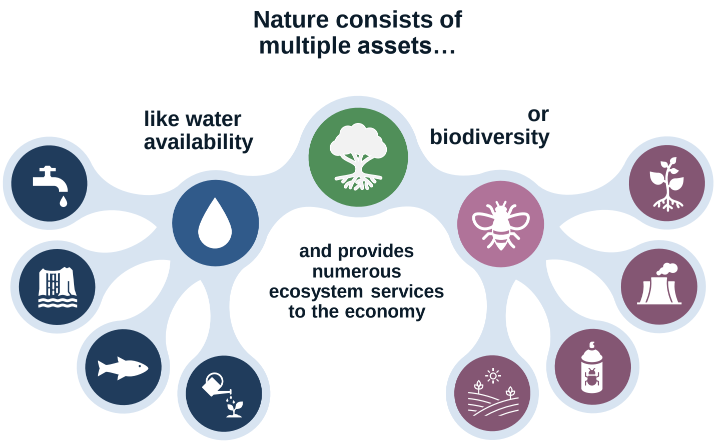
The exposure assessment allows us to reveal the share of the financial portfolio that is dependent on a variety of ecosystem services. However, the exposure itself does not consider the likelihood and the magnitude of the shocks caused by nature degradation. These can change drastically depending on the region and ecosystems affected. Furthermore, as mentioned in the previous section, the multidimensionality of ecosystems represents an important feature of nature-related risk. It is therefore important to assess possible amplification effects caused by the simultaneous degradation of multiple ecosystems. This section, although not yet a full risk assessment, introduces a first-of-its kind exercise to try to understand how nature-related risk could materialise in banks' losses.

Specifically, we build on the materiality scores computed in the previous section to develop a preliminary sensitivity analysis framework for the change in the expected losses of banks' credit portfolios due to possible biodiversity losses. Biodiversity loss leads to the degradation of ecosystems that rely on it, which, in turn, poses a risk for economic activities that depend on them. However, quantifying the precise links between biodiversity losses and ecosystem degradation and the consequent transmission into economic losses is challenging and still largely lacking. In the absence of a risk assessment framework, we propose a metric capable of gauging the magnitude of potential losses in the euro area financial system as a consequence of future biodiversity losses.

The sensitivity analysis framework builds on the notion of natural capital assets. Natural capital assets are specific elements within nature which provide the ecosystem services that the economy depends on. In other words, the 21 ecosystem services introduced in the previous section rely on several natural capital assets to be able to sustain economic activities. Examples of such capital assets are minerals, water, the atmosphere and biodiversity (ENCORE, Chart 14). Biodiversity is important for numerous ecosystem services such as soil quality, climate regulation and pest control. In other words, should biodiversity decline, the provision of certain ecosystem services could be drastically impaired.

Chart 14
Example of natural capital assets

Graphical representation of the linkages between natural assets and ecosystem services



Source: ENCORE.
Note: Graphical representation of how natural assets provide the ecosystem services necessary to allow economic activities.

For each NFC, we compute a dependency score with respect to biodiversity. Specially, in the previous section we compute, for each NFC, a direct and an indirect dependency score with respect to the 21 ecosystem services. Using the materiality scores provided by ENCORE, it is possible to aggregate these dependencies at a natural asset level. In the specific case of biodiversity, the direct/indirect dependency score in the baseline model for an NFC *j* can be obtained as a weighted average

$$DS_j^{bio} = \sum_{i=1}^{21} \frac{DS_j^i \times DS_i^{bio}}{\sum_{i=1}^{21} DS_i^{bio}}$$

where DS_j^i is the dependency score of NFC j on ecosystem service i and DS_i^{bio} is the dependency score of ecosystem service i on biodiversity. These values are taken from ENCORE and normalised so that the values fall between 0 and 1. This weighted average can be computed separately for the direct dependency score and the indirect one. In the case of the indirect dependency score, it is important to note that the borrower level takes into consideration the suppliers' weights and their dependency scores. This is also factored in when aggregating at the natural asset level.

4.1.1 Biodiversity shocks

To measure the decline in biodiversity and the respective impediment of the provision of ecosystem services, we compute biodiversity shocks (σ_{MSA}) worldwide. The computation of biodiversity shocks is based on mean species abundance (MSA)[19], an indicator of biodiversity intactness, as a function of multiple anthropogenic pressures such as land use and climate change (Schipper et al., 2020). The biodiversity shocks are computed using MSA changes under three different scenarios of how future socio-economic development may affect biodiversity intactness by 2050. A decline in biodiversity intactness is the result of a variety of anthropogenic pressures on nature such as land use, climate change, road disturbance, nitrogen decomposition and hunting (Schipper et al., 2020). Specifically, in our case, the level of change in MSA indicates the decline or gain in biodiversity intactness from the present day to 2050.

MSA losses under different future scenarios are obtained from GLOBIO model calculations (Schipper et al., 2020; Appendix B).[20] The first scenario represents a **sustainability scenario** paired with a low level of climate change (SSP1 x RCP2.6)[21]. This scenario is based on the assumption of relatively low population and consumption growth due to less resource-intensive lifestyles, more resource-efficient technologies and increased regulation. The second scenario combines a **regional rivalry scenario** with moderate levels of climate change (SSP3 x RCP6.0), which is characterised by high population growth, resource-intensive consumption, low agricultural productivity and limited regulation of land use change, leading to continued deforestation. The third scenario integrates a **fossil-fuelled development scenario** with high levels of climate change (SSP5 x RCP8.5) and is characterised by low population growth, strong economic growth, a consumption-oriented and energy-intensive society, and highly intensive agricultural practices. The first scenario represents the Paris-aligned future oriented towards sustainability and serves as our best case, while the second and third scenarios include only modest or even no climate change mitigation policies and are considered as adverse scenarios.

Numerically, the biodiversity shock is computed using the MSA level in 2015 as the baseline value. Specifically, this shock is computed as the rate of change in MSA under all three scenarios compared with 2015:

$$\sigma_{bio}^{s} = \frac{MSA_s - MSA_{2015}}{MSA_{2015}} \quad with\ s = SSP1, SSP3, SSP5$$

where MSA_s is the MSA level provided by GLOBIO under scenario *s* for 2050, while MSA_{2015} is the historic level of MSA. Both values are provided in a 300-by-300-metre grid, then geographically aggregated.

Certain economic activities are affected locally due to biodiversity loss (such as agricultural production), while others suffer from more aggregate or regional-level deteriorations (such as manufacturing and trade). To capture this differential spatial dependency, we compute shocks to biodiversity in two levels of

19 Mean species abundance (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/.

20 All data for the MSA level under the different scenarios are provided on a ten-arcsecond spatial resolution, which equates to roughly 300 by 300 metres.

21 GLOBIO considers shared socio-economic pathways (SSPs) combined with different levels of climate change expressed as representative concentration pathways (RCPs).

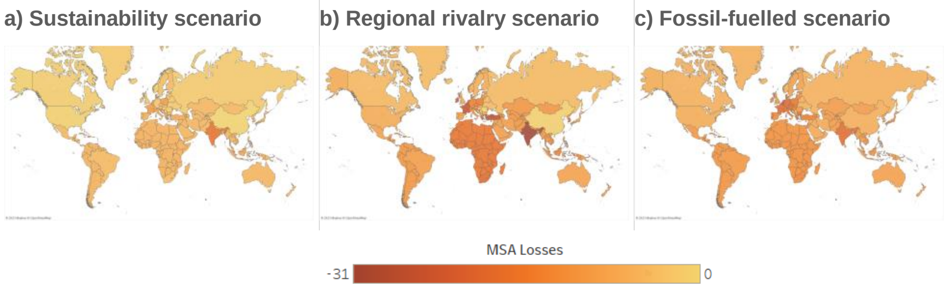
aggregation, depending on the economic sector (NACE categorisation) of the borrower: (i) country-level MSA changes and (ii) water basin-level MSA changes. Water basins are used here as fundamental and objective divisions of the landscape, controlling the flow of water where biodiversity and ecosystems tend to loosely align (Patterson et al., 2023). For example, in the case of the Rhine river basin, aggregations are carried out for all sub-basins belonging to Rhine tributaries. The type of aggregation used for each NACE sector can be found in Appendix B (Table 1B).

Chart 15 depicts the maps of biodiversity loss computed under the three different scenarios. Compared with the sustainability scenario, the regional rivalry scenario (SSP3 x RCP 6.0) is characterised by a higher overall degradation level across the globe. It is possible to see how this regional rivalry could generate particularly high values of biodiversity depletion in specific regions like India, Turkey and Africa. In the euro area, France is particularly affected under this specific scenario. Compared with the others, the fossil-fuelled scenario (SSP5 x RCP 8.5) is characterised by the highest degradation worldwide. However, compared with the regional rivalry scenario, the particularly larger values are now absent. Nevertheless, the overall level of species depletion is far greater than under the sustainability scenario.

Chart 15

Country-level projected losses of mean species abundance by 2050

Changes in biodiversity intactness by 2050 (expressed as percentage losses compared with the baseline year of 2015) following three different shared socio-economic pathways (SSPs) combined with different levels of climate change expressed as representative concentration pathways (RCPs)



Source: Schipper et al., 2020
Notes: Country-level percentage points of MSA losses under the three different scenarios. Sustainability scenario (SSP1 x RCP 2.6), regional rivalry scenario (SSP3 x RCP 6.0) and fossil-fuelled scenario (SSP5 x RCP 8.5).

4.1.2 Transmission of shocks to banks' portfolios

Biodiversity shocks and dependency scores are then combined to compute a proxy for changes in probability of default (PD) (hereinafter proxy PD) for each NFC. Specifically, we calculate how big the losses will be in 2050 for each given scenario as

$$\Delta PD_j^s \approx DS_j^{bio} \times \sigma(j)_{bio}^s$$

where DS_j^{bio} is the NFC *j* dependency on biodiversity, while $\sigma(j)_{bio}^{s}$ is the respective biodiversity shock. The shock considered is NFC-specific because its aggregation depends on the economic activity of the NFC. The calculation of the proxy PD assumes a one-for-one translation between loss of MSA and change in PD, weighted only by the dependency score of the NFC. This computation does not consider accounting data or quantify possible losses of revenue due to biodiversity losses. Nevertheless, in the absence of an established procedure and data, we decided to include it in the current exercise. Notwithstanding the clear limitations, this novel exercise could help us understand how the possible manifestation of biodiversity loss could affect the financial viability of NFCs and of the institutions lending to them.

We then use these proxy PDs of an NFC to assess the possible expected losses that a bank might face when lending to it. To do so, we compute for each bank-borrower relationship the change in expected losses as follows:

$$\Delta Expected\ Loss_j^{b;\,s} = EAD_j^b \times LGD_j^b \times \Delta PD_j^s$$

where EAD_j^b is the exposure at default of the borrower *j* with respect to bank *b*. For simplicity, this is obtained as the overall outstanding loan amount of NFC *j*. LGD_j^b is the loss given default and is computed as the uncollateralised share of the loan between NFC *j* and bank *b*. Finally, ΔPD_j^s is the proxy PD explained in the previous paragraph. We then aggregate all $\Delta Expected\ Loss_j^{b;\,s}$ across a given scenario for the same bank to obtain bank-level losses. In addition, we also compute bank-level proxy PDs by aggregating all the bank's borrower PDs, using as weights the respective loan exposures. Further details on the methodology can be found in Appendix B.

4.2 Results

Expected losses under the sustainability scenario are substantially smaller compared with other scenarios. Specifically, in the case of the regional rivalry scenario, euro area bank losses could be on average as much as 2.54 times those under the sustainability scenario (Chart 16, panel a). Looking at the fossil-fuelled scenario, the expected losses may be more than 2.73 times those under the sustainability scenario (Chart 16, panel b). Countries like Germany, Lithuania, Ireland and Belgium are the hardest hit, with losses up to five times larger than under the sustainability scenario. The reason for the German result is twofold; one relates to the high level of dependency of Germany's strongest sectors, such as manufacturing, on biodiversity levels, while the second is directly related to the relatively high reduction in species intactness in central and western Europe under the fossil-fuelled scenario compared with the sustainability scenario. It is important to note that under both scenarios the indirect component significantly contributes to overall losses. Indeed, in certain cases the losses caused only by local shocks are close to the ones obtainable under the sustainability scenario. This means that supply chains of euro area NFCs are heavily reliant on biodiversity abroad, and possible foreign shocks could result in significant losses for euro area banks. Once again, this suggests the importance of looking at the problem of nature-related risk as a global risk.

Chart 16

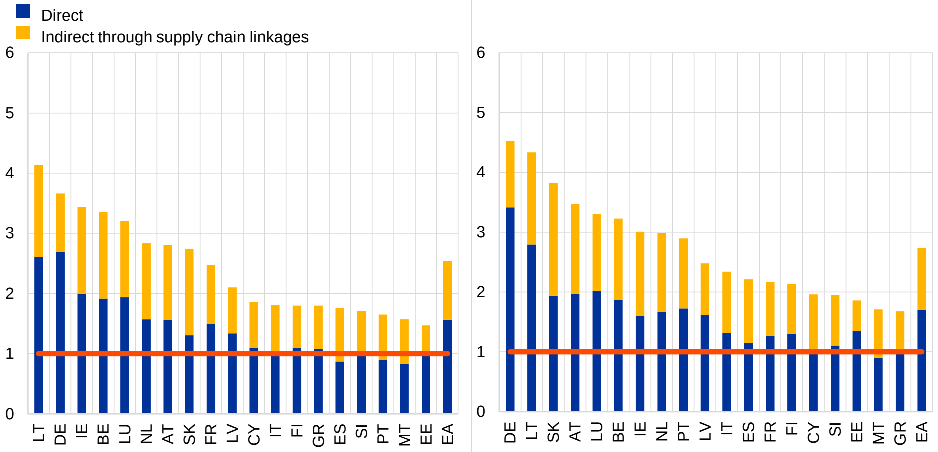
Banks' expected financial loss under different biodiversity loss scenarios by 2050

a) Expected losses caused by biodiversity loss under the regional rivalry scenario compared with the sustainability scenario

(Dec. 2021, ratio of banks' expected losses)

b) Expected losses caused by biodiversity loss under the fossil-fuelled scenario compared with the sustainability scenario

(Dec. 2021, ratio of banks' expected losses)



Sources: ENCORE, EXIOBASE and AnaCredit.
Notes: Ratio of changes in expected losses between the worst-case scenario (either SSP3 x RCP6.0 or SSP5 x RCP8.5) and the best-case scenario (SSP1 x RCP2.6). Expected losses are initially computed at borrower-lender level using mean species abundancy (GLOBIO) changes as a shock. The shock is then multiplied by the dependency score of the borrower computed using ENCORE and EXIOBASE and the uncovered amount of loan issued to the borrower. The results are aggregated at country level using the amount of loans as weights.

Certain countries are more affected by the regional rivalry scenario, even when compared with the fossil-fuelled scenario. From Chart 17, panel a), we can see that NFCs in countries like France, Ireland and Luxemburg are more affected by the regional rivalry scenario. Indeed, under this scenario, the average proxy PDs are even greater than under the fossil-fuelled scenario. By contrast, we can see that the economic sector does not strongly discriminate between the two worst-case scenarios (Chart 17, panel b). Nevertheless, we can clearly see how certain sectors like agriculture and the production of electricity have the largest proxy PDs compared with other sectors.

Chart 17

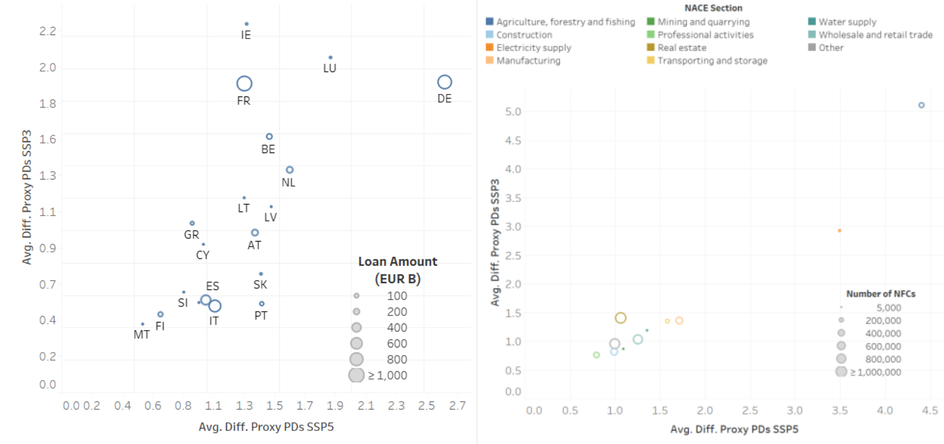
Differences between NFC-level proxy PDs under the adverse and sustainable (Paris-aligned) scenarios. Biodiversity losses are simulated for the mid-21st century.

a) Differences in proxy PDs under the worst-case and best-case scenarios by country of NFC

(Dec. 2021, percentages, differences between proxy PDs)

b) Differences in proxy PDs under the worst-case and best-case scenarios by sector of NFC

(Dec. 2021, percentages, differences between proxy PDs)

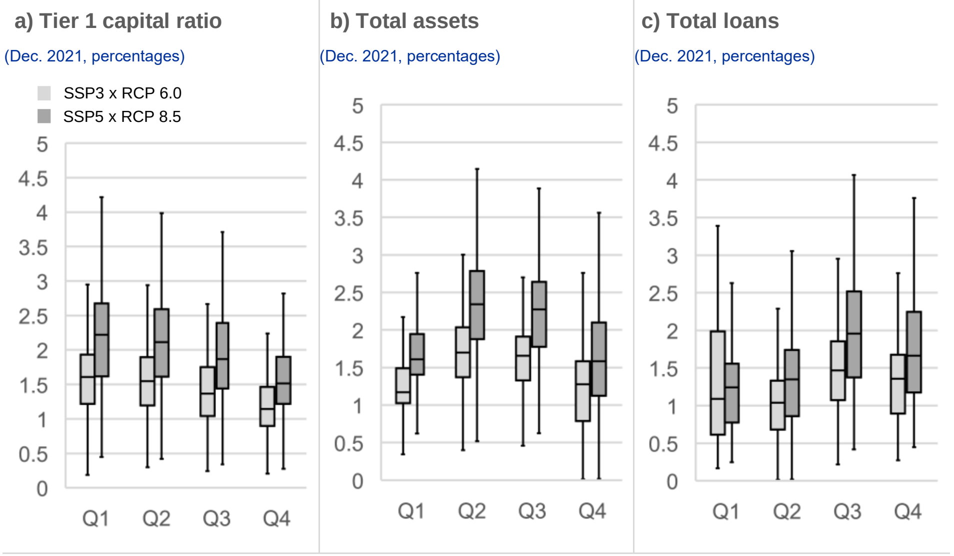


Sources: AnaCredit, ENCORE, EXIOBASE, Schipper et al., 2020 and ECB calculations.
Notes: Differences in proxy PDs under the worst-case scenario (either regional rivalry or fossil-fuelled) and the best-case scenario aggregated at NFC level. The differences are plotted by grouping for the country where the NFCs are headquartered (panel a) or by the NACE section of the NFC (panel b).

Proxy PDs of individual banks could be much greater under the fossil-fuelled scenario compared with the baseline scenario, specifically for banks with low Tier 1 capital ratios (Chart 18, panel a). This is important because it may suggest that banks with lower capital are more exposed to biodiversity risk. If we compare the proxy PDs of either worst-case scenario (regional rivalry and fossil-fuelled) with the best-case scenario, we see that these are greater when banks have low Tier 1 capital ratios. This result is in line with our previous findings on exposure. The distributions of these differences when looking at the size of the bank (Chart 18, panels b and c) are similar to those seen in the previous section. It is worth noting that for banks with a smaller corporate loan portfolio (first quantile in terms of loans granted), the regional rivalry scenario generally leads to higher proxy PDs than the fossil-fuelled scenario. Once again, these results show that smaller banks tend to have their portfolios less dispersed and focus on smaller regions, while larger banks are able to better diversify their portfolios.

Chart 18

Differences between bank-level proxy PDs under the adverse and sustainable (Paris-aligned) scenarios. Biodiversity losses are simulated for the mid-21st century.



Sources: ENCORE, EXIOBASE, AnaCredit, Orbis and iBach.
Notes: Distribution of the differences in PDs under the worst-case scenario (either regional rivalry or fossil-fuelled) and the best-case scenario aggregated at bank level. The proxy PDs are computed without allowing for amplification effects. The distributions are shown depending on the respective quantile of the bank in terms of Tier 1 capital (panel a), total assets (panel b) and total corporate loans granted to the sample (panel c).

5 Limitations of our study and future research needs

One important limitation of the current study is its focus on corporate loans. The current analysis uses an AnaCredit sample, i.e. only loans issued by banks to financial and non-financial corporations. Loans represent an important share of NFCs' funding, specifically for smaller and medium corporations that might not have access to market-based financing. Nevertheless, this represents a clear limitation given that bonds and equity could also be used to finance potentially environmentally degrading activities (Beyene et al., 2022). Notwithstanding this, the main focus of the paper is to provide new methodologies to assess nature-related risks to financial stability that can be easily expanded to other types of financing instruments.

Understanding the local to global trade-off is essential when it comes to the impact of local biodiversity loss and related cascading effects on different ecosystems and the global economy through the supply chain. The ENCORE dataset is an extremely valuable and much-needed tool to map the dependency of the economy on ecosystem services. Nevertheless, we should note that the ENCORE version used in this study does not provide location-specific information. To fully capture the heterogeneities derived by the globality of the problem, more granular (i.e. location-specific) data on the regional dependency of economic activities on nature are required.

The ENCORE materiality ratings consider present-day technologies and industrial processes, not accounting for potential future developments to reduce dependency on nature. A company could have mitigation measures in place to avoid or reduce its actual dependency on a specific ecosystem service. Furthermore, the materiality ratings for a specific production process were assigned independently of others. However, the impact of nature on production processes could be multifaceted and go beyond purely "mechanical" effects on production; it may be intermediated by shifting societal norms and goals (e.g. consumer preferences; Pascual et al., 2023).

Our analysis represents a static view of dependency. When considering supply chain characteristics using EXIOBASE, we do not account for the fact that NFCs may change suppliers after possible problems caused by depletion of natural assets. Our analysis therefore provides a static view of dependency and should be used as a general guideline. The dependency of economic activities on ecosystem services may change over time or depending on the specific context.

It is important to note that the dependency score used in our study does not capture macro-financial and intra-financial feedback loops belonging to the broader category of indirect effects that can amplify an initial nature-related shock. Such feedback loops can arise, for example, due to the interconnectedness between NFCs and between financial institutions. This type of amplification of initial shocks has occurred in a number of past crisis episodes (e.g. Reinders et al., 2023; Battiston et al., 2017).

Nature-related risks are multidimensional with no main aggregate metric characterising the drivers of nature loss, such as greenhouse gas (GHG) emissions in the climate space. The lack of a standardised metric and, at the same time, the availability of multitude of nature-related metrics poses a challenge for risk assessment. The selection of dependency and/or impact metrics requires a careful examination and evaluation of existing metrics, which need to be fit for the specific purpose. One way to deal with uncertainty and increase the robustness of our analysis would be to make use of multiple metrics and assess the level of convergence or divergence of obtained results. Furthermore, the multidimensionality of nature requires a better understanding of the interdependencies between different ecosystems.

Different metrics are becoming readily available for dependency and impact assessment, but a consensus is still missing. For example, the Integrated Natural Capital Accounting (INCA) platform develops an ecosystem account at the EU level that is in line with System of Environmental-Economic, Accounting[22]. An alternative is the Biodiversity Risk Filter developed by the World Wide Fund for Nature (WWF). This tool can be used to assess physical and reputational biodiversity risks for corporations through the usage of multiple indicators.[23] Finally, Copernicus, the European Union's Earth observation programme, provides time series of many biophysical and climate variables, which can support dynamic forms of comprehensive risk assessment.[24]

To assist financial institutions in measuring nature-related risks, data gaps need to be addressed and common frameworks developed. Specifically, we need to improve our understanding of interdependencies among different ecosystems and between biodiversity and climate change (i.e. climate-nature nexus), which can cause compounding, cascading and spillover effects. Moreover, understanding these interdependencies is a prerequisite to measure the effectiveness of nature preservation policies. Multiple indicators and aggregate measures to capture the impact of environmental pressures will likely be needed to fully capture all aspects of nature-related risks.

22 INCA Ecosystem accounting framework.

23 WWF Risk filter suite.

24 Copernicus is the Earth observation component of the European Union's space programme.

6 Policy implications

The loss of ecosystem services may have far-reaching consequences for humanity and the economy, including through the amplified effects of close interaction between biodiversity loss and climate change. Recognition of biodiversity loss as a potential source of economic and financial risks is only a first step in the development of a response strategy to maintain financial and price stability. The results of this study are relevant to inform the public of the consequences of certain economic activities for the environment that could further hamper financial stability, as well as policymakers to support the possible introduction and calibration of mitigating policies and central banks to explore further courses of action.

For capital markets to better take into account the risks stemming from nature loss and limit their impact, gaps must be filled in disclosure and quantitative risk modelling frameworks. Policymakers should strengthen the information architecture on nature. A global framework for nature-related disclosure requirements by NFCs and financial institutions should be put in place, and several developments are heading in that direction. In September 2023 the TNFD issued recommendations for a nature risk management and disclosure framework for organisations to report and act on evolving nature-related risks. The EU Corporate Sustainability Reporting Directive (CSRD) will enter into force on 1 January 2024 and sets requirements for NFCs and banks on nature-related disclosures, such as biodiversity, water and pollution.

The results of our research are also relevant for different tasks the ECB has at hand, which could be further explored. For example, the degradation of soil quality or pollination services may result both in more volatile food prices, with macroeconomic implications, and in a higher risk profile for the financial sector through lending (or investments) to the agricultural sector and the food production and processing industry (van Toor et al., 2020). Thus, biodiversity loss could have consequences for monetary policy and financial stability. The materiality of nature-related risks, including biodiversity loss, has increasingly also been recognised by prudential supervisors and banks and was recently laid out in a publication by the NGFS of a conceptual framework for nature-related financial risks to guide policies and action by central banks and financial supervisors (NGFS, 2023).

Work on assessing environmental risks has already started at ECB Banking Supervision. In 2020 a guide was published with supervisory expectations for the risk management of climate-related and environmental risks. In this guide, it is explicitly recognised that environmental factors related to the loss of ecosystem services, such as water stress, biodiversity loss and resource scarcity, have also been shown to drive financial risk. The ECB therefore expects banks to evaluate all environmental risk-related information beyond just climate risks to ensure that their risk management is all-encompassing.

Financial institutions, regulators and private NFCs have made significant steps in recent years to improve their ability to quantify the implications of climate change for their business and risk profiles. One example in this regard is represented by the NGFS, which since its inception in 2017 has issued numerous reports and recommendations for central banks and supervisors to account for climate change and, within their respective mandates, contribute to greening the financial system. For example, the NGFS has joined forces with leading academic institutions to design climate scenarios that are currently used by regulators worldwide and also by financial institutions. The knowledge and experience developed in addressing climate change should be leveraged to ensure a smooth and rapid application of an enhanced, integrated climate-nature framework. Finally, working towards a complete picture based on the interdependencies between the provision of ecosystem services and climate change is needed to correctly identify the areas where action is required and act accordingly with the introduction of appropriate policies.

7 Conclusions

The results of our research show that Europe’s economy is highly dependent on ecosystem services and that these risks can spread to the financial system, potentially triggering instability. Our analysis sheds light on euro area economy and financial system dependency and its impact on ecosystem services and biodiversity respectively. We also show that an integrated approach to climate and nature is critical because they are interconnected and may amplify the effects of physical and transition risks. Given the high level of uncertainty regarding effects, non-linearities, tipping points and irreversibility, gauging nature-related risks is complex. Further scientific research and input are needed to learn more about the transmission channels to our economies.

Of the 4.2 million euro area NFCs that were included in our research, around 3 million are highly dependent on at least one ecosystem service. Geographical analysis of these NFCs based on their headquarters indicates that the overall dependency of these NFCs on ecosystem services is quite homogeneous across euro area countries. In turn, euro area banks’ loan portfolios are significantly dependent on several ecosystem services. Overall, approximately 75% of euro area banks’ corporate loans to NFCs (nearly €3.24 trillion) are highly dependent on at least one ecosystem service. In the euro area, almost 74% of corporate loans to NFCs, or around €3.21 trillion, have at least a medium dependency score across the relevant ecosystem services. Banks with lower Tier 1 capital ratios tend to have a slightly higher average total dependency.

The progress made so far in measuring and understanding nature-related risks is less advanced than the climate. Gaps must be filled in disclosure and quantitative risk modelling frameworks, focusing also on quantifying the key transmission channels. This should be a co-development process, involving a number of parties such as policymakers, researchers and civil society organisations. From the ECB’s perspective, different business areas, such as the Single Supervisory Mechanism and the Directorate General Macroprudential Policy and Financial Stability, play an important role in this process. Supervisory authorities must ensure, through good practice, that financial institutions produce a clear picture of their risk profile and resilience (van Toor et al., 2020).

The impact of nature degradation, including biodiversity loss, and climate change on financial systems is increasingly being addressed by the scientific community. While ongoing and future research will help us to better understand many questions related to risk quantification for financial institutions (such as scenario narratives and economic and ecosystem models), we have enough data and knowledge available to enable timely and nature-friendly decision-making.

The follow-up work will address transition risk by looking at the contribution of the euro area economy and financial system to the drivers of biodiversity loss. Additionally, since climate change and biodiversity loss are inextricably intertwined, the identification of the interdependencies and reinforcing mechanisms between the climate system, environmental pressures and biodiversity is needed to fully capture the nature-related risk profile. The follow-up work will therefore also present the nature-climate nexus conceptualisation.

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Appendix A: data sources

ENCORE

The ENCORE dataset was developed by the Natural Capital Finance Alliance (NCFA) in partnership with UN Environment Programme World Conservation Monitoring Centre (UNEP-WCMC).[25] Specifically, ENCORE focuses on goods and services that nature provides to enable economic production and on the possible impacts that economic activity might have on nature. It maps production processes based on the Global Industry Classification Standard (GICS) with 21 ecosystem services and considering 157 industries. In turn, the ecosystem services are related to eight natural assets. For a given ecosystem service, ENCORE attributes a materiality score ranging from "very low" to "very high" in a five-step discrete classification. These scores were obtained from a literature review of the relevant research. Where information on the ecosystem service dependencies was missing in the literature, ENCORE interviewed relevant experts in the field to define the score. As for the dependency, a literature review was carried out to determine the impact drivers that each production process has on nature. The scope of the literature review was global and justifies the country invariance of the dependency and impact metrics.

The dependency measures capture two main aspects: how significant the loss of functionality in the production process would be if the ecosystem service is disrupted, and how important the financial loss would be if the production process is disrupted. Therefore, a high materiality score signifies that the disruption of the ecosystem service will prevent the production process and, as a result, will be likely to affect the financial viability of the non-financial corporation (NFC).

EXIOBASE

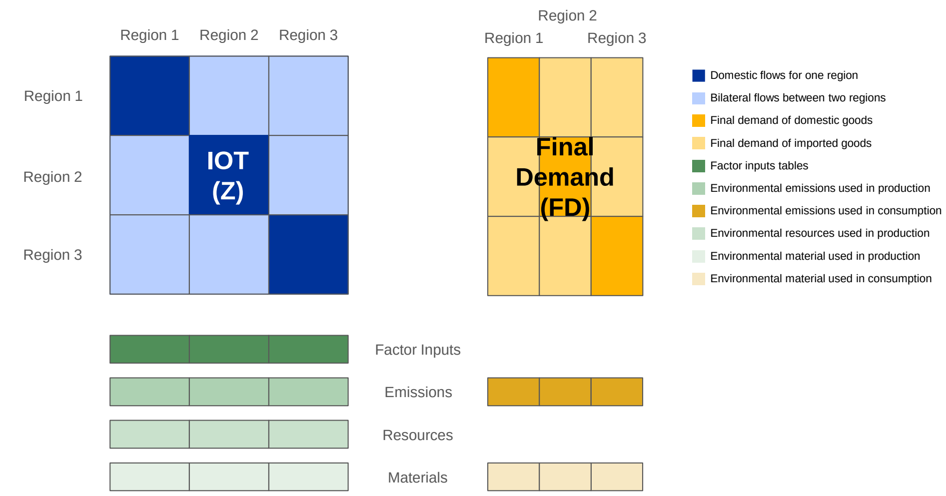
EXIOBASE is a global, environmentally extended multiregional supply-use table (MR-SUT) and input-output table (MR-IOT). The dataset is obtained as a harmonisation of different supply-use tables (SUTs) and input-output tables (IOTs). SUTs provide a picture of the how domestic production and imports of goods are ultimately used as intermediate components of consumption. The SUTs are then transformed into symmetric IOTs. IOTs can be either product-by-product or industry-by-industry and contain inter-industry or inter-product relationships within an economy. These tables can then be aggregated considering multiple regions at the same time.

25 The NCFA is a global alliance of financial institutions with the objective of pioneering new tools and best practices to manage natural capital and opportunities. The UNEP-WCMC represents a group of experts, ranging from economists and scientists, working on intersecting science, policy and practice to tackle global nature loss and support the transition to a greener economy.

Environmentally extended input-output (EE-IO) tables combine these data on economic flows with information on environmental flows. Because of this, these tables have been used to better measure the greenhouse gas (GHG) emissions of production chains, considering a consumption perspective. EXIOBASE is an example of an environmentally extended multiregional input-output (EE-MRIO) table consisting of 44 countries, five rest-of-world regions and 163 different industries. It enhances the depiction of economic flows by also including 417 emissions and 662 material and resources categories. The data are available from 1995 to 2021 (and are nowcasted from 2011 onwards).

Chart 1A

EXIOBASE version 3 structure



Source: EXIOBASE.
Note: EXIOBASE stylised structure.

In a traditional IOT matrix, Z represents the intermediate relationship between industries for each year. In other words, each row contains the intermediate output produced by a given region/sector that is then exported to all other regions/sectors (columns) in a given year, measured in current basic prices (EUR millions). Conversely, each column contains the intermediate inputs needed from a given region/sector and from where these are imported (rows).

Not all the output of a given region/sector is used as intermediate goods, as some products are directly consumed by households/governments. These data are contained in the final demand matrix (FD). Depending on the IOT considered, there might be more or less granularity in terms of categories considered. For example, EXIOBASE differentiates between final consumption by households, non-profit organisations, government and NFCs (gross fixed capital formation). Our focus will nonetheless be on the production side and thus on the Z matrix (Chart 1).

Summing the intermediate output and the final demand, it is possible to obtain the total output for a given region/sector (x vector). The difference between the intermediate inputs and the total inputs is labelled gross value added, which in turn is split into taxes less subsidies (TLS) and net value added (V). Overall, the total output can thus be represented as:

$$x = Z1 + f$$

Where 1 is a compatible vector of 1s and f is a vector containing the total final demand $f = FD1$

Let us now define the matrix of technical coefficients A such as $a_{i,j} = z_{i,j}/x_j$. This matrix contains the production recipes for the product of a given region/sector (column) and shows how much of various products (rows) are needed to produce one unit of output.

Hence, we can rewrite the previous equation as

$$x = Ax + f$$

which allows us to write

$$f = x - Ax = (I - A)x \rightarrow x = (I - A)^{-1} f$$

Here we can define the inverse Leontief L matrix as

$$L = (I - A)^{-1}$$

The inverse Leontief matrix contains the coefficients that map all the input requirements, both direct and indirect, necessary to produce a given unit of consumed output. Both A and thus L are $n \times n$, where $n = C \times S$ and C represents the number of total countries considered, while S represents the number of sectors considered.

GLOBIO model

The GLOBIO model is a global model of biodiversity intactness, expressed by the mean species abundance (MSA) metric, as a function of multiple anthropogenic pressures on the environment (Schipper et al., 2020; Alkemade et al., 2009). Mathematically, the GLOBIO model quantifies the relationships between anthropogenic pressures and biodiversity. Specifically, the GLOBIO model considers how environmental pressures, namely climate change (expressed in terms of GHG emissions), land use change, road disturbance, atmospheric nitrogen decomposition, mining and habitat fragmentation may affect the MSA of a determined region. The MSA captures the changes in the biodiversity community composition in relation to each environmental pressure and is calculated by dividing the abundance of each species found in the presence of the pressure by its abundance when undisturbed. The value is truncated at 1 and then averaged across all species present in the reference region (Alkemade et al., 2009). The GLOBIO model integrates the pressure-impact relationships with spatially resolved data on the pressures, resulting in high-resolution spatial maps with impact-specific MSA values.

The GLOBIO model is especially appropriate for scenario-based modelling, which is a powerful approach to evaluate how possible future socio-economic

developments may affect biodiversity. GLOBIO can also be used to quantify various policy-relevant dimensions behind human-nature interactions, such as theimpacts of human activities on biodiversity and ecosystem services, the effectiveness of large-scale policy options for conserving biodiversity and ecosystem services, production and consumption-based biodiversity impacts (footprints) and benefits that people can obtain from nature (i.e. nature's contribution to people or nature based solutions).

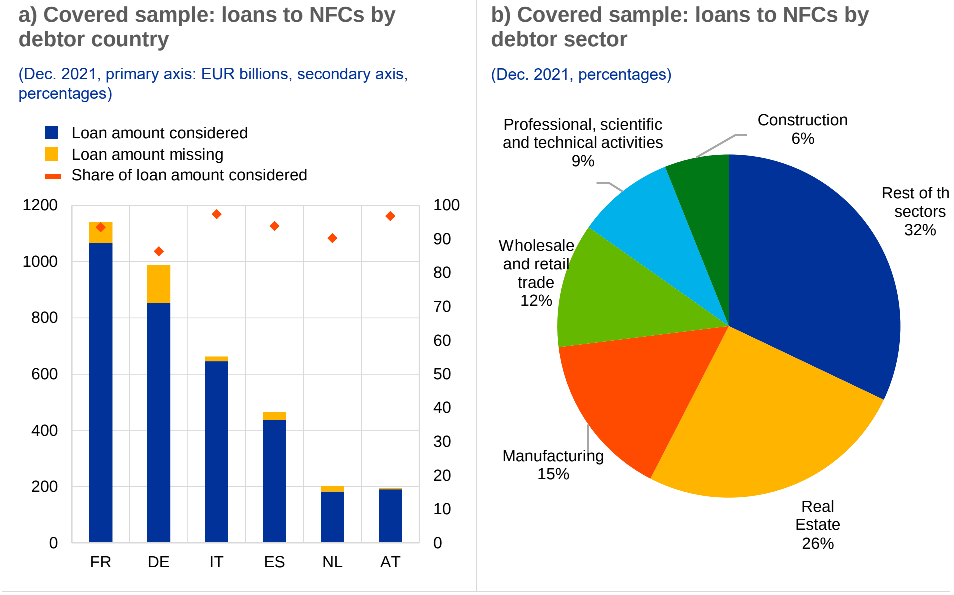
Banks' corporate loan exposure

The ECB's analytical credit dataset, or AnaCredit, contains instrument-level data on individual euro area banks' loan portfolios, harmonised across Member States. The dataset provides data on both the creditor and the debtor and contains information on credit risk. The loans covered by the dataset consist of conventional lending products (derivatives and off-balance sheet items are excluded) extended only to legal entities. Our analysis thus does not consider credit to households (i.e. mortgages). The dataset is updated on a monthly basis.

Our sample refers to December 2021 and maps €4.3 trillion to around 4.2 million NFCs (Chart 2). Compared with the entirety of AnaCredit, we were able to retain almost 90% of its observations in terms of loan amount. The missing share is due to the absence of information on the borrower (like NACE) or reporting mistakes.

Chart 2A

Sample coverage of loans to NFCs



Source: AnaCredit.
Notes: Panel a contains the coverage of our sample in terms of loan amount compared with the entire AnaCredit offering for the reference period of December 2021. The loans are grouped by the country of residence of the borrower, and only the largest five countries are represented. Panel b instead contains the share of loans by economic sector of the borrower.

Appendix B: methodology

Exposure assessment

The total dependency score between a borrower and the ecosystem services of nature is obtained as the sum of the direct and indirect dependency scores. The direct dependency score is obtained directly from the ENCORE dataset, while the indirect score is obtained using the EXIOBASE IOT. Specifically, the indirect component is computed at a regional and sectoral level and corresponds to the weighted average of the dependency scores of all suppliers of a given NFC based on the importance of a given region/sector in the production of its output.

To obtain the indirect dependencies of all the *n* combinations of country-sector, we compute the $21 \times n$ matrix of indirect dependencies U of each country/sector pair from ecosystem processes:

$$U = D \times \overline{(L - I)}$$

where D is a $21 \times n$ matrix of direct dependencies obtained from ENCORE. Each row of the matrix $(D_{eco,\cdot})$ represents one of the ecosystem services and is obtained as

$$D_{eco,\cdot} = [eco_1 \quad \cdots \quad eco_S \quad eco_1 \quad \ldots \quad eco_{S-1} \quad eco_S]$$

It is worth noting that since ENCORE does not depend on the region, the vector is obtained by appending C concatenated $1 \times S$ vectors.

Meanwhile, the matrix $\overline{(L - I)}$ is obtained by dividing each element of $(L - I)$ by the sum of the respective column. Therefore, it can be computed as $\overline{(L - I)} = (L - I) \times \operatorname{diag}\left(\left(1(L - I)\right)^{-1}\right)$. Ultimately, this matrix contains the share in percentage of the input from each supplier (expressed in countries/sectors) in the value chain required to produce one unit of good.

The resulting U matrix is a $21 \times n$ matrix of indirect dependencies of each of the n country/sector pairs from 21 ecosystem processes. It is worth noting that, although the direct dependency scores are geographically invariant, utilising the U matrix we compute a total dependency which will be dependent on the country. Indeed, the overall indirect dependency relies on the shares of inputs in the value chain of the NFC, which in turn depend on the country where it is headquartered. Hence, two NFCs with the same economic activities but operating in different regions will have the same direct dependency but different indirect ones. This represents a plausible first-order approximation in the absence of country-specific direct dependencies. Nevertheless, it is likely that direct dependency of production processes on ecosystem services will not differ substantially across countries.

Sensitivity analysis

Table 1B
Geographical aggregation of biodiversity shock

List of NACE sectors for which biodiversity is assumed to have local or country-level dependency

Country	Water basin
Manufacturing	Agriculture, forestry and fishing
Electricity, gas, steam and air conditioning supply	Mining and quarrying
Construction	Water supply; sewerage, waste management and remediation activities
Wholesale and retail trade	Professional, scientific and technical activities
Transportation and storage	Administrative and support service activities
Accommodation and food service activities	Public administration and defence; compulsory social security
Information and communication	Human health and social work activities
Financial and insurance activities	Arts, entertainment and recreation
Real estate activities	Other service activities
Education	
Activities of household as employers	
Activities of extraterritorial organisations and bodies	

Source: NACE classification.
Note: Type of geographical aggregation considered for the biodiversity shocks depending on whether the economic activity relies on biodiversity locally or not.

Expected loss computation

In the sensitivity analysis, the change in expected losses for NFC *j*, bank *b* and sector *s* is computed as follows:

$$\Delta Expected\ Loss_j^{b;\,s} = EAD_j^b \times LGD_j^b \times \Delta PD_j^s$$

EAD_j^b is the total amount bank *b* is exposed to loan default by NFC *j*. In our case, this value is sourced directly from AnaCredit. Specifically, we consider the outstanding notional amount that a given lender has with respect to a given borrower.

LGD_j^b in our case represents the percentage of uncovered amount that the lender would face even when selling the collateral provided to the loan. This information can be obtained from AnaCredit. It is worth noting that this is likely to represent a lower bound of the loss given default; in the event of a shock, the physical collateral may lose significant value, and the banks would recover a smaller amount.

ΔPD_j^s as described in Section 4.1.2. The changes in probability can be thought of as the combination of two elements: one linking the economic activity to the depletion of biodiversity DS_j^{MSA} and the other representing the rate of loss of biodiversity σ_{bio}^s.

Changes in expected losses include changes in both direct and indirect losses. Direct expected losses are computed using the direct dependency score as computed in Section 3. In this case, $\Delta Expected\ Loss_{direct}{}_j^{b;\,s}$ is computed using the direct dependency only, while σ_{bio}^s contains the country-level/water basin-level loss corresponding to NFC *j* (Table 1B).

By contrast, the changes in indirect expected losses due to the supply chain are computed using the indirect dependency score. Specifically, $\Delta Expected\ Loss_{indirect}{}_j^{b;\,s}$ is computed using the indirect component of the total dependency $(1 - DS_{Direct}) \times DS_{Indirect}$. This way, the direct and indirect changes in expected losses are directly summable.

In this case, σ_{MSA}^s is computed using the indirect values of MSA for a given NFC $MSA_{s;\,indirect(j)}$. These values are obtained as weighted averages of country-level MSA changes based on the share of input from each supplier (expressed in countries only)[26] in the value chain required to produce one unit of good for NFC *j*. These weights are obtained from the matrix $\overline{(L - I)}$.

[26] EXIOBASE also considers five rest-of-world regions. In this case, MSA is aggregated at regional level. This aggregation is done using the area share of the countries belonging to the same region and the respective MSA changes.

Appendix C: additional results

Exposure

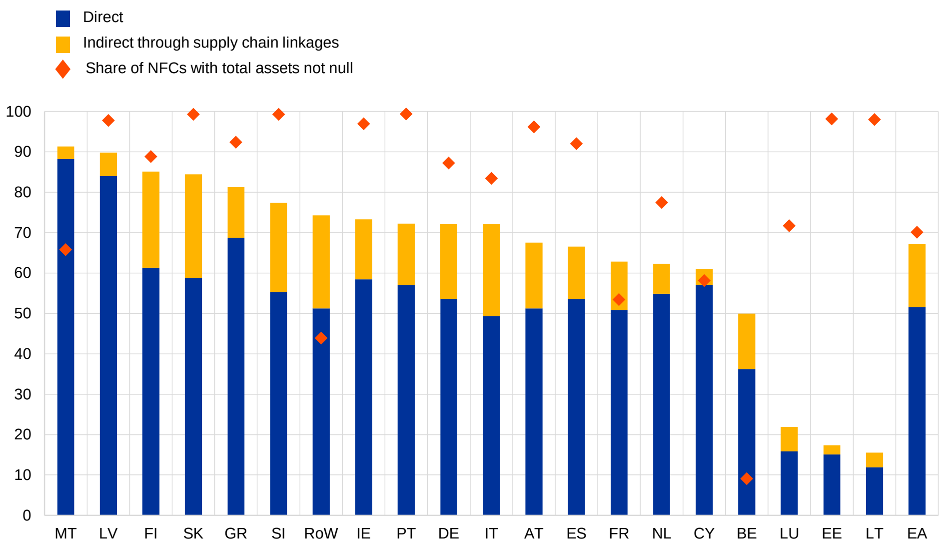
Overall, total assets of NFCs with high dependency account for roughly 67% of assets in the euro area non-financial sector (Chart 1A). The lower number compared with the share of NFCs suggests the presence of small and medium-sized firms that are highly dependent on nature but are overall of smaller size. It is also worth noting that, in contrast to Chart 7, when looking at the share of total assets, there is extreme variability between countries, with Malta reaching almost 91% while countries like Estonia and Lithuania have values of around 20%.

Chart 1C

Dependency of euro area NFCs and their total assets in euro area countries on ecosystem services

Share of total assets of NFCs with a high dependency score (greater than 0.7) for at least one ecosystem service. NFCs are allocated to the country where they are headquartered.

(Dec. 2021, percentage points)



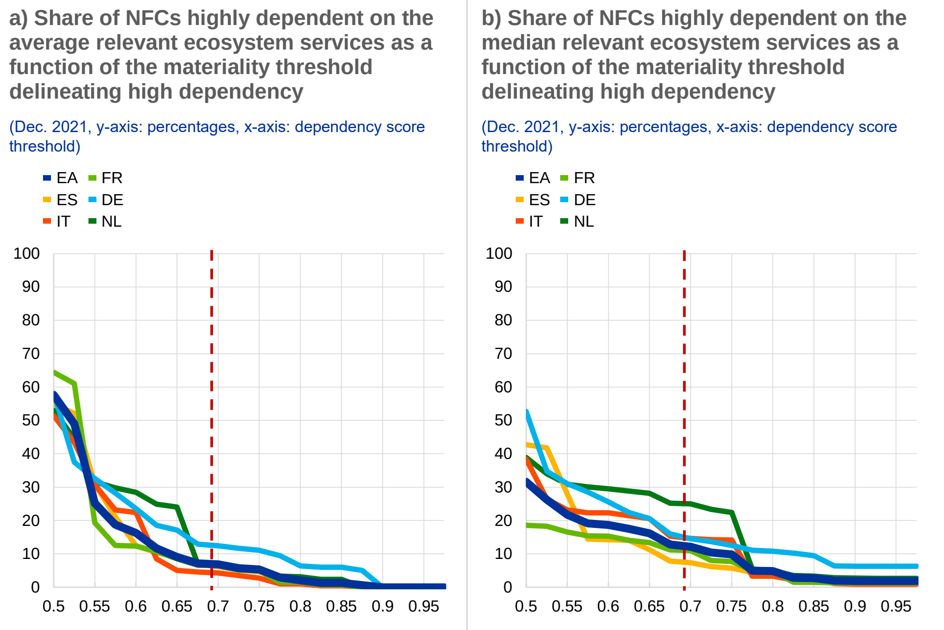
Sources: ENCORE, EXIOBASE and AnaCredit.
Notes: Share of total assets of NFCs with a high dependency score (greater than 0.7) for at least one ecosystem service. An NFC is labelled as highly dependent when it has a sufficiently high direct dependency score (blue bar) or sufficiently high dependency when also taking into account possible supply chain linkages (yellow bar). The chart is augmented with the share of firms for which we had data on total assets.

Additionally, it is worth analysing multiple ecosystem services at once instead of only the most relevant one (Charts 7 and 10) Indeed, the multidimensionality of nature is one of the key characteristics that separates it from climate change. In our analysis, we consider 21 ecosystem services. However, it is evident that not all of them may be relevant for each NFC. Therefore, as done in Chart 12, we consider an ecosystem service as relevant if it has a total dependency score greater than 0.2, that is if it has a dependency higher than "very low". On average, euro area firms have eight of these relevant services (seven if we consider the median). Computing the mean/median average total dependency across only relevant ecosystem services for each NFC generates the results in Charts 2C and 3C.

Looking at the share of NFCs with high total dependency (as in Chart 7) and allowing for multiple thresholds, we can see how the aggregation using mean/median across ecosystem services reduces the number of highly dependent NFCs. This is normal given the relatively large number of ecosystem services considered in the computation. Indeed, to have similar results as those obtained in Chart 7, we need to lower the threshold to 0.5 when considering the mean total dependency score across relevant services (Chart 2C, panel a). Moreover, considering the median (Chart 2C, panel b), the values are even smaller across countries and thresholds. This means that the distribution of the dependencies of the relevant ecosystem services tend to be positively skewed, suggesting that the mass of the dependencies have low materiality. Nevertheless, this result also suggests the presence of infrequent yet very large dependencies on one or two ecosystem services. This analysis is particularly important given that we do not yet know the extent of which the loss of one ecosystem service might be enough to drastically impede the economic activity of a firm and we do not know the degree of substitutability across services. Similar considerations can be applied to the share of loans (as in Chart 10), as depicted in Chart 3C.

Chart 2C

How the share of NFCs with a high dependency score across relevant ecosystem services changes with the threshold considered



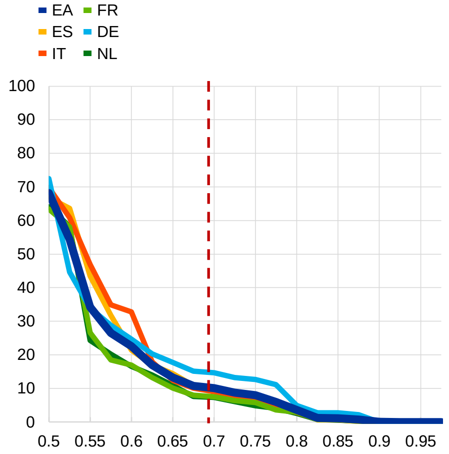
Sources: EXIOBASE, ENCORE, AnaCredit and ECB calculations.
Notes: Share of NFCs with a determined average/median dependency score across relevant ecosystem services. An ecosystem service is labelled "relevant" if it has a total dependency score greater than 0.2 (very low dependency). The share of NFCs is represented on the y-axis with the corresponding threshold on the x-axis. The share of the five largest countries by corporate loan amount considered are shown.

Chart 3C

How the share of corporate loans from banks to NFCs with a high dependency score across relevant ecosystem services changes with the threshold considered

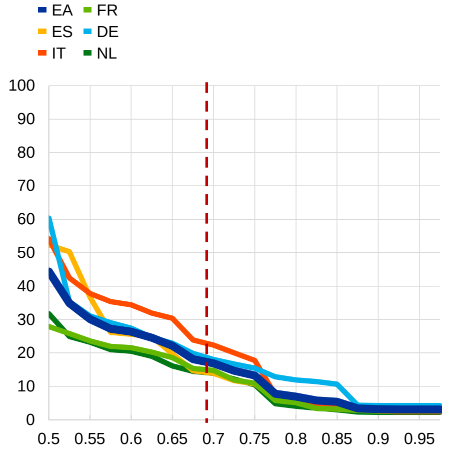
a) Share of euro area banks' corporate loans highly dependent on the average relevant ecosystem services as a function of the materiality threshold delineating high dependency

(Dec. 2021, y-axis: percentages, x-axis: dependency score threshold)



b) Share of euro area banks' corporate loans highly dependent on the median relevant ecosystem services as a function of the materiality threshold delineating high dependency

(Dec. 2021, y-axis: percentages, x-axis: dependency score threshold)



Sources: EXIOBASE, ENCORE, AnaCredit and ECB calculations.
Notes: Share of loans with a determined dependency score across relevant ecosystem services. An ecosystem service is labelled "relevant" if it has a total dependency score greater than 0.2 (very low dependency). A loan is labelled as dependent when the borrowing NFC has a sufficiently high mean/median dependency score. The share of corporate loans is represented on the y-axis with the corresponding threshold on the x-axis. The share of the five largest countries by corporate loan amount considered are shown.

Acknowledgements
We would like to thank Stefano Borgioli, Angelos Vouldis and Carmelo Salleo for their valuable comments and suggestions to improve the paper. We would also like to thank Alexandra Marques from the PBL Netherlands Environmental Assessment Agency for her valuable advice on biodiversity impacts and the GLOBIO model. We accept full responsibility for any errors or omissions.
The views expressed in this paper are our own and do not necessarily reflect those of the ECB, nor of the people mentioned in these acknowledgements.

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PDF ISBN 978-92-899-6232-2, ISSN 1725-6534, doi:10.2866/670314, QB-AQ-23-024-EN-N