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Nature at risk: Implications for the euro area economy and financial stability

Economic and financial risks stemming from degradation of ecosystem services

No 380

Contents

Abstract

Degraded ecosystems undermine productivity, disrupt supply chains and heighten vulnerability to shocks, creating risks for the real economy and the financial sector. Biodiversity loss and ecosystem degradation also pose a growing risk to price stability, with increasing evidence that ecosystem shocks contribute to inflationary pressures in the euro area. This paper moves from dependency mapping to a risk-based assessment of the euro area economy and banks, applying the nature value-at-risk (NVaR) framework, which links biophysical shocks to ecosystem services with sectoral-production functions[1]. Water-related risks, including flood protection, surface water and groundwater scarcity, and water quality, emerge as the most material for the euro area economy. Surface-water scarcity alone could expose up to 24% of euro area output to risk under a drought event with a 100-year return period. A complementary endogenous-risk analysis that was conducted, quantified the extent to which euro area firms and banks may contribute to the very ecosystem degradation on which their activities depend, creating feedback loops that could amplify financial risks over time. The results showed material feedback loops between ecosystem degradation and banks' own portfolios, with water-related risks being the dominant transmission channel. Overall, this study takes a first step towards the identification of risk hotspots and provides a more robust assessment of nature-related risks than prior studies. It also discusses the remaining data gaps and methodological constraints, and outlines the next steps to be taken, as a priority, to address this.

Keywords: nature-related financial risks, ecosystem degradation, water scarcity and quality, endogenous risk, sectoral output at risk, price stability

JEL codes: Q51, Q54, E31

[1]Appendix 1 contains more detailed description of the 18 ecosystem services concerned.

Non-technical summary

Natural ecosystems are fundamental to economic development and human survival. In the euro area, about 72% of non-financial corporations (around three million firms), accounting for nearly 75% of corporate bank lending, are highly dependent on at least one ecosystem service. However, European Union (EU) and global ecosystems are under mounting pressure, with biodiversity loss accelerating across many regions. In the EU, water ecosystems are particularly distressed, with persistent threats from pollution and overextraction. Degraded ecosystems undermine productivity, disrupt supply chains and increase vulnerability to shocks, creating risks for the economy and the financial sector.

Nature degradation and biodiversity loss threaten price stability, with growing evidence that ecosystem shocks raise inflation in the euro area. Nature degradation is now explicitly integrated into the ECB's monetary policy strategy assessment, alongside climate change, reflecting its relevance for price and financial stability. Although impacts are most visible in agriculture, other highly exposed sectors, such as manufacturing, utilities and electricity, remain under-studied. Moreover, climate and nature risks are closely interconnected, with compound effects that amplify macrofinancial vulnerabilities.

This study advances assessment of ecosystem-service dependencies in the euro area by providing a risk-based analysis of sectoral economic output. The NVaR framework was applied to the euro area economy and banking system, providing a structured approach to quantifying systemic risks from ecosystem degradation. The NVaR framework operationalises nature-related risk by linking biophysical shocks to ecosystem services with sectoral-production functions. As such, it serves as an agile, globally consistent risk-assessment tool for identifying portfolio-level macroeconomic and macrofinancial vulnerabilities, as well as risks arising from specific ecosystem degradation.

The results indicated that water-related ecosystem services dominate in terms of risk; surface- and groundwater scarcity, together with regionally declining water quality, constitute the most material nature-related threats to the euro area economy. Flood and storm protection is also highly material, followed closely by reduced climate regulation. Importantly, about half of the total risk originates outside the euro area through international supply chains. This provides new insight, namely that euro area economy dependencies on ecosystem services do not always translate into the highest risk for euro area economic output. This demonstrates the importance of a risk-based approach.

NVaR results are sensitive to data granularity and methodological choices, which can materially change estimates of sectoral exposure and loss from ecosystem shocks. Country-scale inputs tend to underestimate the economic output at risk. By contrast, higher-resolution ecosystem and exposure datasets are more reliable in revealing regional risk hotspots. This was demonstrated for water-scarcity risk by comparing country-level inputs with higher-resolution data. Country-level data showed that 9% of euro area output was at risk from water scarcity, whereas a more granular, subnational approach with methodological enhancements estimated that the output at risk would increase to about 24% under a drought event with a 100-year return period. A key difference driving this finding was the more accurate specification of the spatial distribution and intensities of the hazard, and its co-location with specific economic assets and activities. This highlights the importance of using granular nature and firm-level data for risk assessment. Furthermore, it confirms that risk-assessment frameworks, such as the NVaR, applied to such risks should clearly document the assumptions used, apply harmonised protocols and incorporate systematic uncertainty analysis, especially as regards the macrofinancial and microprudential dimensions.

Agriculture emerged as the most exposed sector, with potential output losses of up to 30% under a 25-year drought scenario and 38% under a 100-year event. Other sectors, such as manufacturing, mining, water supply, construction, publishing, and accommodation and food services, also showed high vulnerability, with more than 20% of their output at risk even under moderate drought conditions. Mapping these results to euro area bank portfolios using the ECB Analytical Credit (AnaCredit) dataset (for December 2022) revealed that around 19% of loans are exposed to surface-water scarcity and 22% to groundwater scarcity, while 12% are linked to risks from degraded water quality. The most affected loan exposures were in real estate, manufacturing, wholesale and retail trade, mining and construction. These findings suggest that worsening water scarcity and declining water quality could become material drivers of credit risk, potentially amplifying systemic vulnerabilities in the euro area financial system.

A complementary analysis, conducted separately from the NVaR analysis, looked at the ways in which economic activity and bank lending was not only dependent on ecosystems, but also put those systems under pressure, creating endogenous risk. The results showed material feedback loops between ecosystem degradation and bank portfolios, with water-related services being the dominant transmission channel. Endogenous risk was concentrated in the manufacturing sector and propagated through upstream supply chains, creating not only risk hotspots, but also leverage points for managing risks. This is important given that when banks finance activities that degrade nature, they amplify their own future exposures to risk. Funding water-intensive, polluting processes can, for example, worsen water scarcity and quality, which then raises operational and credit risks for borrowers and lenders alike. Targeted financing of water efficiency, pollution reduction and sustainable sourcing in manufacturing and primary production would lower future exposure. Collating and combining dependency and impact data would help to direct these interventions to where they would be the most effective in reducing systemic risk and strengthening the resilience of the financial sector and the real economy.

The results of this study are a first step toward a more robust assessment of nature-related risks and the identification of risk hotspots. Data gaps and methodological constraints remain, however. Continued macroeconomic research and financial-stability assessment are essential to gauge how biodiversity loss and ecosystem degradation could trigger shocks that affect inflation and the transmission of monetary policy. Further work is required to deepen analysis of the macroeconomic and financial impacts of nature degradation. The priority areas include further enhancing the NVaR framework, advancing macrofinancial modelling, developing forward-looking scenarios, improving nature-related data and firm-level disclosures, and strengthening interdisciplinary collaboration.

1 Introduction

Natural ecosystems are fundamental to economic development and human survival. Around half of global gross domestic product (GDP) depends directly on nature, while more than half of the world's population relies on biodiversity for a livelihood, including 70% of the poor and vulnerable (IPBES, 2022). Dasgupta (2021) underscores this dependency by stressing that the entire global economy ultimately rests on nature, given that neither human life nor economic activity can exist without it. Beyond supporting production and livelihoods, ecosystems also provide critical regulating services, such as absorbing anthropogenic greenhouse gas emissions (Ke et al., 2024), thereby playing a central role in mitigating climate change.

EU and global ecosystems are under mounting pressure, with biodiversity loss accelerating across many regions (EEA, 2025a). Persistent pressures from unsustainable production and consumption patterns continue to accelerate habitat destruction, the overexploitation of resources, pollution, the spread of invasive species and climate change. While certain pressures, such as land use, air pollution and nitrogen deposition, are declining in the EU, their absolute levels remain too high to allow ecosystem recovery (EEA, 2023). At EU level, only 15% of habitats are assessed as having a good conservation status, with 81% being poor to bad and 60-70% of soils being degraded (EEA, 2020). Forests, peatlands and mountain ecosystems face cumulative pressures from unsustainable land use and climate change, while EU forests are increasingly vulnerable to monocultures, overharvesting, droughts, fires and pest outbreaks, all of which erode their resilience and carbon sequestration capacity (Forzieri et al., 2021; EEA, 2024a).

Water ecosystems are particularly distressed: just 38% of surface-water bodies achieve good ecological status and only around 30% have a good chemical status (EEA, 2024b). Progress on chemical status is hampered by long-lived pollutants, especially mercury and brominated flame retardants. Furthermore, water stress already affects about 30% of EU territory and 34% of its population each year, with the pressures likely to intensify with climate change. In recent years, droughts have impacted nearly all EU regions, disrupting agriculture, public water supply, energy production, river transport and ecosystems, and these impacts are projected to grow over the coming decades (Rossi et al., 2023).

Degraded ecosystems undermine productivity, disrupt supply chains and increase vulnerability to shocks, creating risks for the economy and the financial sector (Ceglar et al. (2025); UNEP, 2022). Biodiversity loss and ecosystem degradation are key megatrends shaping how future risks may emerge and evolve in Europe, and are therefore increasingly important for understanding long-term threats to economic growth and financial stability in the EU (Joint Research Centre, 2025). Research by the ECB shows that 72% of euro area non-financial corporations critically depend on at least one ecosystem service and that around 75% of corporate bank loans are linked to these firms (Boldrini et al., 2023). This high dependency highlights the vulnerability of economic activity to ecosystem degradation and reinforces the need for financial regulators and policymakers to integrate nature-related risks into risk assessments and supervisory frameworks.

Nature degradation and biodiversity loss pose a growing risk to price stability, which is the core objective of monetary policy. One of the most direct transmission channels is through agriculture: the degradation of farmland reduces productivity, driving higher and more volatile food prices. Today, around 80% of arable land worldwide is already affected by soil erosion, salinisation and loss of biodiversity, which is critical for pollination and pest control (Prăvălie et al., 2021). These pressures are projected to reduce global food productivity by 12% and increase food prices by up to 30% by 2040 (Wegner et al., 2025; UNEP, 2021; Kopittke et al., 2019). In the EU alone, soil erosion already causes an estimated €1.25 billion in annual productivity losses (Panagos et al., 2018). Global soil erosion was projected to rise by up to 66% by 2070, with a substantial macroeconomic toll that would result in cumulative global GDP losses of USD 216-625 billion (some €188-540 billion) over the period from 2015 to 2070 (Sartotri et al., 2024).

The decline of pollinators further illustrates the economic risks linked to biodiversity loss. Animal pollination directly affects the yield and/or quality of approximately 75% of global food crop types, including most fruits, seeds and nuts and several high-value commodity crops, such as coffee, cocoa and oilseed rape (Potts et al., 2016). These crops face significant threats, with global trade and food security increasingly exposed. While the ecological damage often occurs in low-income, crop-exporting countries, the economic consequences reverberate globally. Economic modelling shows that high-income import-dependent economies, such as the United Kingdom, Germany and Japan, may incur substantial losses when pollinator declines occur abroad (Murphy et al., 2022). These disruptions reshape the value of global crop production and highlight the deep interdependence of ecosystems, international trade and financial stability.

Empirical evidence also confirms the inflationary effects of ecosystem shocks in the euro area (Kotz et al. (2025); Beirne et al. (2021); Parker, 2017). For instance, droughts, aggravated by overextraction from water bodies, lead to persistent impacts, with regional output remaining 2.4 percentage points lower even four years after an event (Usman et al., 2025). In France, a one-off temporary crop shock raised food prices by about 13% and pushed up food inflation by more than 2 percentage points, with effects that persisted well beyond the initial event (Wegner et al., 2025). At the global level, harvest shocks account for around 30% of medium-term volatility in euro area inflation (Peersman, 2022). This underscores the extent to which ecosystem degradation worldwide can directly undermine price stability in the euro area.

Evidence of nature-related impacts is most visible in agriculture, but less attention has been given to other sectors that are also highly dependent on ecosystem services, such as manufacturing, utilities and electricity production. Disruptions to water availability, soil health and pollination can transmit well beyond agriculture, affecting supply chains and raising costs across the real economy. These dependencies mean that nature degradation, alongside climate change, can have a direct impact on bank balance sheets through higher credit risk, increased operational costs and potential market volatility. A systematic assessment is therefore necessary to inform financial supervision and ensure that nature-related risks are adequately captured in financial-stability analysis.

Climate- and nature-related risks are deeply interconnected, with compounding effects that amplify macrofinancial vulnerabilities (Ceglar et al., 2025). The EU faces overlapping hazards, ranging from acute climate shocks (such as floods, wildfires, heatwaves and droughts) to chronic ecosystem degradation (including soil erosion and water scarcity), which could have compounding and cascading impacts that would persist and intensify over time (Wegner et al., 2025), jointly threatening productivity, public finances and financial stability. For the euro area, the most significant risks are likely to stem from a convergence of droughts and declining surface water and groundwater availability. The condition of the ecosystem would then become a critical risk amplifier: healthy ecosystems can buffer shocks by bolstering water regulation services, but degraded ecosystems exacerbate vulnerabilities, particularly for firms heavily reliant on water.

Importantly, economic activity, and the bank lending that supports it, not only depends on ecosystems, but also exerts significant pressure on them (double materiality). Ceglar et al. (2025) assessed the environmental impacts of euro area companies and banks by applying the concept of biodiversity footprints, focusing on two key drivers of ecosystem degradation: land-use change and climate change. These pressures contribute to habitat loss and ecosystem damage, creating material transition risks. Strengthening understanding of double materiality is therefore essential to inform policymakers as to how lending practices by banks can amplify environmental pressures and, in turn, feed back into financial risks.

Building on a dependency analysis (Boldrini et al., 2023), the current study advances understanding of how ecosystem degradation affects economic activity and financial stability by applying a dedicated, granular NVaR framework with asset-level exposure data to systematically quantify direct and indirect risks to euro area sectors (Ranger et al., 2024). It replaces static dependency assessments with a risk-based approach and introduces key methodological enhancements. An endogenous-risk (double materiality) perspective was adopted to offer a complementary analysis, showing how bank lending amplifies pressures on nature that feed back into the risks banks need to manage (NGFS, 2024a).

1.1 Structure of the paper

Chapter 2 sets out the NVaR framework used to map the euro area economy and bank portfolios to ecosystem-service-related risks. It first presents the estimated sectoral output losses from the degradation of 18 key ecosystem services in the EU and globally. It then shows the extent to which these sectoral exposures are linked to the financial system. This was derived by using the AnaCredit dataset to allocate NVaR-based risk to the loan portfolios of euro area banks, making it possible to identify the ecosystem services that are the most critical for macrofinancial stability. A baseline country-sector level NVaR analysis (developed in Ranger et al., 2024) was first conducted. This was followed by the application to three water-related ecosystem services of an enhanced version of the baseline NVaR framework that made use of high-resolution ecological and economic datasets to provide a far more granular assessment. The findings of both analyses were then compared across the three ecosystem services.

Chapter 3 looks at endogenous risk and quantifies the extent to which euro area firms and banks contribute to the degradation of the very ecosystems on which their activities depend. It examines areas where bank portfolios both depend on and impact the same ecosystem services and introduces an endogenous-risk exposure metric that measures the overlap between dependency and impact at the service level.

The two analytical components presented in Chapters 2 and 3 provide complementary perspectives on the interaction between ecosystems, the economy and the financial system. The enhanced NVaR framework introduced in this paper provides a first-order, system-wide screening of nature-related vulnerabilities and risks by mapping ecosystem-state degradation to sectoral productivity shocks and portfolio-level loss metrics for the euro area. This screening was undertaken at granular resolution and covered specific return periods for acute events, learning from catastrophe risk models commonly used in the insurance sector. An endogenous-risk analysis then traced how firms' activities and banks' lending contributed to those same ecosystem pressures (an impact/causation view), revealing feedback loops that could amplify future losses. The analysis showed where endogenous risk originates, looking across sectors, regions and supply-chain steps.

The study concludes with a discussion of the methodological limitations (Chapter 4), policy implications (Chapter 5) and avenues for future research (Chapter 6). Overall, this paper lays down the foundations for embedding nature-related risks into supervisory assessments and macroprudential frameworks and sets out the priorities for future research.

2 Nature value-at-risk

The NVaR framework used in this study provides a structured methodology for quantifying potential economic output at risk from ecosystem degradation. NVaR is conceptually aligned with the financial value-at-risk (VaR) measure, but can be forward-looking and be applied to the real economy. In economic terms, NVaR measures the share of sectoral economic output that is at risk of loss under a given scenario of ecosystem-service degradation. It is designed to support financial and policy decision-making. The framework assesses how hazards caused by ecosystem degradation, financial exposures and sectoral vulnerabilities interact. In doing so, it translates ecosystem-service shocks from pressures such as climate change, resource overuse and biodiversity loss into a measure of potential economic output at risk. The NVaR metric applied in this study was a single financial-risk measure that combined environmental and socio-economic data, sectoral dependency insights and economic modelling (Ranger et al., 2023 and 2024). The objective of NVaR framework is to provide a spatially scalable, transparent, globally consistent and versatile tool for nature-related risk assessments, with sufficient flexibility to be applied across multiple types of financial data and capable of generating policy-relevant insights.

The NVaR framework operationalises nature-related risks by linking biophysical pressures and shocks to ecosystem services, sectoral-production functions and national-level vulnerability metrics. In practice, it estimates the share of sectoral value added that could be lost under ecosystem-service degradation scenarios at a specific probabilistic return period. Conceptually, it mirrors financial VaR. While the latter captures potential losses from market volatility, NVaR framework captures potential losses from disruptions in natural capital, be the impact direct (own operations) or indirect (supply chain), including reduced input availability, higher production costs and output declines.

This study applied the NVaR framework to the euro area and expanded on previous applications of the baseline NVaR conducted for the United Kingdom and at the global level. As regards the United Kingdom, the NVaR framework developed in Ranger et al. (2024) found that around 50% of the country's GDP was generated in sectors with high or very high dependence on ecosystem services, with water-related ecosystem services identified as being the critical bottlenecks. That study, and the previous global study set out in Ranger et al. (2023), also highlighted the importance of cross-border transmission, showing that shocks originating abroad could propagate to national economies through trade and financial channels. Both studies demonstrated the potential of NVaR to capture both the domestic and international dimensions of systemic risk.

2.1 Methodology

The indicators incorporated into the NVaR framework used in this study were grouped into the three principal components of disaster risk: Hazard (HS), Exposure (ES), and Vulnerability (VS). Each component was constructed using tailored aggregation rules to reflect its conceptual role in the risk framework. To ensure comparability across diverse environmental and socio-economic datasets, all the raw indicators were first transformed to reduce skewness and to enhance statistical robustness. Depending on the underlying data distribution, the transformations included linear adjustments, logarithmic scaling and power transformations across return periods, spatial and temporal extents. These procedures generated more symmetrical distributions and mitigated the risk of distortion from extreme values, thereby improving suitability for aggregation. Following their transformation, all the indicators were rescaled to a uniform scale using min-max normalisation. This approach standardised the indicators to a [0,1] range, while preserving proportional relationships, in order to ensure comparability across variables with different units and magnitudes.

2.1.1 NVaR metric calculation

In line with the methodology developed in Ranger et al. (2023), the baseline NVaR metric was calculated as the multiplicative interaction of the three components:

$$NVaR_{s,e,c} = HS_{e,c} \times ES_{s,c} \times VS_{c,e,s}$$

$\mathrm{NVaR}_{s,e,c}$ captured:

- Hazard: the location (c) and ecosystem-service-specific (e) Hazard Score $HS_{e,c}$, integrating the likelihood of an ecosystem service being degraded – this includes both pressure on, vulnerability to and the state of the ecosystem services.
- Exposure: the monetary quantity of sectors/production systems (s) exposed within countries and the spatial distribution of assets, i.e. Exposures (ES).
- Vulnerability: the production systems output and services vulnerability to ecosystem degradation within countries and across supply chains, i.e. Vulnerability Score (VS).

The resulting NVaR metric was a single value representing the monetary VaR at a given sectoral level in a given country, expressed in the same financial units as the exposure unit. This formulation reflected the conceptual principle that systemic economic and financial risk emerges when ecosystem hazards coincide with high financial exposures and structural vulnerabilities. By construction, if any component approaches zero (e.g. low exposure or strong adaptive capacity), the overall NVaR is attenuated. Conversely, high values across all components generate high-risk scores, highlighting potential systemic hotspots.

2.1.2 Hazard

The Hazard dimension captured both environmental and anthropogenic threats to ecosystem services, encompassing climate-induced shocks (e.g. droughts, floods and temperature extremes), pollution and overconsumption. In line with the methodology developed in Ranger et al. (2023 and 2024), the hazard indicators were combined with measures of the state and vulnerability of the ecosystem concerned (e.g. water quality, soil fertility and biodiversity indices) to reflect both the drivers of the stress and the underlying condition of the ecosystems. Indicators of concurrent threats were aggregated, primarily through additive methods, consistent with the cumulative nature of hazards. By contrast, indicators of the state of ecosystems were combined using less compensatory approaches (e.g. geometric means), ensuring that weak performance in one dimension (such as severe soil degradation) was not fully offset by stronger conditions elsewhere. The resulting Hazard Score integrated both the threat and state dimensions into a single, transparent metric of ecosystem stress, providing a systematic basis for linking biophysical risks to macroeconomic and financial-stability analysis.

To maintain transparency and avoid subjective bias, all the indicators within a given Hazard component were initially assigned equal weights. This approach was validated through sensitivity testing, which showed that alternative weighting schemes (e.g. entropy-based, expert-judgement or variance-driven weighting) yielded minimal changes in the aggregate outcomes. In selected cases, where strong empirical evidence existed of the relative importance of risk drivers, the weights were adjusted.

Hazard indicators were defined at the ecosystem-service and location levels, enabling macroeconomic and macrofinancial analysis. While macroeconomic assessments are typically conducted at the country level, this approach may be insufficient for nature-related risks, given the inherently local nature of ecosystems and their influence on economic activities. To address this limitation, the second part of the analysis undertaken took a deep dive into the most material ecosystem services for the euro area economy, adapting the methodology to incorporate more granular data (Jwaideh et al., forthcoming). This also made it possible to assess the importance of input data granularity for ecosystem-service-related risk measurement and its implications for financial-stability analysis. Examples of hazard indicators at national level can be found in Ranger et al. (2023 and 2024).

2.1.3 Exposure

Exposure quantified the direct and indirect dependencies of the economy and financial system across sectors and countries that are at risk of disruption. Scope 1 (direct operations) measured exposures linked to corporate assets and loan portfolios that rely directly on local ecosystem services, while Scope 3 (supply chains) captured indirect monetary flows through global value chains. These exposures were operationalised using a multi-regional input-output (MRIO) framework, based on the Leontief matrix, that mapped upstream and downstream linkages across production networks (Boldrini et al., 2023).

In this study, use was made of EXIOBASE3 input-output data (Boldrini et al., 2023; Svartzman et al., 2021).[2] The EXIOBASE database provides an estimate of the likely sector-region breakdown for the upstream supply chain of each sector in each region (Stadler et al., 2018). While EXIOBASE3 provides wide sectoral coverage, its limited representation of lower-middle and low-income countries remains a constraint. The demonstrator approach adopted in this study therefore used EXIOBASE3 for consistency, although future work will explore its combination with other data sources to improve geographical coverage. The approach adopted here captured the transmission of local ecosystem shocks to broader country-level economic and financial risks.

To assess bank portfolios at risk, country-specific sectoral economy exposures were replaced with country-level banking exposures to different sectors. In practice, this meant calculating the volume of loans in each country that were extended to firms operating in specific sectors. While this approach did not provide a highly granular measure of financial risk exposure, it gave a first-order estimate of potential financial-risk hotspots. Crucially, it moved beyond the dependency-based analysis in Boldrini et al. (2023) by directly linking ecosystem-service risks to bank loan portfolios, highlighting where nature-related shocks could translate into credit risks for the financial system. The integration into the current study of financial data from AnaCredit constituted a substantial advance as compared with the methodologies developed in Ranger et al. (2023 and 2024). An analysis was made at sectoral level of the loan portfolios of 2,500 euro area banks that lent to non-financial corporations, those loans having amounted to €4.4 trillion.

2.1.4 Vulnerability (VS)

Vulnerability reflects the probable maximum loss, sensitivity and adaptive capacity of sectors and production systems to ecosystem-service shocks, measured across five interlinked macrosystems, with the indicator selection being specific to the ecosystem service and based on the academic literature on this matter.

- Socio-economic (e.g. health, inequality, adaptive institutions), measured through indicators such as population, access to drinking water, healthcare access and governance indices (e.g. the European Space Agency (ESA) Copernicus indicators, the World Health Organization Global Health Observatory indicators; the World Bank Governance indicators) specific to the service concerned.
- Food (e.g. agricultural productivity, food access and security), captured through datasets on crop yields, the prevalence of undernourishment and market access (e.g. the global statistical

[2] More information on EXIOBASE3 can be found on the EXIOBASE website.

database of the Food and Agriculture Organization of the United Nations (FAO FAOSTAT) and the Global Food Security Index).

- Ecological (e.g. biodiversity and the resilience of natural systems), informed by indicators such as species richness and protected area coverage, as well as ecosystem resilience indices (e.g. the International Union for Conservation of Nature Red List; Global Biodiversity Information Facility data and the Spatial Life Cycle Assessment Methodologies).
- Energy Production (e.g. hydropower dependency and bioenergy inputs), based on hydropower capacity, national energy balance sheets and renewable energy dependency (e.g. the International Energy Agency World Energy Statistics and US Energy Information Administration International Energy Data).
- Economic (e.g. infrastructure, services and physical assets), assessed through metrics such as building volume and critical infrastructure (e.g. ESA Copernicus indicators and Critical Infrastructure Spatial Index (Nirandjan et al., 2022)).

Indicators within each macrosystem were first aggregated, and the macrosystem scores were then combined to capture cross-cutting vulnerabilities specific to the ecosystem service. Macrosystem and cross-cutting vulnerabilities were integrated with the probable maximum loss, calculated from the Exploring Natural Capital Opportunities, Risks and Exposures (ENCORE) knowledge base (ENCORE, 2024), which provides dependency materiality ratings for each sector and each ecosystem service. This multidimensional approach ensured that vulnerability reflected sectoral dependency, structural weaknesses and adaptive capacities, generating a vulnerability score that was both country and sector-specific and was propagated through supply chains.

2.1.5 Calibration

In addition, the $NVaR_{s,e,c}$ was calibrated against a loss probability distribution based on 30 years of historical sector-output variability (1992-2022, World Bank World Development Indicators database). This distribution set an upper bound on the maximum NVaR in line with observed historical volatility. While this assumption was conservative, given that future risks may exceed historical experience, it provided a consistent baseline across countries and sectors. However, it also limited the suitability of the approach for long-term risk analysis because it does not capture the possibility of catastrophic output losses that go well beyond historical experience. The NVaR estimates were calculated at the 99th percentile, corresponding to a 1-in-100-year event (1% annual probability), unless otherwise stated.

2.1.6 Enhancements

Different approaches exist for the formulation of value-at-risk (VaR metrics in response to environmental change. These approaches vary depending on the environmental domain under consideration, such as nature (Ranger et al., 2023 and 2024; Jwaideh et al., forthcoming), climate (Mandel et al., 2025), or biodiversity (Posth et al., 2024), as well as on their intended purpose and on data availability. In this study, enhancements to the baseline methodology developed in Ranger et al. (2023 and 2024) were made for selected ecosystem services to ensure improved spatial resolution and reflect the availability of return-period data. This paper presents the results of enhancing that baseline methodology and applying that new framework to water supply (groundwater and surface water) and quality ecosystem services.

The enhancements introduced (as developed in Jwaideh et al., forthcoming) included the following.

- Increasing data granularity by advancing the NVaR framework from a country-level model to a five-arcminute resolution grid (approximately 9 km × 9 km at the equator).
- Integrating probabilistic physical hazard threat datasets that embedded return periods explicitly, ensuring improved representation of statistical properties.
- Refining aggregation techniques to account for the higher-resolution data and improved datasets, ensuring that scores meaningfully captured local detail while still aggregating to reflect the financial visibility of credit and loan data at the national scale.

These enhancements improved granularity, accuracy and suitability for sectoral and asset-level applications of the methodology.

2.2 Results

2.2.1 Macroeconomic and macrofinancial impacts

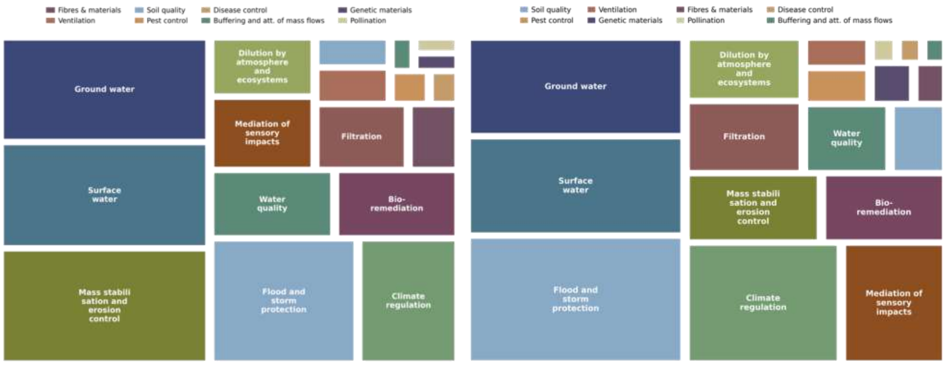
The ecosystem services on which the euro area economy has the highest dependencies differ, in some cases, from the ecosystem services creating the highest risk for economic output (Chart 1). Water-related services, such as surface water and groundwater provision and flood protection, consistently ranked at the top for both dependency and NVaR, underscoring the critical consequences of their degradation for ecosystems and dependent sectors. Differences arose, however, for other services. For instance, while the dependency analysis identified mass stabilisation and erosion control as a key dependency for the euro area economy, the level of associated risk attributed to these factors in the NVaR assessment was substantially lower (similar results were found for the UK economy in Ranger et al., 2024). Although dependency was high, given that all buildings and infrastructures depend on stable ground, the probability of widespread destabilisation from soil erosion or landslides with significant financial impacts was relatively low. Even so, the risk remains material in mountainous and coastal areas, where such hazards are more frequent.

Chart 1

Dependency and nature value-at-risk across ecosystem services by share of euro area economic output

a) Euro area ecosystem services dependency **b) Euro area nature value-at-risk**

(percentage shares)



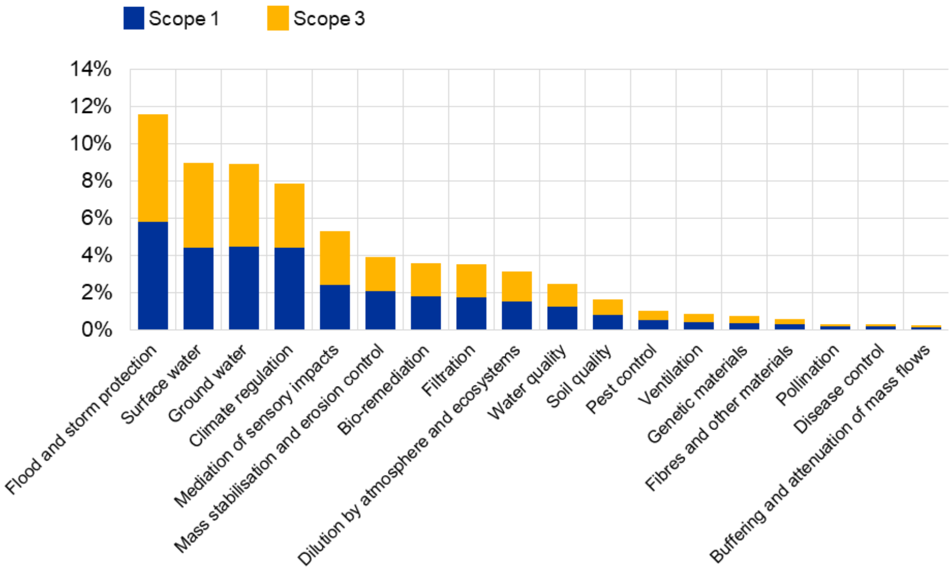
Sources: NVaR Systemic Risk data layers (Ranger et al., 2024), EXIOBASE3 input–output data, and the ENCORE (Exploring Natural Capital Opportunities, Risks and Exposures) knowledge base.
Notes: Panel a) shows the dependency of the euro area economy on 18 ecosystem services. Panel b) shows the nature value-at-risk (NVaR) for the 18 ecosystem services concerned, representing the material importance of these services for the EU economy and capturing the risks arising from their degraded condition. The NVaR was calculated using the baseline systemic risk methodology developed in Ranger et al. (2024). The ecosystem-service shock was parameterised using a 1-in-100-year (100-year return period) event. The 18 ecosystem services shown are those used in the ENCORE knowledge base.

The analysis suggests that the most significant risks come from water-related ecosystem services, with nearly 12% of economic output at risk due to degraded flood protection (Chart 2). Floodplains cover about 7% of Europe's land area and up to 30% of terrestrial Natura 2000 sites, but 70-90% of those plains have been environmentally degraded over the past two centuries owing to river engineering, intensive land use and urbanisation (EEA, 2019). Flood mitigation and protection apart, healthy floodplains provide critical ecosystem services such as carbon sequestration, water purification, biodiversity and recreation. Yet only 17% of floodplain habitats in the EU are in a good state of conservation (EEA, 2019). This also leads to direct financial implications: more than 60% of bank loans are granted to companies located in areas where ecosystems fail to meet more than half of flood protection demand, leaving asset values increasingly exposed to flood risk, particularly in central and southern Europe (Ceglar et al., 2025).

Chart 2

Economy-wide nature value-at-risk (Scope 1 and Scope 3 risks) by ecosystem service – share of euro area economic output at risk

(percentage shares)



Sources: NVaR Systemic Risk data layers (Ranger et al., 2024), EXIOBASE3 input–output data, and the ENCORE (Exploring Natural Capital Opportunities, Risks and Exposures) knowledge base.
Notes: Nature value-at-risk (NVaR) for the 18 ecosystem services concerned, representing the material importance of these services for the euro area economy and capturing the risks arising from their degraded condition. The NVaR was calculated using the baseline systemic risk methodology developed in Ranger et al. (2024). The ecosystem-service shock was parameterised using a 1-in-100-year (100-year return period) event. The 18 ecosystem services shown are those used in the ENCORE knowledge base.

Surface water and groundwater scarcity, combined with regionally declining water quality, emerged as highly material risks and together represented the most significant nature-related threat to the euro area economy. Three dominant drivers were at play here: climate change, overexploitation and pollution. Since 2010, water abstraction has increased across nearly all sectors other than electricity cooling, underscoring the need to improve water-use efficiency (EEA, 2025b). Quantity apart, pollution and overall water use also have significant implications for pollutant concentrations. Water scarcity amplifies water-quality issues; droughts, in particular, intensify the effects of pollution by reducing dilution capacity, raising pollutant loads and stressing aquatic ecosystems. Likewise, where the quality of water is negatively affected by pollution and other factors, the quantity of water usable for human consumption, agriculture and industry is reduced.

Water scarcity persists in regional hotspots, with drought frequency and intensity having risen markedly over recent decades (Rossi et al., 2023). Projections suggest that these pressures will intensify; for example, droughts comparable to the extreme 2018 event could become the norm by the 2040s (Toreti et al., 2019). Southern Europe and densely populated regions are particularly at risk, given that climate change amplifies demand-driven pressures on limited water resources. As a result, both surface and groundwater availability and quality are increasingly threatened by the combined effects of over-abstraction, pollution and more frequent droughts. These broad risk patterns are consistent with the enhanced

NVaR results presented in Section 2.3, albeit the estimated risk magnitudes were higher in the latter.

Reduced climate regulation emerged as an important systemic risk, following closely after the water-related ecosystem services described above. Climate regulation refers to the role of ecosystems in absorbing atmospheric carbon dioxide (CO_2) and in mitigating local climate extremes, such as heatwaves. In Europe, forests are the cornerstone of this function, but they are increasingly vulnerable to climate change, land-use pressures and pollution. Droughts, insect outbreaks, wildfires and ageing forest stands are driving higher mortality and lower growth rates, with one-third of forests already showing declining vitality (Maes et al., 2023; Forzieri et al., 2021). As a result, the EU's land sector (land use, land-use change and forestry or LULUCF) carbon sink has weakened sharply. It declined by about 30% between 2014 and 2023, with some regions even shifting from net sinks to net sources of emissions (EEA, 2024d). This erosion of the carbon sink undermines the EU's capacity to meet its climate targets and exposes the economy to greater transition and physical risks.

The degradation of ecosystem services such as bioremediation, filtration, mediation of sensory impacts and atmospheric dilution undermines the environment's capacity to absorb pollution, regulate air and water quality, and safeguard human health. As these regulatory ecosystem functions weaken, economic activities that rely on clean water, clean air and healthy living conditions face growing vulnerabilities. This not only threatens sectors directly dependent on these services, such as agriculture, manufacturing, utilities and labour, but also creates knock-on risks for supply chains and productivity. As a result, a significant share of the euro area economy is increasingly exposed to these risks.

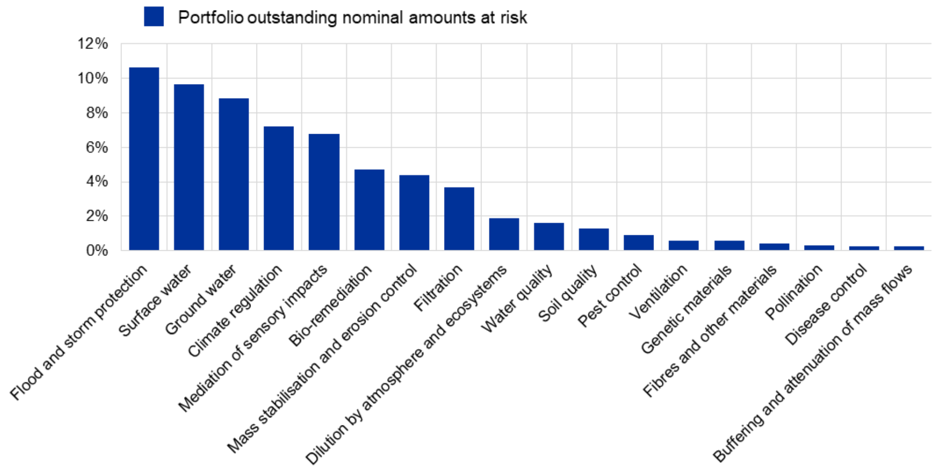
Importantly, around half of the risks stem from international supply chains (Scope 3) and consequently originate from outside the euro area (Chart 2). This underscores the vulnerability of the euro area economy to ecosystem degradation occurring overseas, given the EU's strong integration into global trade and supply networks. The EU's reliance on imported raw materials and foreign goods and services means that environmental degradation in supplier countries directly translates into risks for the euro area, whether through disrupted supply chains, increased costs or diminished availability of critical resources. Global harvest shocks currently account for around 30% of medium-term inflation volatility in the euro area (Peersman, 2022). Moreover, 80% of the world's arable land is under strain from soil erosion, salinisation and loss of biodiversity, which is critical for pollination and pest control. These pressures are projected to reduce global food productivity by 12% and drive food prices up by as much as 30% by 2040 (Wegner et al., 2025; UNEP, 2021; Kopittke et al., 2019).

The degradation of ecosystem services also poses material risks to financial stability. The analysis conducted for this report indicated that more than 10% of euro area bank loans are at risk from degraded flood protection alone (**Chart 3**), reflecting a high concentration of lending to firms located in areas where ecosystems cannot provide adequate protection. In particular, regions where ecosystems fail to deliver more than half of the required flood protection (leaving asset values highly vulnerable) are concentrated in central and southern Europe (Ceglar et al., 2025). The analysis showed that significant additional exposures arise from surface water and groundwater scarcity, putting around 10% and 9% of loans at risk respectively. Over 40% of bank loan portfolios were linked to companies highly exposed to drought and strongly dependent on surface-water provision, with more than three-quarters of these exposures concentrated in southern and western Europe (Ceglar et al., 2025). These vulnerabilities reflect broader macroeconomic risks, given that water stress and flood damage are already materialising across the Continent. Water-related services apart, climate regulation, bioremediation and the mediation of sensory impacts also emerged as critical channels through which loan portfolios are increasingly exposed. Taken together, these results suggest that banks' credit risk is closely tied to the condition of ecosystems and that continued degradation, if left unaddressed, could increasingly affect both portfolio resilience and financial stability.

Chart 3

Nature value-at-risk of euro area bank loan portfolios by ecosystem service – outstanding nominal amounts at risk

(percentages)



Sources: NVaR Systemic Risk data layers (Ranger et al., 2024), AnaCredit data, EXIOBASE3 input–output data, and the ENCORE (Exploring Natural Capital Opportunities, Risks and Exposures) knowledge base.
Notes: Nature value-at-risk (NVaR) for the 18 ecosystem services concerned, representing the material importance of these services for euro area banks. The NVaR was calculated using the baseline systemic risk methodology developed in Ranger et al. (2024). The ecosystem-service shock was parameterised using a 1-in-100-year (100-year return period) event. The 18 ecosystem services shown are those used in the ENCORE knowledge base.

2.3 Deep dive into water-scarcity and quality-related risks

The results set out above highlight the fact that water-related ecosystem services, including water surplus (flood and storm protection), scarcity and quality, are among the most material for the euro area economy and banking system (see Appendix 1 for more detailed description of these ecosystem services). We therefore undertook a focused deep dive into water scarcity and quality. In the baseline analysis, hazard indicators were defined at the ecosystem-service and country levels, providing a macroeconomic and macrofinancial perspective. However, this level of aggregation was seen as insufficient for realistically capturing nature-related risks, given the inherently local nature of water ecosystems and their strong spatial influence on economic activities. Capturing high-resolution hazard, vulnerability and exposure data is particularly important for water-related hazards owing to the highly spatially heterogenous nature of the risks. To address this limitation, the NVaR framework was refined by incorporating more granular socio-economic and biophysical data on water scarcity and quality (Jwaideh et al., forthcoming). This approach made it possible to capture regional heterogeneity, identify risk hotspots and provide a more accurate assessment of how water-related risks could propagate into the real economy and the financial system. While this enhanced analysis advances risk modelling only for the most material ecosystem services, similar high-resolution data and refined methodologies could be applied in the future to additional ecosystem services, such as flood protection and pollination.

The fact that water-related risks are already materialising in the EU, owing to widespread water scarcity, recurrent flood events and deteriorating water quality further underscores the need for a dedicated deep dive and methodological refinements of the NVaR framework. Any stress on water resources can trigger cascading effects across multiple sectors of the economy. For instance, dry soils lower agricultural yields, water scarcity disrupts manufacturing processes and raises operational costs, and reduced river flows limit hydropower generation and hinder inland shipping. In 2022, roughly 34% of Europe's land and 41% of its population experienced water scarcity (with southern regions facing shortages for up to 70% of the summer months). Fewer than 30% of surface waters had "good" chemical status[3] and fewer than 37% had good ecological status[4] (EEA, 2024b). Between 1980 and 2023, climate-related extremes resulted in asset losses in the EU amounting to approximately €738 billion, with floods accounting for the largest share (44%).[5]

These physical shocks manifest as financial risk through interconnected channels. Droughts threaten credit risk in sectors such as agriculture, energy and tourism, putting major loan portfolios at risk (OECD, 2025a). The 2022 pan-European drought, described by the European Drought Observatory as the worst in 500 years, simultaneously disrupted hydropower generation, nuclear plant cooling and crop yields across several Member States (Toreti et al., 2022). Per-and poly-fluoroalkyl substances (PFASs) and other persistent contaminants are increasingly present in EU waters, generating annual health costs estimated at €52-84 billion.[6] In the EU the cost of remediating legacy PFAS contamination and addressing ongoing emissions could rise to €2 trillion over the next 20 years (Horel and Aubert, 2025). Flood losses have averaged €7.8 billion per year between 1980 and 2023 and

3 Concentration of specific priority substances and pollutants (e.g. heavy metals, pesticides and industrial chemicals).

4 The overall quality of the structure and functioning of aquatic ecosystems.

5 See the article entitled "Economic losses from weather and climate related extremes in Europe", published on the European Environment Agency website on 14 October 2025.

6 See the article entitled "PFAS pollution: a growing public health and environment concern.", published on the Safe Food Advocacy Europe website on 5 June 2025.

peaked at €48.2 billion in 2021.[7] The European Commission estimates that about €55 billion is invested in building water resilience each year, but identifies an additional €23 billion a year investment gap.[8]

Risk mapping has become an indispensable tool for visualising and anticipating water-related risks across the EU. Early efforts, such as the European Environment Agency's Water Exploitation Index Plus (WEI+) atlas, provided basin-level insights into freshwater withdrawals by mapping them against availability, flagging hotspots of chronic stress.[9] The Joint Research Centre's drought risk maps further overlaid hazard and exposure metrics to highlight regions where water scarcity could intersect with critical infrastructure and agricultural lands. Likewise, the World Resources Institute's Aqueduct Water Risk Atlas combined indicators of stress, flood and drought to rank river basins by overall water-risk scores (Hofste et al., 2019).

These initiatives have significantly advanced awareness-raising and risk mapping, while also revealing opportunities for further methodological enhancement. High spatial granularity beyond the river-basin level is essential to capture sub-basin variability, supporting more locally relevant decision-making. Broadening the scope of indicators to systematically integrate water quality, socio-economic dimensions, governance capacity and ecological vulnerability would provide a more holistic view of the risks. Additionally, greater methodological alignment across providers, such as harmonised thresholds for "high risk" and more consistent weighting schemes, would enhance comparability and strengthen confidence in cross-national analyses. The enhanced NVaR framework used for this paper sought to address these challenges and represents a step towards a more systemic assessment of nature-related risks.

2.3.1 Enhanced nature value-at-risk framework – water scarcity and quality

The enhanced NVaR framework is sensitive to both the granularity of input data and the methodological choices applied, which can significantly affect estimates of sectoral exposure and vulnerability to ecosystem-related risks, such as water scarcity. A 5-arcmin working resolution (approximately 9 km by 9 km at the equator) was used for the datasets to characterise the hazard dimension for the enhanced NVaR. The datasets were aggregated or disaggregated to this resolution for standardisation purposes and based on computational demand and meaningfulness across the varying resolutions of the input datasets. The datasets considered for surface-water provision included sectoral water consumption, environmental drought indicators and terrestrial water storage (**Appendix 2**).

7 See the article entitled "Floods in Europe", published on the European Environmental Agency website.

8 See the article entitled "Questions and answers on Water Resilience Strategy", published on the European Commission website on 4 June 2025.

9 See the article entitled "Water Exploitation Index plus for river basin districts (1990-2015)", published on the European Environmental Agency website on 10 October 2019.

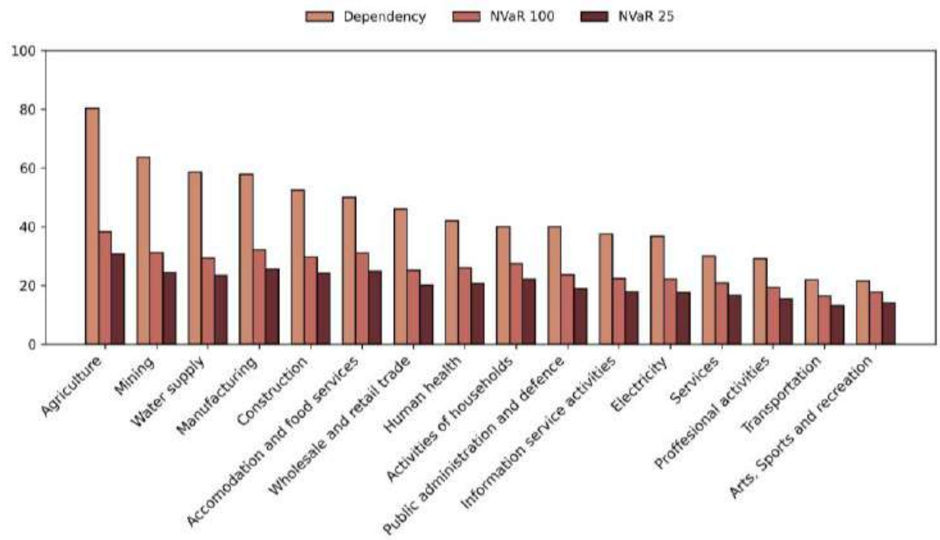
Higher-resolution inputs and methodological enhancements consistently yield larger risk estimates than the country-level aggregates typically used in macro assessments. Compared with the baseline, the economy-wide NVaR for surface-water provision under a drought event with a 100-year return period increased from about 9% to 24% when granular ecosystem-service and activity-location data were applied. A similar pattern was observed for groundwater provision: groundwater scarcity could expose up to 30% of euro area economic output to risk under a 100-year drought scenario, while degraded water quality could affect up to 19%. These findings underscore the importance of conducting sector-specific and location-based analyses and of using high-spatial-resolution datasets to avoid underestimating the risks associated with the loss of ecosystem services.

Using more granular data for sectoral activities ensures more detailed and accurate NVaR estimates at the sector level. Chart 4 shows the distribution of NVaR for surface-water provision across sectors relative to their total economic output in the euro area. Agriculture was the most exposed sector, with potential output losses of up to 30% under a drought event with a 25-year return period and up to 38% under a 100-year drought event. Other sectors, including manufacturing, mining, water supply, construction, publishing, and accommodation and food services, also faced substantial impacts, with more than 20% of their output already at risk under a 25-year drought scenario. The values calculated for the 100-year return period should, however, be interpreted with caution, given that there are considerable uncertainties in characterising droughts that happen less frequently, including those related to the non-stationarity of the climate system, and owing to the limitations of the underlying datasets. Recent observations confirm that the share of global land affected by drought has increased markedly over recent decades, roughly doubling between 1900 and 2020 (OECD, 2025b). In addition, actual water availability for economic activities could be further constrained by regulatory restrictions, an issue not captured in the current analysis. It is likely, therefore, that the NVaR values for the 100-year return period underestimated the risk.

Chart 4

Sectoral distribution of nature value-at-risk for a surface-water provision shock – relative sectoral output losses as a share of euro area sectoral economic output

(percentage shares)



Sources: Enhanced NVaR Systemic Risk data layers, EXIOBASE3 input–output data, and the ENCORE (Exploring Natural Capital Opportunities, Risks and Exposures) knowledge base.
Notes: The nature value-at-risk (NVaR) was calculated using the enhanced NVaR systemic risk framework developed in Jwaideh et al. (forthcoming). The ecosystem-service shock was parameterised using a 1-in-25-year (25-year return period or NVaR 25) and 1-in-100-year (100-year return period or NVaR 100) drought events. Dependency represents the share of sectoral economic output dependent on water supply and is based on ENCORE materiality scores.

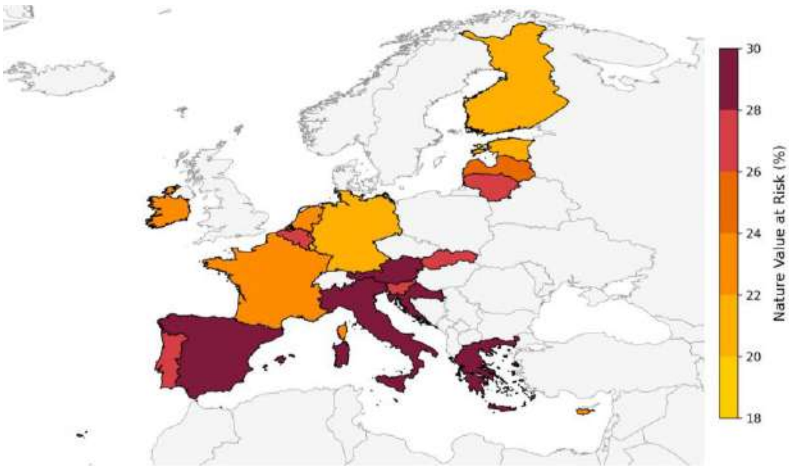
Building on the analysis of relative output losses first conducted, the sectoral impacts in absolute monetary terms were examined to show which parts of the economy present the largest value-at-risk. The results indicated that manufacturing represents the largest share of value-at-risk from water scarcity, followed by wholesale and retail trade, construction and transportation. This is important confirmation of the fact that many water-intensive manufacturing subsectors, such as chemicals, food and beverage processing, and textiles, are highly dependent on reliable water supply and quality (OECD, 2025a). Construction and transportation followed manufacturing in terms of the share of economic output at risk, reflecting their sensitivity to water availability. At the aggregate level, the relative contribution of agriculture to NVaR was smaller, not because the sector is less dependent on water, but because its share in total euro area economic output is comparatively limited. Together, these results underline the cross-sectoral nature of water-related risks and the need for supervisors, regulatory bodies and policymakers to look beyond agriculture when assessing systemic vulnerabilities.

Chart 5 presents the share of national economic output at risk from surface-water scarcity for each euro area country. While southern Europe faced the most severe water-scarcity pressures, the analysis indicated that central and northern European countries were also increasingly exposed. Drought frequency and intensity have risen markedly across the Continent over the past few decades, with a clear shift towards more widespread and prolonged events (Rossi et al., 2023). Historically, dry regions, such as the Iberian Peninsula and southern Italy, continue to experience chronic water stress, but recent drought episodes have also severely affected countries traditionally considered to be water-abundant, including Germany, France, and the Benelux region. The summer droughts of 2018, 2022 and 2023, which were among the most intense of the past few centuries, illustrated that extreme water deficits are no longer confined to southern Europe (Toreti et al., 2019). This trend reflects broader climatic shifts, higher average temperatures, altered precipitation patterns and declining soil moisture, which are expected to increase drought risk further, even under moderate global-warming scenarios. Consequently, drought has become a pan-European phenomenon, posing systemic risks to sectoral production, energy generation, transport and agricultural output across the entire euro area.

Chart 5

Share of national gross economic output at risk from surface-water scarcity by euro area country

(percentage shares)



Sources: Enhanced NVaR Systemic Risk data layers, EXIOBASE3 input–output data, and the ENCORE (Exploring Natural Capital Opportunities, Risks and Exposures) knowledge base.
Notes: This chart shows the impact of surface-water scarcity in the euro area and reflects the global spread of that impact through supply chains. The nature value-at-risk (NVaR) was calculated using the enhanced NVaR systemic risk framework developed in Jwaideh et al. (forthcoming). The ecosystem-service shock was parameterised using a 1-in-100-year (100-year return period) drought event.

The analysis showed that share of sectoral economic output at risk from groundwater scarcity broadly reflects that of surface-water scarcity, albeit with notable regional differences. Regions characterised by intensive industrial and agricultural water abstraction, including Belgium, Estonia, northern France, northern Germany, large parts of northern Italy and southern Spain, exhibited heightened economic vulnerability linked to poor groundwater status (EEA, 2023). Belgium stood out as particularly at risk, with a significant proportion of its deep aquifers classified as overexploited. Recent drought events have led to considerable disruptions in agriculture and inland navigation, exacerbating existing pressures on water availability. In parallel, extreme weather episodes have further degraded water ecosystems and water-dependent terrestrial habitats, such as wetlands, which play a critical role in climate change adaptation and ecosystem resilience.[10]

Water quality is another important concern, given that the EU's freshwater ecosystems continue to be heavily impacted by chemical pollution. Clean freshwater, as a vital ecosystem service, underpins a wide range of economic and social activities. Many sectors depend on a stable supply of high-quality freshwater – for example, agriculture for irrigation, manufacturing and energy for process water and cooling, construction for material preparation, and healthcare and accommodation services for sanitation and hygiene. Contamination of rivers, lakes, and groundwater directly affects production efficiency, increases operational costs and can disrupt supply chains. At the euro area level, accommodation and food services, human health, agriculture, construction, manufacturing, mining, water supply and electricity were identified as the sectors currently most at risk due to water-quality issues (**Chart 6**).

Recent evidence shows the scale of risks linked to declining water quality. For instance, deterioration in actual or perceived water quality has already led to a sharp decline in recreational visits to affected areas, resulting in economic losses estimated at over €100 billion annually (Borger et al., 2021). Without further action, more than 100 million EU citizens could face long-term health risks from polluted drinking water by 2030, leading to higher healthcare expenditure and increased water treatment costs (EEA, 2024b). EU-wide monitoring also confirms widespread exceedances of PFASs in surface waters, underscoring emerging transition risks as water-quality standards become stricter. From January 2026, the EU Drinking Water Directive[11] will introduce a limit value of 0.1 microgram per litre (sum of specified PFASs) in drinking water (EEA, 2024c). These developments highlight the growing materiality of water-quality risks for the EU economy and the importance of integrating such considerations into financial and policy assessments.

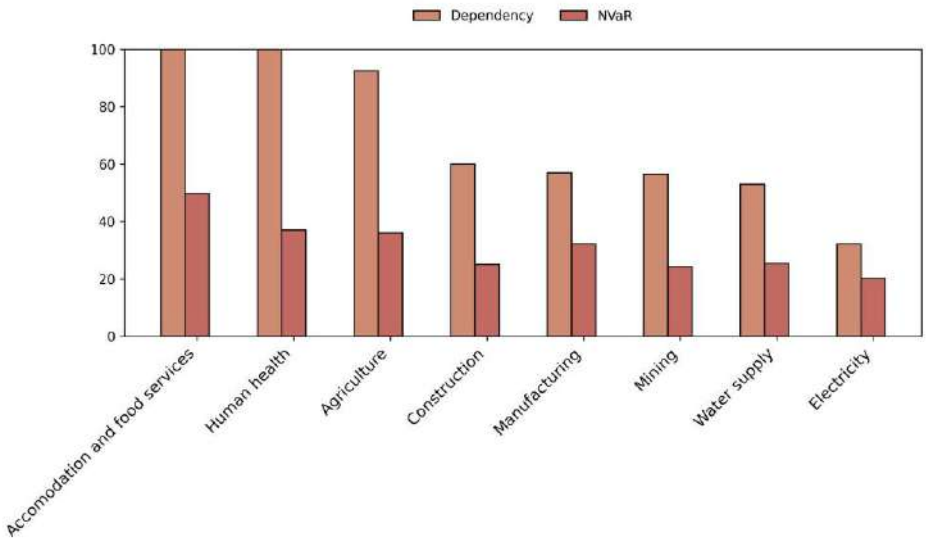
[10] See the article entitled "Biodiversity", published on the Climate-ADAPT website.

[11] Directive (EU) 2020/2184 of the European Parliament and of the Council of 16 December 2020 on the quality of water intended for human consumption (recast) (OJ L 435, 23.12.2020, p. 1).

Chart 6

Sectoral distribution of nature value-at-risk associated with the current status of freshwater quality as a share of euro area sectoral economic output

(percentage shares)



Sources: Enhanced NVaR Systemic Risk data layers, EXIOBASE3 input–output data, and the ENCORE (Exploring Natural Capital Opportunities, Risks and Exposures) knowledge base.
Notes: The nature value-at-risk (NVaR) was calculated using the enhanced NVaR systemic risk framework developed in Jwaideh et al. (forthcoming). Dependency represents the share of sectoral economic output dependent on the water purification ecosystem service and is based on ENCORE materiality scores. Water-quality shock was parameterised based on the current ecological and chemical status of freshwater bodies.

Using AnaCredit data for December 2022, which provided granular coverage of around €4.4 trillion in outstanding loans, the updated NVaR results were mapped to euro area banks' portfolios, aggregated at the sector-country level. More than 19% of loans across the analysed sectors were exposed to risks from surface-water scarcity under a drought scenario with a 100-year return period (**Chart 7**). When groundwater scarcity was taken into consideration, the share of loans at risk increased slightly to around 22%. However, because surface and groundwater systems are hydrologically interconnected, these two risk categories cannot be added together. The highest concentrations of loans at risk from water scarcity were observed in loans to real estate activities, manufacturing, wholesale and retail trade, mining, and construction. In comparison, around 12% of total loans were associated with risks from degraded water quality, with a somewhat different sectoral distribution. Manufacturing and mining sectors were the most exposed, reflecting their high reliance on clean process water. The difference in sectoral hierarchy of risks between the banking and real-economy perspectives largely reflected the composition of bank lending. In particular, the real estate sector appeared to be the most at risk. This was not because of strong ecosystem dependency but was due to the sector's significant weight in bank portfolios, accounting for about 26% of total AnaCredit exposures. This amplified its contribution to aggregate loan risk, despite its relatively lower dependence on water-provision ecosystem services.

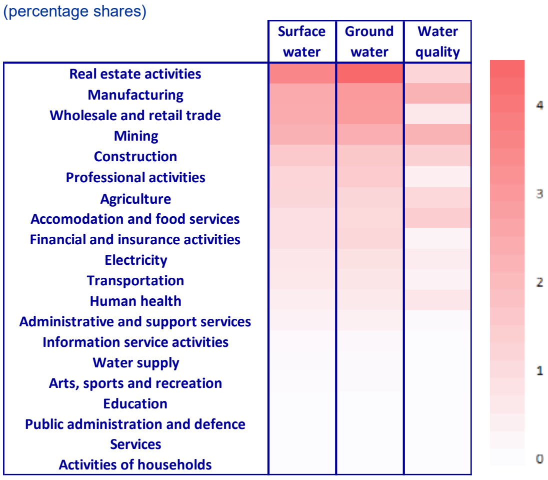
For banks, these concentrations of exposures suggest that increasing water scarcity and deteriorating water quality could become material sources of

credit risk, with the potential to amplify systemic vulnerabilities in the euro area financial system. Further research is needed to assess the full materiality of these risks for banks and develop a dedicated nature stress test that quantifies their impact on key credit-risk parameters, such as probability of default.

Chart 7

Share of sectoral bank loan outstanding nominal amounts at risk from water scarcity and water quality degradation in the euro area by borrower sector

(percentage shares)



Source: Enhanced NVaR Systemic Risk data layers, AnaCredit database, EXIOBASE3 input–output data, and the ENCORE (Exploring Natural Capital Opportunities, Risks and Exposures) knowledge base.
Notes: The share of sectoral loans reflects the proportion of total loans to each sector that are at risk due to the degraded status of the relevant ecosystem service. The ecosystem-service shock was parameterised as a 1-in-100-year drought event (100-year return period) for surface water and groundwater scarcity risks, while the water-quality shock was parameterised based on the current ecological and chemical status of freshwater bodies.

3 Endogenous risk – bank level exposures and impacts

Economic actors are not only exposed to nature-related physical and transition risks; through their negative impacts on ecosystems, they also contribute to (endogenous) risks (NGFS, 2024a). This relationship is often imbalanced: some activities put significant pressure on biodiversity and ecosystems. They may rely little on those same ecosystem services yet still increase physical risks across the whole system. The financial sector is not solely responsible, and its influence is indirect, but it enables real-economy activities and thus influences these risks. Moreover, impact-intensive activities are likely to face transition risks as policymakers, investors and consumers respond. By supporting conservation and restoration, lenders can, however, help lower system-wide physical risks.

Endogenous risk, often described as double materiality, captures the two-way link between finance and nature by showing how banks' lending and investment decisions create biophysical pressures that feed back into future financial risks. In simple terms, endogenous risk can perhaps best be understood through the idiom derived from one of Aesop's fables which warned against "killing the goose that laid the golden eggs". The fable highlights the risks of the short-sighted destruction of a valuable resource. In the case of banks, this would be akin to investing in activities that harm ecosystems. The concept extends materiality beyond exposure to ecosystem-service disruptions to include firms' and banks' own impacts on nature, adding an impact pathway that complements dependency-based assessments and can alter risk trajectories (Schoenmaker and Schramade, 2019; van Toor et al., 2020). Framed this way, financial institutions and regulators can gain a better understanding of how to reduce nature-related risks by lowering financed impacts. Evidence from biodiversity footprinting studies indicates that substantial proportions of bank loan and equity portfolios are tied to sectors driving land-use change and greenhouse gas emissions (Ceglar et al., 2025; WWF and AXA, 2019). This feedback loop highlights endogenous risk as a framework for capturing and understanding nature-related financial risks more accurately.

Financing firms that degrade critical ecosystem services increases banks' exposure to credit, market and operational risks. This chapter provides an aggregate measure of the overlap between euro area banks' own portfolio dependencies on ecosystem services and the impacts generated by their own lending activities. The analysis drew on the AnaCredit dataset, which offers highly granular credit information that links €4.4 trillion in outstanding loans to around 4.2 million companies across 2,500 reporting banks. For the purpose of calculation and given the computationally intensive process involved, a subset of AnaCredit banks was selected. The subset consisted of the top five banks per country-sector pair across five sectors: manufacturing, agriculture, real estate, electricity and construction. This amounted to a total 237 banks across the euro area, representing roughly half of the total AnaCredit outstanding loan amount. These banks accounted for the majority of the total habitat-loss impact across all AnaCredit banks (Ceglar et al., 2023).

3.1 Methodology

The core of the analysis was the measurement of endogenous risk, i.e. the overlap between nature degradation and dependency across a bank's lending portfolio, drawing upon the method from O'Donnell et al. (2025). The metric that was used for this section captured the share of loan value that both impacts and depends on the same ecosystem service. It highlighted the share of bank loan portfolios that faced increased risks from ecosystem-service degradation as a result of activities financed by those very portfolios **(Chart 8)**. The analysis looked at a subset of bank exposures to ecosystem-service shocks, focusing on risks stemming from ecosystem degradation caused by banks' own-financed activities and portfolios, rather than by exogenous factors.

The first step involved calculating impact and dependency scores for each ecosystem service for all sectors using ENCORE data. The ENCORE knowledge base (ENCORE, 2024) provided dependency and impact materiality ratings for each sector and each ecosystem service. Using these materiality ratings, an impact and dependency score was computed. This provided an estimate of the level of dependence or impact of sectors on specific ecosystem services.

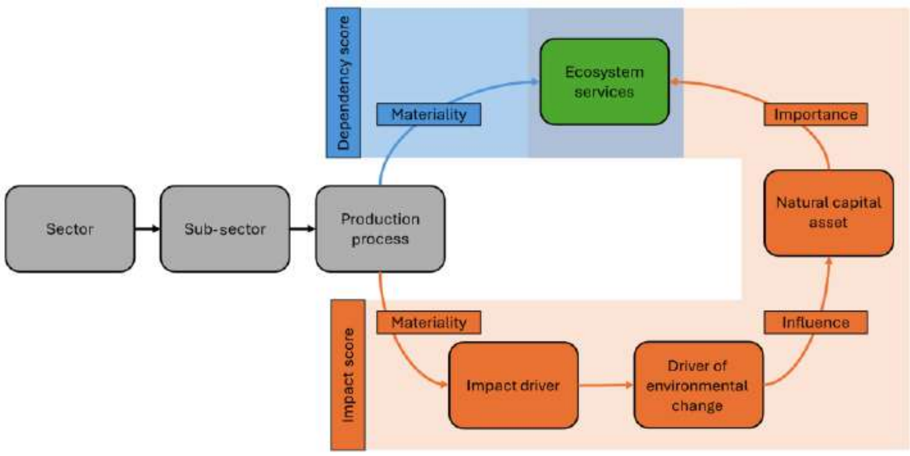
The second step quantified the overlap between the impact and dependency of bank portfolios on ecosystem services within specific regions. The impact and dependency scores were matched with the sector-country breakdown of bank loans derived from AnaCredit data, which links each loan to the economic sector and country of the borrower. It was then possible to map where bank portfolios were simultaneously dependent on and impacted the same ecosystem service within the same country (**Chart 8**). The resulting metric represented the share of loan portfolios forming part of banks' direct operations (Scope 1) that met those criteria. This made it possible to measure the extent to which banks, through their direct operations in terms of loans, increased their own nature-related financial risk exposure and provided an estimate of their Scope 1 endogenous risk.

The third step used EXIOBASE3 input-output data to investigate the extent to which bank portfolios drive their own nature-related financial risk exposure in the upstream supply chains of their investments. Applying the approach adopted in Svartzman et al. (2021), the share of upstream (Scope 3) supply-chain exposures that both depend on and impact a given ecosystem service were quantified by mapping AnaCredit loan data to sector-region input-output linkages and applying ecosystem-service dependency and impact weightings. The resulting metric estimated the proportion of the upstream supply chains of loans in bank portfolios that impacted the ecosystem services they depended on, referred to as Scope 3 endogenous risk.

The Scope 1 and Scope 3 metrics provided distinct and complementary insights, capturing different dimensions of how bank lending portfolios contribute to endogenous risk. Scope 1 values estimated how a company's own actions and business model directly affected the ecosystem services it depended on. This highlighted how a company's own operations might be increasing its own risk. Scope 2, purchased energy dependency, related to indirect risk and was internalised through Scope 3 (supply chain) and sector-to-sector linkages. Scope 3 values estimated how the upstream supply chain, a company's suppliers, affected the ecosystem services that those suppliers relied on. This last metric highlighted how risks in the supply chain can translate into risks for the company itself. The higher Scope 1 values that were observed may reflect the fact that direct operations usually affect ecosystems in just one specific country; consequently, the damage is more likely to overlap with the same ecosystems on which the company directly depends, resulting in increased endogenous risk. By contrast, supply-chain impacts are spread across many countries, which lowers the chance of increased endogenous risk.

Chart 8

Methodological steps taken in conducting an endogenous-risk assessment for a subset of euro area banks

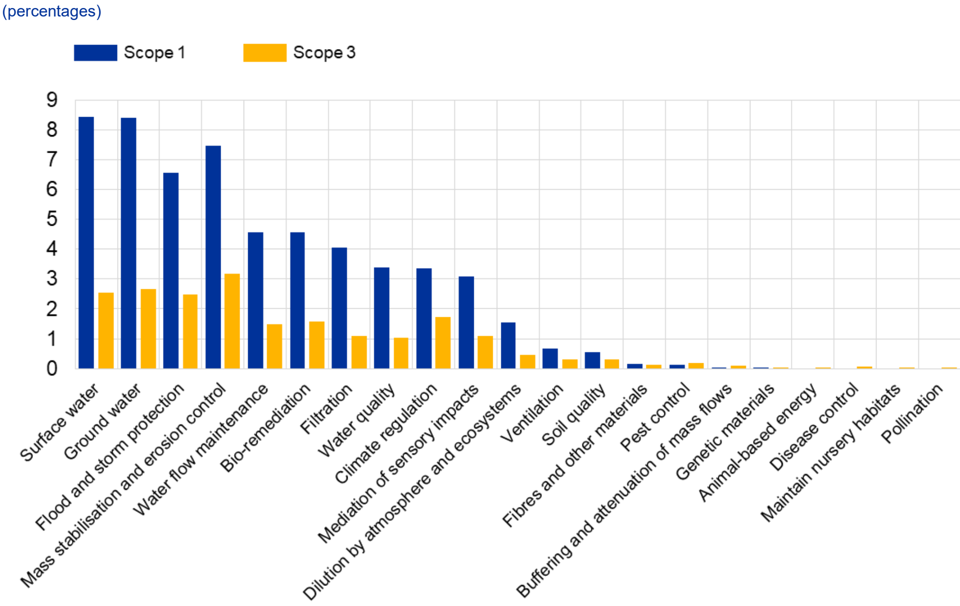


3.2 Results

Euro area banks endogenously contribute to a share of their nature-related financial risk through their lending activities. Chart 9 shows endogenous risk by ecosystem service, and water risks stand out as the key component. Approximately 8% of aggregate loan value was exposed to surface-water dependency risk in counterparties' direct operations, and this exposure was further amplified by the activities financed by those portfolios. Both surface water and groundwater-related risks arose primarily from over-abstraction and pollution, both of which reduce access to the clean water needed for production. Consistent with prior ENCORE-based studies, Scope 1 exposures exceeded Scope 3 exposures (Ranger et al., 2024; Boffo et al., 2024; Boldrini et al., 2023; Calice et al., 2021 and 2023; Ceglar et al., 2023; Hadji-Lazaro et al., 2024; Svartzman et al., 2021; van Toor et al., 2020).

Chart 9

Endogenous-risk exposure of euro area banks from their own direct operations and from supply chains



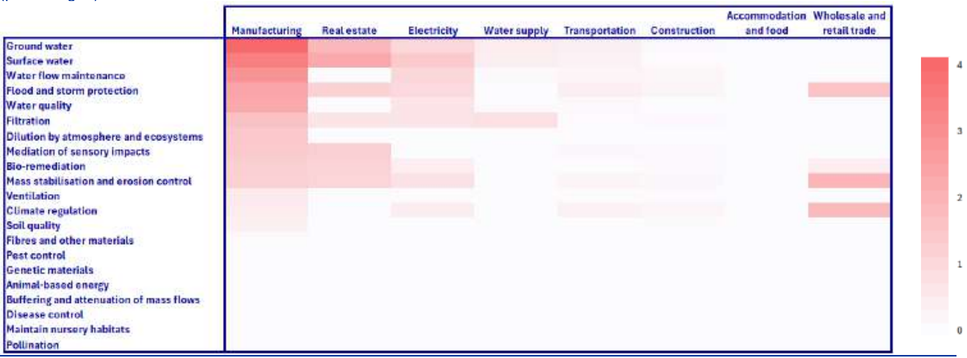
Source: Endogenous-risk score data layers, AnaCredit database, EXIOBASE3 input–output data, and the ENCORE (Exploring Natural Capital Opportunities, Risks and Exposures) knowledge base.
Notes: Scope 1 (direct operations) relates to exposures linked to corporate assets and loan portfolios that rely directly on local ecosystem services, while Scope 3 (supply chains) captures indirect monetary flows through global value chains. The endogenous-risk score was based on the framework developed in O'Donnell et al. (2025).The endogenous-risk exposure metric measured the share of loan value where both a borrower's dependence on a given ecosystem service and the degradation of that same service financed by the portfolio coincide. The ecosystem services shown are those used in the ENCORE knowledge base.

Across Scope 1 and upstream Scope 3, manufacturing accounted for the largest share of endogenous risk exposure (Charts 10 and 11). Within Scope 1, manufacturing was followed by real estate, electricity, water supply and transportation, which showed more moderate exposures. Wholesale and retail trade displayed lower direct exposure but notable endogenous risk contributions for flood and storm protection, climate regulation, mass stabilisation and erosion control. The strongest transmission channels were water related: manufacturers were simultaneously highly dependent (process water, cooling and cleaning) and high impact (large abstractions, thermal discharges, and nutrient and chemical effluents), degrading the very resources on which production relies. Water-flow maintenance, water quality and filtration thus emerged as systemically important services from an endogenous-risk perspective (see Appendix 1 for definitions of the ecosystem services concerned).

Chart 10

Endogenous-risk exposure from the direct operations by sector for selected euro area bank portfolios

(percentages)



Source: Endogenous-risk score data layers, AnaCredit database, EXIOBASE3 input–output data, and the ENCORE (Exploring Natural Capital Opportunities, Risks and Exposures) knowledge base.
Note: The endogenous-risk score was based on the framework developed in O'Donnell et al. (2025).

Looking at the upstream supply chains for the economic sectors, the value chains for manufacturing and for wholesale and retail trade had the highest endogenous-risk exposure (Chart 11). The suppliers to manufacturing and to wholesale and retail trade companies are impacting the same ecosystem services that other suppliers within the supply chain depend on, posing risks to manufacturers and to wholesale and retail traders. In both cases, the two dominant underlying mechanisms are: (i) the geographic concentration of suppliers in specific countries in which impacts and dependencies strongly overlap; and (ii) high-impact upstream activities (e.g. raw material extraction, primary agriculture and bulk chemicals) that cause significant degradation in regions supporting other supply-chain nodes.

Upstream supply-chain results showed greater cross-sector dispersion than those for direct operations. In Scope 1, manufacturing clearly had the highest endogenous-risk exposure. In Scope 3, by contrast, a broader set of sectors showed moderate endogenous-risk exposure, indicating that cross-cutting upstream nodes, notably energy and manufacturing, drive much of the ecosystem-service impact that overlaps with dependencies across portfolios. For example, manufacturing constitutes a substantial upstream input to wholesale and retail trade, propagating water-related and other ecosystem-service pressures along the chain.

Chart 11

Upstream supply-chain endogenous-risk exposure by sector for selected euro area bank portfolios

(percentages)

Source: Endogenous-risk score data layers, AnaCredit database, EXIOBASE3 input–output data, and the ENCORE (Exploring Natural Capital Opportunities, Risks and Exposures) knowledge base.
Note: The endogenous-risk score was based on the framework developed in O'Donnell et al. (2025).

Taken together, these results revealed that euro area banks' lending activities create material feedback loops between ecosystem-service degradation and portfolio risk, with water-related services emerging as the dominant transmission channel. The concentration of endogenous risk in manufacturing, and its propagation through upstream supply chains, underscores the systemic importance of a few highly resource-intensive sectors and geographies. This concentration creates both a risk hotspot and a potential leverage point: targeted mitigation efforts, such as financing water-efficiency measures, pollution reduction and sustainable sourcing in manufacturing and primary production, could substantially reduce banks' future exposure. Such findings highlight the value of combining dependency and impact data to identify where interventions could most effectively lower systemic risk and strengthen the resilience of both the financial system and the real economy.

4 Limitations of the study and need for further research

While providing insights into economic and financial risks stemming from the degradation of ecosystem services, the NVaR risk framework is highly sensitive to both the granularity of input data and the methodological choices made in assessing vulnerability, hazard, and exposure. The current analysis shows that the level of detail in nature-related data and the modelling approach can significantly affect risk estimates. This underlines the importance of improving both granular data availability and methodological rigour when applying NVaR for macrofinancial and, more especially, microprudential risk assessment. Going forward, transparent and well documented assumptions, harmonised protocols and systematic uncertainty analysis should be core to methodological development and operationalisation in risk frameworks.

The updated ENCORE dependency indicators capture the overall exposure of economic activities to water scarcity, but do not represent firm-specific water use or distinguish between groundwater and surface-water use. While this distinction is relatively clear for some sectors, such as agriculture and energy production, it is more difficult to establish for others, including manufacturing, where water use often depends on complex supply chains and mixed sources. This uncertainty should be taken into consideration in interpreting sectoral risk estimates, given that the type of water dependency can substantially affect the magnitude and timing of potential impacts. More granular company-level disclosures on water consumption and sourcing would therefore be valuable to improve the quality and accuracy of such analyses.

The enhanced NVaR framework (Jwaideh et al., forthcoming) developed for the current analysis serves as an agile, globally consistent risk-assessment tool for identifying portfolio-level and macroeconomic and macrofinancial vulnerabilities and risk arising from specific ecosystem degradation. It represents an advance on existing dependency analysis and high-level risk-screening tools and is the first to provide quantitative estimates of risks at the portfolio level. The enhanced NVaR captured first-order direct and indirect (supply chain) risks only. It did not, for example, incorporate second-round effects on prices, nor did it capture how risks to one ecosystem might impact others. Future research should therefore advance towards an integrated NVaR framework that captures the combined effects of multiple interdependent ecosystem services (such as water scarcity, flood protection and water quality), together with their sectoral and cross-border spillovers. Such a framework would enable regulators, banks and insurers to better quantify tail-risk exposures. Key methodological improvements might include: (i) accounting for non-linear interactions between hazards, exposures and vulnerabilities; (ii) expanding the coverage of the enhanced methodology to a wider set of ecosystem services (e.g. carbon sequestration, soil formation and flood protection); (iii) integrating dynamic feedback loops to reflect temporal lags between ecosystem shocks and financial responses; and (iv) enhancing spatial resolution by embedding geospatial datasets in order to capture regional heterogeneity and cross-border transmission channels.

To enhance NVaR reliability and utility, next-generation risk assessments must make three improvements: (1) increase spatial and temporal resolution, leveraging remote-sensing data and downscaled hydrological models, in order to be able to pinpoint micro-scale hotspots; (2) expand the suite of indicators to encompass water stress, flood return periods, water-quality status and ecological and socio-economic vulnerability in order to be able to provide a more holistic portrait of systemic risk; (3) adopt a standardised, open-source methodology, with transparent indicator definitions and clear weighting and validation procedures, to foster consistency, enabling peer review and supporting harmonised application by regulators, investors and infrastructure planners across the Single Market. To analyse individual counterparties, the enhanced NVaR methodology developed for this report could be refined by being combined with granular supply-chain data and geolocated corporate assets.

In double materiality analysis, there are some key limitations that might lead to an underestimation of risk exposure. First, the ENCORE materiality ratings for impact and dependency are globally consistent; consequently, they do not include any ecosystem- or geography-specific considerations (as captured by NVaR). Furthermore, the materiality ratings do not differentiate between those management practices within individual firms that might be more damaging to ecosystems and those that may have less of an impact. Finally, the materiality ratings only consider first-order effects, meaning that they do not capture any second or third-order effects, which can be much larger.

For Scope 3, there were additional limitations related to the use of EXIOBASE input-output data for estimating supply-chain risk in this analysis. First, the regions are concentrated on European and Western countries, with many emerging economies falling into the broad category of “Rest of the World”. This is particularly problematic given that most of the world’s intact biodiversity is to be found in emerging economies, making these countries disproportionately important for investigating nature-related risks. Second, because EXIOBASE input-output data represent average supply chains, they cannot capture firm-specific supply-chain structures for individual loans in bank portfolios and can only approximate upstream supply-chain risk. They are also static and do not represent how input-output linkages could change in the event of a major shock or stress to the economy. Finally, the downstream supply chain is not captured through EXIOBASE tables; consequently, the supply-chain risk emerging from this study was only partial.

To address these limitations, future research should: (i) localise materiality beyond global ENCORE scores; (ii) move from sector-level MRIO averages to company- and process-level supply-chain pathways; and (iii) explicitly model second/third-order, non-linear cascade effects. Scope-3 measurement could be strengthened through hybrid MRIO firm-level supplier mapping (e.g. Gamarra et al., 2023), finer regional disaggregation (especially disaggregating the “Rest of World” category) and explicit inclusion of the downstream-use phase. To enhance supervisory relevance, NVaR and double materiality frameworks should be integrated into a nature stress test that maps the results to standard credit-risk parameters (e.g. probability of default, loss given default and exposure at default) and is validated against historical disruptions. Methods should be harmonised with prior ECB stress-test practice and aligned with the work being undertaken by the Taskforce on Nature-related Financial Disclosures (TNFD) and the Network for Greening the Financial System (NGFS) in order to ensure comparability.

5 Policy relevance

The ECB's updated Monetary Policy Strategy assessment, concluded in June 2025, states that "within its mandate, the Governing Council is committed to ensuring that the Eurosystem fully takes into account, in line with the EU's goals and objectives, the implications of climate change and nature degradation for monetary policy and central banking".[12] By adding the term "nature degradation" to the official strategy statement, the Eurosystem has made it clear that a broader set of environmental factors are relevant for monetary policy deliberations.[13] The economic transmission channels for climate change and nature degradation – through disrupted productivity, regulatory shifts, asset repricing and litigation (NGFS, 2024b) – and market sentiment are now becoming clear. Integrating nature degradation into monetary and financial analysis is therefore critical to preserving price stability and maintaining financial stability in an increasingly nature-dependent economy and falls within the mandate of the ECB (O'Connell, 2024).

Continued macroeconomic research and assessment will be essential to ensure that the central banks are able to assess and forecast how nature degradation can lead to economic shocks and trends affecting inflation and the effectiveness of monetary policy. Work has already been embarked on in this area. Last year, the NGFS released a comprehensive nature-related financial risks conceptual framework, guiding central banks towards integrating nature-related physical and transition risks into supervisory and macroprudential tools (NGFS, 2024a).

An integrated approach to climate and nature-related risks will be needed to fully capture the cascading effects of combined nature degradation and climate change on the real economy and financial stability. The ECB has already developed, in conjunction with the Potsdam Institute for Climate Impact Research, the University of Minnesota and NatureFinance, a pioneering integrated climate-nature scenario framework to improve financial risk assessments (Stevanovic et al., 2024). This framework combines macroeconomic and biophysical models to simulate economic, climate and ecosystem outcomes (such as pollination and soil erosion) under different policy pathways from 2020 to 2050. Ranger et al. (2024) adopted a similar framework for the United Kingdom to develop three integrated climate-nature scenarios (two domestic and one international) and found that the integration of climate and nature could almost double the total macroeconomic implications of nature loss. Importantly, this implies that climate scenario analysis could underestimate the risks if feedback with environmental degradation is excluded. Further developments in endogenous growth modelling are needed that explicitly incorporate natural capital, making it possible to examine

12 The ECB's monetary policy strategy statement (2025), published on the ECB website.

13 See the welcome address by Frank Elderson at the International Monetary Fund OEDNE/World Bank Group EDS19 Constituency Meeting entitled "Deepening our commitment to confronting the climate and nature crises", published on the ECB website on 4 July 2025.

interactions between nature and the economy, as well as the economic implications of both private and public nature conservation efforts.

Addressing nature-related risks also has implications for financial stability and banking supervision. The ECB's supervisory Guide on climate-related and environmental risks, published in 2020,[14] makes it clear that banks should manage material risks stemming from nature degradation just as they do other financial risks. While the ECB already integrates environmental factors into its supervisory activities, supervised institutions' efforts to specifically tackle nature-related vulnerabilities are less advanced than for climate. Ongoing work at the ECB aims to garner better insights, develop approaches, identify where risks may potentially materialise and decide how best to manage them. The analysis in the current report may provide banks and supervisors with insight into where these risks are most likely to materialise.

Robust assessment of physical and transition risks along with their transmission channels requires reliable firm-level disclosures. Firm-level identification, location, evaluation and assessment of nature-related risks would greatly enhance location-specific materiality assessment (TNFD, 2023). For water risks, location-specific materiality assessment should capture local water scarcity and quality conditions. Enabling data would include: (i) consistent reporting of water-abstraction volumes and effluent intensities; (ii) disclosures on investment in water efficiency, recycling and treatment (best available techniques); and (iii) supply-chain traceability for water-intensive inputs. Policymakers should therefore continue to pursue efforts to ensure the availability of harmonised, standardised and reliable sustainability information, including under the Corporate Sustainability Reporting Directive (CSRD).[15] In the context of efforts to simplify the CSRD, it is important for policymakers to strike the right balance to ensure that the benefits of sustainability reporting for the EU economy and for the financial system are retained while ensuring that the framework is proportionate (ECB, 2025).

Endogenous-risk analysis lets banks target the biggest risk reduction by linking (i) where their portfolios impact ecosystems to (ii) where borrowers depend on those same services. The results of such analyses would serve as a guide as to which countries, sectors and ecosystem services to prioritise to ensure that impact mitigation (e.g. curbing water abstraction and pollution) also shrinks banks' own dependency risks. This approach would align with evolving supervisory expectations (the ECB Guide on climate-related and environmental risks states that it expects environmental risks to be integrated into strategy, governance and credit processes). In policy terms, double materiality enables: (1) risk pricing and allocation; (2) reduction of financed impacts where they inflate counterparty risk; and (3) disclosure and strategy consistent with EU reporting and supervisory expectations.

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14 *Guide on climate-related and environmental risks - Supervisory expectations relating to risk management and disclosure*, European Central Bank, Frankfurt am Main, November 2020.

15 Directive (EU) 2022/2464 of the European Parliament and of the Council of 14 December 2022 amending Regulation (EU) No 537/2014, Directive 2004/109/EC, Directive 2006/43/EC and Directive 2013/34/EU, as regards corporate sustainability reporting (OJ L 322, 16.12.2022, p. 15).

6 Conclusions and next steps

From a risk-assessment perspective, NVaR offers a scalable entry point for embedding nature-related risks into macroprudential and macrofinancial stability analysis. It facilitates scenario-based exploration of ecosystem shocks, sectoral vulnerabilities and cascading systemic effects. In this study, the baseline NVaR framework was enhanced and applied to assess the euro area's economic and financial risks from global ecosystem degradation. The main findings revealed that water-related risks – such as flood protection, surface water and groundwater scarcity, and water quality – are the most material for the euro area economy and banks. Surface water scarcity alone could put up to 24% of euro area economic output at risk.

Water-related stress can trigger cascading impacts across other ecosystems, undermining a broader range of services critical to economic functioning. To address these complex, interconnected risks and build on the pioneering work already done, a deeper understanding is needed of the interactions between different ecosystem services and their role in amplifying compound risks from climate hazards and nature degradation. This requires continued investment in data, modelling and analytical tools, supported by close collaboration between central banks and the scientific community. Nature-related risks are not merely environmental concerns; they are systemic economic challenges demanding an integrated, forward-looking and coordinated policy response.

Nationally averaged input data to characterise ecosystem services mask local hotspots of water scarcity and quality decline, leading to underestimation of NVaR. By capturing regional heterogeneity, such as drought-prone areas or declining groundwater reserves, granular datasets reveal stronger exposures across all water services. This highlights the importance of integrating spatially-detailed biophysical and socio-economic data into NVaR assessments, alongside methodological enhancements that account for higher data granularity, so as to more accurately capture systemic risks to the euro area economy and banking system.

For financial supervisors and central banks, NVaR could serve as a screening tool for identifying potential hotspots of systemic risk exposure rather than as a complete macroeconomic model. It could be built on to design nature-related stress test scenarios, support macroprudential surveillance and guide financial institutions in assessing portfolio risks linked to ecosystem dependencies (Ranger et al., 2023). Even given the current data and methodological limitations, the estimated losses signal the need for urgent action, both to improve modelling approaches and to integrate nature-related risks into monetary policy and supervisory frameworks.

Endogenous-risk assessment results can help banks to identify which countries and sectors to target for impact reduction in order to achieve the biggest decrease in dependency risk exposure within their own portfolios. It would also help banks to understand which ecosystem services to prioritise in order to ensure they are not inflating their own risk. Taken together, such analyses would inform risk pricing practices and portfolio decisions, particularly where dependencies and financed impacts overlap.

The next steps to be taken will include the development of a nature-related stress test for euro area banks. Forthcoming work will also focus on the macroeconomic and financial impacts of nature degradation. Additionally, the research into the following areas should be prioritised to strengthen the integration of nature-related risks into monetary policy frameworks and financial-stability actions: enhanced data-driven risk tools, advanced macrofinancial modelling, the co-development of forward-looking scenario narratives, improved availability and usability of nature-related data and disclosures, and strengthened interdisciplinary collaboration.

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Appendix 1: Description of the ecosystem services used in the nature value-at-risk analysis

Ecosystem service	Description
Fibres and other materials	Harvestable vegetation, livestock, fish and other biomass supporting food, fibre, and energy production (e.g. crops, timber, forage, wild catch)
Surface water for drinking/non-drinking purposes	Freshwater from rivers, lakes and reservoirs for drinking, industrial or agricultural purposes
Groundwater for drinking/non-drinking purposes	Potable and non-potable groundwater for municipal supply, irrigation and industrial processes
Animal-based energy	Labour and transport provided by domesticated animals (e.g. oxen, horses)
Genetic materials	Genes and genetic information from wild plants, animals and microbes used for crop breeding, pharmaceuticals, biotechnology and industrial applications
Air filtration	Ecosystem's capacity – especially vegetation – to remove airborne pollutants from the atmosphere
Dilution by atmosphere and ecosystems	Moderation of pollutants in air and water by ecosystems to reduce concentration and risk
Flood and storm protection	Coastal and inland vegetation and habitats that buffer floods and storm surges through absorption and flow regulation
Soil quality, mass stabilisation and erosion control	Ecosystem contributions to soil stability, erosion mitigation and protection against land loss and landslides
Pollination, pest control and biological disease control	Natural regulation of crop pollination, pest populations and disease risk provided by biodiversity and ecological interactions
Climate regulation (global)	Sequestering carbon and regulating atmospheric composition to mitigate climate change
Climate regulation (local) and ventilation	Moderating microclimates, such as providing shade and urban cooling. Improving airflow (ventilation) through vegetation and landscape design to disperse heat, moisture, and pollutants
Water-flow maintenance	Regulation of water retention, groundwater recharge and steady availability of freshwater
Water quality and bioremediation	Ecosystem's ability to filter and purify polluted water, including through soils and wetlands
Nursery population and habitat maintenance	Protection and provisioning of habitats needed for species reproduction, migration and lifecycle completion
Noise attenuation (mediation of sensory impacts)	Reduction of noise impacts by ecosystems (e.g. vegetation acting as natural sound barriers)

Source: The ecosystem services classification produced by the Exploring Natural Capital Opportunities, Risks and Exposures (ENCORE) knowledge base.

Appendix 2: Sample of indicators for the nature value-at-risk surface-water-scarcity model

Indicator category	Indicator	Unit	Description
Hazard	Standardised Precipitation Evapotranspiration Index (SPEI)	Unitless	Number of months with a specific SPEI below -1.5 for a drought event with a specified return period (25 years or 100 years)
Hazard	Sectoral water consumption use	Km3/yr	Spatial distribution of sectoral water intensity gridded data on 0.5° resolution artificial surface and cultivated land grids
Hazard	Baseline water stress	Ratio	Measures the ratio of total water demand to available renewable surface and groundwater supplies. Water demand includes domestic, industrial, irrigation, and livestock consumptive and non-consumptive uses
Hazard	Terrestrial water storage	Cm	Temporal changes in the Earth's gravity field are interpreted in terms of changes in the terrestrially stored water masses over the continents
Vulnerability	Percentage of area irrigated with surface water	%	Area irrigated with surface water, expressed as a percentage of total area equipped for irrigation
Vulnerability	Access to drinking water	%	Reflects the percentage of the population collecting drinking water from unprotected dug wells or springs, or directly from a surface-water source
Vulnerability	Government effectiveness	Unitless	Captures perceptions of the quality of public services, the quality of the civil service and the degree of its independence from political pressures, the quality of policy formulation and implementation, and the credibility of the government's commitment to such policies

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