

Article

European SMEs' Exposure to Ecosystems and Natural Hazards: A First Exploration

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Abstract: Nature-related financial risks have emerged as critical concerns for policymakers and financial actors. Central to this issue are ecosystem services, which play an integral role in various production processes but may be interrupted due to the degradation of nature. This article delves into the vulnerability of European SMEs by combining firm-level exposures to ecosystem service dependencies with regional information on the relative abundance of ecosystem services provisioning and the risk of natural hazards. Focusing on long-term debt positions to gauge financial stability implications, the results reveal moderate nature risks for European SMEs at the current stance but also highlight a possible concentration of risks and a need to further refine the use of available indicators.

Keywords: ecosystem services; natural capital; nature degradation; physical risks; environmental risks; ENCORE; risk management; SMEs



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1. Introduction

Developing a better understanding of nature-related financial risks has become a focal point for policymakers, the financial community and regulators. This is because economic activities are intrinsically linked to the health of natural ecosystems, which provide, for instance, material and regulating services such as direct physical inputs (e.g., water) for production or protection from natural hazards (e.g., floods). Consequently, ecosystem degradation can be a source of production disruptions, potentially posing significant risks to economic growth and financial stability. This study proposes a more comprehensive view of nature risks by refining pure ecosystem-service exposures with regional conditions of ecosystem services provision.

While a relation between nature and economic activities is undisputed, it is not immediately clear why and how ecosystem services relate to production processes. For this, we start with a definition of what constitutes an ecosystem. According to the Convention on Biological Diversity (see Convention on Biological Diversity, accessed on 5 February 2024: <https://www.cbd.int/convention>), an ecosystem is defined as “a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit”. Ecosystems can be terrestrial (land-based) or aquatic (water-based). They comprise nonliving (abiotic) elements, such as, for instance, minerals, climate, soil, water, sunlight and living (biotic) elements. Ecosystems face natural disturbances, such as variations in temperature and precipitation, wildfires, and pressures from economic activities, particularly polluting ones and overuse or land transformation. All in all, these non-sustainable practices can disrupt ecosystems, leading to imbalances and irreversible alterations. In turn, poorly maintained ecosystems provide less effective protection against natural hazards and fewer direct physical inputs than needed, resulting in unmet demand.

Analyses that provide insight into how ecosystems and natural hazards affect economic growth and financial stability are advancing rapidly (for instance, see [1,2]). Yet, research to integrate those and understand the broader consequences for the financial system and the entire economy is still in its infancy. Advancing quantitative capacities is

warranted as a first step to identify the many facets of the problem and mainstream the consideration of nature-related risks into economic and financial decision-making. Similarly, international institutions at the global level are increasing efforts to reach a common language and a transparent approach to conceptualize and measure nature-related risks [3–5].

Against this background, the European Commission put forward a comprehensive long-term plan, the so-called Biodiversity Strategy 2030 (see https://environment.ec.europa.eu/strategy/biodiversity-strategy-2030_en (accessed on 10 January 2024)) with specific actions and commitments to protect nature and reverse the degradation of ecosystems. Among the many actions, the strategy envisages, for instance, the creation and expansion of protected areas on land and sea, and a nature restoration plan. In addition, the objectives of the EU (European Union) water policy (see European Commission, Water scarcity and droughts: Preventing and mitigating water scarcity and droughts in the EU, accessed on 29 December 2023, https://environment.ec.europa.eu/topics/water/water-scarcity-and-droughts_en) foresee ensuring access to good quality water in sufficient quantity for all Europeans, economic sectors, and the environment. It also intends to ensure the good state of European water bodies by moving towards a water-efficient and water-saving economy. From a technical point of view, water scarcity results from temporary or spatial water mismanagement, leading to a state where supply cannot cover anthropogenic and environmental demand. In addition, in July 2023, the EU proposed a new Soil Monitoring Law (see <https://ec.europa.eu/newsroom/env/items/803760/> (accessed on 20 February 2024)) to protect and restore soils and ensure their sustainable use. While these actions may improve the long-run health of ecosystems, they may impose constraints on current economic activity.

This study is a first attempt to offer a thorough understanding of nature-related risks faced by small and medium-sized European enterprises (SMEs) that extends beyond the level of sectoral exposure. To achieve this, it uses firm-level exposures (sector-level approximation) for ecosystem dependencies provided by the Encore (Exploring Natural Capital Opportunities, Risks and Exposure) framework, as described in [6] (see Section 2), and refines those with geospatial information on relative ecosystem service provision and natural hazard risks. As for the latter, we argue that the dependency on ecosystem services can also be understood and serve as a nexus for a company's vulnerability to corresponding natural hazards. For instance, the dependency of agriculture on soil retention (ecosystem service) might make it susceptible to soil erosion risk; similar relations hold for flood and drought risk. Combining this data provides a more precise formulation of nature-related physical risks. This helps to unveil the actual share of European SMEs' long-term debt, which we use as a proxy for loans held by European banks that might be exposed to those risks and be a source of possible financial instability.

The rest of this study is structured as follows. Section 2 describes in more technical terms how ecosystems relate to economic activities and why this is important for financial risk assessment. Section 3 describes the data used. Section 4 displays European SMEs' exposures to ecosystems and natural hazards. Section 5 concludes.

2. Economic Dependency on Ecosystem Services

The starting point for our nature-related financial risk (NRFR) analysis is the Encore framework, as described in [6]. While many different approaches for ecosystem and biodiversity assessments exist, the financial community has widely accepted the NRFR framework (for instance, see [1,2,7]) as it comprehensively and transparently provides materiality ratings for various ecosystem service dependencies and impacts for the different economic sectors. For instance, it provides a dependency on groundwater for a specific industry subsector, and hence also a company that operates in this subsector.

While companies are dependent on ecosystem services, they can also harm ecosystems. This so-called double-materiality relationship is known from climate risk assessments. Dependencies reflect the fact that the economy or a firm benefits from using ecosystem services as inputs and is subject to vulnerabilities stemming from a disruption of those

(*nature physical risks*). At the same time, economic activities adversely impact ecosystem services via various modes of pollution, making certain types of production susceptible to prohibitive legislation (*nature transition risks*).

This study focuses solely on ecosystem dependency and climate (physical) risks (see Figure 1). European data on the former are provided by the European Commission's Joint Research Centre (JRC) Integrated Assessment of Ecosystem Services (INCA) project in the form of ecosystem accounts, and the JRC Risk Data Hub (RDH) provides natural hazard data for Europe (see <https://ecosystem-accounts.jrc.ec.europa.eu/> (accessed on 29 December 2023) and <https://drmhc.jrc.ec.europa.eu/risk-data-hub/> (accessed on 29 December 2023)). A sector or firm that is highly dependent can suffer higher costs or even production failure in the case of an ecosystem services interruption. For this reason, we inform the share of highly exposed firms with geospatial data on exposures concerning local ecosystem provisioning shortage and natural hazards. In addition, we complement natural hazard metrics, which are complementary and studied in the context of physical climate risks. An ecosystem dependency (physical risk) block, as proposed in this paper, and an ecosystem impact (transition risk) building block would be necessary to run a comprehensive nature-related stress test.

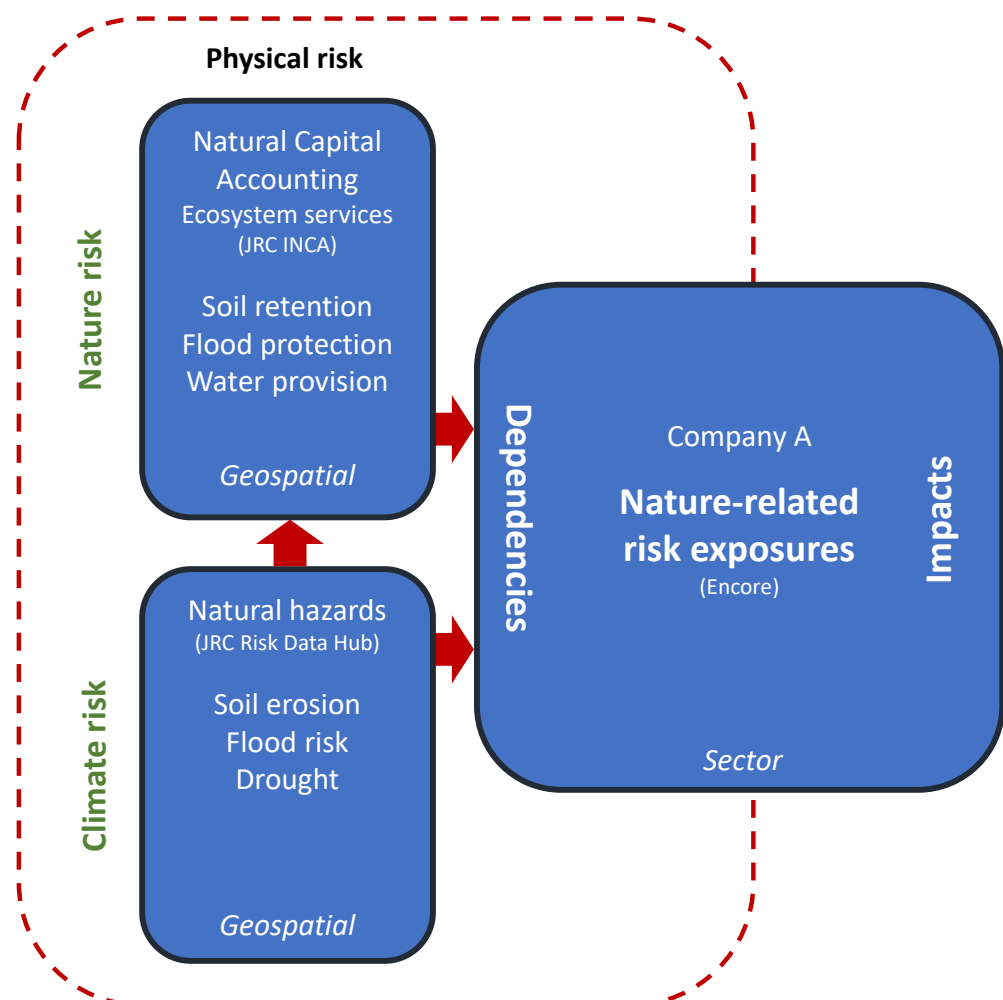


Figure 1. Firm dependency on ecosystem services. Source: [8].

Table 1 lists all ecosystem dependencies incorporated by Encore with a grouping and highlights the subset of services evaluated in this study. Ecosystem services can be grouped according to their functionality into four categories: material services, e.g., serving as direct physical inputs to production such as water; non-material services, e.g., helping to purify

water; and two groups of regulating services, e.g., weakening the impact of natural hazards such as soil erosion or flood risk.

Table 1. Ecosystem service dependencies. Source: [6].

Category	Ecosystem Service
Direct physical input (Material services)	Animal-based energy Fibres and other material Genetic material Groundwater Surface water
Enables production process (Non-material services)	Maintain nursery habitats Pollination Soil quality Ventilation Water flow maintenance Water quality
Mitigate direct impact (Regulating services)	Bio-remediation Dilution by atmosphere and ecosystems Filtration Mediation of sensory impact
Protection from disruption (Regulating services)	Buffering and attenuation of mass flow Climate regulation Disease control Flood and storm protection Mass stabilisation and erosion control Pest control

The primary advantage of using the Encore approach lies in its ability to provide fundamental insights into the structural significance of an ecosystem service for a sector or firm without requiring detailed firm-level information and knowledge of local ecosystem service conditions. Yet the latter data do exist and can help refine the risk analysis. Integrating local data on the relative provision of ecosystem services is informative on businesses' risk of facing an underprovision due to ecosystem degradation, for instance, due to overexploitation, or as the severity of natural hazards exceeds the potential of the ecosystem service to provide protection. This is because the actual flow of ecosystem services is determined as the match between potential and actual demand. Moreover, degraded ecosystems that protect against disruption will provide less protection against natural hazards, allowing those risks to unfold more disastrously. Despite all those difficulties, we attempt to link this data, acknowledging the complexity of the underlying relations in reality.

We focus on two regulating ecosystem services relevant to economic activities: soil retention and flood protection. In addition, we explore a material service using measures of water provisioning. The top layer of soil contains essential nutrients relevant to agriculture. Water and wind can cause soil erosion that decreases soil fertility, finally reducing crop yield once it exceeds the sustainable threshold of 2 tonnes per hectare (see [9]). Although this can be compensated with costly energy-intensive fertilizer, the degradation of soil retention ecosystems can lead to soil eroding more quickly than it can be formed or substituted, which eventually causes areas to become unsuitable for agriculture. Ecosystems that provide flood protection services protect the integrity of buildings and other economic capital. Local degradation of those ecosystems can result in higher economic losses that may also go beyond the local scale and require expenses for adaptation and mitigation measures.

A key figure for understanding ecosystem dynamics is underprovision or mismatch. Underprovision refers to the portion of demand not being met by existing supply, indicating a risk of insufficient service provision in addressing natural hazards. Panagos et al. [10] have investigated how a changing climate until 2050, particularly more intense precipitation, will affect soil erosion. In Europe, soil erosion may increase by 13 to 22.5%, while between

15.7 and 25.5% globally. Borrelli et al. [11] find a global increase of water erosion till 2070 of between 30 and 66%.

Water provision is another pivotal ecosystem service of abiotic type. Poor water management practices and high evapotranspiration (water evaporation and transpiration) during heatwaves can cause water stress, a situation when water demand exceeds the available sustainable provision rate. This ultimately leads to the quantitative and qualitative deterioration of freshwater resources. At the same time, a desert in the South of Europe may not require any abstractions and cannot be considered under stress. Encore provides an approximated distinction of water dependencies sourced from surface or groundwater for each sector, and hence firm. Water is a special case as it is not only an ecosystem service dependency but, with total and freshwater use, also a transition risk. Hence, water is at the crossroads between being a physical and a transition risk, and only the state of protective legislation decides whether companies might be more exposed to transition risks (short-run) or physical risks (short- or long-run). Advanced studies, for instance, Haas et al. [12] have started to tentatively model the hydrological cycle for Austria by linking groundwater levels, stream stages and precipitation at the regional level. The authors show groundwater levels have been trending downward until 1980 despite favorable precipitation, suggesting that water use might have been particularly intense and resource-depleting.

When it comes to natural hazards, we consider river flooding, droughts and soil erosion, which are often a result of increasing and more intense weather conditions. River flooding is the most costly natural disaster in Europe. Due to global warming and development in flood-prone areas, flood risk might increase up to six times current losses by the end of the century in case of no climate mitigation and adaptation (see [13]).

Ahopelto et al. [14] show that severe droughts can affect water security even in water-rich countries and, consequently, impact agriculture, household and industry water supply. While the annual water stress currently still appears muted across Europe, the European Environment Agency has shown that water stress can be observed in Belgium, Netherlands, Germany, Poland and the Mediterranean area when looking into this issue on a seasonal level (see European Environment Agency: Seasonal water scarcity conditions across Europe, measured by the water exploitation index plus (WEI+) for sub river basins, 2019; <https://www.eea.europa.eu/data-and-maps/figures/seasonal-water-exploitation-index-plus-4> (accessed on 5 January 2024)). In at least one season during 2019, 29% of the EU territory has been affected by water scarcity, despite abstraction declining by 15% since 2000 (see European Environment Agency: Water scarcity conditions in Europe; <https://www.eea.europa.eu/ims/use-of-freshwater-resources-in-europe-1> (accessed on 3 January 2024)). Usually, this is due to a combination of dry weather, reduced flows and increased abstractions for agriculture, tourism and other activities. In addition, projections in a 3-degree temperature increase scenario highlight increased levels of water stress in the South of Portugal, Spain and Italy, as well as Greece (see European Environment Agency: Areas in Europe with additional water stress in the future; <https://www.eea.europa.eu/data-and-maps/figures/areas-in-europe-with-additional> (accessed on 3 January 2024)). Being worried about curtailments in electricity generation during heat periods, Behrens et al. [15] investigated the security of the water supply of 1326 EU thermoelectric plants in 818 water basins between 2020 and 2030. The authors expect the number of regions experiencing reductions in power availability due to water stress will rise from 47 basins to 54 basins between 2014 and 2030, with the majority of vulnerable basins lying in the Mediterranean region, as well as France, Germany and Poland. In this context, Huynh et al. [16] show that firms exposed to severe droughts face higher costs of equity capital (almost 1%) and risk premiums in the United States. Firms with geographically diversified business operations are significantly less affected.

Environmental degradation and natural hazards are likely particularly disruptive for small and medium-sized enterprises because they lack geographically diversified business operations. Similarly, the limited capacity to share risk within business groups or via capital markets makes them particularly vulnerable to nature-related risks. Fatica et al. [17]

have shown that these compound other risk factors related to their capital structure and access to finance, resulting in an intrinsically higher financial fragility of smaller firms than their larger peers. In turn, the fact that risks related to the state of ecosystems and natural hazards are highly localized compounds the geographic concentration of traditional credit risk in bank lending to smaller borrowers, with potentially significant implications for financial stability.

The importance of the flood control ecosystem service is indirectly highlighted by the severe effects of floods on European firms' financial performance. For instance, Fatica et al. [18] shows that a severe flood deteriorates firms' assets between 2 and 5%. Moreover, focusing on the financial channel, Barbaglia et al. [19] document that a risk premium is charged on interest rates on loans to small and medium-sized firms in European regions exposed to high flood risk. However, the premium is comparatively small on average and does not adequately reflect the deterioration in loan performance in the aftermath of flood episodes. As floods have become more frequent and severe in recent decades and are projected to intensify with the rise in global temperatures, understanding the potential of nature-based solutions for flood protection is crucial. In a stylized modeling framework, Fatica et al. [20] show that flood protection measures that reduce the size of inundated areas are an effective adaptation strategy. Protection against relatively mild disasters reduces the negative impact of flooding on firms' turnover, assets and employment by roughly 40% compared to a no-protection benchmark.

3. Data

This study combines various data sources, namely company data from ORBIS, ecosystem dependency exposures from Encore, ecosystem services and natural hazards (see Figure 2). Every company is assigned a NUTS3 (Nomenclature of Territorial Units for Statistics) region based on its postcode using the TERCET postcode-NUTS correspondence tables provided by Eurostat (see <https://gisco-services.ec.europa.eu/tercet/flat-files> (accessed on 28 December 2023)).

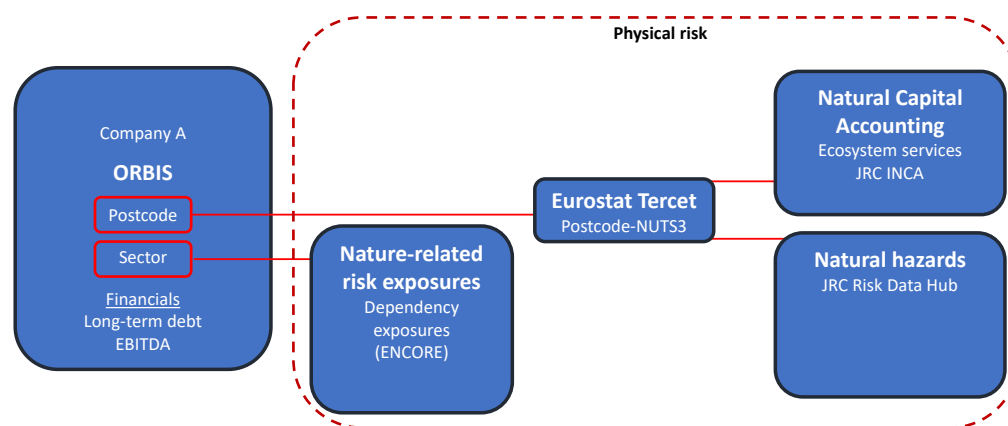


Figure 2. Dataset construction. Source: JRC elaboration.

We draw firm-level information from the ORBIS database provided by Moody's Bureau Van Dijk. ORBIS contains detailed information on firms' balance sheets and income statements, collected from official business registers, annual reports, webpages and commercial information providers, and harmonized into an internationally comparable format. Specifically, we assemble a large sample of non-financial companies for which we retain data on selected balance sheet items, and profit and losses.

We further classify firms according to their size using the official EU classification into micro, small and medium enterprises. The classification is available at https://single-market-economy.ec.europa.eu/smes/sme-definition_en (accessed on 4 December 2023) and is based on average values of total assets, turnover and employees of each firm observed

in the period of analysis. In the main analysis, we consider all the relevant variables as in 2020.

Figure 3 reports the share of long-term debt by size category and country to total long-term debt in Europe. As is apparent, micro and small firms account for the sheer majority of enterprises across virtually all EU countries. The relative shares indicate a representative distribution of debt across countries.

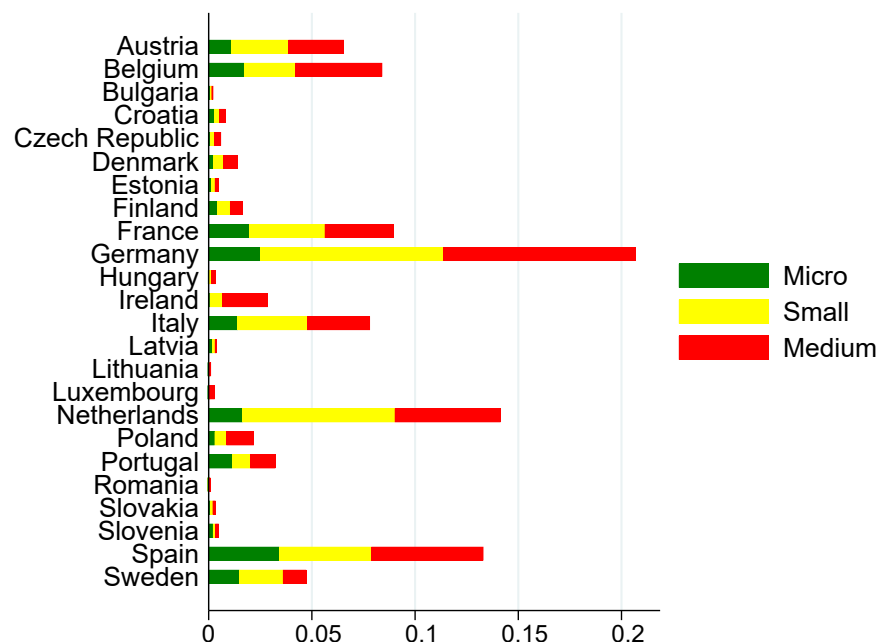


Figure 3. Share of long-term debt by size to total EU long-term debt. Source: JRC elaboration.

Table 2 reports summary statistics for the main variables used in the analysis, namely long-term debt, total assets, earnings before interest, taxes, depreciation, amortization (EBITDA) and employment, broken down by firm size. Micro firms have, on average, long-term debt of EUR 129,000 and five employees, while small companies have about ten times as much long-term debt and 30 employees. There are about 5.7 million micro firms in our sample. While more numerous, their economic weight remains below that of small and medium-sized companies.

Table 2. Summary statistics (mean) by firm size category. Source: JRC elaboration.

	Micro	Small	Medium
Long term debt (EUR)	129,000	1,614,134	7,128,637
Total assets (EUR)	564,241	8,028,849	40,092,799
EBITDA (EUR)	31,619	461,856	2,100,109
Number of employees	5	30	123
Observations	5,732,128	734,262	171,003

3.1. Encore Sectoral Risk Exposures to Ecosystem Services

Encore is a holistic framework that links ecosystem services and economic activities. In this version of the mapping, economic activities are provided in the GICS (Global Industry Classification Standard) classification, which is converted into 4-digit NACE(rev.2) (European statistical classification of economic activities). This allows the linking of ecosystem service dependency risk exposures with firms in ORBIS. The EU energy mix is used to calculate a weighted average of dependency exposures for the electricity sector. Risk exposures are provided as a materiality rating (see Table 3). No direct dependency and very low dependency ratings are aggregated as the separation is, in our analysis, not economically

meaningful. High and very high materiality ratings display a firm's high susceptibility, including production failure, to an interruption of an ecosystem service. However, high materiality ratings can also indicate vulnerabilities to corresponding natural hazards.

Table 3. Materiality ratings for ecosystem services. Source: [6].

Materiality Rating		Impact on the Production Process
Very High (VH)	(5)	The ecosystem service is critical and irreplaceable in the production process.
High (H)	(4)	Production process is extremely vulnerable to the disruption of the ecosystem service.
Medium (M)	(3)	Production process can take place without the ecosystem service due to availability of substitutes.
Low (L)	(2)	Most of the time, the production process can take place even with full disruption of the ecosystem service.
Very Low (VL)	(1)	Production process can take place even with full disruption of the ecosystem service.
No link	(0)	Production process is independent of the ecosystem service.

Figure 4 displays an overview of the Encore ecosystem dependency exposures of long-term debt in the sample for the relevant ecosystem services used in this paper, which are flood protection, erosion control and three categories of water (surface, ground and an additional metric that uses the maximum materiality of each). The ecosystem dependency is purely determined based on the sector of a firm and does not contain geospatial information on whether the ecosystem service is stressed in a region. This descriptive analysis suggests that about 10.1% of European firms' long-term debt depends highly (H) or very highly (VH) on the ecosystem service flood protection. Similarly, 67.2% of agricultural companies' long-term debt is high or very highly exposed to the ecosystem service erosion control, while in the rest of the economy, 27.9% of the portfolio is critically exposed to surface water and 7.5% to groundwater. The subsequent analysis will, in part, also provide ecosystem dependency exposures by firm size category or other variables, but also a refined insight into highly reliant companies using geospatial information.

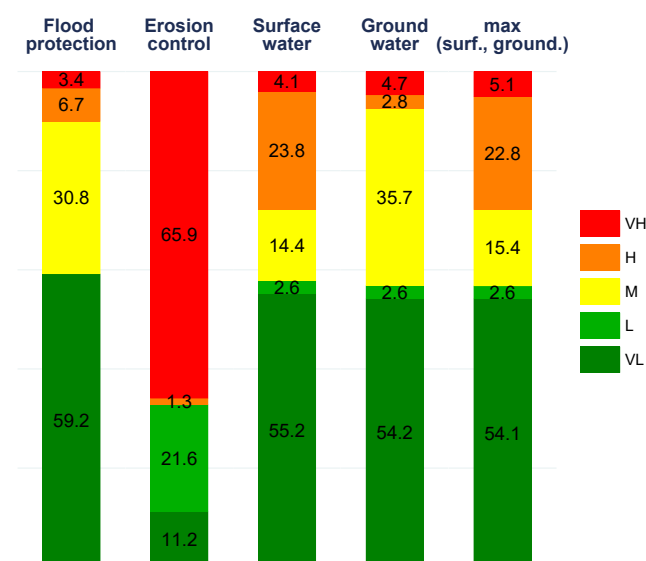


Figure 4. Long-term debt risk exposure to various ecosystem service dependencies (erosion control for agriculture solely, NACE < 400), 2020. Source: JRC elaboration.

In the first part of the analysis, this study investigates key variables, e.g., long-term debt, of companies and their exposure to a particular ecosystem service of interest. This is achieved by utilizing Encore sectoral risk exposures. The share of companies' long-term debt that has a high (*H*) to very high (*VH*) exposure is susceptible to ecosystem service interruption as, by definition, it implies production failure. This share is then decomposed using geospatial information on the specific ecosystem or natural hazard risks (see Figure 5).

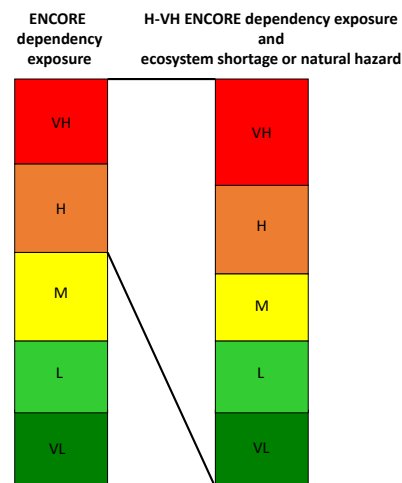


Figure 5. Illustration of exposure versus risk Source: JRC elaboration.

3.2. Ecosystem Services

The ecosystem service data (Table 4) utilized were sourced from the INCA project (see [21]). This data follows Ecosystem Accounting (EA), which is based on the global standard System of Environmental Economic Accounting (SEEA) and tracks the state of ecosystems. Ecosystems are complex, and they are often calculated using proxies that best represent the ecological process. Further, when no direct data are available, biophysical models are used to estimate the proxy for the process. Some of these models also take specific natural hazard metrics as observable input. While not reflecting the same mechanism, one needs to be aware of possible endogeneity when combining this data. The value of ecosystem services, measured in physical and monetary terms, estimates what an ecosystem can provide yearly. In the subsequent analysis, the data are processed at the NUTS3 level. Data for ecosystem services accounts are produced under the INCA project, which has provided data for four accounting periods: 2000, 2006, 2012, and 2018 (see [22]). We rely on the 2018 observation in the subsequent analysis.

Table 4. Data description. Source: JRC elaboration.

Data	Type (Unit)	NUTS3 (Year)	Source
Flood control	Ha (mean value)	2021	JRC INCA
Soil retention	Tonnes/ha yr ^{−1} (mean value)	2021	JRC INCA
Groundwater	m ³	2021	JRC
WEI+	percentage of water use against renewable freshwater resources	2021	JRC
Flood risk	25 yr, absolute	2013	JRC Risk Data Hub
Soil erosion	tonnes per ha per year	2016	JRC ESDAC
Drought	3-month anomalies of accum. precipitation	2021	JRC Risk Data Hub

The approach employed for modeling soil retention and flood protection services involves assessing the interplay between two key components: ecosystem service potential

and ecosystem service demand (see [23]). Ecosystem service potential represents what ecosystems can provide, irrespective of whether it is utilized. In contrast, ecosystem demand refers to the total demand by the economy and society, regardless of whether it is fulfilled or unmet. The spatial interaction between potential and demand determines the actual flow, which identifies what is eventually utilized as ecosystem service flow by the economy and society. A mismatch can occur either because the potential supply exceeds the demand or because of an economically relevant shortage when demand exceeds supply, resulting in unmet demand. The unmet demand becomes particularly relevant when examining vulnerability to hazard risks. Table 5 reports a taxonomy of definitions.

Table 5. Ecosystem service components in ecosystem accounting. Source: JRC elaboration.

Ecosystem Service	Component	Definition	Units of Measurement
Flood control	Demand	The extent of economic assets located in floodplains that can be delineated using flood hazard maps	Ha
	Unmet demand	The extent of economic assets located in floodplains that are not covered by the service potential	Ha
Soil retention	Demand	Soil loss per hectare by ecosystems when ecosystem protection is not provided	Tonnes/ha yr ^{−1}
	Unmet demand	Net soil losses	Tonnes/ha yr ^{−1}

We calculate an indicator for local ecosystem service provisioning shortage (EPS) for each ecosystem service as

$$EPS = \frac{Demand}{Demand - Unmet Demand} \quad (1)$$

which results in a metric indicating insufficiency of ecosystem provision if larger than 1. Negative values are discarded, as unmet demand cannot exceed demand, indicating that those values might result from measurement errors, potentially due to geographically complex structures. We assign materiality ratings (Very Low (VL), Low (L), Medium (M), High (H) and Very High (VH)) for ecosystem underprovisioning based on the thresholds outlined in Equation (2) and geospatially illustrated in Figure 6.

$$\text{Ecosystem Provisioning Shortage} = \begin{cases} VL & \text{if } EPS \leq 1.025, \\ L & \text{if } 1.025 < EPS \leq 1.05, \\ M & \text{if } 1.05 < EPS \leq 1.15, \\ H & \text{if } 1.15 < EPS \leq 1.25, \\ VH & \text{if } 1.25 < EPS. \end{cases} \quad (2)$$

3.2.1. Flood Control

In the case of flood control, both potential and demand are established using a spatially explicit model developed by the European Commission's JRC for the INCA project, specifically through the accounting application of ESTIMAP (see [24]). Table 5 delineates the components of ecosystem accounting for each service, along with their corresponding units of measurement. The evaluation of ecosystem supply involves five primary steps: (1) scoring land cover classes using the curve number; (2) adjusting the curve number

based on imperviousness; (3) modifying the curve number score according to slope; (4) incorporating natural and semi-natural land cover in riparian zones; and (5) mapping the service providing area (detailed explanation in [24]). The demand for flood control is determined by the expanse of economic assets in floodplains. Floodplains were determined based on those outlined in the flood hazard maps at the EU level for the maximum available return period, which is 500 years. This map is accessible in the JRC Data Catalogue; <https://data.jrc.ec.europa.eu/> (accessed on 15 December 2023); Flood Hazard Map for Europe, 500-year return period.

Flood control as an ecosystem service involves the regulation of water flow by ecosystems to mitigate or prevent potential damage to economic assets (such as infrastructure and agriculture) and human lives (see [25]). Various ecosystems, particularly forests, shrublands, grasslands, and wetlands, can reduce runoff by retaining water in the soil and aquifers and slowing the water flow. This action helps prevent the rapid downstream runoff of surface water, resulting in a decrease in peak runoff and, consequently, mitigating the adverse impacts of flooding on farmland, buildings and infrastructure. The derived measure of ecosystem provisioning shortage for flood retention is displayed in the left panel of Figure 6. Countries that are also experiencing water scarcity, for instance, Spain and Italy, but also water-richer countries, such as Sweden and Finland, have a high unmet demand.

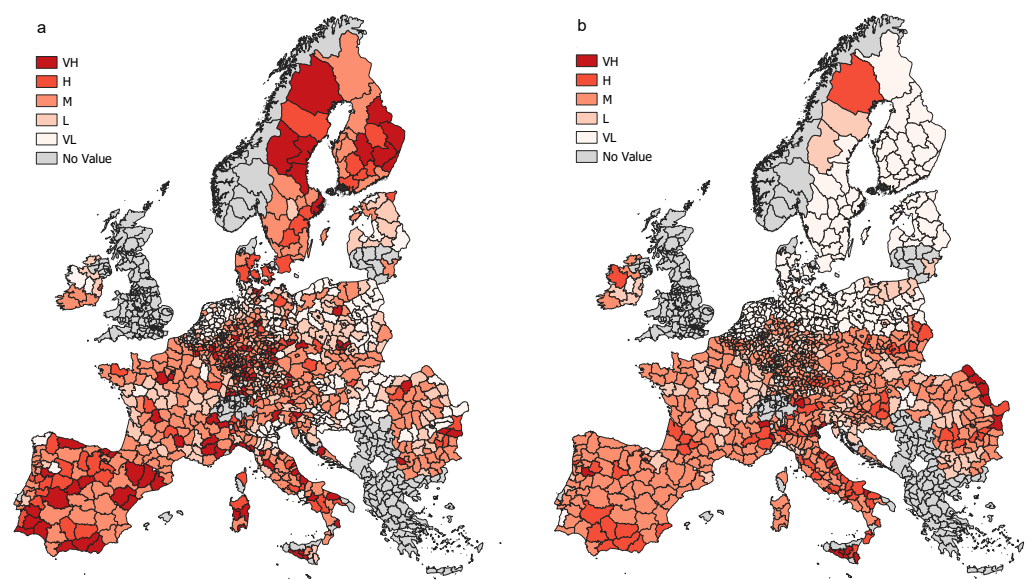


Figure 6. Ecosystem provisioning shortage, (a) flood protection and (b) soil retention. Source: JRC elaboration.

3.2.2. Soil Retention

For soil retention, ecosystem supply is determined through the vegetation cover factor, which incorporates physiological and ecological characteristics of vegetation (see [26]). These include factors like vertical and horizontal canopy structure, root systems, and specific functional traits of plants, all within specific abiotic conditions. The potential for soil retention is determined by the Vegetation Cover Factor (C-factor), which is calculated in relation to the maximum C-factor and rescaled to a range between 0 and 1 (see [27]). Consequently, lower C-factor values correspond to increased soil retention within the ecosystem. Augmenting vegetation cover, adopting protective crops, and deploying soil conservation measures have the potential to elevate soil retention within ecosystems. The determination of C-factor estimates for arable and non-arable land necessitates distinct approaches and data sources, as outlined by [26]. Ecosystem demand represents the societal requirement for soil retention. It is estimated based on the counterfactual model applied in the Revised Universal Soil Loss Equation (RUSLE) (see [28]), and it is calculated as the

total soil loss ($\frac{\text{tonnes}}{\text{ha}}$ per year). The absence of ecosystem protection represents the worst-case scenario with the least potential for ecosystems to retain soil. Areas with higher risks of erosion present higher demands for the protective role of ecosystems. In INCA, the focus is on the contribution of cropland to the agricultural economic sector. By applying a constant C-factor of 0.55 for the whole EU in the RUSLE equation, it is possible to quantify and map the amount of soil that could potentially be lost due to water erosion under the lowest ecosystem supply.

On-site soil retention is a vital ecosystem service that profoundly impacts soil quality and agricultural productivity. Soil retention is provided by almost all terrestrial ecosystem types, but only when provided on cropland it is accounted as ecosystem service (see [21]). Defined as the ability of ecosystems to mitigate on-site erosion rates resulting from rainfall (see [25]), this service plays a crucial role in maintaining soil health. If left unchecked, erosion can lead to the loss of topsoil, adversely affecting cropland productivity and triggering a detrimental cycle of further degradation. The significance of on-site soil retention is manifold. Ecologically, it sustains optimal soil conditions by preventing erosion, thereby preserving the fertility and characteristics of soils. Economically, it is indispensable for agricultural production, as the retained soil provides and preserves nutrients, diminishing the need for additional inputs like fertilizers. This not only benefits the environment by minimizing the use of potentially harmful chemicals but also carries economic implications by reducing production costs for farmers. The South of Spain, Italy and Eastern Romania experience a comparatively high unmet demand for this ecosystem service (see Figure 6b).

3.2.3. Water

We use the WEI+ to measure unsustainable water use and hence provisioning. The metric already displays a provisioning at-risk perspective. We follow [29] in calculating the WEI+ indicator, which illustrates the pressure on renewable freshwater resources due to water demand. The authors show that in many regions, annual renewable freshwater use is unsustainable across Europe. Notably, 29% of the EU-27 territory, excluding Italy, was affected by water scarcity in 2019, while total water abstraction has been declining by 15% between 2000 and 2019. The authors find water scarcity more common in southern Europe, with approximately 30% of the population living in areas with permanent water stress and up to 70% experiencing seasonal water stress during the summer. However, water scarcity is not limited to the southern part of Europe. It extends to Western Europe, where water scarcity is caused by high urban population density, joined with high levels of abstraction for energy and industry. For our purposes, we calculate the index at the NUTS3 instead of the sub-river-basin district level, as usually done. Otherwise, we calculate the water exploitation index similar as in the literature:

$$WEI+ = \frac{\text{net consumption}}{\text{local availability} + \text{upstream inflow}} \quad (3)$$

In this context, water availability reflects the local precipitation minus the evapotranspiration plus river inflow coming from upstream. Net consumption is all water abstractions minus return flows, meaning water lost from the water cycle. Hence, water consumption excludes power plant cooling and drinking water, which return largely to the water cycle. A WEI+ above 20% indicates water scarcity, while values above 40% indicate severe scarcity and that the freshwater use is likely unsustainable. We calculate a seasonal metric, investigating whether water scarcity exists for at least two months per year and annually, with the latter being usually less sensitive. Then, we take the maximum value for each region between 2015 and 2021. Materiality ratings are assigned according to the thresholds outlined in Equation (4).

$$\text{Water stress} = \begin{cases} VL & \text{if } WEI+ \leq 0.2, \\ H & \text{if } 0.2 < WEI+ \leq 0.4, \\ VH & \text{if } 0.4 < WEI+. \end{cases} \quad (4)$$

For regions that suffer severe water scarcity, using freshwater resources is likely unsustainable, potentially going along with or resulting in groundwater depletion. To investigate this, we employ a measure of groundwater depletion as described in [29,30]. So far, a statistically significant decline in the trend of groundwater storage is mainly observed in the South of Europe, such as Southern Spain, Greece, Sicily, Bulgaria and South-Eastern France, but also in the South of Germany and Switzerland. As we are interested in current developments and as more efficient water use might be implemented, we use this measure's mean between 2019 and 2021, acknowledging the limitations of the proposed metric. Any unsustainable amount used is assigned a materiality rating VH. To be fully aligned for sustainability assessments, the unsustainable use would have to be reported as a share of groundwater total. The obtained measures for these periods are illustrated in Figure 7. Particularly, Spain, Sardinia and Southern Italy experience seasonal water scarcity as measured by the WEI+, with unsustainable groundwater use primarily reflecting this water stress.

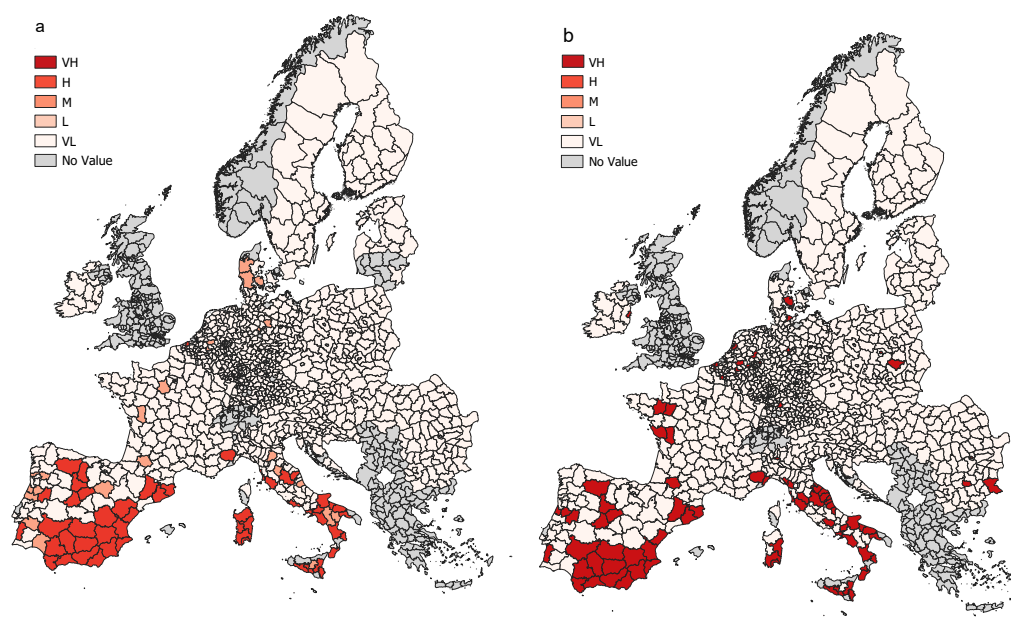


Figure 7. Ecosystem provisioning shortage, (a) WEI+ seasonal and (b) unsustainable groundwater use. Source: JRC elaboration.

3.3. Natural Hazards

Further, we use the natural hazard data (Table 4) hosted on the JRC Risk Data Hub, a web-based platform that contains harmonized risk data and methodologies for disaster risk assessment in Europe (see [31]). The RDH is set to become the reference platform for the standardized recording and collection of comprehensive and granular climate-related losses and physical climate risk data at the EU level in the context of the new EU Strategy on adaptation to climate change. We use the absolute measure of flood risk for commercial buildings for a 25-year return period, estimated mean soil erosion risk from 2016, and the SPI 3-month mean value between 2016 and 2022 to capture drought risk. It is important to mention that the described natural hazard data may partially serve as input for calculating the ecosystem services described above.

3.3.1. Flood Risk

The flood risk indicator measures the potential impact of a hazard for a specific area or community in a given period of time. It compounds two different components associated with the occurrence of a natural hazard, measuring respectively the exposure and the vulnerability to the specific hazard. The exposure component is calculated from geo-localized information on relevant flood metrics, such as frequencies and intensities, with

layers for physical assets that account for land use at the local level. In practice, available information on the share of industrial/commercial, residential and agricultural areas at risk of being flooded by floods of different return periods is used. The average expected impacts are assessed at different projection horizons, notably for 1, 2, 5, 10, 15 and 25 years, computing the probabilities of occurrence associated with floods with the specified return periods. By its very nature, the exposure metric captures the maximum potential impact of flooding at a given location. As such, it is not sufficient to determine flood risk, which also requires an assessment of the actual vulnerabilities associated with a particular hazard. The vulnerability component of the risk indicator captures precisely the lack of capacity of the exposed entities or areas to withstand the different types of natural hazards. In practice, it compounds a social, economic, political, environmental and physical dimension. By combining exposures and vulnerabilities, the RDH flood risk indicator measures the potential impacts of floods on different assets.

In this paper, we use the risk indicator for the projection horizon of 25 years for commercial buildings. In contrast to drought and soil erosion, which are geospatially dispersed phenomena, the use of NUTS3-level approximations of flood risks is not unproblematic. Despite showing significance in empirical applications, geocoding should be used to refine flood risk exposures in future applications, as the exact location of an asset will matter. Yet, there will still be some imprecision due to the resolution of flood risk maps. For this measure, as thresholds are unknown, quintiles are applied. To preserve observations, missing values are filled with the mean. Figure 8 displays the geospatial distribution of the applied measure, with Central Europe and Northern Italy being very highly exposed.

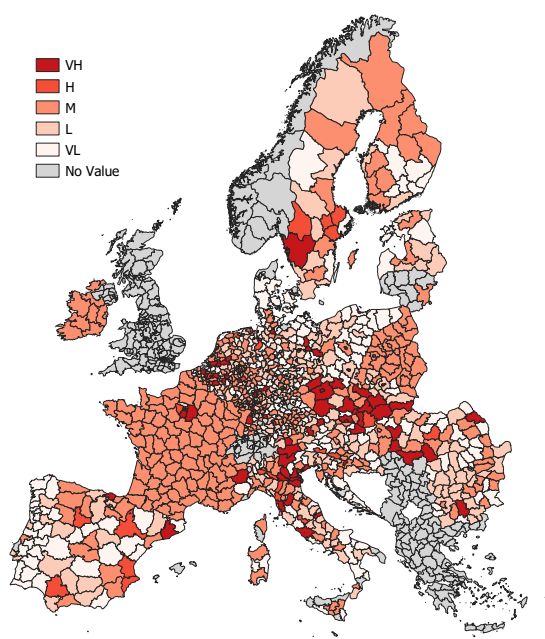


Figure 8. Natural hazard, flood risk. Source: JRC elaboration.

3.3.2. Soil Erosion Risk

The European Soil Data Centre (ESDAC) provides the estimated mean soil erosion risk by water in tonnes per hectare per year from 2016. The mean soil erosion rate in Europe for all lands is about $2.4 \frac{\text{tonnes}}{\text{ha}}$ per year (in agriculture 2.7), slightly higher than the recommended sustainable threshold of $2 \frac{\text{tonnes}}{\text{ha}}$ per year, while up to 5 to 10% of the agricultural area in Austria, Italy and Slovakia is affected by severe erosion (>11 tonnes per ha per year, see [9]). The data are taken from JRC ESDAC Soil erosion by water, <https://esdac.jrc.ec.europa.eu/themes/indicators-soil-erosion> (accessed on 3 January 2024). We assign materiality ratings to soil erosion risk (SER) based on the thresholds

outlined in Equation (5). Figure 9 highlights the geographical distribution of soil erosion by water metric, with the Southeast of France, Italy, Austria and Spain experiencing very high risks.

$$\text{Soil Erosion} = \begin{cases} VL & \text{if } SER \leq 0.5, \\ L & \text{if } 0.5 < SER \leq 2, \\ M & \text{if } 2 < SER \leq 4, \\ H & \text{if } 4 < SER \leq 11, \\ VH & \text{if } 11 < SER. \end{cases} \quad (5)$$

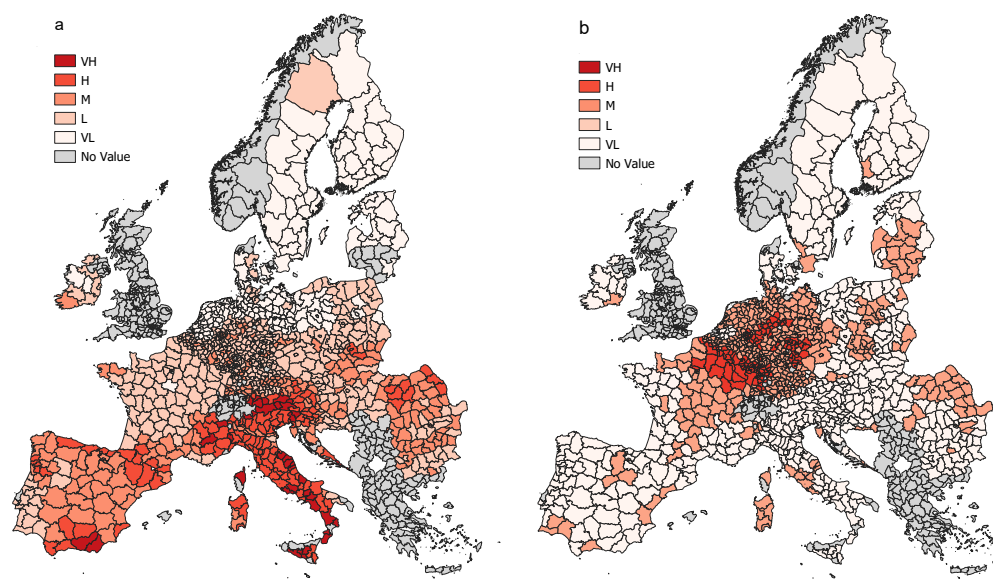


Figure 9. Natural hazards, (a) soil erosion by water risk and (b) SPI-3 drought. Source: JRC elaboration.

3.3.3. Drought Risk

As a measure of drought risk, we use the Standardized Precipitation Index (SPI), produced by the Copernicus European Drought Observatory (EDO). The indicator has been developed by [32], and is fully described in [33]. See also European Drought Observatory, December 2023, SPI Factsheet for Europe; https://edo.jrc.ec.europa.eu/documents/factsheets/factsheet_spi.pdf (accessed on 2 February 2024). It measures precipitation anomalies at a given location based on a comparison of observed total precipitation amounts for different accumulation periods (e.g., 1, 2, 3, 12, 48 months).

We use the one for a three-month accumulation period (SPI-3). As a rule of thumb, SPIs for smaller accumulation periods (1 to 3 months) can serve as an indicator for immediate impacts such as reduced soil moisture, flow in smaller creeks and snowpack. However, the SPI-3 also constitutes the lower bound to a medium accumulation period (3 to 12 months), indicating reduced stream flow and reservoir storage, while the SPIs with longer accumulation periods (12 to 48 months) indicate reduced reservoir and groundwater recharge. However, all of this also depends on human interference (e.g., water use for irrigation schemes). Values smaller than -2 to -1 indicate periods that are drier than normal. Normal conditions are characterized by values between -1 and 1 , while wetter than normal periods are indicated by values larger than 1 .

In this study, we consider the SPI-3 pre-warning metric indicating regions in which agricultural activities may be difficult but, more generally, regions susceptible to water cycle disruptions. We use the SPI as described, calculate the mean of the daily observations for each month, create dummies for each period and region with values lower than -1.5 , and accumulate observations across all periods between 2015 and 2022 (DI^c).

We implement a threshold such that regions that experience, on average, one to two significant periods per year are characterized as H risk, while regions that suffer two or more are characterized as VH risk (see Equation (6)).

$$\text{Drought} = \begin{cases} VL & \text{if } DI^c \leq 1, \\ H & \text{if } 1 < DI^c \leq 2, \\ VH & \text{if } 2 < DI^c. \end{cases} \quad (6)$$

In addition, we calculate this drought metric solely for spring and summer, using the same thresholds but for six months of the year. North-eastern France and central Germany, more continental areas, are more plagued by a lack of precipitation over extended periods (see Figure 9b).

4. European SMEs' Exposure to Ecosystems and Hazards

In this section, we apply our refined measures of dependency risk to several firm-level outcomes, namely long-term debt, total assets, EBITDA and employment. As for the ecosystem services, we focus on flood control and on-site soil retention, two essential services for hazard mitigation and prevention. In addition, we consider water a material service that is essential as a direct physical input for production.

4.1. Flood Control

Figure 10 provides an assessment of the vulnerability of firms to floods. The left panel shows the ecosystem dependency as provided by Encore of firm key variables such as total assets, EBITDA, employment and long-term debt. This metric is solely an approximation of sectoral dependency on this ecosystem service, providing helpful intuition by showing that 10.1% of long-term debt is associated with companies that critically depend on this ecosystem service. Micro companies are slightly more exposed than the other firm sizes to this ecosystem service, with 13.1% of their debt being dependent on this ecosystem service. Finally, the third panel shows which share of the high-to-very high exposed debt (10.1%) is exposed to flood risk (column 1) or a flood protection ecosystem under stress (column 2). For flood risk, materiality ratings have been calculated based on quintiles, as no thresholds exist for this metric. Then, 29.6% of 10.1% ($0.296 \times 10.1\% = 2.99\%$ of total debt) is located in NUTS3 areas highly exposed to flood risk. However, while NUTS3 regions can provide a good indication, future analysis might rely on the exact location of assets and flood risk. At the same time, only 20.9% of the 10.1% total debt (2.11% of total debt) susceptible to the ecosystem service flood protection may experience a shortage in ecosystem provisioning signaled by an unmet demand that can result from an ecosystem operating below potential or too high of an anthropogenic demand.

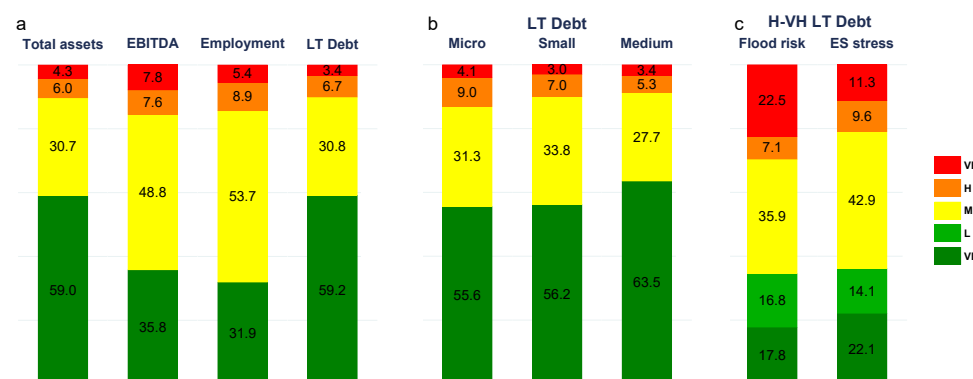


Figure 10. (a) Flood and storm protection ecosystem service dependency exposure of firm key variables, (b) long-term debt by firm size, and (c) flood risk and ecosystem provisioning shortage exposure as a share of High to Very High-exposed long-term debt. Source: JRC elaboration.

4.2. Soil

Soil erosion by water is an increasing risk for agricultural firms as it reduces soil fertility, creating an additional need for increasingly costly fertilizer. The analysis in this section solely considers firms classified as part of the agricultural sector (NACE < 400). The left panel of Figure 11 displays the share of assets, profits, employment and long-term debt reliant on the soil retention ecosystem as described in Encore.

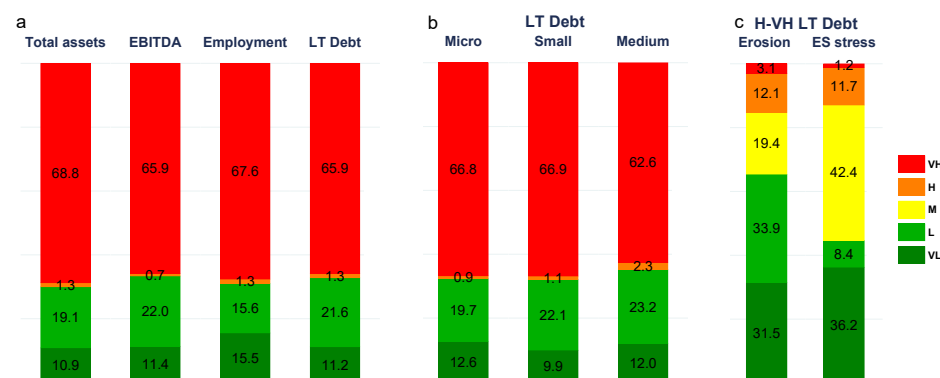


Figure 11. Agricultural firms, (a) mass stabilization and soil erosion dependency exposure of firm key variables, (b) long-term debt by firm size and (c) soil erosion risk and ecosystem provisioning stress as a share of High to Very High-exposed long-term debt. Source: JRC elaboration.

Around 70% of agricultural companies' key variables depend on soil retention, with medium-sized companies being a bit less dependent (mid-panel). The right panel shows that 15.2% (of 67.2% of highly exposed debt) are operating in areas with high soil erosion. Further, 19.4% are operating in areas with slightly too high soil erosion that is not sustainable. Similarly, 12.9% (of 67.2% of highly exposed long-term debt) suffer from ecosystem stress that reflects unmet demand.

4.3. Water

Figure 12 displays the exposure of SMEs to various forms of water dependencies. The left panel displays the exposures of long-term debt to dependencies of surface water, groundwater and the maximum of both. A larger share of debt, up to 27.9%, appears to be exposed to high surface water dependencies, while only 7.5% of total debt appears to be highly reliant on groundwater. To facilitate further analysis, the subsequent analysis uses the maximum dependencies provided by surface and groundwater dependencies. The mid panel illustrates the exposure of alternative firm key variables to water dependency. Interestingly, about 10% of profits and employment appear to be very highly dependent on water, while only half of the long-term debt might be exposed. The right panel shows a similar distribution of water dependencies by firm size, with between 25 to 30% of long-term debt being at least highly exposed to water dependencies.

The left and the right panel of Figure 13 display the shares of surface and groundwater H and VH-exposed long-term debt (see Figure 12) that are exposed to seasonal water scarcity as measured by a 6-month WEI+, a measure of annual drought and groundwater unsustainable use—all indicating distortions to the water cycle. Comparatively little, solely 9% of 27.9% of all long-term debt exposed to surface water dependencies (2.51% of total long-term debt) occasionally suffer seasonal water scarcity. In contrast, 48.1% of this debt share is also exposed to drought conditions, while only 2.6% of this debt is located in areas with unsustainable groundwater use. In contrast, high groundwater-dependant (H-VH) long-term debt has high exposures to seasonal water scarcity (19%) and drought conditions (37.1%). At the same time, 19.1% of highly groundwater risk-exposed debt (7.5% of all long-term debt) operates in areas already experiencing unsustainable groundwater use. Despite a lower share of companies appearing to be exposed to groundwater dependencies,

2.6% of European SME total long-term debt in the sample might suffer from groundwater shortages in the long run.

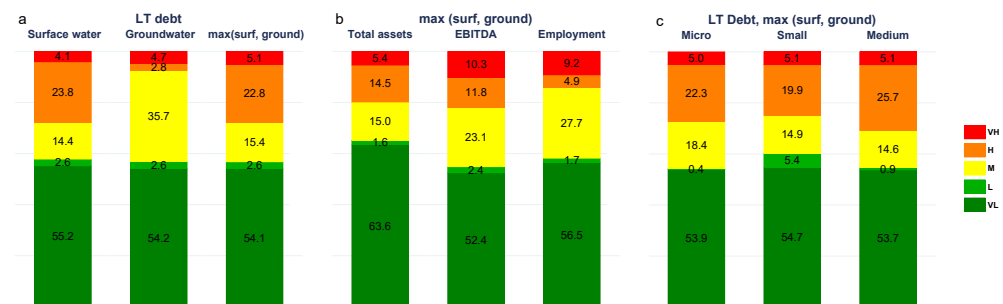


Figure 12. (a) Encore different water dependency exposures of long-term debt, (b) maximum water exposure measure of firm key variable and (c) maximum water exposure measure by firm size. Source: JRC elaboration.

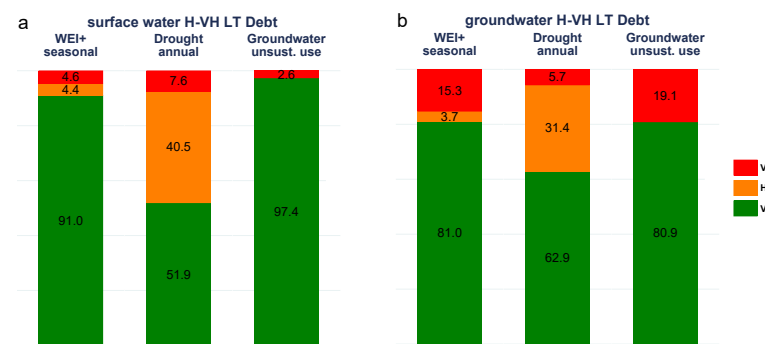


Figure 13. Long-term debt exposure to Water Exploitation Index + seasonal, annual drought and unsustainable groundwater as a share of long-term debt exposed to High to Very High (a) surface water and (b) groundwater. Source: JRC elaboration.

5. Conclusions

This article investigates nature-related risk exposures of European SMEs' performance variables and connects long-term debt with regional measurements of ecosystems and climate risks to gauge possible implications for financial stability. The analysis reveals moderate direct risks under current conditions in the EU aggregate long-term debt portfolio. Possible ecosystem degradation or potentially intensified natural hazards due to changing future climatic conditions may increase the risks in the coming decade, which, however, goes beyond the scope of the current analysis. Both ecosystem provisioning shortages and natural hazards tend to be regionally concentrated, potentially adversely affecting companies' operations and locally operating banks in some regions.

At the same time, the current results solely constitute a first assessment that requires careful interpretation. In particular, more work appears needed to achieve the complete suitability of current variables for sustainability assessments as required in the context of economic or financial analysis. In this context, the regional concentration of the current—potentially not yet perfect—measures may draw the attention of policymakers as the pricing of these potential risks may imply the risk of economically weakening periphery regions going forward. Further, the analysis could be extended to include more ecosystem services, such as soil quality or water purification. It may be interesting to extend the analysis to non-EU supply chain considerations to complete the picture of possible vulnerabilities. The derived indicators could be evaluated as factors in asset pricing analysis. Finally, reliable short-term scenarios on natural hazards and ecosystem services could aid in refining risk analysis and developing models to investigate whether these risks have the potential to intensify in the near term.

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Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

EA	Ecosystem accounting
EBITDA	Earnings before interest, taxes, depreciation and amortization
EDO	European drought observatory
ENCORE	Exploring natural capital opportunities, risks and exposure
EPS	Ecosystem service provisioning shortage
ESDAC	European soil data centre
EU	European Union
GICS	Global industry classification standard
INCA	Integrated assessment of ecosystem services
JRC	Joint research centre
NACE	Statistical classification of economic activities in the European community
NRFR	Nature-related financial risks
NUTS	Nomenclature of territorial units for statistics
RDH	Risk Data Hub
RUSLE	Revised universal soil loss equation
SEEA	System of environmental economic accounts
SME	Small and medium enterprises
SPI	Standardized precipitation index
WEI+	Water exploitation index plus

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