Research Paper

Indirect emission accounting and effectiveness of market regulation toward sustainability

Orsolya Szendrey [1] and Mihály Dombi [2]*

1 Faculty of Economics and Business, University of Debrecen. Debrecen, Hungary

2 Centre of Excellence for Sustainability Impacts in Business and Society, Budapest Business University. Budapest, Hungary; and Department of Business Economics, Faculty of Finance and Accountancy, Budapest Business University. Budapest, Hungary

* Correspondence: dombi.mihaly@uni-bge.hu

Abstract: The consideration of sustainability aspects has become increasingly essential and explicitly required by regulatory bodies and financial market participants so that efforts for mitigating climate change and avoiding a global ecological collapse could be strengthened. However, the methods used to measure transition risks do not always adequately describe the relationship between financial assets and environmental pressures. The currently implemented methods are limited to assessing the risks of financial portfolios based on their industrial sector classification and consider only direct emissions. In contrast, Scope 3 effects, which account for a significant part of total emissions, are excluded from the calculations. To reveal how reliable recent knowledge on climate risks is, in this study we investigate the currently used methods of climate exposure evaluation and conduct an analysis for the EU-27 countries by extending the calculation to indirect impacts. Our calculations reveal that the most affected industries are hotels and restaurants, construction, manufacturing, and other services, in which overall emissions are seven times higher on average than direct values. These results also suggest that the aforementioned segments need different risk assessments and additional examinations as part of investment and lending processes.

Keywords: climate change; sectoral exposure; greenhouse gas emissions; embodied carbon; climate risks

1. Introduction

The environmental and social challenges the global economy faces are indisputably complex. Due to their vital effects on humanity, lately sustainability considerations have influenced several stakeholders' attitude towards environmental issues. Thus, sustainability objectives have become a strategic imperative for companies, governments, and supervisory authorities (Shanaev & Ghimire, 2022; Dimson et al., 2020). As the financial system is considered the primary provider of capital, its prominent role in the green transformation of the global economy is unquestionable (Battiston et al., 2021; Steffen & Schmidt, 2021). Therefore, information about the green performance and sustainability goals of financial and corporate market players deriving from e.g. external environmental, social and governance (ESG) ratings (Dimson et al., 2020; Krueger et al., 2020) has become increasingly important. This phenomenon also implies properly managing risks from climate change, such as the mitigation of transition and physical risks.

The primary responsibility to tackle sustainability risks and challenges of economies rests with governments as they possess legislative, administrative, and economic measures to steer the incentives of private economic actors, companies, their shareholders, and consumers. A global policy response to climate change was laid down in the 2015 Paris Agreement (United Nations, 2015), in which all the countries decided to mitigate climate risks and improve their adaptation to the effects of climate change.

Even though governments have one of the most critical roles in acting against climate change, actions beyond government measures are needed to achieve climate objectives and

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to address market failures and transformations. A comprehensive strategy to effectively manage climate change requires different fiscal and monetary policy instruments, regulatory frameworks, and structural measures (D'Arcangelo et al., 2022; ECB 2021; Di Mauro, 2021). From the taxation of CO_2 emissions through the support of researching and investing in the development of sustainable technologies, fiscal and monetary political interventions can also significantly contribute to the success of initiatives aiming to protect our environment (Hansen, 2022; Boneva et al., 2021; Boneva et al., 2022). According to a study by Dikau and Volz (2021), 52 percent of the 135 central banks involved in the research strive to promote sustainable growth either directly or by supporting governmental policies that target objectives on sustainability.

Confirming this, Campiglio et al. (2018) state that the primary responsibility for appropriately managing transition risks still rests on elected governments. However, implementing comprehensive policies requires the collaboration of central banks and regulatory authorities. During this adaptation process, corporate lending, financing, and decision-making can be transformed towards more sustainable operations by influencing capital markets through regulated tools and measures. For this reason, supervisory authorities and central banks must address climate risks and rely on their mandate to develop appropriate strategies and frameworks for supervised entities (NGFS, 2020). This is also reinforced by the fact that central banks are increasingly expected to support the orderly transition to a low-carbon economy through financial stability measures and their monetary policy instruments (Boneva et al., 2022). In addition to all these, central banks must consider the introduction of additional protection and awareness strategies to ensure the success of measures taken to protect the climate, to ensure a continuous, smooth monetary policy and to plan the introduction of green monetary policy thereby supporting the successful implementation of the given government's environmental protection measures. Garcia-Villegas and Martorell (2024) have developed a dynamic stochastic general equilibrium model and conclude that the level of capital requirement held by the banking sector should also reflect the level of transition risks it is exposed to. Oehmke and Opp (2023) also consider whether the level of capital requirement could be a valuable tool to capture climate risks, and they get less promising results as higher capital requirements are different from less financed emissions.

Currently published reports (EBA, 2021a; EBA, 2022) and standards set up regulatory criteria to determine whether products, activities, and overall operations could be considered "green" or sustainable. In contrast, with these methods (e.g., intensity measures, industrial classification-based approaches considering direct emission, etc.), the fundamental relationship between them and natural resources still needs to be explored. Therefore, the appropriate evaluation of climate risks is vital even though regulatory standards only require supervised institutions to quantify the direct and sometimes indirect effects of the operations of their own entity. All direct and indirect environmental impacts should be considered to accurately evaluate financed assets, investments, and financial institutions. The relevance of the appropriate measurement of climate risks is further emphasized by the new regulation of the European Banking Authority [EBA] (EBA, 2022), which determines several new reporting and methodological requirements for institutions that issue securities traded on regulated markets. These institutions must report their ESG risks through qualitative disclosures from 2024 on and should quantify their green transition and physical risks using quantitative methods and indicators.

In our analysis, we will first take stock of the analytical tools of climate risk and exposure currently in use, then quantify the values of greenhouse gas emissions (GHG emissions) of each economic sector of EU member states and consider different emission categories afterwards. We will comprehensively analyse the EU-27 countries by comparing direct impacts with the amounts defined by environmentally extended input-output tables that consider both direct and indirect impacts.

The application of input-output tables for capturing sectoral dependencies and transition risks is increasingly emphasized in the literature. To emphasize the importance of sectoral dependencies, Cahen-Fourot et al. (2020) use a linkage measure to describe the role of natural resources in the supply chain, and they conclude that raw material sectors have high linkages as they produce the input of other members of the value chain. The authors highlight that during production process, highly industrialized economies rely on several intermediate goods from other countries and industries, and that indirect linkages should also be captured. By calculating sectoral multipliers Cahen-Fourot et al. (2021) also analyse risks deriving from marginal losses in primary inputs used in the fossil sector of a given country through focusing on both direct and indirect effects. Throughout this analysis, the authors accumulate more detailed information about systemic risks of value chains.

Adenot et al. (2022) show that if direct emissions are considered, the evaluations could be misleading because less carbon-intensive industries such as Industrials, Consumer Staples, Consumer Discretionary, and Information Technology can significantly increase transition risk throughout their indirect impacts exerted in the overall supply chain.

Demeter et al. (2022) primarily focus on tourism businesses and conclude that direct and indirect carbon emissions should be identified, and that environmentally extended input-output analysis could be a valuable approach for estimations. De Bortoli and Agez (2023) reach similar results when examining the Canadian road industry regarding the application of input-output models in quantifying indirect impacts.

From another perspective, Csutora and Vetőné Mózner (2024) analyse private carbon cost pay-offs for China using input-output tables and reveal that changes in the price of fossil inputs and carbon dioxide emissions can have opposite effects on the sectors' carbon strategies.

These results also confirm that direct and indirect impacts should be considered in risk management frameworks, since the current dominance of direct emission centred assessment in the discussion jeopardizes the efficacy of sustainability transition. In this study, we shed light on a systematic error rooted in the one-sided consideration of emissions, namely in the exclusive consideration of direct emissions, which the case is in all of the EU member states involved in this analysis.

The remainder of the article is organized as follows. Section 2 presents regulations and methods for measuring climate risks currently utilized by stakeholders. Section 3 discusses the applied methodology, data, and results. Finally, Section 5 discusses future research perspectives and conclusions.

2. Current regulations and methodology for measuring climate risks

Several new regulations, recommendations, and directives have been published in recent years to promote the green transformation of the financial intermediation system. The Taxonomy Regulation of the European Union built up a three-pillar comprehensive framework by laying down the basic definitions and principles related to lending and disclosure obligations of the financial system. The regulation is effective from 1 January 2022.

The EU regulation on sustainability-related disclosures (SFDR – Sustainable Finance Disclosures Regulations) establishes the central concept of sustainability risk, its possible effects on investment returns, and the possible harmful effects of potential investments on the environment. Under Article 1 of SFDR, any environmental, social, or management event or circumstance the occurrence or existence of which may have an actual or potentially significant negative impact on the value of investment is considered a sustainability risk. It is important to note that the regulation, for the first time, differentiates between sustainable and ESG products. ESG products have some green and/or social properties, while in the case of sustainable impact-oriented products, sustainability objectives are targeted.

The directive related to non-financial reporting and the publication of non-financial data (NFRD – Non-Financial Reporting Directive), effective from 2018, sets up expectations regarding the non-financial data that institutions must report in their business reports. Non-financial disclosures include discussion of environmental, social and employment issues, the respect of human rights, anti-corruption, and anti-bribery topics.

The principles of corporate sustainability reporting are laid down in the Corporate Sustainability Reporting Directive (CSRD), which covers the evaluation of sustainability risks affecting companies and the sustainability effects of companies.

At the macroscale, as part of compliance with current regulations, one may refer to direct and indirect environmental loads. The former considers the very latest stage of the production process as the source of all land use, emissions, waste streams, etc. In contrast, the latter identifies the responsibilities of this last stage in overall environmental load. These two perspectives deliver the same number of indicators globally. Scopes 1, 2 and 3 are commonly used emissions classifications at the organizational level. Scope 1 emissions refer to those pollutants that are generated at the facility, and Scope 2 entails emissions associated with energy usage. In contrast, Scope 3 emissions cover the ones embodied in production inputs (Hertwich & Wood, 2018). These emissions result from activities not directly controlled by companies: both in terms of production (upstream) and distribution (downstream) stages. In that sense, the organization itself does not influence the environmental pressures caused by indirect and Scopes 2 and 3 emissions. They are, however, required for production. Regarding Scope 3 emissions, Ducoulombier (2021) warns that due to the uncertainty surrounding related data, it is advisable to be cautious about incorporating value chain considerations into business decisions.

As a supervisor in the European Union, the European Central Bank [ECB] is committed to addressing climate change. It aims to manage climate-related risks by monetary policy instruments, to support the transition to a net zero economy and to make climate-related disclosures more transparent. High-quality data and well-defined aggregate indicators are needed in this process. To choose the appropriate calculation methodology, it is necessary to distinguish at which level of the value chain of company (Scopes 1, 2, 3) emissions occur.

The ECB regularly calculates and publishes carbon emission indicators to capture the financial portfolios and institutions' carbon emissions and assesses the role of the financial sector in financing carbon-related activities. The indicators are calculated for 2 types of products and 3 types of institutions in the following way:

Loans for

- Deposit-taking corporations without central banks, such as credit institutions, financial intermediaries, and electronic money institutions;

Securities for

- Deposit-taking corporation without central banks;
- Investment funds;
- Insurance and Pension Funds.

The necessary underlying data come from AnaCredit, Securities Holdings Statistics, Refinitiv, Eurostat, analytical credit datasets, and company disclosures, and cover Scopes 1 and 2 emissions (ECB, 2023c). Scope 3 emissions are excluded from the calculation due to the lack of sufficient and reliable data.

Based on the ECB's latest carbon emission indicator calculations and publicly available aggregated data, Table 1 shows Scopes 1 and 2 financed emissions and carbon intensities regarding the type of financial institutions in the Euro area. Data show that in absolute terms, most financing of Scopes 1 and 2 emissions are realized by investment funds. As far as the intensity values are concerned, we can state that the most carbon-intensive activities are financed by the banking sector (ECB, 2023a).

Table 1. Financed emissions and intensities in terms of type of financial institutions.
Source: Edited on the basis of ECB (2023a) data

	Loans	Securities		
Indicator \ Institution type	Deposit-taking corporations	Deposit-taking corporations	Investment funds	Insurance and pension funds
		Financed emissions		
Scope 1 emissions (Million tonnes of CO_2)	144.74	45.96	404.14	97.13
Scope 2 emissions (Million tonnes of CO_2)	-	7.90	82.54	17.76
		Carbon intensity		
Scope 1 emissions (Tons of CO_2 per EUR million of revenue)	43.88	298.31	255.98	242.41
Scope 2 emissions (Tonnes of CO_2 per EUR million of revenue)	-	50.31	52.18	44.26

Another group of indicators measures the exposures related to transition risks. Weighted average carbon intensity (WACI) could be determined as the sum of total GHG emissions of the actor, standardized by the overall production value of the company and weighted by investments in related activities as a share of the total investment portfolio value (ECB, 2023c). Carbon footprint could be derived from the financed emission indicator, standardised by the total investment portfolio value.

According to the ECB (ECB, 2023b) results, the carbon footprint of the corporate segment decreased by 26% from 2018 to 2022 due to reduced activities of the segment. This phenomenon emphasizes that further steps and efforts are needed from the market participants to comply with the Paris Agreement properly, to reach its fundamental goals, and to become more carbon efficient.

In addition, another standard and straightforward method for quantifying climate risks can be the calculation of GHG emissions in the economic sector. The Climate Policy Relevant Sectors (CPRS) methodology, as defined by Battiston et al. (2017), has become widespread in determining individual sector exposures in the financial sector. Based on the CPRS methodology, sectors typically affected by transition risks (CPRS 1-6 category) are fossil fuel, utilities, energy-intensive, housing, transport, and agriculture. At the same time, finance, scientific research and development, and other industries (CPRS 7 and 8) have negligible climate risk exposures.

In 2021, EBA (2021b) performed a pilot exercise based on the CPRS method to calculate climate-relevant exposures. The exercise results showed that EUR 1.36 trillion of reported corporate exposures were assigned to CPRS 1-6 categories. In contrast, EUR 940 billion was allocated to lower transition risk categories, that is, to CPRS others (7 and 8).

In Table 2, the EBA's results show that CPRS 1-6 exposures are concentrated. More than 50% of the total exposure (EUR 1.195 billion) is assigned to the riskiest categories, that is, manufacturing (C), electricity, gas, steam and air conditioning supply (D), construction (F), transporting and storage (H), and real estate activities (L). In the case of half of the banks in the observed sample, the share of CPRS 1-6 exposures assigned to manufacturing (C), construction (F), transportation (H), water supply (E), and mining and quarrying (B) is greater than 70%.

Table 2. Distribution of CPRS 1-6 exposures (Source: Edited on basis of EBA (2021b) data).
Source: Edited on the basis of ECB (2023a) data

Industry	Exposure (bn EUR)	Share
C – Manufacturing	464	34%
D – Electricity	175	13%
F – Construction	132	10%
H – Transportation	126	9%
L – Real Estate	297	22%
Others	164	12%
Total	1358	100%

In addition, the EBA pilot exercise included the analysis of carbon intensity indicators considering six risk categories (very low, low, medium, medium/high, high, and very high). The EBA's results of the carbon intensity classification showed that EUR 828 billion of the total EUR 1.96 trillion of exposure classified was assigned to the GHG emission intensity bucket above the medium category, which is considered more sensitive to the possible reduction of GHG emissions (e.g., introduction of a carbon tax, decreasing fossil fuel subsidies, etc.). Regarding the two riskiest categories, Electricity and Manufacturing proved to be the most GHG-intensive sectors (EBA, 2021b).

The above-mentioned analysis and methodologies share the common feature of quantifying the climate risk exposure of sectors/portfolios based on the GHG intensity data published by Eurostat or data reported by the supervised entities or companies. The body of literature related to sectoral dependencies is very limited (see e.g., Allen et al., 2020; Bokor, 2022; Guth et al., 2021; Vermeulen et al., 2018) and so Scope 3 data are typically not disclosed, or they are not reliable even if reported.

In the remaining part of our study, we prove that accounting for emissions that occurred along the whole supply chain substantially alters the evaluation of the risks of portfolios. For this purpose, sector-level direct and indirect emissions of EU member states are compared.

3. Indirect and direct emissions in the measurement of climate risks

3.1. Methodology

We assessed indirect emissions with the help of input-output modelling due to its corresponding scale to ESG regulations: this reflects climate risks at the sectoral level. Life cycle analysis (LCA), agent-based system modelling, or surveys among the economic actors are limited to describing emissions at the company level. Here, results are prone to be affected by numerous influential factors, harming the explanatory power of sectoral affiliation on climate risks. Indirect GHG emissions have been explored through the widely used Leontief transformation of an environmentally extended multi-regional input-output table (EE-MRIOT) (Tukker et al., 2013; Wood et al., 2015; Stadler et al., 2018; Dombi et al., 2018). A standard monetary input-output table reports the revenue flows of an economy and collects these processes in three different parts: inputs, intermediate flows and final demand. Environmental extensions refer to additional information on several environmental issues, such as land use, emissions, and water utilization as inputs of the production processes.

During the composition of an EE-MRIOT, research groups handling the data add the ecological indicators to production inputs; that is why they are called ‘extension’. Some databases incorporate even social characteristics of the production to evaluate the unintended effects of the supply chain, e.g., child labour, corruption, and mining conflicts. This way, all the sustainability issues are mapped with the help of EE-MRIOTs.

Intermediate flows (matrix A) describe the links between the sectors on the way to delivering the product for end-use purposes, which occurs in the final demand section (y). In other words, matrix A translates inputs onto final demand without residuals in the economic system. In the case of open economies, imports are part of production inputs, while exports are accounted for in the final demand.

Let x refer to the gross output, I be the identity matrix, matrix A represent the direct relationship among the sectors, yi be the type of final demand, and LGHG mark the Leontief inverse matrix. Then, mathematically, the Leontief model can be formulated as follows:

$$x = (I - A)^{-1} \cdot y$$

$$M = L_{GHG} \cdot y_i$$

When the Leontief inverse of the per monetary output coefficients of these very environmental indicators is multiplied by the final demand, cumulative environmental impacts of the distinct final demand category will be obtained in the sectoral structure (Steen-Olsen et al., 2016; Schaffartzik et al., 2014). Sometimes these indirect flows are also referred to as ‘footprint’ or ‘consumption-based accounts’ in the literature.

3.2. Data

For input-output analyses, several available databases exist (e.g., EORA, Exiobase, WIOD, E3IOT). In our analyses, we chose the EORA database, which is a freely available EE-MRIOT broadly used by the academic community and decision-makers to capture Scope 3 indirect emissions. It comes with the longest data coverage (1970-2016) worldwide for various environmental indicators (e.g., Lenzen et al., 2012; Lenzen et al., 2013). We have used the sectoral-harmonized version, i.e., EORA26, to maintain the comparability of the European countries during the analysis.

Direct emissions are derived from a widely used Eurostat database of air emissions. In this database, economic activities are classified based on their NACE Rev2 codes, which results in 21 industrial sectors (Eurostat, 2008). Sectoral GHG emissions have been available since 2008 in an annual breakdown. Since the Eurostat GHG emissions are assigned to the sectors that actually produce emission, the data quantify direct emissions only.

To harmonize Eurostat and EORA sectoral differences and to make our database more transparent, we synthesized the two classifications using a merging table for both databases. As a result of the merging processes, industries were assigned to 9 different industry categories. The overview of the sectoral activities and the merged categories that were taken into account in the analysis can be seen in Appendix 1.

3.3. Results

To capture the actual emissions generated from end-to-end operations of industrial sectors, based on the mentioned methodology and the Eurostat and EORA26 datasets, we calculated and compared Scope 1 and overall (direct and indirect) GHG emissions of the EU-27 countries. Figure 1 shows the results of the analysis in tonnes. Direct emissions can be identified on axis y, while axis x refers to the overall values.

Data points above the diagonal line represent industries with Scope 1 emissions outweighing overall emissions. These industries typically belong to the primary sectors of the economy, which are electricity or gas production and transportation. In these industrial sectors, the higher direct emission values resulting from the outputs of the above-referred segments at the end of the value chain do not appear in the same industry since further industrial transformations occur. This means that other industries and countries require the outputs of these segments as input for production. This way, the overall emissions could be captured in a different sector, and several sectoral and international re-arrangements could be observed.

Cahen-Fourot et al. (2020) also highlight that raw material sectors have more forward linkages, which implies they have an expanding cascade influence on the value chain, which emphasize their indirect impacts on the economic networks.

Similarly to our results, based on their empirical study, Sánchez-Chóliz and Duarte (2004) classify agriculture and livestock, fishery, mining and energy, non-metallic industries, chemical, rubber and plastics, metal, paper, and transportation in this category, while Hertwich and Wood (2018) also show that the indirect emissions for the energy sector were only about one third as large as Scope 1 for the OECD countries in 2015. The transport sector accounted for two-fifths of Scope 1 if driving by consumers is included in direct emissions. Figure 1 shows that electricity, gas, and water production of Germany, Poland, and Italy result in the most significant direct emissions, followed by transportation services in Germany and the agricultural sector of France. In 2021, among the EU Member States, Germany still had the highest level of net electricity generated (20.1% of the EU total), followed by France (19.1%) and Italy (10.2%) (Eurostat, 2023c).

Data points below the diagonal line represent the industries with higher Scopes 1, 2, 3 embodied emissions. The aggregated emissions of these sectors are much higher than the direct values associated with them. For example, if we consider manufacturing or construction, we can state that their direct emissions are typically low, while their overall contribution to the total GHG emission is exceptionally high. Figure 1 supports this statement since manufacturing in Germany, France, Italy, Poland, and Spain and construction in Germany and Spain produce the most significant overall emissions in the observed sample. In 2020, among the five largest EU Member States, Germany's manufacturing output accounted for 32.4% of the EU, and its production in value added term was the largest in 20 out of 24 manufacturing subsectors. At the same time, Italy had the most significant contribution to 3 manufacturing subsectors, and France was the leading manufacturer of other transport equipment (Eurostat, 2023b). As far as the construction sector is concerned, in 2020, in value-added terms, Germany had the largest share (19%) of EU value added in both subsectors: construction of residential and non-residential buildings subsector (14.5 %) and development of building projects (4.5 %) (Eurostat, 2023a).

Acquaye and Duffy (2010) also showed that 17% of the overall emission of the Irish construction sector is direct, 41% is domestic indirect, and 42% is foreign indirect emission. In the case of the Swedish building sector, direct emissions account for only 23%, indirect domestic for 46%, and indirect imported emissions for 31% of the total emissions (Nässén et al., 2007). As far as the service activities are considered, their low direct emissions could also be misleading. Activities of hotels and restaurants, real estate, as well as wholesale and retail trade industries require essential inputs from other elements of the supply chain.

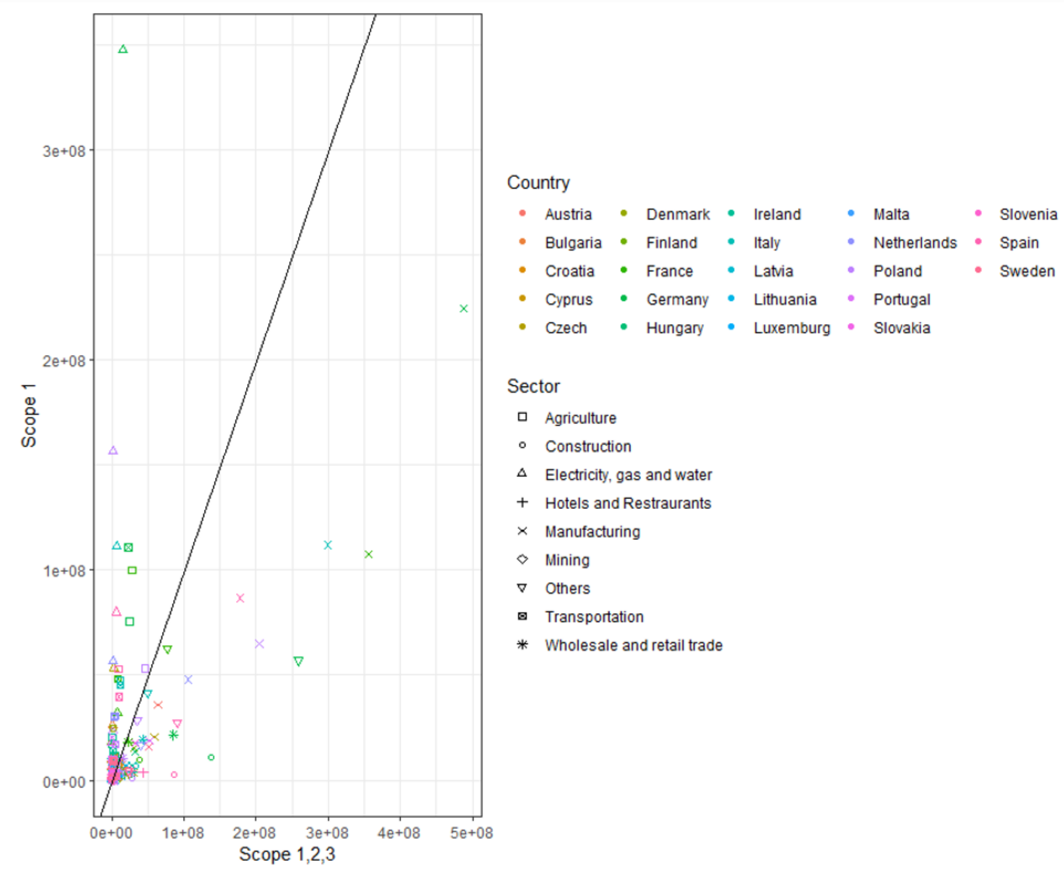

Figure 1. Scope 1 and overall emissions of the EU-27 countries in tonnes. *Source: Author's own*

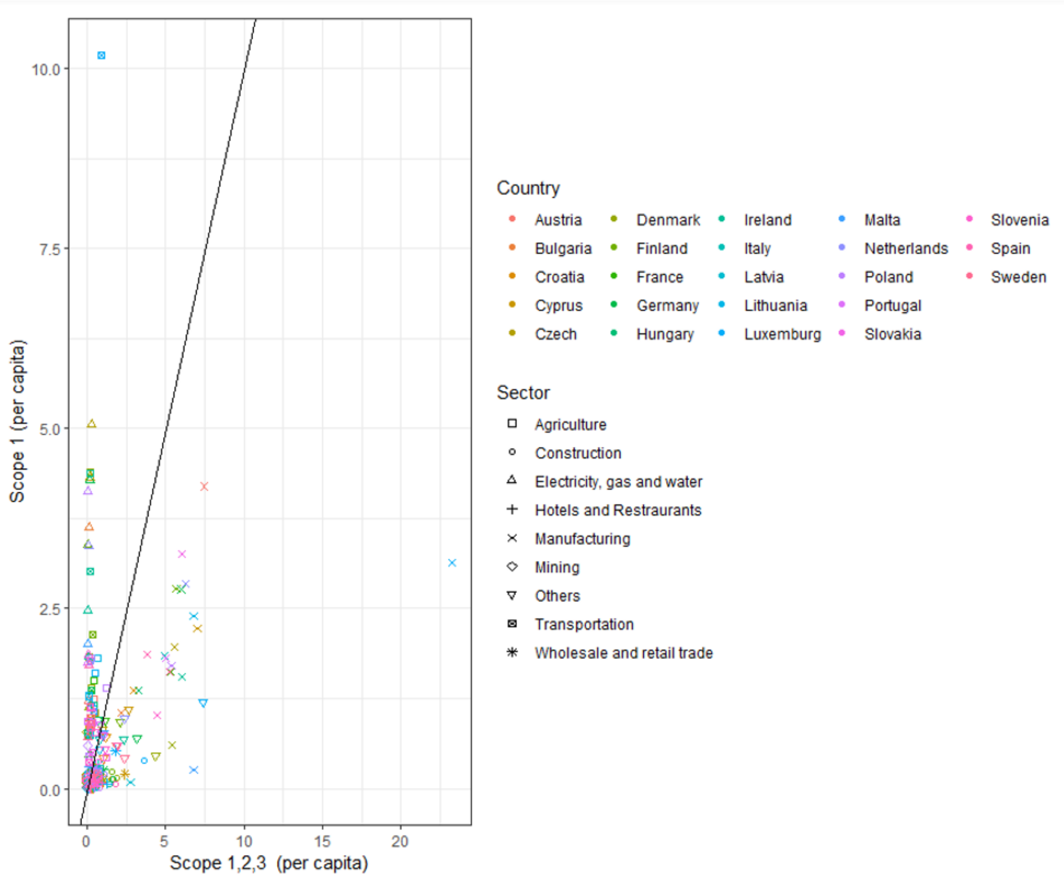

Figure 2. Per capita Scope 1 and overall emissions of the EU-27 countries. *Source: Author's own*

The same results could be observed if we perform the calculations using per capita emission values. Figure 2 shows that transportation in Luxembourg accounts for the highest per capita direct emissions, followed by the electricity, gas, and water industry of the Czech Republic, the transportation industry of Denmark, and the agriculture industry of Ireland. In 2019, Luxembourg still had the highest per capita direct GHG emissions in the EU (20.6 tonnes of carbon dioxide equivalent per capita) (OECD, 2021). Regarding indirect emissions, the largest per capita indirect emissions can be identified in the manufacturing sector. Countries with the highest per capita values include Luxembourg, Austria, Cyprus and Lithuania.

Those sectors in the EU member states with overall emissions outweighing Scope 1 emissions are thus typically processing sectors: namely, hotel and restaurant, construction, manufacturing, and other services. These sectors perform at least 1.2 times higher overall emissions than direct emissions, and this ratio even reaches 42.67 in the hotel and restaurant sectors of Latvia. The second largest ratio (41.93) was realized in the construction segment of Poland. The overall mean and median ratios for the affected industries are 7.65 and 4.4, respectively.

As we have mentioned before, the currently applied methods typically quantify the transition risks of financial instruments only with respect to direct emission data. This practice implies that ranking economic activities based on their industrial classification could be misleading. For example, exposures in the construction or manufacturing industries could be assigned to lower risk categories, even though they could be responsible for significant risks based on their end-to-end total operation. Adenot et al. (2022) also confirm our results in intensity terms, i.e., the classification of industrial sectors could only be accurate considering the cascading effect realized in the overall value chains.

This phenomenon reveals that considering indirect emissions is not negligible because financial institutions may accelerate the setup of environmentally harmful portfolios through their inappropriate lending activities. To capture the actual impacts of economic activities, institutions should build up their lending policies also considering direct and indirect emissions and should increase investments in those portfolios that really do not cause significant harm to the environment – at least not in their capacity as drivers of the total resource use but as a means of transforming raw materials to valuable inputs.

4. Conclusions

Our study has provided a comprehensive overview of current methodologies for identifying and measuring climate risk-related exposures. We have emphasized that the role of the financial market is vital in the green transformations of the global economy since capital flows and market players could have significant impacts on what activities and segments are financed. Regulatory bodies widely recognized the importance of this phenomenon and proactively set up several regulatory standards and requirements for market players.

Concerning the currently implemented methods in the EU, we could state that the European Banking Authority and the European Central Bank support supervised entities in their green transformation in several ways. To make this process more effective, supervisory bodies should clearly define how climate risks could be material for the supervised entities and should determine the asset classes or portfolio segments that could be more vulnerable to transition risks. Regulators should explicitly specify their expectations in relation to the required management of sustainability risks and should set up mitigation strategies for the supervised entities for implementation.

The currently applied methodologies for measuring transition risks typically take only direct emissions into account or Scope 2 indirect emissions generated by the proprietary units of companies at most. In contrast, indirect emissions are excluded from the calculations. Total emissions are more relevant because the regulation issued by the European Banking Authority in 2022 requires measurement and disclosure of Scope 3 emissions by financial market players from 2024. The reason why institutions neglect indirect emissions is the lack of data to quantify them properly.

However, our results reveal that the industrial classification of financial portfolios can be misleading if direct emissions are considered only. In several cases, raw material and resource-intensive industries can have very low direct emissions because GHG gases are emitted in different sectors of the value chain while intermediate goods and services are produced. The most affected industries are hotels and restaurants, construction, manufacturing, and other services, in which overall emissions can be seven times higher on average than Scope 1 values. These results imply that the industries above need particular investment policies and risk management strategies from the banking and investment sectors.

Our analyses could guide financial institutions and companies on how to assess industrial exposures and where to find data. Through the use of EE-MRIOT tables and the Leontief method, market participants will be able to identify the riskiest industries, and after determining their measurements, they can adjust their lending policies to the actual ranking of industrial activities. Moreover, besides the comprehensive measurement of GHG emissions, moving towards carbon neutrality requires disclosing and publishing information. This way, setting up environmentally harmful and unsustainable portfolios would be avoidable. Our results can also be helpful in complying with regulatory disclosures throughout estimating a given sector's overall emissions in portfolio reports.

As part of further research, the currently applied indicators could be recalculated using supervisory or banking data, and lending activities could be adjusted to future results. Based on our results and methods, market participants and advisors can develop models and estimation processes to calculate the overall emissions of portfolios or companies on an industrial basis. Moreover, supervisory authorities should also extend their calculations to the indirect emissions and should introduce new Green Monetary Policy Measures and Green Capital Requirement Allowances for portfolios that do not cause significant harm to the environment. Our method could be further extended to corporate levels and could be made more sophisticated through the hybrid Life Cycle Assessment – Input-Output models.

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Appendix 1

Summary table of sectors used in the analysis. *

Eora	Eurostat	Final sectors
Agriculture	Agriculture, forestry and fishing	Agriculture
Fishing	Agriculture, forestry and fishing	Agriculture
Mining and Quarrying	Mining and quarrying	Mining
Electricity	Electricity, gas, steam and air conditioning supply	Electricity, gas and water
Food & Beverages	Manufacturing	Manufacturing
Wood and Paper		Manufacturing
Textiles and Wearing Apparel		Manufacturing
Other Manufacturing		Manufacturing
Petroleum		Manufacturing
Electrical and Machinery		Manufacturing
Metal Products		Manufacturing
Transport Equipment		Manufacturing
Construction	Construction	Construction
Transport	Transportation and storage	Transportation
Hotels and Restaurants	Accommodation and food service activities	Hotels and Restaurants
Maintenance and Repair	Wholesale and retail trade; repair of motor vehicles and motorcycles	Wholesale and retail trade
Wholesale Trade		Wholesale and retail trade
Retail Trade		Wholesale and retail trade
Financial Intermediation and Business Activities	Information and communication	Others
Post and Telecommunications	Financial and insurance activities	Others
Private Households	Administrative and support service activities	Others
Public Administration	Public administration and defence; compulsory social security	Others
Others	Human health and social work activities	Others
Re-export & Re-import	Arts, entertainment and recreation	Others
Recycling	Other service activities	Others
Education	Professional, scientific and technical activities	Others
	Education	Others
	Water supply; sewerage, waste management and remediation activities	Others
	Real estate activities	Others

* Source: Edited on the basis of Eurostat and EORA26.