Carbon Footprint of Bank Loans: Is Europe Really Going in the Green Direction?

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Abstract

Ambitious environmental goals set by the EU are striving to make Europe a global leader in decarbonizing the whole planet Earth. Based on the euro area data, we investigate whether the banking sector actively supports these initiatives via its loan portfolio carbon footprint. Our main conclusion is that during the observed period, the banking sector acts as a free rider, with emission reductions occurring independently within corporate economic sectors. Spatial intermediation in the context of the green financing paradox does not play a key role. To aid policy-maker decisions, we propose the Composite Carbon Footprint Indicator (CCFI) as a socio-economic tool for classifying economic sectors. By combining GDP and employment data, we can differentiate between economic sectors based on the risk/reward ratio, reflecting the environmental cost of economic expansion and employment goals.

Keywords: *green finance, carbon footprint of bank loans (CFBL), carbon footprint calculation (CFC), ESG risks, climate transition risks, I-O analysis*

JEL Classification: Q50, Q56, G10, G21

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Introduction

The banking sector is now seen as crucial in directing financial resources to sustainable projects. This role is particularly significant in the context of the green transition, requiring a fundamental rethink of traditional banking models. Banks must now integrate environmental factors into lending and investment decisions, significantly altering their credit portfolios. Traditionally, banks have been key intermediaries in financial transactions. Now, they are expected to play a crucial role in *spatial intermediation* and to shift their portfolios towards sectors driving the green transition. The green agenda changes are among the most significant in banking history, surpassing even the Basel Accords' impact. This shift means that banks must incorporate a "green dimension" into their everyday activities, a requirement with far-reaching consequences. This situation can be described as the *green financing paradox*. On the one hand, banks must withdraw and reallocate funds from "brown" enterprises (those with high pollution levels) to "green" enterprises (those with low pollution or net-reducing effects) firms. On the other hand, they must also provide additional funds to "brown" firms to finance their green transition and reduce carbon emissions. Our analysis directly engages with the green financing paradox by examining whether banks are actively reallocating credit from high-emission sectors to support the green transition, or merely benefiting from emission reductions occurring independently within the corporate sector.

The urgency of the green transition is underscored by major international and EU-level commitments. The 2015 Paris Agreement set the global goal of limiting warming to well below 2°C, ideally 1.5°C, prompting the EU to adopt ambitious climate policies such as the European Green Deal and the legally binding EU Climate Law. The Fit for 55 package, part of the EU Green Deal, outlines a comprehensive plan to reduce net greenhouse gas emissions by at least 55% by 2030 compared to 1990 levels. The EU Climate Law legally enshrines the 2050 climate neutrality target and the intermediate target of reducing net greenhouse gas emissions by at least 55% by 2030. These initiatives position Europe as a global leader in environmental standards. Further, the long-term nature of these goals directly impacts the green financing paradox, adding a temporal dimension, or to be specific, vision introduces a temporal mismatch with the typically short-term nature of bank loan portfolios. As Archarya et al. (2023) argue, short maturities limit the impact of long-term climate goals on current credit risk assessments.

Voluntary initiatives like the Net Zero Banking Alliance (NZBA) and the Science Based Targets initiative (SBTi) further reinforce the EU's leadership, with European banks representing over 40% of global assets committed to net-zero targets (NZBA, 2024; SBTi, 2024). In that context, a growing body of research confirms that climate risks are becoming financially material. For example, Aiello and Angelico (2023) show that carbon taxes increase borrower default risk, though within manageable levels. Altavilla et al. (2023) find that banks adjust interest rates based on firms' carbon intensity, especially under tighter monetary policy. Yet, studies like Giannetti et al. (2023) reveal inconsistencies between banks' green disclosures and actual lending behavior, raising concerns about greenwashing. In contrast, Reghezza et al. (2022) and Mueller and Sfrappini (2022) document a post-Paris shift in European bank portfolios toward greener sectors.

Let us mention that a crucial component in credit risk implication is the average maturity of bank loans. In that regard, Archarya et al. (2023) argue that short-term bank loan portfolios mean long-term green goals, like the EU's 2050 targets, and minimally impact default probabilities for existing customers.

The whole concept of the green transition is closely intertwined with the rise of Environmental, Social, and Governance (ESG) principles. This acronym was coined in the 2004 United Nations Global Compact Report. Our research focuses on the "E" in ESG – Environmental. The significance of this component is highlighted by the European Central Bank (ECB), which issued its first guidelines for climate-related and environmental risks in 2020 (European Central Bank, 2020). This document marks the initial step in the regulatory framework, requiring European banks to integrate climate-related risks into their governance structures. Although these requirements are not binding, they signal the ECB's expectations for banks in this area. ESG risks currently trending in the banking industry include climate-related financial exposures, greenwashing concerns, regulatory compliance pressures, and the growing need for reliable ESG data to inform lending and investment decisions.

Environmental risks are categorized into two types: physical risk (the direct adverse impact of climate change) and transition risk (the direct and indirect adverse impact of the process adjustment towards a low-carbon economy). The green financing paradox is closely related to transition risk, as banks need to finance the "greening" of companies. This is central to the Carbon footprint of bank loans (CFBL).

In summary, the EU's proactive approach to the green agenda, backed by strong regulatory frameworks and voluntary initiatives, highlights the crucial role of the banking sector in supporting the green transition. By aligning financial practices with environmental sustainability goals, banks can significantly help to achieve global climate targets. The main research question of this paper is: To what extent does the structure of the EU banking sector's loan portfolio reflect a shift toward lower-emission sectors, and how does this relate to the overall reduction in CFBL in the context of the EU's climate goals? While articles typically explore the CFBL on a national level, such as results for Spain (Maza, 2022) and Italy (Faiella and Lavecchia, 2020), our research focuses on the entire European region. Our analysis introduces an additional analytical tool, the Composite Carbon Footprint Indicator (CCFI), which combines Gross Domestic Product (GDP) and employment data, which has a socio-economic dimension, as it simultaneously measures two categories closely related to national welfare: GDP and employment.

Our study builds on this insight by extending the analysis to the Euro area as a whole, allowing for a supranational comparison of CFBL dynamics. By incorporating a decomposition analysis and introducing the CICF, we provide a more granular understanding of whether observed reductions in financed emissions are the result of deliberate financial intermediation or structural shifts in sectoral emissions. In doing so, we offer a broader policy perspective on the effectiveness of green finance strategies across diverse regulatory and economic environments.

The structure of the paper is as follows. Section 1 reviews the key literature, focusing on the CFBL calculation. Section 2 outlines sources and research design. In section 3, we introduce a new composite indicator that classifies industries based on the GDP and employment risk/reward ratios in the context of pollution. Section 4 presents core calculations for the CFBL in a European context. The final Section concludes the paper with a summary of conclusions and findings.

1. Literature Review

The intersection of climate change, carbon emissions, and bank lending has become a central focus in both academic and policy discussions, particularly in the context of the financial sector's role in supporting the green transition. Recent literature has explored this nexus from multiple angles, including credit risk, portfolio reallocation, regulatory responses, and methodological innovations in measuring financed emissions.

A growing body of research has examined how environmental risks are increasingly shaping credit risk assessments and lending behaviour within the banking sector. These studies collectively underscore the financial materiality of climate-related exposures and the evolving role of banks in managing them. For instance, Aiello and Angelico (2023) conduct a counterfactual analysis of Italian banks and find that the introduction of carbon taxes leads to higher default probabilities among borrowers. However, even at elevated tax levels (EUR 50 to EUR 800 per ton of CO_2), the resulting credit risk remains below historical stress thresholds, suggesting that while climate policy introduces new financial risks, these may be manageable within existing risk frameworks.

Building on this, Altavilla et al. (2023) explore how banks price climate risk into lending decisions across the Eurozone. Their findings reveal that banks systematically adjust interest rates based on firms' carbon intensity to reduce emissions by offering more favourable terms to those committed to decarbonization. Moreover, they show that tighter monetary policy amplifies these effects, increasing the credit risk premium for high-emission firms more than for their low-emission counterparts.

This emerging evidence base supports the broader argument that banks must integrate environmental considerations into their credit risk models and lending strategies. As climate-related risks become more quantifiable and financially relevant, they are increasingly influencing the allocation of capital. The implications are clear: climate risk is no longer peripheral to financial stability, but a central factor in shaping the future of banking and credit intermediation.

Another strand of the literature examines the alignment – or often the misalignment – between banks' environmental disclosures and their actual lending behaviour. Giannetti et al. (2023) uncover the evidence of potential greenwashing, showing that banks with strong environmental disclosures frequently continue to finance high-emission ("brown") firms. This suggests that public commitments to sustainability may not always translate into meaningful changes in credit allocation. In contrast, Reghezza et al. (2022) and Mueller and Sfrappini (2022) document a different trend in broader literature: following the Paris Agreement, many European banks began to reallocate their portfolios toward greener sectors, reducing exposure to polluting industries. These divergent findings highlight the complexity of evaluating banks' true environmental impact and underscore the need for robust, transparent, and standardized metrics in this context.

To address this need, several methodological contributions have emerged. Kutlukaya et al. (2023) introduced the CFBL indicator as part of the IMF's Climate Change Indicators Dashboard. This macro-level tool quantifies the carbon intensity of bank-financed activities and has been applied to assess transition risks across countries. Maza (2022) provides a detailed application of the CFBL methodology to the Spanish banking sector, offering one of the earliest national-level empirical assessments of financed emissions. The study finds that the carbon footprint of business loans in Spanish credit institutions declined significantly over the observed period. This reduction was attributed to two main factors: a structural shift in the loan portfolio toward less polluting sectors, and a general decline in emission intensities across the Spanish economy.

Importantly, Maza's work highlights the dual role of both financial intermediation and real-sector decarbonization in shaping the CFBL trend. By decomposing the drivers of change, the study underscores the importance of distinguishing between active credit reallocation by banks and passive improvements in sectoral emissions. Our research builds on this approach by extending the analysis to the Euro area level, enabling a supranational comparison and offering broader policy insights into the effectiveness of green finance strategies across diverse economies. Faiella and Lavecchia (2020) conducted a comparable study for Italy, emphasizing the role of sectoral composition in shaping the carbon footprint of bank loans. Hence, this analysis provides a pioneering national-level application of the CFBL framework to the Italian banking sector. Their study investigates the carbon footprint of loans issued by Italian financial institutions and explores how sectoral composition influences the overall emissions profile of bank portfolios. The authors find that while there is some evidence of a gradual shift in lending toward less carbon-intensive sectors, the overall reduction in CFBL is modest and largely driven by improvements in emission efficiency within sectors rather than by active credit reallocation. This distinction is critical, as it suggests that banks may not be proactively steering capital toward greener activities, but are instead passively benefiting from broader decarbonization trends in the real economy.

Additional contributions in the literature further contextualize our approach. Umar et al. (2021) find that carbon-neutral lending is associated with lower credit risk in the Eurozone, while Degryse et al. (2023) show that green firms benefit from more favourable loan pricing, particularly after the Paris Agreement. De Bandt et al. (2023) provide a comprehensive review of climate-related risks in banking, reinforcing the need for integrated risk assessment tools. Finally, the Partnership for Carbon Accounting Financials (PCAF, 2022) has established standardized methodologies for GHG accounting in financial institutions, which underpin many of the indicators used in this study.

2. Data

Given our interest in a macroeconomic perspective, the basis for our analysis is the credit portfolio of the European banks on a global level. Unlike other studies that have access to loan-level portfolio analytics databases, such as AnaCredit or large exposure data provided to ECB, we do not have access to such microdata. Specifically, our focus is on the corporate part of the credit portfolio, as the core green transition must occur there. This includes classes Business loans and unlisted equity, Project finance, and Commercial real estate, as defined by PCAF (2022).

When we refer to "European", we mean the Euro area due to data availability. According to EUROSTAT, the Euro area represents approximately 85% of the European Union (EU) GDP, which also accounts for a significant portion of Europe as a whole. Given this high participation, we approximate the EU with Euro area data and, ultimately, with the entire European continent.

The European Central Bank (ECB) monitors loans from Euro area monetary financial institutions to non-financial corporations (NFC) by economic activity on a quarterly basis. This dataset forms the foundation of our research, as it reflects the structure of a corporate credit portfolio, and it enables us to track its evolution over time. Our methodological approach relies on the use of NACE Rev. 2 classification for defining business activity (Level 1), acknowledging that the scope and level of detail can vary from country to country (European Central Bank, 2024). Financial and public sectors are excluded,[1] focusing solely on exposures to pure corporate NFCs and data for the loan portfolio represents outstanding amounts of the loans. Some business sectors are aggregated, and the ECB tracks their data cumulatively due to their homogeneity. We refer to this classification as ECB sectors throughout the research, with the final list and scope description provided by the ECB (see Table 1).

Table 1

ECB Sectors Scope and Definition

Sections	Description
A	Agriculture, forestry and fishing
B	Mining and quarrying
C	Manufacturing
D + E	D. Electricity, gas, steam and air conditioning supply + E. Water supply, sewerage, waste management and remediation activities
F	Construction
G	Wholesale and retail trade; repair of motor vehicles and motorcycles
H + J	H. Transport and storage + J. Information and communication
L + M + N	L. Real estate activities + M. Professional, scientific and technical activities + N. Administrative and support service activities
I	Accommodation and food service activities
Z	All remaining activities (P. Education; Q. Human health and social work activities; R. Arts, entertainment and recreation; S. Other service activities; T. Activities of households as employers; undifferentiated goods – and services – producing activities of households for own use; U. Activities of extraterritorial organisations and bodies)

Source: European Central Bank.

The evolution of ECB sector loan data provides a valuable lens through which to examine the structural changes occurring in the Euro area banking sector. This data enables us to track shifts in the composition of corporate loan portfolios over time (Figure 1). Although data collection by the ECB began in Q1 2003, for ease of tracking changes, we present data from 2008 onwards. It is evident that there has been a shift towards service sectors,[2] as the LMN sector has significantly increased

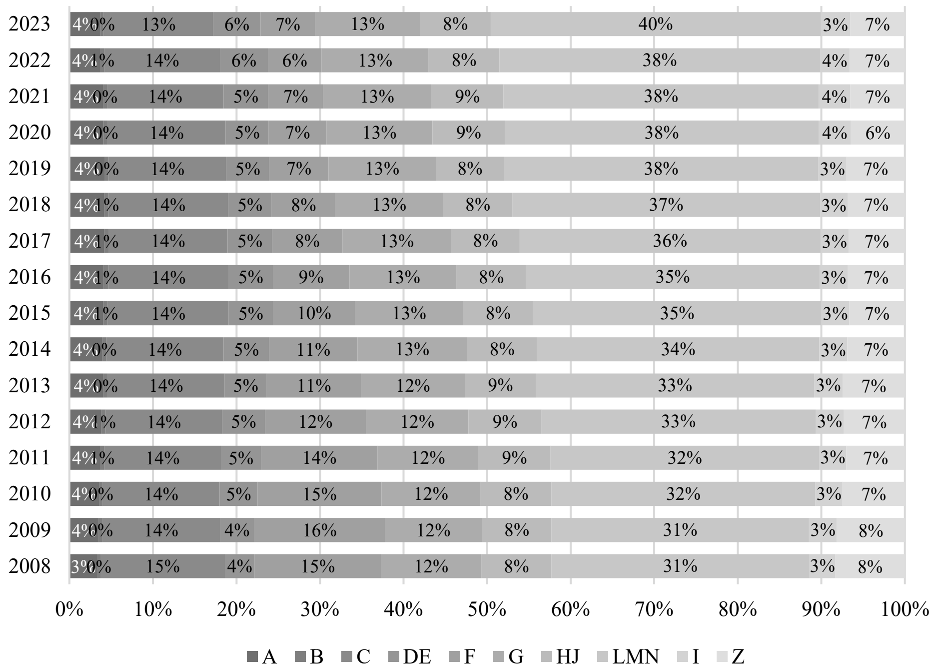
[1] Section K (Financial and insurance activities) and Section O (Public administration and defence; Compulsory social security) of the NACE Rev. 2 classification are excluded from the data collecting process.

[2] According to the (European Commission, 2013), Service sectors are G, H, I, J, K, L, M, N, O, P, Q, R, S, T and U.

its share at the expense of the construction sector (F section). As previously explained, the ECB monitors these sectors on an aggregate basis, and we do not have an analytical breakdown by individual NACE Level 1 categories. However, we can infer that the real estate segment is driving this change.

F i g u r e 1

Loans from Euro Area Monetary Financial Institutions to NFC by Economic Activity



Source: European Central Bank.[3]

The remaining datasets are sourced from EUROSTAT, aligned with the Euro area scope. A crucial dimension in our research design is GHG data related to atmospheric pollution. All harmful gases (carbon dioxide – CO_2, methane – CH_4, nitrous oxide – N_2O, hydrofluourcarbons – HFCs, perfluorcarbons – PFCs, sulfur hexafluoride SF_6, and nitrogen trifluoride NF_3) are expressed in CO_2 equivalents, as CO_2 is the most relevant and acts as a synonym for the pollution. Presentation is done on a country level and we aggregate it for our research purposes.[4] The

[3] Data are extracted for every ECB sector and, for example, for industry activity A can be found on: <https://data.ecb.europa.eu/data/datasets/BSI/BSI.Q.U2.N.A.A20EST.A.1.U2.2240A.Z01.E> Every attribute of the ECB database code is the same except for BS counterpart sector which is changing, i.e. in this example, it is 2240A and last letter represents the ECB sector.

[4] Source for the data: <https://ec.europa.eu/eurostat/databrowser/view/env_ac_ainah_r2__custom_12781118/default/table>.

GHG data is expressed in tonnes of CO_2 by the economic sector, classified by NACE Rev. 2, on an annual basis. Our methodological framework follows the ECB sector definitions, summarizing the corresponding Level 1 sectors. For a detailed analysis of the emission intensities, we used the Level 2 granularity, prescribed as NACE A*64 in the European System of Accounts – ESA 2010 (European Commission, 2013). A list with this level of granulation is presented in Appendix: NACE A*64.

To analyse direct emissions produced by each economic activity sector, we need GDP data for the corresponding sectors to calculate intensities.[5] The same level of granularity is applied to GHG data. Another aspect that we analyse is per capita intensities, i.e. the average CO_2 emissions contribution per employee in each sector. For this, we obtained employment data (total employment domestic concept) by economic activity, aligning all structures with the GHG data.[6]

CFBL varies significantly between developed and developing countries. Aggregating these differences into a single average can mask critical disparities, limiting the indicator's usefulness for targeted policy-making. Disaggregated analysis is essential for more effective, context-specific interventions and in our future work we have intention to make such an extension.

The main relations between economic sectors are presented in the input-output (IO) tables. This inter-sector analysis provides valuable information, showing all interactions among sectors. The main component of IO tables is intermediary output from one sector which is used as an input for another, allowing us to reconstruct all connections as coefficients. The most challenging step in the preparation of the IO data was summarizing effects at the NACE A*64 level, which EUROSTAT monitors, to the level of ECB sectors.[7] The procedure required us to aggregate columns and rows in matrix format to summarize results from the NACE A*64 level and express them in terms of the ECB sectors. This complex data aligns with the calculation for the CFBL, giving us the final period for observation 2010 – 2022.

Energy consumption is measured in physical units, while economic activity is quantified in monetary terms, necessitating compromise between these aspects. Generally, energy IO analysis determines the amount of energy required for

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[5] Source for the GDP data on L1 level: <https://ec.europa.eu/eurostat/databrowser/view/nama_10_a64__custom_12767661/default/table> and L2 level (NACE A*64 level): <https://ec.europa.eu/eurostat/databrowser/view/nama_10_a64__custom_12797369/default/table>.

[6] Source for the number of employees data: <https://ec.europa.eu/eurostat/databrowser/view/nama_10_a64_e__custom_13266652/default/table>.

[7] Source for the IO tables L2 level (NACE A*64 level): <https://ec.europa.eu/eurostat/databrowser/view/naio_10_cp1750__custom_12879933/default/table>.

a product to meet final demand, involving both direct and indirect energy consumption. In production, the required materials, parts, and energy are analysed within the technological process of a product, with a similar approach applied to services. Each production process includes specific energy and non-energy elements, and energy inputs necessary for producing non-energy elements are also considered.

From an IO perspective, assessing energy needs essentially involves determining how much energy, both direct and indirect, is required for a sector to produce one monetary unit of its identified product. Direct energy needs refer to the energy directly consumed in production, while indirect energy needs include the energy used in producing non-energy elements of the production process. Summing direct and indirect energy needs gives us the total energy requirements.

For example, in a bakery production process, the energy used for baking is a direct energy need, while the energy used to mill the grain is an indirect energy need. This approach can encounter complications with imported inputs or the production of energy as a by-product.

In IO analysis, the "energy intensity" of an industry often refers to total energy needs, analogous to the Leontief inverse matrix. An energy (technical) coefficient matrix is formed, defining how many monetary units of input are needed to produce one monetary unit of output. In energy IO analysis, energy needs are generally expressed in physical units. One way to incorporate physical units is to first determine energy needs in monetary units using conventional IO methodology and then convert these values into physical units. This approach has drawbacks, particularly in maintaining consistency in energy consumption coverage and applying specific criteria.

We distinguish between primary energy sectors (coal, crude oil, solar energy, hydro energy) and secondary energy sectors (refined oil, electricity, etc.). Secondary energy sectors use energy from primary sectors as inputs and convert it into secondary energy forms. The total energy of the primary energy sector needed to produce industry output must equal the total energy of the secondary energy sector needed to provide the same output, accounting for energy losses during the conversion (e.g., electricity production in coal-fired power plants). Different technologies have varying efficiencies; for example, nuclear power plants are far more efficient than solar power plants.

Overall, it is crucial to ensure that the total primary energy intensity and total secondary energy intensity, increased by the energy lost in conversion (or used in other ways during the conversion process), are equal. This condition, termed the energy conservation condition, is essential for providing a credible representation of an economy's energy flows through an IO model.

The IO tables and value-added data used in this study are expressed in current prices. While this reflects actual monetary flows, it also introduces sensitivity to inflation and sectoral price shifts over time. As a result, emission intensity indicators involving value added may partially capture price effects rather than purely physical changes. This should be considered when interpreting overall results.

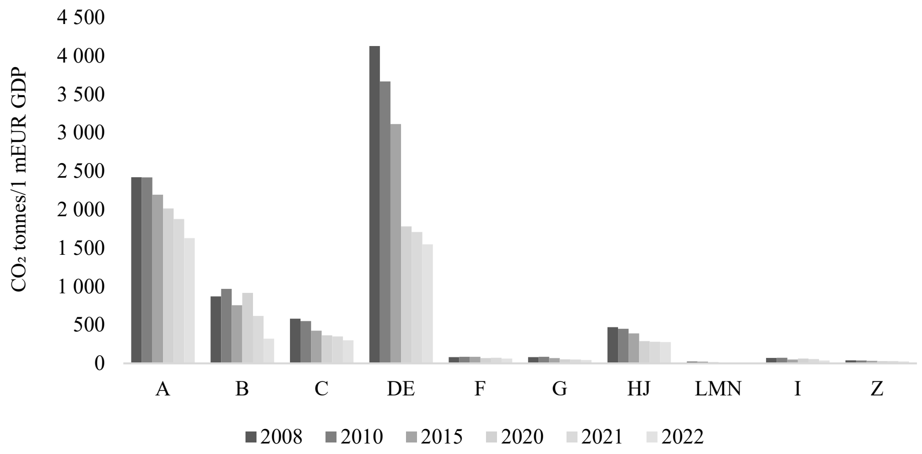
3. Carbon Footprint (GHG) Economic Activity Indicators in Europe

Direct emissions are the starting point in GHG analysis. We adopt the methodology proposed and applied by Kutlukaya et al. (2023) and Maza (2022) for calculating the emission intensities within the corresponding sector:

$$q\_GDP_{it}^{direct} = \frac{Greenhouse\ gasses_{it}}{Value\ added\ gross_{it}} \tag{1}$$

Direct emission intensity coefficients are calculated as a ratio between GHG emissions and GDP (*Value added gross*) in every sector of activity (*i*) and year (*t*). This typical intensity indicator provides information on how many CO_2 tons are emitted per 1 million EUR generated in the corresponding sector. In other words, it indicates opportunity cost in terms of environmental pollution, showing how much CO_2 is emitted for every 1 million EUR of GDP created. A detailed analysis is conducted at the L2 level (NACE A*64) to obtain comprehensive information for industry classification. For further analysis, calculations are performed at the ECB sector level.

Figure 2
Direct Emissions per 1 mil. EUR of GDP – ECB Sector



Source: Authors' calculation based on ECB and EUROSTAT data.

Data in Figure 2 indicates that the agriculture sector is now the most polluting, as the energy and waste sectors (DE) have significantly decreased their emissions over the past three years compared to 2015. Each sector is presented based on its pollution/development characteristics, akin to a risk-reward ratio, similar to the Sharpe ratio in investment analysis.

As an additional measure, we have created a second indicator – direct emission intensities per capita:

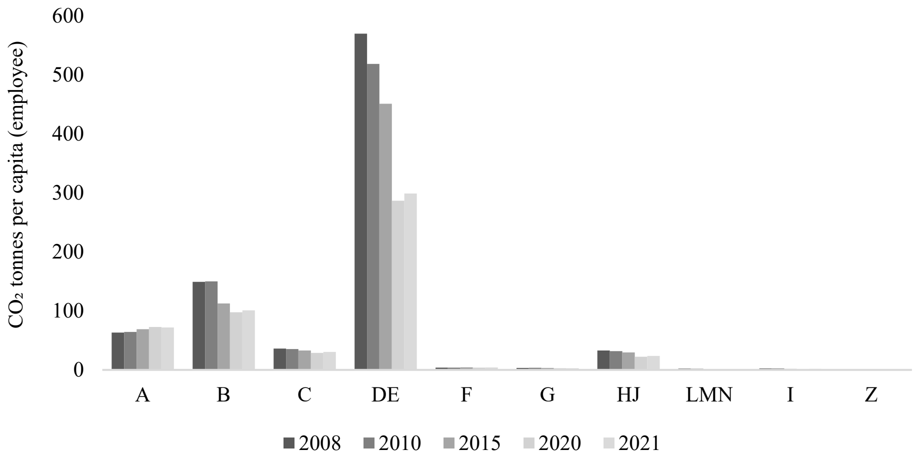
$$q\_EMP_{it}^{direct} = \frac{Greenhouse\ gasses_{it}}{Number\ of\ employees_{it}} \qquad (2)$$

This ratio represents the amount of GHG (CO_2 equivalent) produced by a single employee in each sector (*i*) for every year (*t*). It provides an overview of productivity from an environmental perspective, which can be utilized in economic policy to promote more sustainable development. The results for the ECB sector are presented in Figure 3. The data clearly shows the dominance of the DE sector in terms of pollution per employee.

Similar to the previous indicator for the economic intensity indicator, this ratio functions as a risk/reward measure, indicating how much environmental pollution is associated with job creation in each sector.

F i g u r e 3

Direct Emissions per capita (employee) – ECB Sector



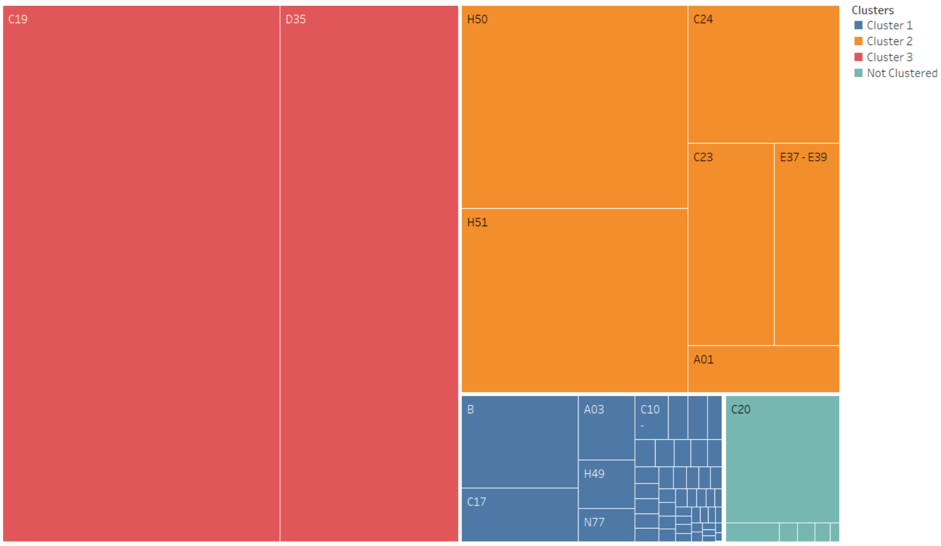
Source: Authors' calculation based on ECB and EUROSTAT data.

These two ratio intensities complement each other. The first ratio, economic intensity, focuses on creating growth and a wealthier society, while the second ratio, intensity per capita, emphasizes full employment, which is also a prominent goal. Both ratios contribute to the ultimate societal objective: the growth of welfare. By combining these ratios, we have created a hybrid indicator called the *Composite Indicator of Carbon Footprint* (CICF). This indicator captures the socioeconomic dimension related to the GHG effects. We use K-means clustering to evaluate industry sectors based on the indicators in Equations 1 and 2.

Specifically, this study employs K-means clustering, a method of vector quantization that aims to partition a given number of observations into a specified number of clusters (Hancock et al., 2018). The objective of K-means clustering is to minimize the within-cluster variance, ensuring that the data points within each cluster are as similar as possible. GHG/VA and GHG/EMP indicators are not mathematically aggregated but are used as input features in a clustering algorithm. The procedure involves initial random assignment of centroids, assignment of data points to the nearest centroids based on Euclidean distance, recalculation of centroids, and iterative reassignment until convergence. The elbow method is utilized to determine the optimal number of clusters. This method involves plotting the explained variance as a function of the number of clusters and identifying the "elbow point" where the rate of improvement slows down, indicating the optimal number of clusters. This comprehensive methodology allows for the identification of clusters that provide insights into the underlying factors driving the carbon footprint of bank loans and helps uncover unique trends related to the green transition in Europe.

F i g u r e 4

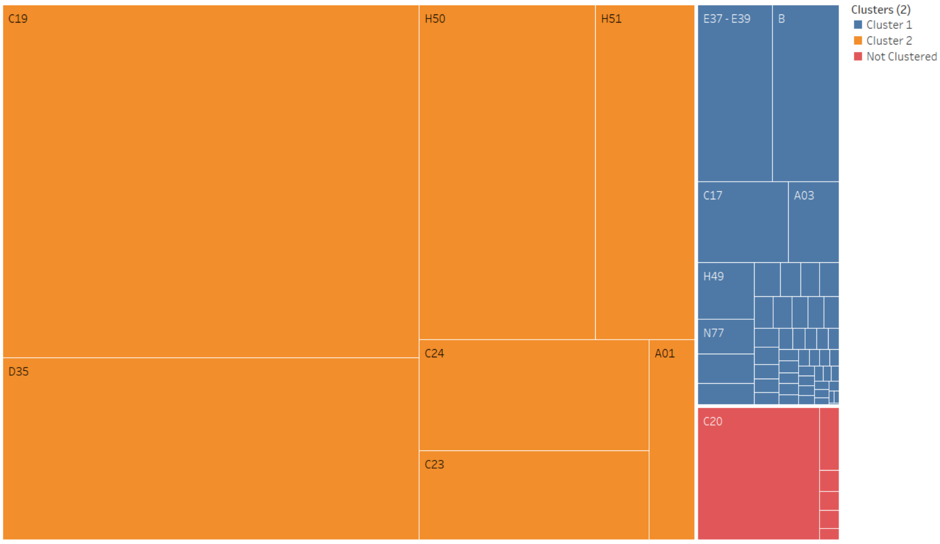
Composite Indicator of Carbon Footprint (CICF) – 2015



Source: Authors' calculation based on ECB and EUROSTAT data.

F i g u r e 5

Composite Indicator of Carbon Footprint (CICF) – 2021



Source: Authors' calculation based on ECB and EUROSTAT data.

For methodological consistency and accurate interpretation, both sub-indicators must exhibit desirable direction. Lower values indicate better efficiency concerning the GHG parameter, and vice versa. This translates to a unique interpretation of CICF. We present results at Level 2 (A*64 level with codes presented in the Appendix) to provide a more granular overview of the industries. This tool allows for a broader classification of the industries. Policymakers can use this heat map as a foundation for their decisions, enabling them to proactively align strategies for each industry. Results are calculated for 2015 because it is the year of the Paris Agreement (Figure 4), and for 2021 as the last year with available data for employment (Figure 5). In 2015 we had 3 clusters, with industries Manufacture of coke and refined petroleum products (C19) and Electricity, gas, steam and air conditioning supply (D35) as critical ones, while in 2021 we have 2 clusters where among these two mentioned industries we can add C23, C24, H50, H51, and A01. Interestingly, E37 – E39 would not be in focus for 2021, while in 2015 it was part of the middle cluster.

4. Carbon Footprint (GHG) of Bank Loans in Europe

A crucial part of our research is the calculation of the Carbon Footprint of Bank Loans (CFBL) in Europe. Our focus is on the corporate segment and the transition required across the entire economy to reduce pollution. The CFBL serves as a key indicator of how the banking industry influences this transition. As with direct emission intensities, we follow the methodology proposed by Kutlukaya et al. (2023), which forms the basis for the IMF's CFBL Climate Finance indicator.

The main component of our model is the input-output (IO) table (Nansai, 2009; Miller and Blair, 2011) used as an analytical tool to describe the interdependencies between sectors. This approach aligns with energy-economic-ecological models (Faucheux and Lavarlet, 1999). It is important to note that in ecological IO analysis, there is an assumption of clear separation of individual fossil (primary) fuels (coal, oil, gas), as each has a different level of pollution per unit of energy produced.

As we emphasized in Section 2, the most demanding data preparation step was the creation of the IO table for the ECB sector because the IO data granularity is at the L2 level (NACE A*64) and aggregation is performed to align the scope of sectors with Table 1. This process is repeated for each year for which we have IO data (2010 – 2022). An example of the final IO presentation for 2022 is provided below.

T a b l e 2

IO Table ECB Sectors for 2022

	A	B	C	DE	F	G	HJ	I	LMN	Z
A	61.320	123	252.217	2.088	1.413	8.720	1.435	15.545	4.847	3.819
B	1.134	4.997	198.946	30.319	13.235	2.824	3.368	698	1.953	1.478
C	101.156	9.722	2.564.451	100.477	388.521	177.752	206.999	123.345	137.726	189.337
DE	14.462	6.849	236.684	442.977	18.000	47.263	45.130	24.147	28.395	51.165
F	5.726	1.530	53.460	30.119	341.091	17.778	30.763	7.313	26.173	31.678
G	37.523	5.260	644.197	40.494	103.801	203.667	172.486	49.640	85.171	103.830
HJ	9.373	6.694	415.096	55.039	44.156	312.310	792.921	22.507	173.214	91.144
I	1.221	612	32.074	3.900	11.793	20.138	37.182	8.376	34.797	32.206
LMN	18.305	6.818	446.247	70.543	141.214	250.649	286.274	38.270	591.955	136.807
Z	2.085	662	49.064	7.991	8.814	23.656	34.697	8.786	41.809	147.520

Note: Data in million EUR.

Source: Authors' calculation based on EUROSTAT data.

The concept of inter-sector intermediation, where the GDP value added from one sector is used as an input for another sector and vice versa, can be used to determine the through-the-value chain. This approach allows for the calculation of indirect emission intensities by translating pollution from one sector to another. This process is quantified using the Leontief inverse matrix (Miller and Blair, 2011):

$$L = \left(I - \underbrace{Z\hat{x}^{-1}}_{A} \right)^{-1} \tag{3}$$

In this context, Z represents the matrix of IO linkages, $\hat{x}^{-1}$ is the diagonal matrix constructed from the inverses of final production in each sector, and A is the technical coefficients matrix obtained by multiplying Z and $\hat{x}^{-1}$. As an example, the L matrix for 2022 is shown in Table 3.

T a b l e 3

L Matrix ECB Sectors for 2022

	A	**B**	**C**	**DE**	**F**	**G**	**HJ**	**I**	**LMN**	**Z**
A	1.161205	0.015005	0.069715	0.014884	0.022621	0.012612	0.011086	0.042318	0.009909	0.009138
B	0.018624	1.075888	0.053438	0.047536	0.026364	0.008521	0.009952	0.014759	0.006963	0.006905
C	0.438548	0.284522	1.679378	0.266074	0.492059	0.181125	0.213597	0.363870	0.153002	0.158841
DE	0.086621	0.160079	0.109479	1.553231	0.059813	0.051125	0.054330	0.086810	0.037614	0.045689
F	0.028256	0.037580	0.027962	0.053698	1.247036	0.018351	0.026223	0.024993	0.021618	0.021081
G	0.157472	0.129303	0.200286	0.103583	0.148980	1.127848	0.124947	0.138228	0.075525	0.072584
HJ	0.110785	0.187693	0.199057	0.151417	0.130950	0.218541	1.423319	0.119001	0.144923	0.085570
I	0.010020	0.015965	0.015661	0.011868	0.016646	0.015302	0.023361	1.019456	0.020887	0.016470
LMN	0.135160	0.189821	0.204316	0.173718	0.208673	0.187282	0.217205	0.146915	1.325876	0.105976
Z	0.014403	0.019056	0.021638	0.018624	0.017348	0.018469	0.024598	0.022650	0.025828	1.061098

Source: Authors' calculation based on EUROSTAT data.

This matrix can be used to calculate the total emission intensities for the corresponding sectors as follows:

$$q'^{total} = q'^{indirect} + q'^{direct} = q'^{direct} L \tag{4}$$

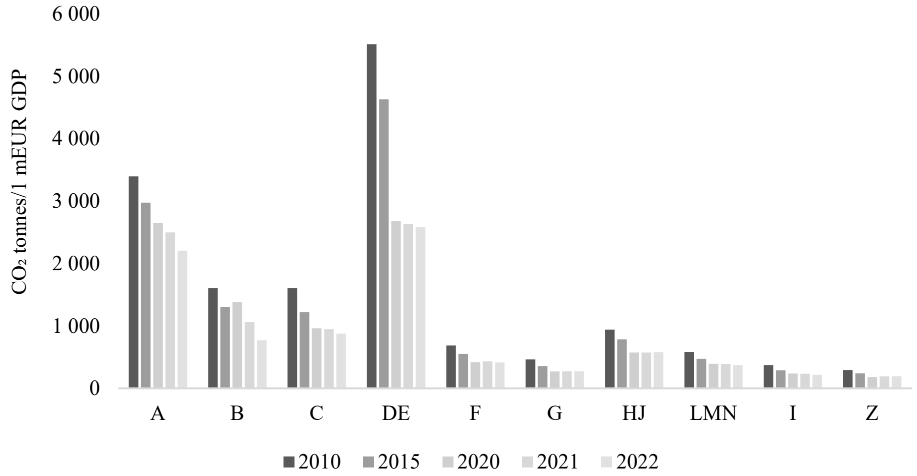
Our methodological approach is intricately linked to the concept of the ecological IO table (Nansai, 2009). In defining the ecological weight of a sector, we utilize a vector representation that quantifies the allocation of ecological units per unit of the sector's product.

This vector encapsulates the environmental impact associated with the production processes within the sector, providing a comprehensive measure of resource utilization and ecological footprint. By assigning specific weights to each unit of product, we can systematically evaluate and compare the sustainability of different sectors, facilitating targeted strategies for reducing environmental impact and promoting sustainable practices. This approach enables a nuanced understanding of the ecological implications of sectoral activities, thereby informing policy decisions and resource management.

Considering only direct emission intensities leads to an underestimation of the total negative effects, potentially distorting sector comparisons. By including the additional negative effects occurring throughout the value chain, we can achieve a more accurate and comprehensive overview of the influences exerted by different economic sectors. The simplest way to incorporate energy issues into the framework of IO analysis is by adding a set of linear energy coefficients that define how much energy is required to produce one monetary unit of output. This approach has essentially remained since the pioneering days of the late 1970s. Although this method has certain methodological shortcomings, it remains justified due to the chronic lack of adequate data often encountered in IO analysis.

For instance, Nansai (2009) discusses the integration of energy coefficients in ecological IO tables, highlighting the importance of accurate data for effective analysis. Similarly, Miller and Blair (2011) emphasize the role of energy coefficients in their comprehensive review of IO analysis methodologies. Despite the limitations, this approach continues to provide a robust foundation for analysing the energy consumption and environmental impact of economic activities.

F i g u r e 6
Total Emissions per ECB Sector



Source: Authors' calculation based on ECB and EUROSTAT data.

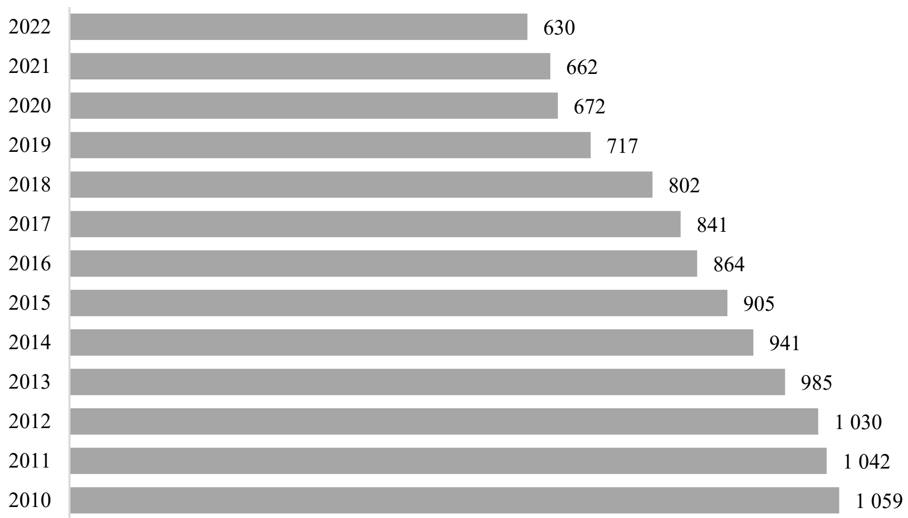
When comparing the results between Figure 2 and Figure 6, we see the importance of including total emissions rather than just direct emissions within a particular sector. The top polluter has changed, with the energy and waste sectors (DE) surpassing agriculture due to greater integration with other sectors. According to IO tables, their intermediation is significantly larger, which amplifies the pollution effect. This shift occurs despite these sectors showing substantial reductions in emissions since 2015. The IO tables provide a detailed framework for tracing the flow of emissions through the entire economic system, highlighting the interconnectedness of sectors and the cumulative impact of their activities.

In the final step, we integrate results from the portfolio composition (Figure 1) and total emission intensities (Figure 6), as a global overview of Europe's banking sector contribution to the goals set through the EU Green deal. This is an aggregate indicator of the CFBL, based on Kutlukaya et al. (2023), that can have informative power about how banks' decisions on directing the funds are influencing environmental pollution:

$$CFBL_{it} = \frac{\sum_i L_{it} q_{it}^{total}}{\sum_i L_{it}} \quad (5)$$

where L_{it} is the total amount of outstanding loans in each sector (i) and year (t), while q_{it} total has its meaning as in Equation 4. CFBL can be interpreted in a usual manner as an intensity indicator, as we described for direct emissions in Section 3. It is practically a risk/reward ratio and tells us how many tons of CO_2 equivalent we are polluting for one million euros that is financed for every sector of the economy. The ultimate goal is the maximum reduction of the CFBL, in the sense that pollution created in Scope 3 that banks are financing is minimized. Results for the Euro area, with what we are approximating the whole of Europe, are presented in Figure 7.

F i g u r e 7
CFBL for the Euro Area



Source: Authors' calculation based on ECB and EUROSTAT data.

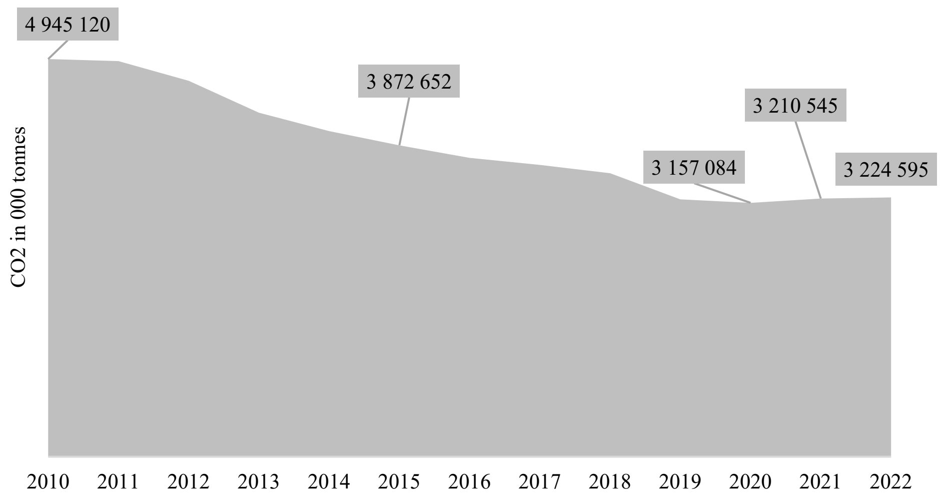
CFBL has two main components, the structure of the portfolio and total emission intensities. The banks can actively influence only the structure of their portfolio while on total emission intensities they can only have an implicit impact. This is a long-term dimension that is under reflection of many other aspects in the business activity pollution of the environment. First of all, regulatory obligations by the state are pushing producers to think about their supply chain and the direct emissions they create. Banks are also actively involved in this process, but their impact is primarily expressed in directing the funds („spatial intermediation“ as we call it) towards green industries. Results in Figure 7 give us an insight into the contribution of the banking sector in the Euro area financing to the pollution of the environment. This contribution is almost half reduced, from 1.059 tonnes CO_2/1 mil. EUR to 630 tonnes CO_2/1 mil. EUR, in the observed period. The conclusion is automatically derived that these results support the EU Green Deal and its overall green agenda. They are in line with Kacperczyk and Peydró (2022) and evidence of the reshuffling of the portfolio as a flow from brown to green firms. The underlying data for this research is from the syndicate loan market, which is by definition big corporate tickets, and in the sample are also present firms from Europe (they represent ¼ of the whole sample size). Also, Altavilla et al. (2023) investigated the pricing of the carbon aspect in the credit decisions using analytical data exclusively for Europe (AnaCredit database from ECB) and found out that banks increase both credit risk premia and carbon risk premia for firms with higher carbon emissions and lower spreads for those that established SBTi targets. It is practically a form of credit rationing but now with an environmental aspect. On the other hand, we have an article Giannetti et al. (2023) where opposite arguments are presented. The basic data also comes from AnaCredit, i.e. it is very important for our research design because Europe is the focus, and the main outcome of the results is that there is no credit supply reallocation because banks still provide additional funds to brown firms, although they officially declare sustainability in their disclosures.

It is evident that from 2020 CFBL is substantially lower and for the first time it is below 700 CO_2/1 mil. EUR. The importance of this year is emphasized twofold. First, the COVID-19 crisis emerged creating lockdowns led by a substantial reduction of the GHG component (European Commission, 2024) with distorted pictures about the true trends. Second, it is the year when the ECB issued its Guidelines (European Central Bank, 2020) where among the expectations are the ones that banks should as part of their RAF (*Risk Appetite Framework*) include limits on economic (sub-)sectors that can cause an anticipated change of the structure, i.e. support spatial intermediation. There is also one of the principles for setting the limits to economic sectors in the (BCBS, 2022). Using the CFBL we can approximate full influence on the environment (Scopes 1, 2, and 3 defined by (PCAF, 2022)) of the whole financing by the banking industry (Figure 8).

Rebound after the COVID-19 crisis left its mark on the absolute pollution that banks in the Euro area are financing. Economic recovery and expansion of the credit portfolio[8] have a direct impact on the overall emissions, which are growing although CFBL as a multiplier is lowering.

[8] Corporate credit portfolio which is in the focus of the research has for the first time exceeded 5 trillion EUR in 2022.

F i g u r e 8
Total Financed Pollution by Euro Area Banks



Source: Authors' calculation based on ECB and EUROSTAT data.

The main question now arises: what component of the CFBL is the driver of its change? Lowering the CFBL values, i.e. improving the contribution of the banks in Europe, is done by the two sides. One side is the change in the structure of the credit portfolio which has occurred in European banks (Figure 1) and the other component is the decreasing trend of total emission intensities which occurred in economic sectors per se (Figure 6).

There is obvious evidence that the portfolio of European banks in recent years has been more in favour of the service sector, which by default has a much less negative impact on the environment than the agriculture and industry sectors. It can be seen as a reflection of the changing structure of the GDP where for Euro area is evident that agriculture and manufacturing are decreasing contribution. Manufacturing still has its dominance, but participation in the overall GDP has declined below 30%. This conclusion is aligned with the results from Reghezza et al. (2022) where it is stated that European banks started to reduce their portfolio towards polluting firms after the Paris Agreement by about 3 percentage points. This research is important because it has micro character, i.e. the underlying data is based on large exposure reports provided to the ECB and individual emissions by firms. Using the large exposures loan-level data means that only big corporate clients are included in the sample (they stated that the average asset size is 90 billion USD), which might give some distorted picture because the whole corpo-rate sector was not involved but, on the other hand, they are the ones that have polluting data on an individual level. Mueller and Sfrappini (2022) also investigated changes in the bank's pattern caused by the Paris Agreement. Although their basis is syndicated loans which are by default big corporate tickets and a low portion of the sample is related to clients from Europe (295 firms which represents only 15% of the whole sample), for our research it is important that there is evidence that banks in Europe shifted credit supply to the so-called positively exposed firms, as opposed to the trends on the USA market. Positively exposed firms are an interesting concept that is not based on carbon emissions but on the perception that the firm will benefit from future regulatory developments. In other words, these firms will not have a negative impact from the green transition, and the expectation is that they will benefit from it.

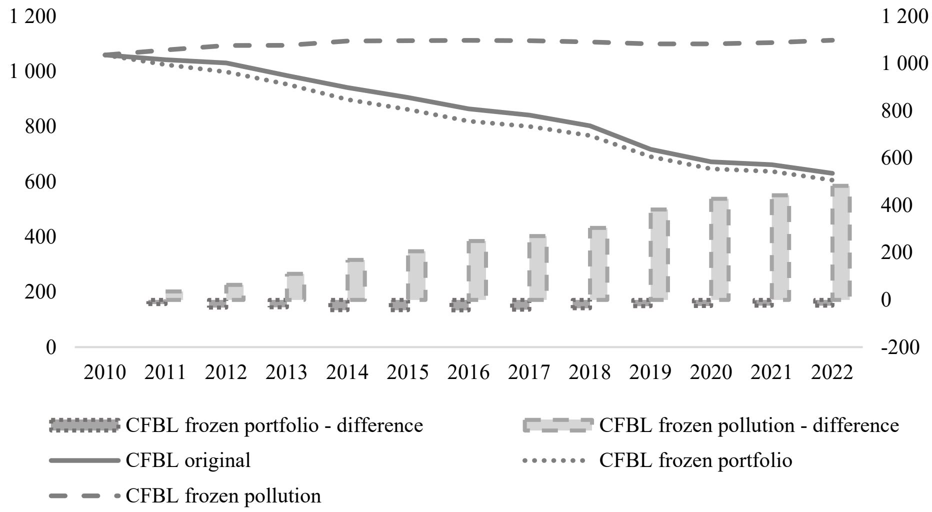
The recomposition of the credit portfolio that happened has a direct consequence on the Scope 3 emissions of the European banks. Shifting towards low-emission economic activities certainly has a positive effect on overall CFBL. This reshuffle of the portfolio can be analysed in conjunction with the argument from Acharya et al. (2023) where it is stated that the average maturity of the bank portfolio is much shorter than long-term goals.

According to the study by Berg et al. (2017), the average maturity of syndicated loans from the large corporate sector is almost 5 years (57 months). The main question is will this change of flows that is happening in the Europe banking industry be consistent with the objectives set by the EU Green Deal. To isolate the effects of the change in the structure of the portfolio and total emission intensities, we recalculate CFBL in two ways. First, we calculate CFBL with frozen portfolio presumption ($CFBL_{frozen\ portfolio}$), i.e. we use the constant structure of the credit portfolio from 2010. Second, we use the presumption of constant pollution ($CFBL_{frozen\ pollution}$) which means that we freeze the results for total emission intensities from the base year. This implies also that all the structural characteristics of the economic parameters stay the same as in 2010. The results of both exercises are presented in Figure 9.

$CFBL_{original}$ as we call it, which is the actual CFBL presented in Figure 7, and the $CFBL_{frozen\ portfolio}$ have converging trajectories. The deductive conclusion is that the change of the structure in the corporate portfolio explained in Section 2 has no dominant influence on the CFBL. This is driven by stable participation in the overall corporate credit portfolio of the two most polluting sectors: agriculture (4% with a gradual decline) and energy and waste sectors (increased its contribution by 1 percentage point to 6%). Manufacturing, which is the 3rd most polluting sector, also has a stable participation of around 14%. On the other extreme, section Z which is a residual category and comprises all other corporate segments having the lowest pollution coefficients has slightly decreased its share. In other words, the progressive dominance of the service sector (especially LMN) had no decisive influence on CFBL. On the other hand, $CFBL_{frozen\ pollution}$ has the opposite trend and substantially is increasing compared to the $CFBL_{original}$. The key message is that lower total emission intensities presented in Figure 6 are driving the change for the $CFBL_{original}$. The overview of these movements can be sublimated as an ultimate interpretation that the banking industry in Europe did not make a final contribution to the lowering of the CFBL. Their spatial intermediation was not enough to determine the portfolio composition with a positive effect on the CFBL. There is no significant change to the flow of funds from brown to green industries because the Top 3 polluting sectors have stable participation in the corporate credit portfolio. A comparison perspective between $CFBL_{original}$ and $CFBL_{frozen\ pollution}$ tells us that the banking industry in Europe for the observed period is a free rider for the reduction of the pollution in corporate sectors that is happening by itself. In other words, the reduction of the GHG emissions that is happening in corporate sectors is driving the change of the CFBL. Here we should have in mind the green financing paradox and that banks should provide additional funds to brown firms to execute the transition to a less polluting environment but we would expect stronger change in the portfolio composition towards green firms. It is evident that this effect has not happened so far and from a macro point of view the banking industry is not actively contributing to the overall EU goals, rather passively exploiting the influence of the broader green agenda that is demanding the corporate sector to pollute the environment less.

F i g u r e 9

$CFBL_{frozen\ portfolio}$ vs $CFBL_{frozen\ pollution}$



Source: Authors' calculation based on ECB and EUROSTAT data.

Conclusion

Europe is the most ambitious continent regarding environmental quality and pollution reduction, aiming for a sustainable future. The EU Green Deal codifies this ambition, setting the goal for Europe to become the first net-zero continent. This means that any negative environmental impact must be offset by activities that benefit nature.

Our research uses euro area data to approximate the entire continent of Europe. We investigate how the banking industry aligns with established goals and its influence on the carbon footprint.

This paper contributes to the literature in two significant ways. First, it is the pioneering approach to using macro data on a supranational level, enabling a global evaluation of Europe. Previous studies typically calculate the Carbon Footprint of Banking Loans (CFBL) on a national level. Second, we introduce the Composite Indicator of Carbon Footprint (CICF), a socioeconomic indicator combining GDP and employment data to classify industries.

Using EUROSTAT and ECB bank corporate portfolio data, we estimate the banking industry's contribution to overall pollution by calculating CFBL, based on the IMF's Climate Change Indicator methodology. Our core analysis focuses on the portfolio structure and total emission intensities. We find that the reduction in total emission intensities is the dominant factor driving changes in CFBL, while portfolio recomposition, directly influenced by banks, is less significant. This suggests that the banking sector in Europe played a minor role in lowering CFBL, acting more as a free rider on reductions achieved by the corporate sector. Despite the known drawbacks of CFBL as an indicator, it remains the best approximation of financed emissions based on available macro data.

The introduction of the CICF is a novel approach to classifying the economic sectors. By applying K-means clustering we integrate data for the GDP and employment simultaneously to evaluate the performance of the economic sectors from the environmental perspective. Policymakers can use this tool to identify and prioritize sectors with high CICF scores for greater attention.

To support effective climate policy, CFBL and CICF offer complementary insights. CFBL quantifies the carbon intensity of bank-financed activities, helping assess whether financial flows align with environmental goals. CICF, meanwhile, identifies sectors that balance economic value, employment, and emissions, guiding where green finance can deliver the greatest societal return. Used together, these indicators enable policymakers to both monitor the environmental impact of financial institutions and strategically direct incentives or regulations toward sectors with the highest potential for sustainable growth.

Although the EA accounts for approximately 85% of EU GDP, this economic weight does not necessarily imply structural equivalence in terms of carbon intensity, sectoral composition, or banking practices. Countries outside the EA – such as Sweden, Poland, Hungary, and Czechia – exhibit distinct energy profiles, industrial structures, and regulatory environments that may significantly influence the carbon footprint of bank loans. Moreover, the EA operates under a unified monetary and supervisory framework, which may not reflect the diverse financial systems and ESG integration levels present in non-EA EU members. As such, the findings presented here should be interpreted with caution when generalizing to the entire EU or Europe.

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A p p e n d i x: NACE A*64

Description	**NACE code**
Crop and animal production, hunting and related service activities	A01
Forestry and logging	A02
Fishing and aquaculture	A03
Mining and quarrying	B
Manufacture of food products; beverages and tobacco products	C10 – C12
Manufacture of textiles, wearing apparel, leather and related products	C13 – C15
Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	C16
Manufacture of paper and paper products	C17
Printing and reproduction of recorded media	C18
Manufacture of coke and refined petroleum products	C19
Manufacture of chemicals and chemical products	C20
Manufacture of basic pharmaceutical products and pharmaceutical preparations	C21
Manufacture of rubber and plastic products	C22
Manufacture of other non-metallic mineral products	C23
Manufacture of basic metals	C24
Manufacture of fabricated metal products, except machinery and equipment	C25
Manufacture of computer, electronic and optical products	C26
Manufacture of electrical equipment	C27
Manufacture of machinery and equipment n.e.c.	C28
Manufacture of motor vehicles, trailers and semi-trailers	C29
Manufacture of other transport equipment	C30
Manufacture of furniture; other manufacturing	C31 – C32
Repair and installation of machinery and equipment	C33
Electricity, gas, steam and air conditioning supply	D35
Water collection, treatment and supply	E36
Sewerage, waste management, remediation activities	E37 – E39
Construction	F
Wholesale and retail trade and repair of motor vehicles and motorcycles	G45
Wholesale trade, except of motor vehicles and motorcycles	G46
Retail trade, except of motor vehicles and motorcycles	G47
Land transport and transport via pipelines	H49
Water transport	H50
Air transport	H51
Warehousing and support activities for transportation	H52
Postal and courier activities	H53
Accommodation and food service activities	I
Publishing activities	J58
Motion picture, video, television programme production; programming and broadcasting activities	J59 – J60
Telecommunications	J61
Computer programming, consultancy, and information service activities	J62 – J63
Financial service activities, except insurance and pension funding	L64
Insurance, reinsurance and pension funding, except compulsory social security	L65
Activities auxiliary to financial services and insurance activities	L66
Real estate activities	M68
Legal and accounting activities; activities of head offices; management consultancy activities	M69 – M70
Architectural and engineering activities; technical testing and analysis	M71
Scientific research and development	M72
Advertising and market research	M73
Other professional, scientific and technical activities; veterinary activities	M74 – M75
Rental and leasing activities	N77
Employment activities	N78
Travel agency, tour operator and other reservation service and related activities	N79
Security and investigation, service and landscape, office administrative and support activities	N80 – N82
Public administration and defence; compulsory social security	O
Education	P
Human health activities	Q86
Residential care activities and social work activities without accommodation	Q87 – Q88
Creative, arts and entertainment activities; libraries, archives, museums and other cultural activities; gambling and betting activities	R90 – R92
Sports activities and amusement and recreation activities	R93
Activities of membership organisations	S94
Repair of computers and personal and household goods	S95
Other personal service activities	S96
Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use	T
Activities of extraterritorial organisations and bodies	U