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Research article

What can green investors learn from funds' value chain carbon footprint? Evidence from Spain

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Abstract: The Task Force on Climate-related Financial Disclosures (TCFD) provides an industry-led framework for the calculation of investment portfolios' carbon footprint metrics aimed to assess their carbon risk exposure. This is the framework that financial institutions (including fund managers) in the European Union should consider when disclosing their sustainability reports according to the EU's Corporate Sustainability Reporting Directive (CSRD). However, currently, global fund data providers either do not publicly offer such metrics (e.g., Morningstar) or do so partly by considering only investees' Scope 1 and 2 carbon emissions in their calculation (e.g., MSCI). In this paper, we analyse how informative the TCFD's fund metrics computed from investees' emissions along their full value chain (including Scope 1, Scope 2, and Scope 3 greenhouse gas (GHG) emissions) are for investors specifically committed to climate change. To that end, we collected reported emissions by Spanish equity funds' investees (from the sustainability reports issued by every investee) as our primary data source and employ a hybrid environmentally extended multiregional input–output model (hybrid EE-MRIO) to fill in the missing data, mainly for Scope 3. We show that disregard for Scope 3 emissions leads to a wrong identification of funds with low/medium-low exposure to carbon risk. The evaluation of funds' risk-adjusted financial performance further indicates that funds with medium-low exposure to carbon risk outperform funds more exposed to carbon emissions. Finally, we find that funds' WACI (weighted average carbon intensity) including Scope 1, 2, and 3 upstream emissions allows for a deeper screening of funds by carbon risk exposure than the Morningstar portfolio carbon risk score.

Keywords: Spanish funds; carbon footprint; value chain; reported emissions; financed emissions; green investment

JEL Codes: G11, G23, Q51, Q54

1. Introduction

Achieving the Paris Agreement's goal of limiting global warning to 1.5°C above pre-industrial levels requires global CO_2 emissions to be reduced by 45% by 2030 and to reach net zero by 2050 (IPCC, 2018)[1]. The key role of the financial sector in the transition to a low-carbon economy is supported by the continuing efforts of different initiatives, such as the Partnership for Carbon Accounting Financials (PCAF), the Task Force on Climate-related Financial Disclosures (TCFD), or the Science Based Targets initiative for Financial Institutions (SBTi-Fis).

Financial institutions measuring and reporting the emissions financed through their investment portfolios (otherwise known as financed emissions) can help them manage climate-related transition risks (i.e., risks posed by policies and regulations affecting their investments in companies with direct exposure to climate-related risks) and take actions to transition their portfolios to net-zero financed emissions by 2050. According to the Global GHG Accounting and Reporting Standard for the Financial Industry (Financed Emissions Standard) developed by the PCAF, financial institutions shall disclose the absolute Scope 1 greenhouse gas (GHG) emissions (direct emissions) and Scope 2 GHG emissions (indirect emissions from the generation of purchased or acquired electricity, steam, heat and cooling) of investees, while a phase-in process ending in 2025 is settled for absolute Scope 3 emissions (the remaining upstream and downstream emissions) reporting depending on the sector (PCAF, 2020, 2022).[2] The TCFD made further progress on the basis of the PCAF's Financed Emissions Standard and provided guidance through the TCFD (2021) on the calculation of common carbon emission intensity and exposure metrics for investment portfolios (ECB, 2023; Kutlukaya et al., 2023; Popescu et al., 2023; Wang et al., 2023).

The relevance of accounting for Scope 3 emissions in the calculation of the carbon footprint of financial institutions' investment portfolios lies in the fact that these are often the most significant portion of companies' emissions inventories, as revealed by the case studies reported by the TCFD (2023). At the sector level, according to the Carbon Disclosure Project (CDP), in 2021 Scope 3 emissions accounted, on average, for 75% of total emissions across all CDP high-impact sectors (CDP, 2022). Adequate measurement of Scope 3 emissions would allow the extension of research that has calculated the climate change exposure of the financial system by considering only Scope 1, or Scope 1 and Scope 2 emissions (Battiston et al., 2017). Thus, for example, the European Central Bank's report on climate-related financial disclosures of the Eurosystem's corporate sector holdings for monetary policy purposes only considers Scope 1 and 2 emissions, in the absence, so far, of detailed reporting of Scope 3 emissions by most companies (ECB, 2023). In addition, accurately measuring the carbon footprint of financial assets and portfolios including Scope 3 emissions is crucial to prevent the risk of financial greenwashing. This contributes to ensuring that market participants have the necessary information to make financing decisions that align with the fight against climate change.

Concerning investment firms, in the EU setting, the Sustainable Finance Disclosure Regulation (SFDR) requires information disclosure on whether investment funds promote environmental or social

[1] https://www.ipcc.ch/sr15/chapter/spm/.

[2] In the European Union, the Commission Delegated Regulation 2023/2772 (European Union, 2023) indicates that financial institutions should consider the PCAF's Financed Emissions Standard (PCAF, 2022) when reporting Scope 3 emissions.

characteristics, or have sustainable investment as their objective, according to Articles 8 and 9, respectively, of the Regulation 2019/2088 (European Union, 2019), and how these are met. Thus, for instance, when visiting the website for the largest Spanish equity fund by assets under management (AUM) (Santander Spanish Equities, €861 million as of December 31, 2022), we find general information on the ESG (environmental, social, and governance) characteristics of the fund and its own classification as an Article 8 fund.[3] However, Spanish equity funds fail to report data on financed emissions or any other carbon footprint metric.

In this setting, this paper calculates the exposure to climate-related transition risk in 2022 of 45 large, medium, and small Spanish equity funds with more than €4000 million in AUM. To that end, we use carbon footprint metrics proposed by the TCFD for asset owners and asset managers by accounting for GHG emissions along the investees' value chain (i.e., Scope 3 emissions), in addition to Scope 1 and 2 emissions. Overall, the carbon footprint metrics employed allow us to compare funds with one another and to conduct portfolio decomposition and attribution analysis for the funds. For the calculation of the TCFD's measures we primarily employ companies' reported emissions. Thus, the number of companies that disclose their emissions across scopes should be representative enough of all funds' stock holdings and of the funds' stock holdings across activity sectors to accurately assess the funds' carbon risk exposure. We find that our data sample meets these criteria. On one hand, 94% of companies included in the Spanish equity funds report Scope 1 and Scope 2 emissions, while 71% of companies also provide data on Scope 3 emissions. On the other hand, the share of companies of Spanish equity funds reporting Scope 1 and 2 emissions and upstream Scope 3 emissions across activity sectors exceeds 75% for most sectors. However, we acknowledge that the coverage of emissions data for Scope 3 emissions is not homogenous across investees. In such cases, the PCAF recommends the use of emissions data estimated from environmentally extended input–output tables providing region- or sector-specific average emission factors to consider emissions through the companies' full value chain (PCAF, 2022). Specifically, we employ a hybrid environmentally extended multiregional input–output model (hybrid EE-MRIO), where we integrate the information relative to Scope 1 and 2 emissions reported by companies and we use their revenue data to estimate missing data on Scope 3 upstream carbon emissions (from cradle to gate).

The empirical analysis is structured as follows. First, we conduct an investee-level analysis, where we calculate the carbon footprint of the Spanish listed companies included in the investigated funds and their contribution to the funds' carbon footprint. Second, we analyse the Spanish funds' exposure to climate-related transition risk based on three carbon emission metrics: WACI (weighted average carbon intensity), relative carbon footprint, and carbon intensity. Then we focus on the funds' WACI to classify funds into carbon risk groups, and we show that the funds' labelling as being more or less carbon-risky is sensitive to the coverage of emissions by scope. Overall, our results emphasise the need for funds' managers to consider Scope 3 emissions to avoid underestimation of funds' exposure to climate-related transition risk and incorrect assignment of funds to carbon risk profiles. Third, we assess the funds' risk adjusted financial performance on the basis of both total risk and downside risk measures according to their carbon risk exposure, and how informative the WACI is in comparison with the Morningstar portfolio carbon risk score.

Our research adds to a small number of recent studies that evaluate the carbon footprint of different portfolios in alignment with the PCAF and TCFD frameworks. Some works measure

[3] https://www.santanderassetmanagement.es/buscadorproductos/#/detalle?tipo=fondo&codigo=ES0138823036&nombre=Santander%20Acciones%20Espa%C3%B1olas,%20F.I.%20-%20Clase%20A.

portfolios' carbon footprint by calculating absolute financed emissions. Teubler and Kühlert (2020) calculated the carbon footprint of the GLS Bank's loan portfolio across loan recipients' industries. More recently, Zhang et al. (2023) evaluated the financed emissions of leading asset managers' equity portfolios from the value chain carbon footprint of Chinese listed companies in 2019. Jindal et al. (2024) examined the portfolio carbon footprint of the Indian banking system, but only Scope 1 and 2 emissions were accounted for. In turn, other studies in the field use relative carbon emission metrics as suggested by the TCFD (2021). Thus, Boermans and Galema (2019) used the WACI to investigate the relationship between Dutch pension funds' carbon footprint and active portfolio management over the period 2009–2017. On the basis of the WACI and the relative carbon footprint, Popescu et al. (2023) showed that the exposure to GHG emissions of European funds is two or three times larger when considering Scope 3 emissions than when including only direct impacts from investees. Popescu et al. (2024) further extended the input–output life cycle assessment (IOLCA) methodology developed in Popescu et al. (2023) to another 12 environmental indicators to estimate the life cycle sustainability impacts associated with Article 8 and Article 9 European investment funds through the companies they invest in. Finally, Wang et al. (2023) analysed the financed emissions and carbon intensities of Chinese fund firms' investment portfolios using the TCFD's guidance, but only Scope 1 and 2 emissions were accounted for.

Therefore, we make several contributions. First, unlike Popescu et al. (2023), Popescu et al. (2024), and Wang et al. (2023), we use companies' reported emissions as our primary data source. According to the PCAF (2022), using emissions as reported by companies for the calculation of investment portfolios' financed emissions is the highest quality option. Second, to assess the funds' exposure to climate change and its contribution by investees through the full value chain, we calculate the absolute and relative carbon footprint measures. Third, we contribute to the literature on funds' financial performance according to ESG labelling by showing a negative association between carbon risk exposure as measured by the WACI and risk-adjusted financial performance that has not been previously studied in the literature. Finally, we assess the accuracy of the WACI vs. the Morningstar portfolio carbon risk score to help investors discriminate across funds on the basis of their carbon risk exposure. Overall, the findings in this paper are of relevance to investors concerned about climate change and carbon emissions, especially considering that, currently, the leading providers of sustainability data either do not publicly provide funds' WACI (e.g., Morningstar) or do so partly by considering only Scope 1 and 2 carbon emissions (e.g., MSCI[4]).

This paper is organised as follows. Section 2 describes the funds' carbon footprint metrics and the financial and emissions data that are required for their calculation and introduces the hybrid EE-MRIO model used to fill in missing emissions data. Section 3 provides the results. Finally, Section 4 concludes and discusses our main results.

2. Methods and data

In this work, we apply the different measures proposed by the TCFD (2021) to quantify the climate-related transition risk exposure of Spanish equity funds in 2022. The main shortcoming that we face when estimating funds' financed emissions is that, as acknowledged by the PCAF (2022), to date, the comparability, coverage, transparency, and reliability of companies' Scope 3 emissions data

[4] https://www.msci.com/our-solutions/esg-investing/esg-fund-ratings-climate-search-tool/funds.

are not homogeneous. In the EU, the Commission Delegated Regulation 2023/2772 requires certain types of undertakings[5] to report information on GHG emissions in accordance with sustainability reporting standards starting in 2024 (European Union, 2023). In particular, it indicates that Scope 3 emissions should be reported for each significant category through the 15 Scope 3 categories identified by the GHG Protocol Corporate Accounting and Reporting Standard (GHG Protocol, 2004) and GHG Protocol Corporate Value Chain (Scope 3) Accounting and Reporting Standard (GHG Protocol, 2013)[6]. However, the qualitative nature of the GHG Protocol's criteria for identifying relevant Scope 3 activities for each category may lead to ambiguity in their interpretation and, hence, to underestimation of companies' reported emissions. To overcome this issue, we develop a hybrid environmentally extended multiregional input–output model (hybrid EE-MRIO). The literature identifies several approaches for the construction of hybrid input–output models that combine sector data with company-level data, thereby enabling the allocation of emissions by scope for companies (Alvarez et al., 2019; Suh et al., 2004). We use a tiered hybrid analysis in which Scope 1, 2, and 3 emissions are collected from companies' sustainability reports, while unreported emissions are estimated by input–output analysis.

2.1. Funds' carbon footprint measures

The TCFD (2021) provides supplemental guidance for asset owners and asset managers to disclose climate-related metrics, where funds' financed emissions should be calculated in line with the PCAF's Global GHG Accounting and Reporting Standard for the Financial Industry (PCAF, 2022) or a comparable methodology. In this paper, we use four different carbon footprint metrics that can be used to better understand the funds' exposure to climate-related transition risk (see Table 3 in TCFD (2021)): At the investee level, we used total carbon emissions contributed by every company to all funds; at the fund level, we use the WACI, relative carbon Footprint, and carbon intensity. We calculate different versions of each metric on the basis of Scope 1, Scope 2, and upstream and downstream Scope 3 emissions. However, to avoid the impact of double-counting of emissions generated by the incorporation of downstream Scope 3 emissions from energy companies (mainly Repsol and Naturgy), only Scope 1, Scope 2 and upstream Scope 3 emissions are included in the analysis of the exposure of Spanish equity funds to climate-related transition risk as measured by the WACI, relative carbon footprint, and carbon intensity.

(1) **Total carbon emissions ($\boldsymbol{TCE_c}$)** for company *c* across funds are defined as:

$$TCE_c = \sum_{f=1}^{m} \cdot\, emissions_c \cdot \frac{investment_f}{capitalization_c}, \tag{1}$$

where the emissions of company c are allocated according to the amount of the company's total market capitalisation that is held by every fund. It measures the contribution of the company to the carbon footprint of all considered funds, expressed in tCO_2e.

[5] Large undertakings and small and medium-sized undertakings with securities admitted to trading on EU-regulated markets, and parent undertakings of large groups.

[6] https://ghgprotocol.org/sites/default/files/standards/Corporate-Value-Chain-Accounting-Reporing-Standard_041613_2.pdf.

(2) **The WACI** for fund *f* is calculated as:

$$WACI_f = \sum_{c=1}^{n} \left(\frac{emissions}{revenue}\right)_c \cdot \frac{investment_c}{value_f}, \tag{2}$$

where the carbon intensity of every company *c* in the fund, $\left(\frac{emissions}{revenue}\right)_c$, expressed in tCO_2e/€ million revenue, is weighted by the current value of the amount invested in company *c* relative to the current market value of the fund. It measures the fund's exposure to carbon-intensive companies.

(3) **The relative carbon footprint (RCF)** for fund *f* is calculated as:

$$RCF_f = \frac{TCE_f}{value_f} = \frac{\sum_{c=1}^{n} \cdot emissions_c \cdot \left(\frac{investment}{capitalization}\right)_c}{value_f}, \tag{3}$$

where funds' total carbon emissions, TCE_f, are normalised by the current fund value. It is expressed in tCO_2e/€ million invested.

(4) **The carbon intensity (CI)** for fund *f* is calculated as:

$$CI_f = \frac{TCE_f}{\sum_{c=1}^{n} \cdot revenue_c \cdot \left(\frac{investment}{capitalization}\right)_c} = \frac{\sum_{c=1}^{n} \cdot emissions_c \cdot \left(\frac{investment}{capitalization}\right)_c}{\sum_{c=1}^{n} \cdot revenue_c \cdot \left(\frac{investment}{capitalization}\right)_c}, \tag{4}$$

where funds' total carbon emissions are normalised by allocating the companies' revenue according to the amount of the company's total market capitalisation that is held by the fund. It measures the fund's carbon efficiency, expressed in tCO_2e/€ million revenue.

Hence, the calculation of the funds' carbon footprint measures implies collecting both financial data (the stock holdings and market value of every fund, and the capitalisation and revenue of investees) and the companies' emissions data, which are described below.

2.2. Financial data

Our dataset comprises all funds within the Morningstar category "Spanish equity",[7] for which the Spanish National Stock Market Commission provides information on the investee companies and the market value of holdings as of December 31, 2022 (see Fang et al. (2021) and Wagner and Margaritis (2017) for references on the use of Morningstar categories for fund screening). The final sample contains 45 funds.[8] Table 1 in the Appendix lists Spanish equity funds across three categories by size according to their AUM: Large-size (over €100 million in AUM), medium-size (from €50 million to €100 million in AUM), and small-size (below €50 million in AUM). We find that the 10 largest funds represent 65% of all funds' AUM. Holdings of equity funds represent 85 out of 120 company stocks listed in the continuous market of the Spanish stock exchange BME (Bolsasy Mercados Españoles) and all companies from the Spanish index IBEX 35.[9]

[7] At least 75% of the total investment of Spanish equity funds is allocated to equities, primarily from Spanish issuers.

[8] Please note that Morningstar's list of funds includes all the fund classes on the basis of the minimum required investment for a given fund. However, the portfolio composition remains the same across all classes. Therefore, we consider fund classes for each fund as a single entity.

[9] ArcelorMittal is the only company that we discarded from our sample, since it is a foreign company that has not designated Spain as its home Member State and therefore is not required to report the regular financial information required for the calculation of funds' carbon footprint measures. The impact of the exclusion of this company on our analysis is very small, as Spanish equity funds only hold €10,656,000 in ArcelorMittal, which represents 0.27% of all funds' AUM.

At the company level, we obtained data on the capitalisation and consolidated revenue of investees as of December 31, 2022, from the websites of BME and the Spanish National Stock Market Commission. The total capitalisation and revenue of investees for the considered equity funds are €591,794 million and €602,311 million, respectively (see Table 2 in the Appendix for detailed information).

2.3. Emissions data

The data on CO_2e emissions for each company in the funds has been collected from their 2022 sustainability reports (emissions at an overall company level, including parent and subsidiary companies). We find that there is no homogeneity across companies in the level of detail of their GHG emissions reporting. Thus, 79 companies (i.e., 94% of funds' stock holdings) provide information on Scope 1 and Scope 2 emissions (differentiating, in some cases, between market-based and location-based methods for Scope 2 accounting, as required by the Commission Delegated Regulation 2023/2772), while 60 companies (i.e., 71% of funds' stock holdings) provide data on Scope 3 emissions. In particular, all 60 companies report upstream Scope 3 emissions, and 23 companies also report downstream Scope 3 emissions, although the number of categories considered varies across companies.[10] Thus, we find that companies mostly disclose upstream Scope 3 emissions for three categories (purchased goods and services, business travel, and employee commuting), whereas downstream Scope 3 emissions are mostly concentrated in two categories (use of sold products and investments).[11] Tables 3 and 4 in the Appendix provide detailed information on the number of companies reporting Scope 1 and 2 emissions, and Scope 3 emissions across activity sectors, and on the number of companies reporting Scope 3 emissions and reported emissions across Scope 3 categories, respectively. We find that the share of companies reporting Scope 1 and Scope 2 emissions, and upstream Scope 3 emissions across activity sectors exceeds 75% for most sectors, which supports the quality of the reported emissions data.

The total carbon footprint for the companies is calculated by summing the Scope 1, 2, and 3 emissions. We also define an upstream total carbon footprint, which considers only upstream Scope 3 emissions, to mitigate the impact of double-counting that occurs when downstream Scope 3 emissions are accounted for. This effect is reflected in the significant weight of two fossil energy companies (Repsol, an oil refinery, and Naturgy, a natural gas supplier) in Category 11 (i.e., use of sold products) within downstream Scope 3 emissions. The downstream emissions of these companies are included in the Scope 1 emissions from the use of fossil fuels of the rest of the companies. In particular, the emissions reported by these two companies (Repsol, 182 $MtCO_2e$; Naturgy, 81 $MtCO_2e$) are so high that they exceed the Scope 1 emissions of the other companies considered (59 $MtCO_2e$)[12].

For the companies that do not report Scope 3 emissions, we use sector-specific average emissions data estimated by means of a hybrid EE-MRIO model, as described below. Specifically, we use the

[10] The GHG Protocol's Corporate Value Chain (Scope 3) Accounting and Reporting Standard (GHG Protocol, 2013) categorizes Scope 3 emissions in 15 categories, where Categories 1 to 8 are identified as upstream emissions and Categories 9 to 15 as downstream emissions. Each category has a minimum boundary to ensure that major activities resulting in emissions are accounted for.

[11] For the calculation of upstream Scope 3 emissions related to purchased goods and services, companies combine emission coefficients from the EE-MRIO with information from the extraction, production, and transportation of goods and services purchased or acquired by the reporting company (GHG Protocol, 2013).

[12] Note that part of the production of these two energy companies is exported and, hence, their emissions are not only generated in the Spanish economy, and that we are just considering a sample of Spanish companies.

EE-MRIO database Exiobase, version 3.7 (Stadler et al., 2018), which provides information in its satellite account on CO_2e emissions by industry and country, covering 163 industries and 44 countries. Before carrying out the calculations needed to estimate the different sectoral emission intensities, the tables have been aggregated into three regions (Spain, the rest of the EU, and the rest of the world). The update frequency and regional granularity of the database may affect the results' accuracy, which has been studied in the literature by Yamakawa and Peters (2009) and Rodrigues et al. (2018). However, in our case, the impact would be minimal, as the model's Scope 3 emissions represent at most 3% of the total emissions included in the investment funds in the WACI measure (10/329) (see Table 1).

2.4. *A Hybrid Environmentally Extended Multiregional Input–Output Model (EE-MRIO)*

Among the papers that are currently using a traditional Leontief input–output model to calculate the exposure to climate-related transition risk and the carbon footprint of different agents or financial institutions, we found those of Wei et al. (2023), Teubler and Kühlert (2020), Wang et al. (2023), or Zhang et al. (2023). To do this, most studies multiply the sectoral direct and total emission intensities reported by the Leontief quantity input–output model and by the companies' reported output to assign these companies' direct or total emissions.

The Leontief quantity model in a multiregional input–output context with *n* regions and *m* sectors is represented by Equation (5):

$$x = (I - A)^{-1} y\,, \tag{5}$$

where x is the vector of total output, A is the technical coefficients matrix (input requirement per unit of output), I is the identity matrix, $(I - A)^{-1}$ is the *Leontief inverse matrix* of the direct and indirect input requirements per unit of output destined to final demand, and y is the vector of final demand that specifies the countries and sectors that produce the final goods and services and the countries where such goods and services are consumed[13].

The environmental extension of the multiregional input–output model (EE-MRIO) for estimating the direct and indirect carbon emissions (E) is shown by:

$$E = \hat{e}(I - A)^{-1}\hat{y} = \varepsilon\hat{y}\,, \tag{6}$$

where $\hat{e}$ is the diagonalised vector of carbon emission factors or coefficients (emissions per monetary unit of output) for every sector and region. The matrix of emission multipliers or total emission factors, $\varepsilon = \hat{e}(I - A)^{-1}$, which quantifies the direct and indirect carbon emissions per unit of production destined for final demand (tCO_2e/€ million) (for a sector i, $\varepsilon_i = \sum_j \varepsilon_{ij}$), is the expression that allows the reallocation of emissions between branches, regions, or countries without double-counting of emissions (López et al., 2023). It is important to note that the emission multiplier quantifies the Scope 1, Scope 2, and upstream Scope 3 emissions incorporated into products sold to final demand (from cradle to gate). On one hand, if the final demand vector is diagonalised by blocks ($\hat{y}$) in Equation (6), summing down the columns, we obtain the measurement of CO_2e emissions under consumption-based accounting (CBA), also known as the carbon footprint, which captures emission transfers along global

[13] The assumptions behind the input–output models and their implications for the calculation of the carbon footprint are well established in the literature (Peters et al. 2016): (a) the inputs are proportional to the outputs, and these proportions are fixed; (b) the models have a high level of aggregation and implicitly assume that an industry produces one output; and (c) input–output models are generally measured in monetary flows, and it is assumed that the price of products is the same in each sector.

supply chains of final demand products and allocates responsibility for the emissions to the final consumers (see Malik et al. (2019) for a review). On the other hand, if we diagonalise the final demand only in the main diagonal ($\bar{\hat{y}}$), the result from the columns' sum is the producer's carbon footprint that allocates responsibility for the emissions to the producing sector that supplies the final demand (Ortiz et al., 2020). Depending on the form of the final demand vector, the results are different among the columns, but they are always the same when summing up by rows, providing the measure of emissions according to production-based accounting (PBA), where responsibility for the emissions is allocated to the producer agent that directly releases the CO_2 emissions (country or sector).

An EE-MRIO model can be used to calculate the emissions associated with companies that are part of investment funds using direct and total industry-average emission factors. However, several challenges arise when it comes to combining company information with sectoral information from an input–output model. The first one consists of identifying the sector to which the company belongs, thus assigning it the appropriate sectoral carbon intensity. The second is the degree of detail available about the company's economic information – specifically, if only information about the total of its production is available or if, in addition, the purchases of intermediate goods and services made by the company are known.

In our case, the information we have about the companies is the revenue of each company *c* that belongs to sector i ($q_{c(i)}$). Once the sector i to which the company c belongs is identified, by multiplying the output (revenue) of each company by the emission coefficient of sector i (e_i), we obtain the direct emissions linked to its production ($E^{io\to d}_{q_{c(i)}} = e_i q_{c(i)}$) (i.e., Scope 1 emissions). This assignment of direct emissions does not generate a double-counting problem when combining the direct emission coefficient, which is divided by the total production of the companies in the sector, with the output (revenue) of the different companies included in that sector.

In the literature, the carbon footprint of company *c* is calculated by multiplying the emission multiplier of sector *i* to which the company belongs by the company's output ($E^{io}_{q_{c(i)}} = \varepsilon_i q_{c(i)}$) (Teubler and Kühlert, 2020; Wang et al., 2023; Wei et al., 2023). However, this method is not entirely correct, as it leads to an overestimation of the footprint insofar as the emission multiplier is designed to calculate the carbon footprint by multiplying it by output destined for final demand, not by a company's total output (Hertwich and Wood, 2018). Therefore, using the emission multiplier to attribute emissions to companies in the WACI measure would also be inappropriate, as it would also overestimate the company's carbon footprint. For this reason, we propose an emission multiplier adjusted by the weight that the final demand of sector *i* has on the total output of sector *i* (Oosterhaven and Stelder 2002). This way, we obtain a *net multiplier* of direct and indirect emissions per unit of output for the final demand of each sector that allows us to assign indirect emissions to the companies that participate in the investment funds ($\varepsilon_i^a = \varepsilon_i \frac{y_i}{x_i}$). The emissions of company c would be given by the expression $E^{io\to t}_{q_{c(i)}} = \varepsilon_i \frac{y_i}{x_i} q_{c(i)} = \varepsilon_i^a q_{c(i)}$, which quantifies the Scope 1, Scope 2, and upstream Scope 3 emissions associated with its sales to final demand[14].

[14] This method of calculating a company's carbon footprint will lead to some underestimation depending on the importance of selling its output as an intermediate good to other sectors of the economy. However, from a theoretical point of view, this method has the advantage that there is no double-counting of emissions for the whole economy when combining the multi-company information with the emissions multiplier from the input–output framework, as this multiplier is constructed to reallocate emissions to the final demand of the different sectors. Another approach consists of calculating the emissions and emission intensities linked to the companies' output using the hypothetical extraction method (HEM) in an input–output framework (Zhang et al., 2023). However, its application leads to double-counting of the emissions associated with the use of conventional emission multipliers when emissions are calculated not only for an individual company but also for all companies in the economy.

To isolate an emission multiplier of only upstream Scope 3 emissions (ε_i^{s3}), (a) from the multiplier, we subtract the direct emissions coefficient of the sector's input–output so as to not include Scope 1 emissions and (b) in each sector, we do not include the coefficient of the emission multiplier associated with electricity purchases accounting for Scope 2 emissions. Then the Scope 3 emissions calculated from an input–output model would be given by $E_{q_{c(i)}}^{io\rightarrow s3} = \varepsilon_i^{s3}\frac{y_i}{x_i}q_{c(i)}$. We find that for all considered companies, the use of a conventional Scope 3 input–output multiplier instead of the proposed Scope 3 net multiplier would imply an overestimation of the impacts by 53%[15].

The expression that quantifies the carbon footprint or total emissions by scope in the hybrid EE-MRIO model for a company c that only provides information on its Scope 1 and Scope 2 emissions would be as follows:

$$E_c^{s1,s2,s3} = \begin{bmatrix} E_c^{f\rightarrow s1} & E_c^{f\rightarrow s2} & \varepsilon_i^{s3} \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & \frac{y_i}{x_i}q_{c(i)} \end{bmatrix}, \tag{7}$$

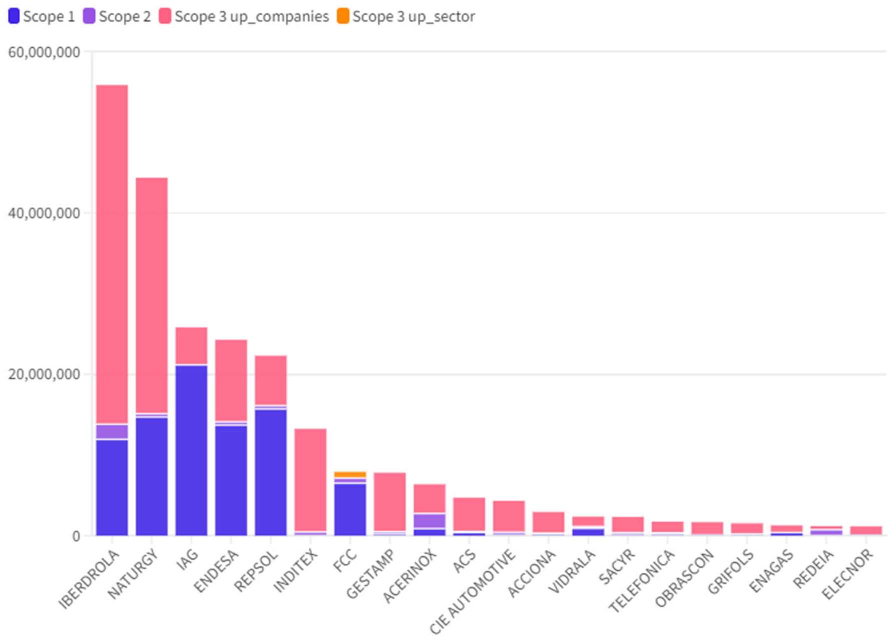
where $E_c^{f\rightarrow s1}$ and $E_c^{f\rightarrow s2}$ are, respectively, the carbon emissions associated with Scope 1 and Scope 2 provided by each of the c companies considered.

The use of emissions by scope for calculating the different carbon footprint metrics proposed by the TCFD, whether they come from data provided by companies or estimated from sectoral averages, always leads to double-counting of emissions (Hertwich and Wood, 2018). This occurs insofar as the Scope 1 emissions of some companies are part of the indirect or Scope 2 and upstream Scope 3 emissions of other companies that are integrated into the emission multipliers. In this regard, authors like Teubler and Kühlert (2020) propose to use, for the calculation of the emissions of assets and loans, an attribution of 100% to Scope 1, 50% to Scope 2, and 0% to upstream Scope 3 emissions calculated with an MRIO model if there is no detailed information about the suppliers. However, considering only the direct emissions would imply the underestimation of climate-related transition risk.

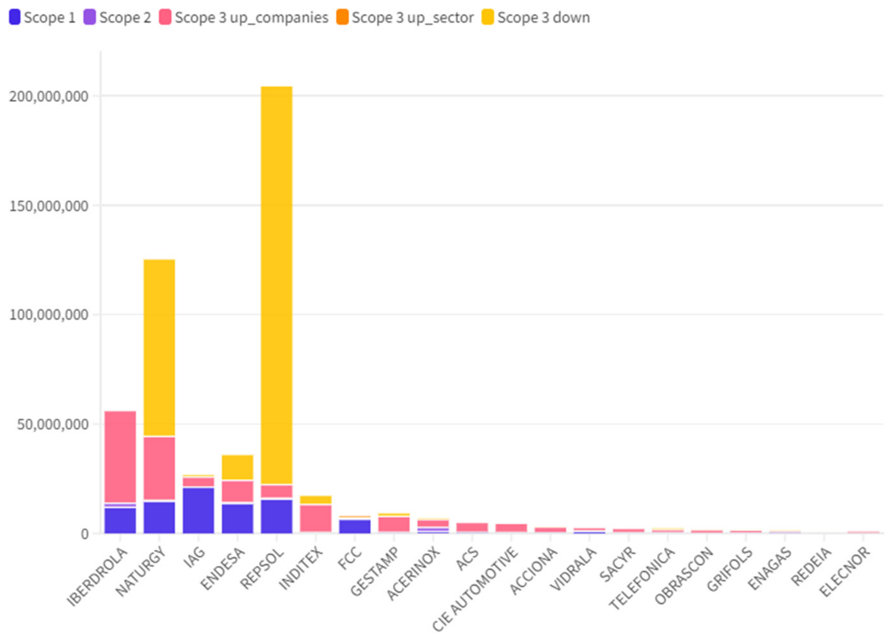
3. Results

3.1. The environmental responsibility of the companies listed on the Spanish stock exchange and their share in the funds' carbon footprint

[15] The upstream Scope 3 emissions estimated by the EE-MRIO model account only for 1.3% of the total Scope 3 emissions of the companies considered when the net multiplier is used, and 2.5% when the conventional multiplier is used. In other words, in our case, the risk of underestimation of the total emissions that we introduce in the calculation of carbon risk measures for funds is reduced (1.2% of the total emissions included in upstream Scope 3).



Panel A.



Panel B.

Figure 1. Absolute emissions (tCO_2e) by scope for the 20 companies with the highest upstream total carbon footprint in 2022. Panel A displays Scope 1, Scope 2, and upstream Scope 3 emissions as reported by the company and average sector-specific upstream Scope 3 emissions; Panel B displays the Scope 1, Scope 2, and upstream Scope 3 emissions as reported by the company; average sector-specific upstream Scope 3 emissions; and downstream Scope 3 emissions

Scope 1 emissions reported by the companies included in the funds amount to 97,035,218 tCO_2e, representing 38% of the total industrial emissions generated in the Spanish economy in 2022 according to the Spanish National Statistical Office.[16] Scope 1 emissions are highly concentrated in a reduced number of companies from the energy sector (Iberdrola, Naturgy, Endesa, and Repsol), the air transport sector (IAG), and the construction sector (FCC) (Figure 1). Scope 2 emissions are far lower, amounting to 10,279,131 tCO_2e. Upstream Scope 3 emissions as reported by the companies (142,923,823 tCO_2e) clearly exceed Scope 1 and 2 emissions, with energy companies accounting for a large portion of total emissions. Also relevant are the upstream Scope 3 emissions associated with two multinational Spanish companies: Inditex, a company dedicated to the production and distribution of textiles, and Gestamp, a company dedicated to the design, development, and manufacture of automotive components. Finally, downstream Scope 3 emissions are the most important (291,531,022 tCO_2e) due to the extremely large volumes generated by two energy companies, Repsol and Naturgy, as noted in the previous section.

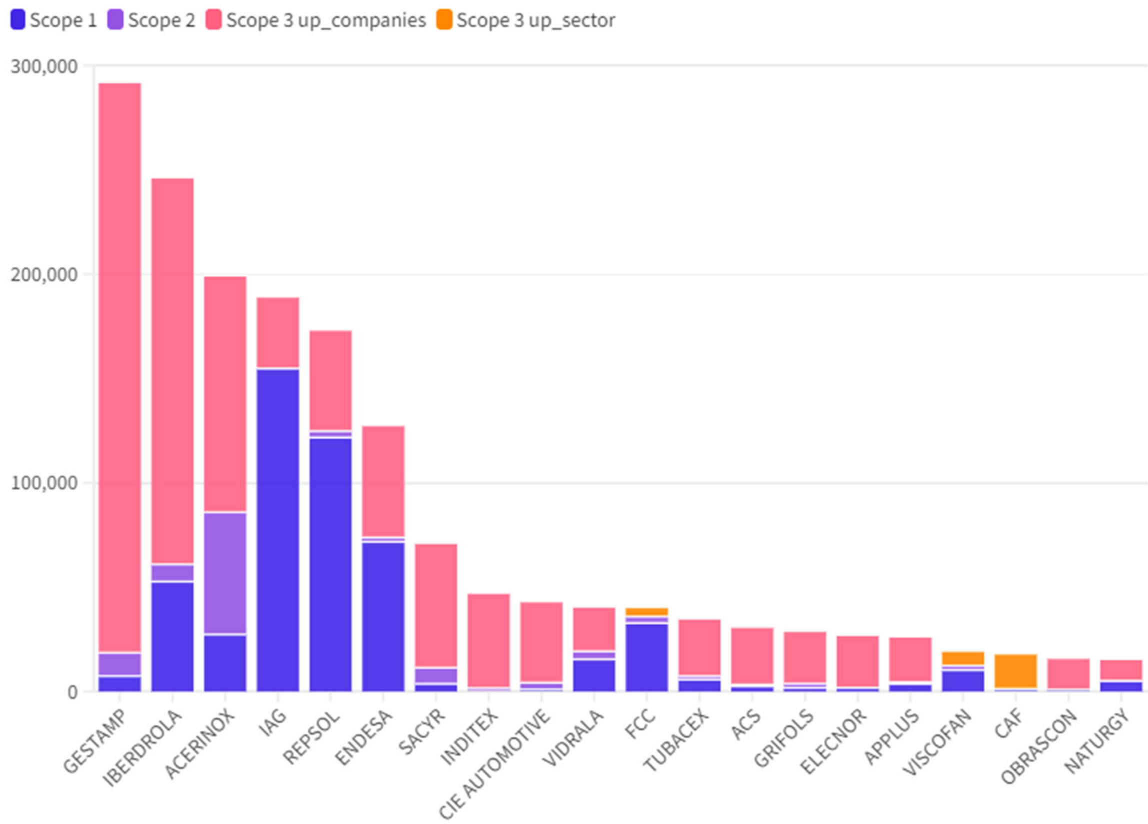


Figure 2. The 20 companies with the highest contribution to the upstream total carbon footprint (tCO_2e) of Spanish funds by scope in 2022. (Notes: To estimate the contribution of each company to the upstream total carbon footprint (tCO2e) of all funds, we calculate the total carbon emissions for a given company across funds. We distinguish between Scope 1, Scope 2, and upstream Scope 3 emissions as reported by the company, and average sector-specific upstream Scope 3 emissions.)

Overall, on average, the upstream Scope 3 emissions of companies included in the Spanish equity funds represent 66% of their upstream total carbon emissions. More interestingly, our results reveal

[16] https://www.ine.es/jaxiPx/Tabla.htm?tpx=50611&L=1.

that while this percentage is relatively low for companies more directly carbon-intensive (e.g., IAG, FCC, and Repsol), it is very significant for the rest of companies, with 40 out of 85 companies reporting values above 80%. In turn, downstream Scope 3 emissions account for 89% and 65% of Repsol's and Naturgy's total carbon emissions, respectively. Therefore, it is of great relevance that fund managers consider Scope 3 emissions in the calculation of the different carbon footprint metrics for an adequate assessment of their climate-related risk exposure.

Next, we focus on the contribution of each company to the upstream total carbon footprint of all investigated funds as measured by TCE*c*. We find that the companies that contribute the most to the upstream total carbon footprint of the investigated funds do not coincide exactly with the companies with the highest upstream total carbon footprint (Figure 2). Thus, Gestamp and Acerinox (a company from the stainless steel sector) stand out as the first and third companies, respectively, with the highest contribution to the funds' carbon footprint, whereas they are placed eighth and ninth in the ranking of companies with the largest carbon footprint. On the contrary, Iberdrola, IAG, and Repsol remain within the five companies that generate more carbon emissions and that account for the highest portion of the funds' financed emissions. Finally, when assessing the relevance of emissions by scope, our results reveal that upstream Scope 3 emissions consistently represent the largest portion of contributed emissions to all funds across companies (66% on average). This percentage is similar to those obtained on the basis of the absolute emissions of all the companies considered.

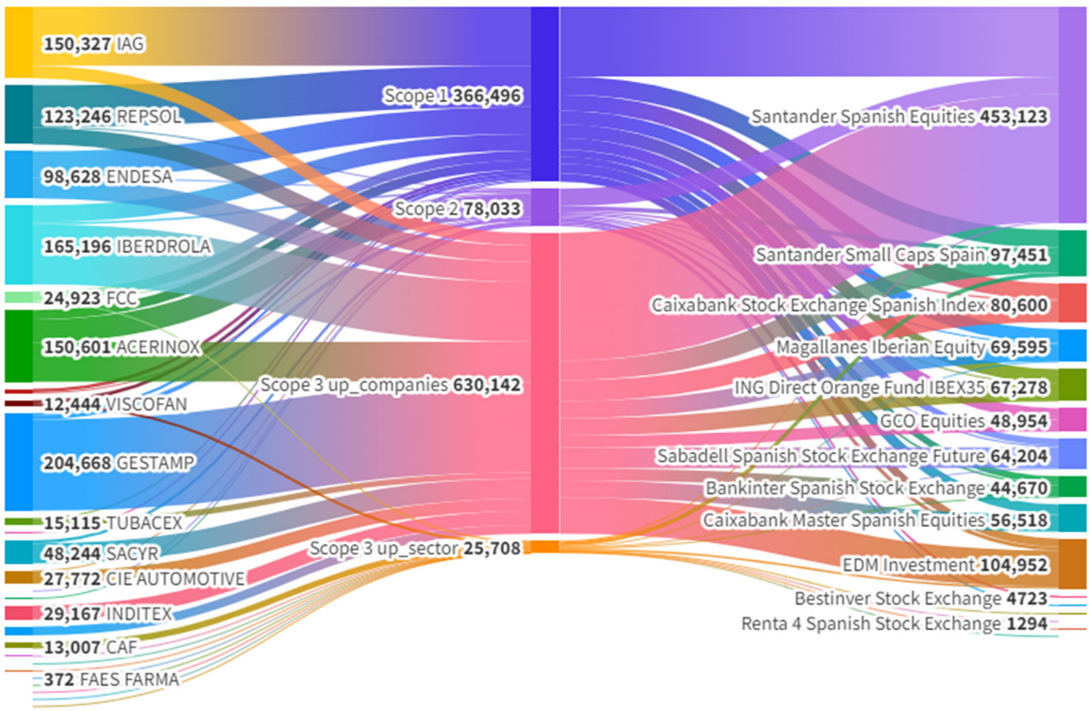


Figure 3. Main GHG emission flows (tCO_2e) by scope (Scope 1, Scope 2, and upstream Scope 3 emissions) transmitted from companies to individual funds. (Notes: The GHG emission flows shown in this graph correspond to the selection of (a) the 10 companies with the largest emissions by scope, which results in 26 companies (represented in the left axis), and (b) the 10 funds with the highest total carbon emissions by scope, which yields 16 funds (represented in the right axis). We distinguish between Scope 1, Scope 2, and upstream Scope 3 emissions as reported by the company, and average sector-specific upstream Scope 3 emissions.)

At the final stage, we provide (Figure 3) the main GHG emission flows by scope transmitted from companies to individual funds. In particular, the flows shown in this graph correspond to the selection of (a) the 10 companies with the largest emissions by scope, which results in 26 companies (represented in the left axis), and (b) the 10 funds with the highest TCE[17] by scope, which yields 16 funds (represented in the right axis).[18] Overall, this graph represents 62% of all funds' TCE. Regarding the reported values, the interpretation is as follows. For companies, the reported values represent the company's contribution to the TCE of the 16 funds (e.g., 150,327 tCO_2e for IAG). For every scope, the reported values measure the TCE of the 10 funds with the highest Scope 1 TCE based on the contribution of the 10 companies with the largest Scope 1 emissions (e.g., 366,496 tCO_2e for Scope 1). Finally, for funds, the reported values represent the funds' TCE that are contributed by the 26 companies (e.g., 453,123 tCO_2e for Santander Spanish Equities).

We find that the carbon footprint of Spanish equity funds is highly concentrated in large-sized funds. Santander Spanish Equities is the fund with the greatest carbon footprint, where the companies' contribution mainly stems from the Scope 1 emissions of IAG and Repsol, and the upstream Scope 3 emissions of Iberdrola, Acerinox, and Gestamp. The volume of emissions associated with the next two funds with the highest carbon footprint is far lower: EDM investment (104,952 tCO_2e) and Santander Small Caps Spain (97,451 tCO_2e).

3.2. Exposure of Spanish equity funds to climate-related transition risk

The exposure to climate-related transition risk of Spanish funds is assessed by employing three relative carbon emission metrics recommended by the TCFD (2021): the WACI, relative carbon footprint, and carbon intensity. In Table 1, we report the main descriptive statistics for carbon footprint metrics based on Scope 1, Scope 2, and upstream Scope 3 emissions (i.e., upstream total carbon emissions) and the mean of each metric by scope.

Table 1. Main descriptive statistics of the WACI, relative carbon footprint, and carbon intensity (tCO_2e/€ million) for Spanish equity funds in 2022.

	WACI	Relative carbon footprint	Carbon intensity
Mean	329	497	364
Scope 1	91	145	110
Scope 2	24	37	26
Upstream Scope 3 (as reported by investees)	204	302	220
Upstream Scope 3 (sector-specific average)	10	13	8
Median	330	482	364
Maximum	508	1027	515
Minimum	180	176	128
Std. deviation	68	172	71

[17] Total carbon emissions (TCE) for fund f is defined as $TCE_f = \sum_{c=1}^{n} \cdot emissions_c \cdot \left(\frac{investment}{capitalization}\right)_c$, where the emissions of company c are allocated according to the amount of a company's total market capitalisation that is held by the fund. It measures the fund's absolute financed emissions, expressed in tCO_2e.

[18] Note that we select the 10 companies with the largest emissions and the 10 funds with the highest TCE across scopes, that is, separately by Scope 1, Scope 2, and Scope 3. Therefore, all the companies/funds that meet these criteria are included in the graph.

We find that the means of the upstream total WACI and carbon intensity are quite similar for the sample of Spanish funds: 329 tCO$_2$e/€ million revenue and 364 tCO$_2$e/€ million revenue, respectively. In turn, the mean obtained for relative carbon footprint is significantly higher (497 tCO$_2$e/€ million invested), as well as the standard deviation.[19] Differences between these metrics stem from the fact that, unlike WACI, for the carbon intensity and relative carbon footprint emissions are allocated to investees on the basis of an equity owner approach by considering the companies' market capitalisation. For companies with the same weight in a fund's portfolio, the greater their carbon intensity, the higher their contribution to the fund's WACI. However, the investees' contribution to a fund's carbon intensity and relative carbon footprint depends on the investees' market valuation. Hence, companies with the same amount invested in a fund's portfolio will contribute less to the fund's carbon intensity and relative carbon footprint if their valuation is higher. We further observe that the average relative weight of each scope is quite homogeneous across the three metrics. Upstream Scope 3 emissions account for the highest portion of the values of the WACI, relative carbon footprint, and carbon intensity (65%, 63%, and 62%, respectively), followed by Scope 1 emissions and then Scope 2 emissions.

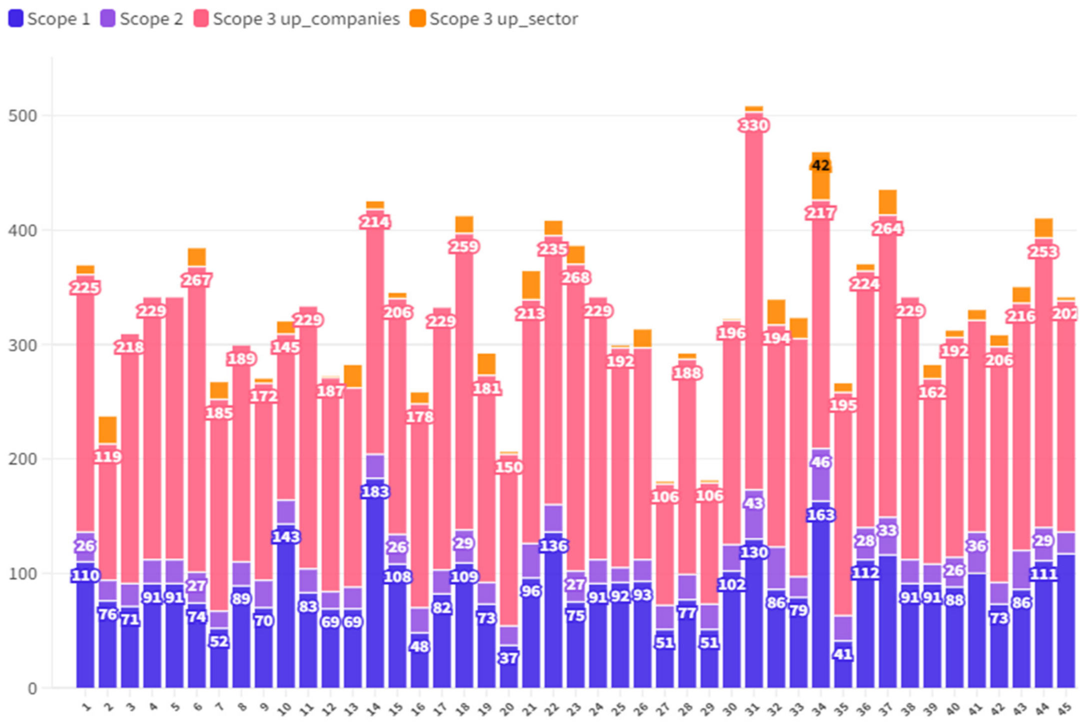


Figure 4. WACI (tCO$_2$e/€ million) by scope for 45 Spanish equity funds. Funds are sorted by size (from larger to lower AUMs). The funds' names can be found in Table 1 in the Appendix.

Throughout the rest of the section, we focus on the WACI to assess the exposure of every fund's equity portfolio to carbon-intensive companies. Figure 4 provides the values of the WACI by scope for

[19] Popescu et al. (2023) report averages values for the WACI and relative carbon footprint of 475 (479) and 346 (408) tCO$_2$e/€ million revenue, respectively, for socially responsible investment (SRI) (conventional) European equity funds using direct and indirect sector emission factors. The average values reported by Wang et al. (2023) for the equity portfolios of Chinese fund firms are significantly higher (the WACI equals 577 tCO$_2$e/$ million and carbon intensity equals 493 tCO$_2$e/$ million) than the ones that we obtain, even though they only consider Scope 1 and 2 emissions. This difference can be explained by the fact that Chinese companies are much more carbon-intensive than Spanish companies.

the 45 funds considered. We find that the notable increase in the WACI when upstream Scope 3 emissions are accounted for in addition to Scope 1 and 2 emissions (189% on average) is consistent across the considered funds, but it is not homogeneous. The rise in the WACI is much higher for funds whose exposure to Scope 1 and 2 emissions is lower, with the upstream Scope 3 WACI being more than two times larger than the Scope 1 and Scope 2 WACI for 18 out of 45 investigated funds (Figure 5). Overall, these results reinforce the need for incorporating Scope 3 emissions in the calculation of carbon footprint metrics to avoid underestimation of the funds' exposure to climate change risk and to ensure an adequate classification of funds according to financed emissions, as measured by the WACI. Additionally, because funds in Figure 4 are sorted by size (from larger to lower AUMs), we can see that, in general, large funds, which account for the highest portion of all funds' AUM, are not prone to having a more negative carbon risk profile as measured by the WACI than small-sized funds. Actually, the three funds with the highest upstream total WACI are small-sized funds according to Table 1 (i.e., Metavalor, 508 tCO_2e/€ million; Mediolanum Small & Mid Caps Spain, 468 tCO_2e/€ million; Laboral Kutxa Stock Exchange, 429 tCO_2e/€ million). On the basis of the top 10 holdings for these three small-sized funds, we find that they consistently invest large amounts of money (between 19% and 24%) in the top 10 companies included in our selection of funds that are most carbon-intensive (see Table 5 in the Appendix). Thus, the contribution of the most carbon-intensive holdings to the funds' upstream total WACI is above 50% in all cases.

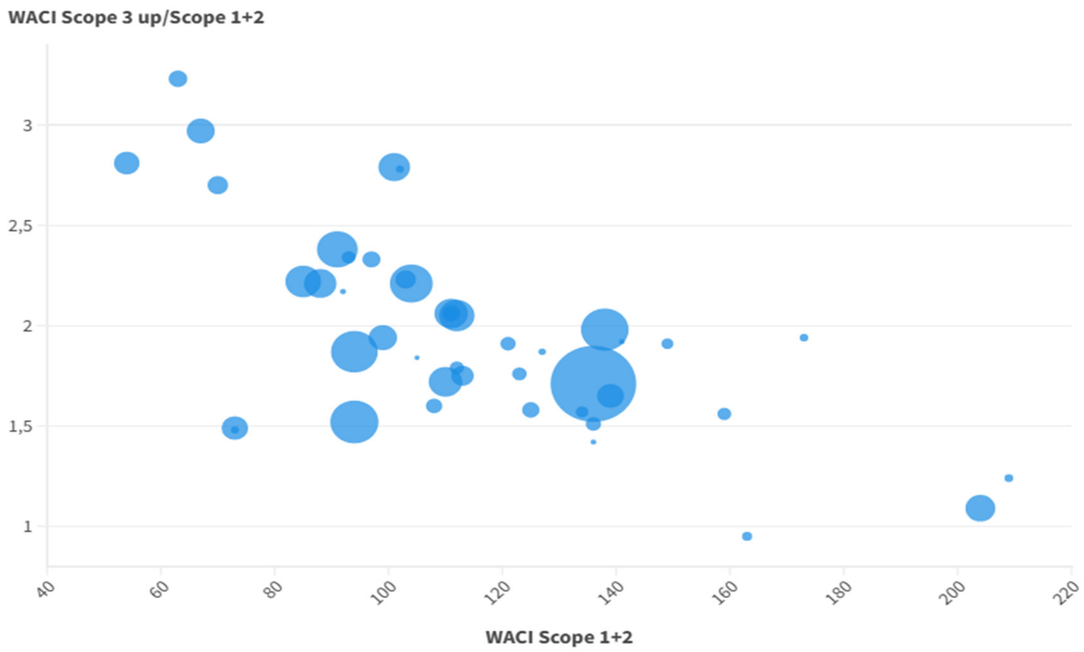


Figure 5. Relationship between the WACI based on Scope 1 and 2 emissions and the WACI based on upstream Scope 3 emissions (tCO_2e/€ million). The bubbles' size indicates the funds' size by AUM as of December 31, 2022.

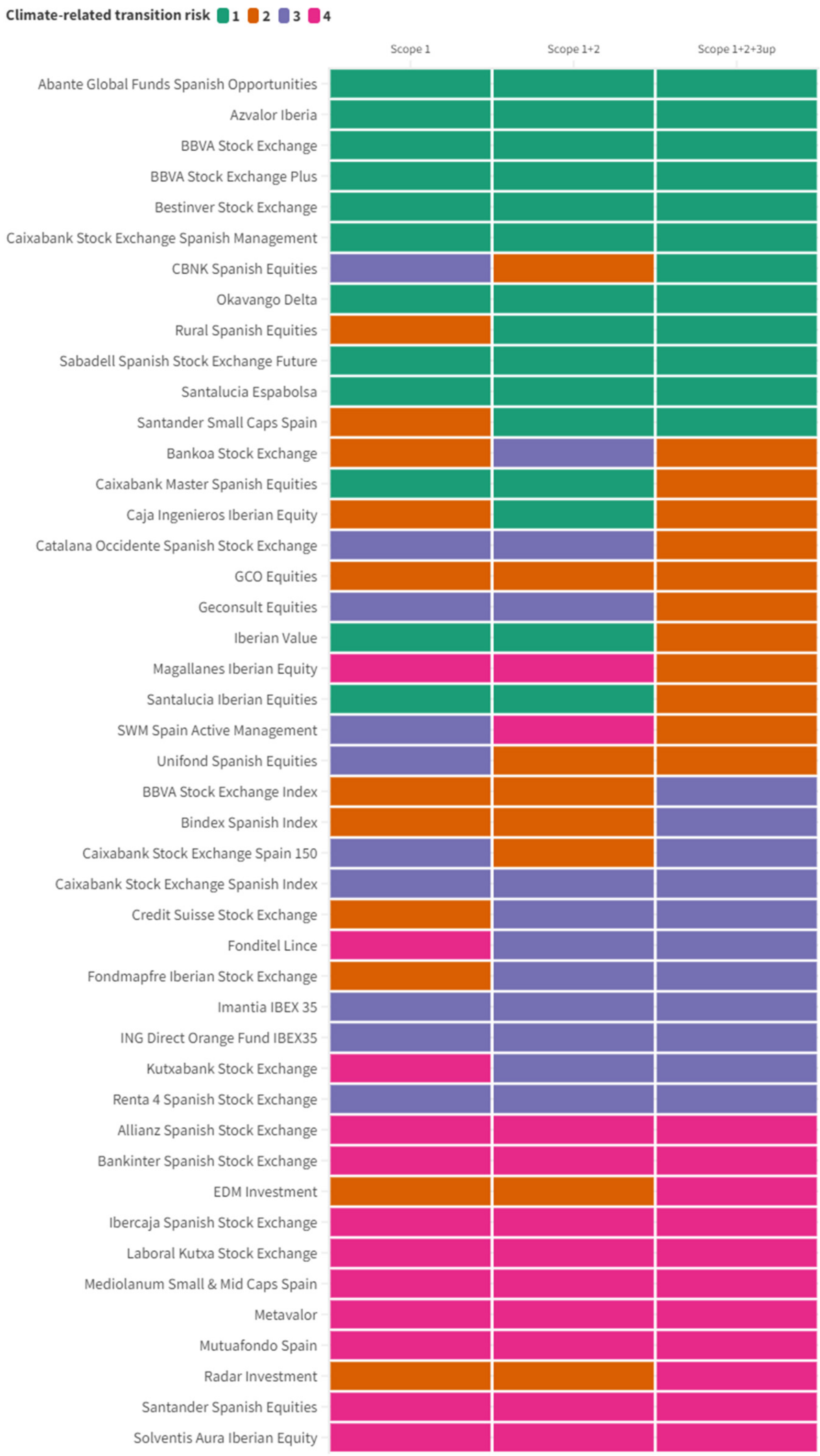
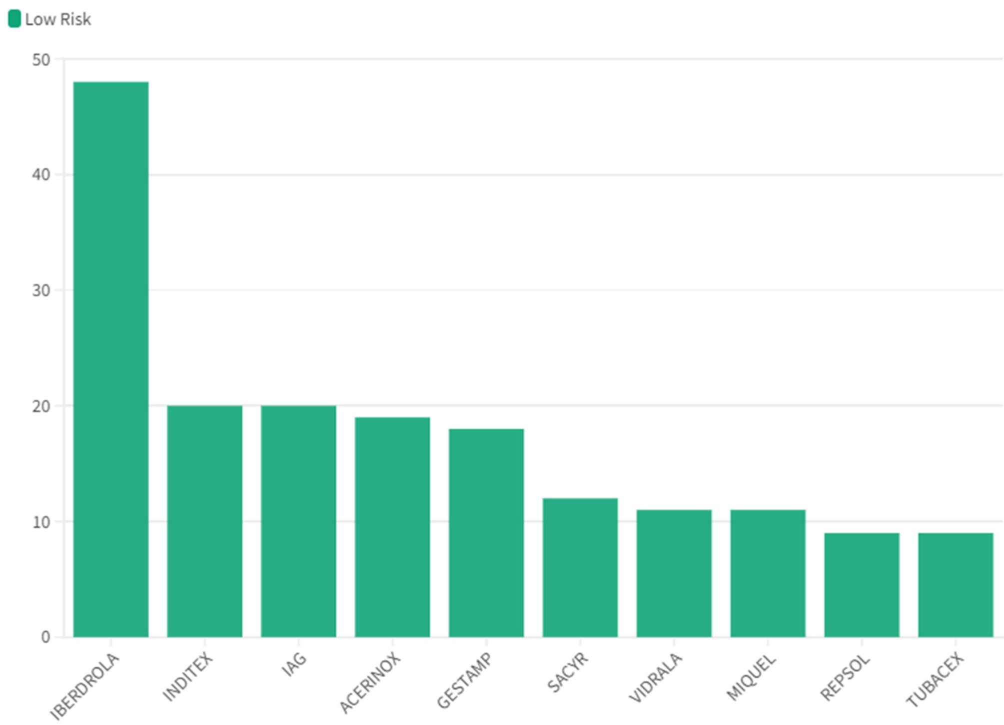


Figure 6. Classification of funds into four groups according to their exposure to climate-related transition risk as measured by the WACI (tCO_2e/€ million) in 2022. Risk groups are as follows: (1) low risk (below the 25th percentile), (2) medium-low risk (25th to 50th percentile), (3) medium-high risk (50th to 75th percentile), and (4) high risk (above the 75th percentile). Funds were initially classified into these four groups on the basis of upstream total WACI (Scope 1, Scope 2, and upstream Scope 3 emissions) as shown in the third column of the graph.

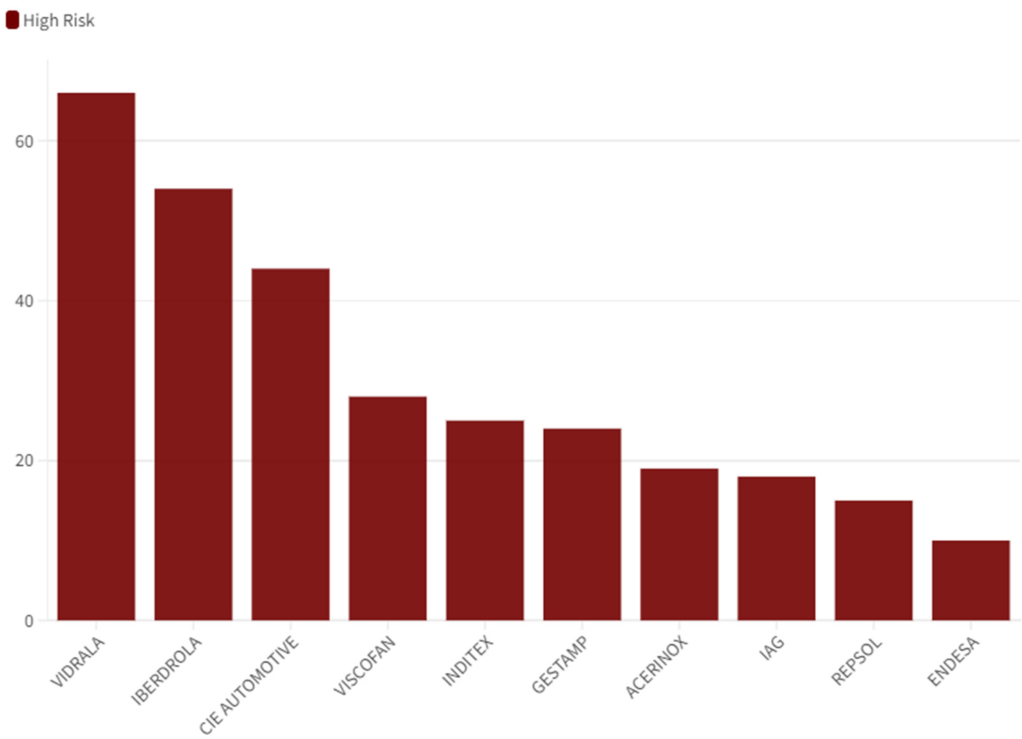
Next, Figure 6 offers a classification of the funds into four groups according to their exposure to climate-related transition risk as measured by the WACI: low risk (below the 25^{th} percentile), medium-low risk (25^{th} to 50^{th} percentile), medium-high risk (50^{th} to 75^{th} percentile), and high risk (above the 75^{th} percentile). Funds are initially classified into these four groups on the basis of their upstream total carbon emissions, as shown in Column 3 of the graph. In columns 1 and 2, we show whether the initial allocation of every fund to a given carbon risk group varies when only Scope 1 emissions (Column 1) or Scope 1 and 2 emissions (Column 2) are considered. We observe that for 19 (15) funds, the group assignment changes when only Scope 1 (Scope 1 and 2) emissions are accounted for. In particular, we find that when all emissions are considered, three low-risk funds according to Scope 1 become medium-low risk funds, four funds move from the medium-low to the medium-high risk group, and two funds move from the medium-low risk to the high-risk group. Regarding the funds' classification accordinf to Scope 1 and 2 emissions, four low-risk and five medium-low risk funds become more exposed to climate-related transition risk when Scope 3 emissions are incorporated. Hence, our results indicate that disregard for Scope 3 emissions leads to incorrect identification of low-risk and medium-low risk funds because these are the funds that increase their financed emissions more notably when Scope 3 emissions are considered.

Our findings align with those of Popescu et al. (2023), demonstrating that even European funds bearing a sustainability label continue to have exposure to companies with high emissions, especially companies that have a high indirect carbon intensity. If we compare our results with those of Popescu et al. (2023), we find that the authors report an average value for the WACI of 479 tCO_2e/€ million for conventional (i.e., not SRI) European equity funds. Several reasons can explain the higher value reported by Popescu et al. (2023). On one hand, Popescu et al. (2023) used 670 European equity funds and calculated upstream Scope 3 emissions using an EE-MRIO model, while our work focuses only on funds investing in Spanish companies, with 71% of the companies reporting upstream Scope 3 emissions. However, the distribution of the WACI by scope is quite similar in both papers, with upstream Scope 3 emissions being the most significant in both, accounting for 71% in our research and 55% in Popescu et al. (2023), followed by Scope 1 emissions, which account for 28% in the former and 36% in the later. Wang et al. (2023) and Jindal et al. (2024) report average WACI values of 577 tCO_2/$ million for the equity portfolios of 105 Chinese fund firms in 2018 and 364 tCO_2/$ million for Indian bank loans in 2016, respectively. Despite Wang et al. (2023) and Jindal et al. (2024) only considering Scope 1 and 2 emissions, the higher values for the WACI can be related to the fact that Chinese and Indian companies are much more carbon-intensive than Spanish companies.

Finally, we analyse the companies' contribution to the upstream total WACI of funds within the two extreme carbon risk categories, which yield average values of 269 tCO_2e/€ million for the low-risk group (composed of 12 funds) and 375 tCO_2e/€ million for the high-risk group (consisting of 11 funds). We observe that the funds' portfolios that are less exposed to carbon risk are more diversified since they include the stock holdings of 77 companies, whereas the holdings of funds' portfolios exposed to higher levels of carbon risk are concentrated in 64 companies. Additionally, low-risk funds are less exposed to carbon-intensive companies than high-risk funds. The 10 companies that contribute the most to low-risk funds' WACI represent 66% of the funds' WACI. However, for high-risk funds, this percentage is 81%. We also observe that the top 10 contributing companies differ between the two risk groups, although there are five common companies (see Figure 7). Iberdrola is a noteworthy company in both groups, contributing the most to WACI in the low-risk group and the second most in the high-risk group. Vidrala (66 tCO_2e/€ million), CIE automotive (44 tCO_2e/€ million), and Viscofan (28 tCO_2e/€ million) are also relevant contributors to the funds' carbon risk exposure in the high-risk group, with their contribution to the low-risk group being far less important.



Panel A



Panel B

Figure 7. The 10 companies with the highest contribution to the upstream total WACI of funds with low exposure (Panel A) and high exposure (Panel B) to climate-related transition risk in 2022 (tCO_2e/€ million). Risk groups are defined as follows: low risk (below the 25th percentile of the funds' upstream total WACI) and high risk (above the 75th percentile of the funds' upstream total WACI).

3.3. Risk-adjusted financial performance of funds across carbon risk groups and Morningstar's carbon risk assessment

Next, we investigate the financial performance of funds according to their exposure to climate-related transition risk. To that end, the funds are classified into four carbon risk groups according to their upstream total WACI (including Scope 1, Scope 2, and upstream Scope 3 emissions), as described in Subsection 3.2. We obtain 1-year returns and calculate the 3-year and 5-year annualised returns of the funds as of December 31, 2022, from the annual returns reported for every fund by Morningstar.[20] We then compute the average returns across carbon risk groups. To assess the funds' risk-adjusted performance, we rely on two ratios: The Sharpe ratio and the Sortino ratio. For the calculation of both ratios, we employ the funds' monthly log returns from March 2020 to December 2022.[21] The Sharpe ratio measures the mean return in excess of the risk-free interest rate per unit of total risk exposure (i.e., the standard deviation of the returns). We use the yield on 1-year Treasury bills issued by the Spanish government as a proxy of the risk-free interest rate. Unlike the Sharpe ratio, the Sortino ratio adjusts the mean excess return by the downside risk (i.e., the square root of the variance computed exclusively over the returns below the risk-free interest rate) (e.g., Ji et al., 2021a; Mirza et al., 2022). To compare the performance of the funds across carbon risk groups, we calculate the monthly log returns for each risk category as an equal weighted portfolio of the funds included in that category and then we compute the Sharpe and Sortino ratios. For both ratios, the greater the value is, the higher the performance of the carbon risk group.

Table 2 (Panel A) provides the returns and the risk-adjusted performance measures for the four carbon risk groups. We find that the funds yield negative average returns across carbon risk categories and investment horizons.[22] The magnitude of the returns further reveals that funds that are more exposed to carbon risk underperform funds with lower exposure at the 1-year investment horizon. However, funds with high exposure to carbon risk perform better at the 3- and 5-year investment horizons, with funds within the low carbon risk group yielding the lowest average returns. Interestingly, when we assess the funds' risk-adjusted performance, the Sharpe and Sortino ratios consistently indicate that funds with medium-low exposure to carbon emissions outperform funds that are more exposed to carbon-intensive companies. To evaluate the statistical significance of the difference in the Sharpe ratios of funds within the medium-low carbon risk group and every other fund group, we employ the Ledoit and Wolf (2008) test.[23] The Ledoit and Wolf (2008) test is conducted under the null hypothesis that the Sharpe ratios of two given portfolios are equal. We report *p*-values within parentheses for each of the carbon risk groups whose Sharpe ratio is compared with the Sharpe ratio for the medium-low risk group. We find that the Sharpe ratio for the funds with medium-low exposure to carbon risk is significantly different from the Sharpe ratio for the medium-high carbon risk category (i.e., the lowest Sharpe ratio) at the 5% significance level. For the low- and high-risk groups, the difference in the Sharpe ratios is not statistically significant. Hence, investors committed to climate

[20] Since returns vary across fund classes, when there is more than one class for a given fund, we select the fund class associated with a retail profile on the basis of the minimum investment and applied commissions.

[21] The registration of two funds (Allianz Spanish Stock Exchange and Solventis Aura Iberian Equity) with the Spanish National Stock Market Commission occurred in late February 2020. Therefore, historical prices for all funds are only available from March 2020 onwards.

[22] The annual returns for 2018, 2020, and 2022 are negative for all funds, all but 2 funds, and 34 out of 45 funds, respectively. In turn, all funds display positive returns in 2019 and 2021.

[23] The corresponding programming code for R and Matlab is freely provided by the authors at https://www.econ.uzh.ch/en/people/faculty/wolf/publications.html#9.

change and concerned about financial risk should consider funds with a medium-low carbon risk profile according to the upstream total WACI. Overall, our findings extend the empirical evidence in Fang and Parida (2022) and Steen et al. (2020), who documented a positive relationship between funds' Morningstar ESG rating[24] and their risk-adjusted financial performance.

Additionally, because our results indicate the incorrect assignment of funds to carbon risk groups resulting from omitting Scope 3 emissions, we investigate its consequences for capital misallocation as measured by the funds' financial performance. To that end, we calculate the Sharpe and Sortino ratios for the funds' carbon risk groups (i.e., low-risk, medium-low risk, medium-high risk, and high risk) according to the WACI calculated only from the investees' Scope 1 and Scope 2 emissions. The results are provided in Table 2 (Panel B). For the two carbon-risk categories where more funds are wrongly identified when Scope 3 emissions are not accounted for, as discussed in Subsection 3.2 (i.e., low-risk and medium-low-risk categories), we find that the former yield the highest Sharpe and Sortino ratios, while the latter yield the lowest ones. Therefore, results on the performance of medium-low risk funds based on the WACI calculated from Scope 1 and Scope 2 emissions contradict those obtained from the upstream total WACI (including Scope 1, Scope 2, and upstream Scope 3 emissions). Overall, these findings suggest that excluding Scope 3 emissions when assessing funds' carbon risk exposure may lead to capital misallocation.

Table 2. Financial performance of funds across carbon risk groups as of December 2022.

	Low carbon risk	Medium-low carbon risk	Medium-high carbon risk	High carbon risk
Panel A: Carbon risk groups based on the funds' upstream total WACI (including Scope 1, Scope 2, and upstream Scope 3 emissions)				
1-year returns (%)	−2.483	−1.962	−3.000	−3.463
3-year annualised returns (%)	−2.938	−1.090	−2.455	−0.550
5-year annualised returns (%)	−2.849	−0.307	−1.478	−0.340
Annualised Sharpe ratio	0.710 (0.817)	0.744	0.583 (0.046)	0.686 (0.531)
Annualised Sortino ratio	1.566	1.667	1.229	1.506
Panel B: Carbon risk groups based on the funds' WACI including Scope 1 and Scope 2 emissions				
Annualised Sharpe ratio	0.766	0.585	0.614	0.747
Annualised Sortino ratio	1.701	1.220	1.314	1.682

Notes. The carbon risk groups are as follows: (1) Low risk (below the 25th percentile), (2) medium-low risk (25th to 50th percentile), (3) medium-high risk (50th to 75th percentile), and (4) high risk (above the 75th percentile). In Panel A, *p*-values obtained from testing the null hypothesis that the Sharpe ratios for the medium-low carbon risk group and any other carbon risk group are equal according to the Ledoit and Wolf (2008) test are provided within parentheses.

Our results so far suggest a negative association between funds' carbon risk based on the upstream total WACI and their risk-adjusted financial performance. Next, we elaborate on this finding and investigate whether active management can help explain this relationship. To that end, we use Fama

[24] Morningstar ESG ratings range from one to five globes. A fund is assigned one globe (the lowest sustainability labelling) if it is in the bottom 10% of funds in its category, whereas the top 10% of funds are given five globes and are ranked as high sustainable.

and French's (1992) three-factor model, according to which, the expected excess return on a diversified equity portfolio is explained by three risk factors, namely, the market risk factor, the size factor, and the value factor. These factors have been proved useful in explaining equity funds' excess returns in different countries/regions (Fooladi and Hebb, 2023; Ji et al., 2021b; Wagner and Margaritis, 2017). An estimate for the relevance of each factor in explaining equity funds' excess returns across carbon risk categories is obtained by running the following regression:

$$r_{it} - r_{ft} = \alpha_i + \beta_{1i}(r_{Mt} - r_{ft}) + \beta_{2i}SMB_t + \beta_{3i}HML_t + \beta_{4i}\Delta EUI_t + \varepsilon_{it}, \tag{8}$$

where r_{it} is the return (at time *t*) on the equally weighted portfolio of the funds included in the carbon risk category i, r_{ft} is the risk-free interest rate as proxied by the yield on 1-year Treasury bills issued by the Spanish government, α_i is Jensen's alpha (Jensen, 1968), r_{Mt} is the return on the market portfolio as proxied by the Spanish stock index IBEX 35, SMB (small minus big) is the return on a portfolio of small stocks minus the return on a portfolio of large stocks, and HML (high minus low) is the return on a portfolio of stocks with high book-to-market values minus the return on a portfolio of stocks with low book-to-market values. The rationale behind the SMB and HML factors is that small-cap stocks and value stocks (high book-to-market ratio) are expected to yield higher returns than their counterparts. We calculate the SMB as the difference between the return on the IBEX 35 Medium Cap and the return on the IBEX 35 (the IBEX 35 Medium Cap is made up by the 20 stocks following those on the IBEX 35 according to the free-floating adjusted market cap). HML returns for Spain have been obtained from the data library publicly provided by Kenneth R. French on his website.[25] We include an additional variable in the regression, namely the energy uncertainty index (EUI) developed by Dang et al. (2023), which enables us to account for the effect of both the uncertainty related to fluctuations in the energy sector and the economic and policy uncertainty that might affect funds' returns. The EUI is constructed as an equally weighted index of two subindices: the energy-related subindex[26] and the uncertainty subindex, which are normalised to a scale of 100. Dang et al. (2023) documented steep fluctuations in the EUI in response to energy-related shocks and economic, financial, or geopolitical events (e.g., the COVID-19 outbreak or the Russian invasion of Ukraine); the significant response of macroeconomic variables linked to the business cycle to shocks in the EUI; and the negative impact of the EUI on industry-level outputs. We collected monthly data on the EUI for Spain and introduce the index in first differences in the regression in light of the evidence that the series in levels is not stationary.[27]

The results from the estimation of Equation (8) from monthly data over the period from March 2020 to December 2022 are shown in Table 3. We find that the market risk factor (i.e., the excess return on the IBEX 35 over the risk-free interest rate) is significantly priced in all cases. For funds within the high carbon risk group, the size factor is also significantly positive at the 1% significance level. From Figure 7 (Panel B), we can see that three of the four companies that contribute the most to the upstream total WACI of funds with high exposure to carbon risk belong to the IBEX 35 Medium Cap (i.e., Vidrala, CIE Automotive, and Viscofan).[28] On the contrary, according to Figure 7 (Panel

[25] https://mba.tuck.dartmouth.edu/pages/faculty/ken.french/data_library.html.

[26] Some energy-related keywords whose frequency of mention is used to construct the energy-related sub-index include "energy price volatility/shocks", "gasoline price", "crude oil", "natural gas", "alternative/clean energy", and "Kyoto protocol".

[27] Data have been retrieved from the webpage https://www.policyuncertainty.com/energy_uncertainty.html. As a robustness check, we have run the regression using monthly relative changes in the EUI rather than absolute changes. The results do not change.

[28] https://www.bolsasymercados.es/bme-exchange/docs/Indices/Avisos/ing/gestorindice/Notice_Index_Manager_23-22.pdf

A), the four companies with the highest contribution to the upstream total WACI of funds with low-carbon-risk exposure belong to IBEX 35.[29] Therefore, the lower market capitalisation of the most carbon-intensive companies within the category of funds highly exposed to carbon emissions is a risk factor investors are compensated for. For the category of funds with medium-low carbon risk exposure, we find that both the SMB and Jensen's alpha are statistically significant at the 5% significance level. A positive alpha suggests that the fund manager is adding value beyond the underlying factor exposures through active management. Thus, Jensen's alpha is a risk-adjusted performance measure that has been used in the literature to compare the performance of green equity funds and conventional funds (Ji et al., 2021b; Naqvi et al., 2021; Reboredo et al., 2017). In this regard, our result that the alpha is only statistically significant for the medium-low carbon risk group suggests the outperformance of this group over the rest of the carbon risk groups. It is consistent with the Sharpe ratio, which indicated the statistically significant outperformance of the medium-low carbon risk category over the medium-high carbon risk category, and with the Sortino ratio, which indicated its outperformance over any other carbon risk category. Finally, the EUI is not statistically significant in any case.

Table 3. Regression of the funds' excess returns on Fama and French's (1992) three factors across carbon risk groups.

	Low carbon risk	Medium-low carbon risk	Medium-high carbon risk	High carbon risk
α	0.0033 (0.0027)	0.0040** (0.0019)	0.0039 (0.0024)	0.0032 (0.0020)
β_1	0.9718*** (0.0562)	0.9286*** (0.0396)	0.9767*** (0.0581)	0.9240*** (0.0426)
β_2	0.3137 (0.1894)	0.2726** (0.1077)	0.0081 (0.1717)	0.4277*** (0.1405)
β_3	0.0863 (0.0624)	0.0139 (0.0436)	−0.0035 (0.0545)	0.0027 (0.0463)
β_4	−0.0001 (0.0003)	0.0000 (0.0002)	−0.0002 (0.0003)	−0.0002 (0.0002)
R-squared	0.92	0.95	0.95	0.94

Notes: The regression equation is given by $r_{it} - r_{ft} = \alpha_i + \beta_{1i}(r_{Mt} - r_{ft}) + \beta_{2i}SMB_t + \beta_{3i}HML_t + \beta_{4i}\Delta EUI_t + \varepsilon_{it}$, where r_{it} is the return (at time *t*) on the equally weighted portfolio of the funds included in the carbon risk category *i*, r_{ft} is the risk-free interest rate, α_i is Jensen's alpha (Jensen, 1968), r_{Mt} is the return on the market portfolio, SMB is the size factor (small minus big returns), HML is the value factor (high minus low returns), and ΔEUI_t denotes the first differences in the EUI for Spain developed by Dang et al. (2023). Standard errors are in parentheses. *** p < 0.01, ** p < 0.05, * p < 0.1. The estimation period spans from March 2020 to December 2022.

Finally, we investigate the accuracy of the Morningstar portfolio carbon risk score to help investors specifically concerned about carbon risk discriminate across funds in comparison with the WACI.[30] The Morningstar portfolio carbon risk score is calculated monthly by Morningstar as a weighted average of the Sustainalytics company carbon risk rating of the equity holdings in a fund, which measures the degree to which a company's activities are aligned with the transition to a low-

[29] https://www.bolsasymercados.es/bme-exchange/docs/Indices/Avisos/ing/gestorindice/Notice_Index_Manager_22-22.pdf

[30] From a different approach, Popescu et al. (2023) calculated the carbon footprint of European equity funds on the basis of overall sustainable tags (i.e., across socially responsible investment (SRI) and conventional funds), as well as by using Bloomberg's specific sustainability attributes (i.e., environmentally friendly, climate change, clean energy, and ESG). However, we note that analysing the funds' exposure to carbon-related transition risk across general sustainable labelling groups may not be entirely appropriate.

carbon economy (see Hale (2018) for further details). The Morningstar portfolio carbon risk scores range from 0 to 100, where lower scores indicate a lower carbon risk.

We collected Morningstar portfolio carbon risk scores from the Morningstar website for our selection of Spanish equity funds as of December 2023[31]. The average risk score for the investigated funds is 8.08, with values ranging from 5.02 to 14.12 (Table 4). The standard deviation (1.61) and the quartile values indicate a low degree of dispersion and a high level of concentration of Spanish funds within the less risky side. This finding is consistent with the evidence in Hale (2018), who showed that 84% of more than 29,000 investigated global funds have Morningstar carbon risk scores below 15, and 97% of funds have risk scores below 20. On the basis of these results, Hale (2018) classified funds into five carbon risk categories: Low (scores below 10), medium-low (scores from 10 to 14.99), medium (scores from 15 to 19.99), medium-high (scores from 20 to 30), and high (scores above 30). Hence, 93% of Spanish funds would fall under the low carbon risk category according to Morningstar, whereas the remaining 7% funds would be labelled as medium-low risk.

Table 4. Main descriptive statistics for the Morningstar portfolio carbon risk score and upstream total WACI for Spanish equity funds.

	Morningstar portfolio carbon risk score	Upstream total WACI
Mean	8.08	18.71
Minimum	5.02	10.28
Maximum	14.12	29
Standard dev.	1.61	3.86
Q(1)	6.89	16.38
Q(2)	8.05	18.79
Q(3)	8.9	20.91
Jarque-–Bera test	25.66***	0.69
Wilcoxon–Mann–Whitney test	8.02***	

Notes: The Morningstar portfolio carbon risk scores range from 0 to 100. Values of the WACI are also rescaled to range from 0 to 100. The null hypothesis for the Jarque–Bera test is that the series is normally distributed. The null hypothesis cc

In order to assess whether the WACI allows for a deeper discrimination of Spanish funds on the basis of their carbon-risk exposure than Morningstar's metric, we rescale the WACI from 0 to 100 by calculating the minimum and the maximum values of the upstream total WACI that our funds might yield (i.e., from 0 to 1754).[32] As reported in Table 4, the average value of the WACI for Spanish funds is 18.71 and the standard deviation is 3.86 (i.e., 2.4 times the standard deviation of Morningstar's risk score). Hence, the WACI values show greater variability than Morningstar's. Thus, if we classified Spanish funds into carbon risk categories as defined by Hale (2018), we would find 5 that funds belong to the medium-low risk group, 28 out of 45 funds have a medium-risk profile, and the remaining 12 funds have medium-high risk. To formally evaluate whether the Morningstar portfolio carbon risk scores and the WACI for Spanish equity funds are not equally distributed, we apply the Wilcoxon–

[31] This is the date for which Morningstar publicly provided data on fund scores when we visited the website. Recall that we calculate the WACI from funds' and companies' financial data as of December 2022. However, because fund scores are averaged over quarterly portfolios over the past 12 months, we consider that score values as of December 2023 can reasonably be used for a comparison with the WACI values calculated as of December 2022. By December 2023, 43 out of 45 Spanish funds had been assigned a score (to receive a Morningstar portfolio carbon risk score, at least 67% of a portfolio's holdings must have a carbon-risk rating from Sustainalytics).

[32] The minimum (maximum) value of the upstream total WACI is obtained for a fund investing uniquely in the company with the lowest (highest) carbon intensity according to its upstream total emissions.

Mann–Whitney nonparametric test (given the non-normality of the Morningstar series according to the Jarque–Bera test). The test indicates the rejection of the null hypothesis that the two series are identically distributed at the 1% significance level.

Sustainalytics' company carbon risk rating, on which Morningstar relies for calculating portfolios' scores, is defined as the unmanaged carbon risk exposure that remains after accounting for a company's efforts to reduce emissions and related carbon risks. However, we find that this residuary measure of carbon risk exposure seems to result in a high degree of funds concentrated in the low-risk range. This result, alongside the fact that it is not aligned with the TCFD's recommended measures of funds' carbon footprint, indicates that investors committed to climate change-related issues should be cautious when using Morningstar's metric for selecting funds according to their carbon risk exposure.

4. Conclusions

Despite progress in the EU in regulations and sustainability reporting, in collaboration with different global initiatives, the Bank of Spain highlights the overall lack of homogenisation across companies in reported information due to different metrics and units, different data aggregation levels (i.e., individual vs. consolidated data), or a lack of official verification of the information presented, among others (Fernández-Rosillo et al., 2023). This study employs the verified reported consolidated emissions data (tCO_2e) of most companies listed in the Spanish stock exchange (BME) to quantify the carbon footprint of Spanish equity funds' portfolios in 2022. To guarantee an accurate assessment of the funds' exposure to climate-related transition risk, we also collected emissions data through the investees' full value chain (i.e., Scope 1, Scope 2, and downstream and upstream Scope 3 emissions) and employed a hybrid environmentally extended multiregional input–output model (hybrid EE-MRIO) to fill in the missing data, mainly of Scope 3. A recent study by Janicka and Sajnóg (2023) on the quality of environmental data disclosure by public companies listed on the regulated markets of the EU documented good quality for CO_2 emissions (in comparison with other environmental indicators, such as water use or waste production) for "old" EU member states (which joined before 2004), although there is some heterogeneity. Thus, for instance, the share of companies that reported CO_2 emissions for 3 years and more in the period 2012–2021 ranges from 12% (Greece) to 79.2% (Austria), with Spain registering a share of 33.1%. Therefore, our methodological approach, which combines reported emissions data with sector-specific average emissions data, can be extended to other countries, given the relevance of missing emissions data in the EU. However, structural differences in EU markets regarding reporting standards (the existence or absence of databases that provide such information), sector composition (the weight of fossil fuel sectors and the use of renewables in electricity production, which determine the importance of Scope 1 and 2 emissions), or trade openness (the more significant the openness, the higher the imported Scope 3 emissions) may limit the applicability of the proposed measures to equity funds in these countries.

We also acknowledge shortcomings in the application of the hybrid EE-MRIO model to emerging countries, where the quality of the information reported by companies is even lower due to the less developed environmental legislation. In such case, an alternative approach would be to calculate the carbon footprint of companies using only an EE-MRIO model without creating a hybrid model that incorporates data from Scope 1 and 2 emissions. This would result in different carbon performance ratings for investment funds by country, depending on whether companies report the necessary information and how it deviates from the average carbon intensities used in the EE-MRIO models.

Overall, a comparison of the effects of missing reporting data on the misallocation of funds according to their carbon risk profile across scopes and countries and their potential implications for capital misallocation open new lines for future research.

We find that Scope 3 emissions represent the largest portion of investees' contributed emissions to all funds' total carbon footprint (66% on average). However, we note that even official financial institutions, like the ECB, still fail to include Scope 3 emissions in the calculation of the emissions financed by their investment portfolios. Two reasons can be argued: (1) The lack of detailed information for the companies whose assets are included in the investment portfolios, and (2) avoiding double-counting of emissions, since the Scope 3 emissions of some companies are the Scope 1 and 2 emissions of other companies. Despite the double-counting issue, the companies analysed in this study are responsible for 38% of the emissions generated in the Spanish economy and, therefore, the effect of double-counting is only partial. More importantly, considering only Scope 1 and 2 emissions would imply the underestimation of climate-related transition risk by not including the emissions embodied in imports, especially in the EU, where imports account for more than 30% of companies' carbon footprint (Ortiz et al., 2020).

In this context, we examine the sensitivity of funds' carbon risk assessment to the coverage of full-scope emissions. Our results reinforce the need to consider emissions through the full value chain to avoid the incorrect allocation of funds to carbon risk categories. Nguyen et al. (2023) investigated the divergence in the composition of Scope 3 emissions data (i.e., which Scope 3 categories are reported) across the leading data providers (Bloomberg, Refinitiv Eikon, and ISS) and found considerable divergence in the aggregated Scope 3 emissions values from three of the largest data providers. In the EU, the efforts of the Corporate Sustainability Reporting Directive (CSRD) for providing standardised and digitised sustainability information, including Scope 1, 2, and 3 emissions, will facilitate an adequate assessment of the carbon risk profile of funds' financial portfolios (European Union, 2023). However, the omnibus package being carried out by the European Commission has just postponed the obligation to report this information until 2028, which will make it challenging to collect the necessary data for calculating the carbon risk exposure of investment funds.[33]

Our results have implications for portfolio management and investment decisions. On one hand, diversification would help the managers of funds with high exposure to carbon risk (through the financed emissions of investees' activities along their full value chain) to align their portfolios with the transition to a low-carbon economy. Excessive exposure to carbon-intensive companies, such as Iberdrola or Vidrala, should be avoided. On the other hand, our study offers three relevant findings for green investors. First, funds' carbon risk labelling (i.e., low, moderate, or high) as measured by the WACI is sensitive to the lack of consideration of Scope 3 emissions. Second, the WACI allows for a deeper screening of Spanish funds by carbon risk exposure than the Morningstar portfolio carbon risk score. This finding, alongside the fact that Morningstar's metric is not aligned with industry-led recommendations and EU policy regulations, suggests that using such metric, may increase the chance of incorrect allocation of green investors' money to funds according to their carbon risk profile. Third, funds with lower exposure to carbon risk have a better risk-adjusted performance than funds that are more exposed to carbon emissions. As long as climate policies are insufficient to mitigate climate change (IPCC, 2022), a late and abrupt policy framework would lead to steep asset value adjustments, thus potentially increasing the funds' volatility (Battiston et al., 2017). Finally, the effects on fund flows according to the funds' WACI calculated from emissions along the full value chain (higher

[33] https://ec.europa.eu/commission/presscorner/detail/en/ip_25_614.

inflows to funds with a lower WACI and outflows from funds more exposed to carbon-intensive companies) might also be expected when its calculation and dissemination become a standard, as happened following the introduction of Morningstar's sustainability rating (Gantchev et al., 2024). These are two potential avenues for future research raised by this study.

Author contributions

Luis Antonio López: Conceptualisation, data curation, formal analysis, funding acquisition, investigation, methodology, project administration, software, supervision, writing – original draft.

Raquel López: Conceptualisation, formal analysis, funding acquisition, investigation, project administration, supervision; writing – original draft.

Use of AI tools declaration

The authors declare they have not used artificial intelligence (AI) tools in the creation of this article.

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Conflict of interest

The authors declare no conflicts of interest.

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