POLITECNICO DI TORINO

Master's Degree in Physics of Complex Systems

Master's Degree Thesis

Portfolio Analysis Through TCFD Metrics:

Total Carbon Emissions and Carbon Footprint

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Abstract

Climate change is driving long-term shifts in global temperatures and weather patterns, already triggering extreme weather events and significant economic disruptions. The Task Force on Climate-related Financial Disclosures (TCFD), established in 2017, provides key metrics to support financial institutions and investors in monitoring and reporting their environmental impact. This study investigates the temporal behavior of Total Carbon Emissions (TCE) and Carbon Footprint (CF) within investment portfolios, addressing their variability and potential misinterpretations.

We analyze TCE and CF across four portfolio types, composed of companies that have disclosed emissions data at least once between 2011 and 2020. By quantifying these metrics and assessing their trends, we determine whether they exhibit alignment or divergence over time. Furthermore, we evaluate the impact of excluding Scope 3 emissions from these calculations.

Our findings reveal that TCE and CF can follow either consistent or divergent trends, influenced by the fluctuations in both emissions and portfolio valuation. Equally weighted portfolios demonstrate lower volatility than market capitalization-weighted portfolios. Regarding CF, market capitalization-weighted portfolios consistently report lower values than equally weighted portfolios, with differences ranging from 31.88% to 41.29% over the full 10-year period. Additionally, Scope 3 emissions play a crucial role, contributing up to 99% of total emissions for individual firms and up to 91.0% at the portfolio level. These results indicate that TCE and CF, depending on Scope 3 emissions, may not always accurately reflect a company's true emissions impact. Furthermore, due to their dependence on market capitalization, CF metrics are susceptible to misinterpretation and potential greenwashing by companies.

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Chapter 1

Introduction

Over the last decade, climate change has been recognized as a financial risk, with regulators urging institutions to assess their exposure and conduct stress tests [1][2][3]. In this context, methodologies for climate stress testing have made notable progress, particularly with the increasing incorporation of complex systems science, such as through network-based approaches and contagion dynamics [2][4][11][12][25].

"Changes in climate policies, new technologies and growing physical risks will prompt reassessments of the values of virtually every financial asset. Firms that align their business models to the transition to a net zero world will be rewarded handsomely. Those that fail to adapt will cease to exist. (...)
The TCFD provides the necessary foundation for the financial sector's role in the transition to net zero that our planet needs and our citizens demand. (...)
The TCFD should consider how asset owners could best disclose how well their portfolios are positioned for the transition to net zero."[1]

Analyzing TCFD[2] metrics, such as Total Carbon Emissions and Carbon Footprint, within investment portfolios is instrumental in assessing whether a company is actively engaged in reducing its emissions and improving its carbon exposure, for instance in the context of efforts to achieve carbon neutrality. Such analysis can contribute to aligning investments with global climate objectives, such as those outlined in the Paris Agreement. However, it is important to note that these

[1] Speech given by Mark Carney at the TCFD Summit, Tokyo, October 8, 2019 [23].
Mark Joseph Carney is a Canadian economist and politician who served as governor of the Bank of Canada (2008–2013) and the Bank of England (2013–2020). He also chaired the Financial Stability Board from 2011 to 2018 [24].

[2] Achronym of "Task Force on Climate-related Financial Disclosures"

metrics primarily focus on Scope 1 and 2 emissions, a limitation that can lead to misleading conclusions, as emissions values may vary significantly when Scope 3 is not considered. A genuine alignment with the Paris Agreement targets necessitates the inclusion of these emissions as well.

1.1 Background

In this section, we explore key aspects of climate-related challenges and responses. Climate scenarios are introduced as essential tools for assessing the impact of greenhouse gas (GHG) emissions and guiding mitigation and adaptation strategies. We then discuss the role of international climate policies, such as the UNFCCC (United Nation Framework Convention on Climate Change) and the Paris Agreement, in setting emissions targets, fostering global cooperation, and supporting sustainable transitions. The analysis extends to climate-related financial risks, emphasizing the systemic impacts of physical and transition risks on markets and the economy. Finally, the concept of greenwashing is examined, highlighting its detrimental effects on trust in sustainable practices and the importance of transparency and accountability.

1. **Climate Scenarios**:
   Climate scenarios simulate the climate system's response to varying GHG and aerosol emission pathways, offering insights into the potential impact of different mitigation strategies [8]. These scenarios are essential for understanding future social systems that cannot be fully captured by traditional models [9]. Human activities have already caused a 1.1°C rise in temperature compared to pre-industrial levels (i.e., the average global temperature before the Industrial Revolution), leading to significant changes in the atmosphere, oceans, and biosphere, including increased extreme weather events that disproportionately affect vulnerable populations [10].

   With continued emissions, global temperatures are expected to rise above 1.5°C compared to those temperatures, making it more difficult to achieve the 2°C target set by the Paris Agreement. Although reducing emissions can slow this increase, the risks of irreversible consequences are escalating. This requires stronger international cooperation, financial investments in vulnerable regions, and inclusive governance. Delaying action risks solidifying high-emissions infrastructure and raising costs. Achieving climate targets necessitates significant investments, requiring disruptive sector transitions. Equity, inclusion, and social justice are key for both adaptation and mitigation. Effective policies, governance, and global cooperation are vital for accelerating climate action and overcoming barriers to redirecting capital toward sustainable efforts [10].

High-quality climate scenarios are essential for long-term adaptation planning, as they help to assess future climate risks and evaluate adaptation strategies. These scenarios are characterized by factors that cannot be fully eliminated but can only be reduced, including the complexity of the climate system, the unpredictability of future greenhouse gas and aerosol emissions, the variability in global climate sensitivity, potential changes in the mass of the Greenland and Antarctic ice sheets, and challenges in regional projections, particularly concerning precipitation [8]. Despite these uncertainties, climate scenarios are crucial for understanding vulnerability and testing adaptation strategies, especially in the face of increasing physical climate risks [8][9]. Underestimating these risks can delay action and increase socio-economic losses, highlighting the importance of reliable climate scenarios for assessing future impacts and strengthening resilience [10].

2. **Climate Policies**:
The United Nations (UN) plays a critical role in the global climate fight through agreements like the UNFCCC, aiming to stabilize GHG concentrations to avoid dangerous climate impacts [13][14]. While the Kyoto Protocol introduced legally binding emissions reduction targets for developed countries, the 2015 Paris Agreement took these efforts further, striving to keep global temperature rise well below 2°C relative to pre-industrial levels, with an ideal target of 1.5°C [13].

The European Union (EU), aiming to become climate-neutral by 2050, leads with ambitious goals and flexible market-based tools such as pollution taxes and green technology initiatives [10]. Both the UN and EU are vital in steering global climate action. From an economic perspective, the best climate policy balances proactive measures with a business-as-usual approach, accounting for both physical and policy risks of climate change [9].

Well-designed climate policies are crucial for managing financial risks, allowing markets to anticipate changes and minimize systemic risks, while delays can lead to market instability and losses, particularly in fossil fuel sectors [4][11]. Given significant uncertainty, strategies are evolving to improve decision-making under such conditions, emphasizing resilience and flexibility in social and economic systems [9].

The precautionary principle advises action despite scientific uncertainty if the potential consequences are severe. Addressing climate risks involves a combination of risk analysis, hedging strategies, and managing psychological factors that affect risk perception [9]. Climate policies will shape asset values and the economy, with sectors like fossil fuels facing negative outcomes while renewables may benefit. Managing these transitions is crucial to avoid systemic disruptions and stranded assets [2].

3. **Climate-Related Financial Risks**:
   Climate risks are complex and challenging to assess due to their systemic unpredictability and potential for extreme events, which can trigger tipping points in ecosystems and socio-economic systems. These risks, driven by physical and transition factors, affect financial assets and portfolios, often leading to significant losses for companies and governments. The IPCC (Intergovernmental Panel On Climate Change) recognizes climate change as a major financial risk, impacting both institutions and personal savings [15].

   Climate risks are categorized as acute (immediate impacts like natural disasters) and chronic (long-term changes like glacial melt). Both types can cause substantial losses, with sectors facing different acute and chronic shocks depending on asset location [12]. Financial risk from climate change is projected to rise, with global gross domestic product losses potentially reaching 7.1% by 2080 if emissions continue at current rates [3]. Traditional diversification strategies may not protect against these risks, emphasizing the need for asset-level assessments and better climate risk management [12].

   Transition risk, linked to the shift to a low-carbon economy, could lead to asset depreciation, while the endogenous nature of climate risk means financial actors' perceptions and actions influence future climate outcomes [2][4]. Businesses also face risks from climate hazards, regulatory changes, and emerging markets for emissions reductions, with significant uncertainties in policy outcomes and their financial implications [9].

   Debate continues on whether climate policies pose systemic risks or provide opportunities for low-carbon investments [11][23]. However, due to the complexities of the interconnected financial system, estimating risks and returns requires a careful, multifaceted approach. A network-based climate stress test suggests that financial actors, while indirectly exposed to fossil fuel sectors, face substantial risks through various interconnected economic sectors [11].

   Ultimately, addressing climate risks requires comprehensive risk management, innovative assessment tools, and robust policy frameworks to ensure financial resilience and sustainable economic growth [9].

4. **Greenwashing**:
   Greenwashing occurs when companies exaggerate or fabricate their environmental efforts, misleading consumers about their sustainability practices [5][6][7]. Coined by Jay Westervelt in 1986, the term highlights misleading claims, such as hotel towel reuse campaigns, that create a false positive image of corporate responsibility [2][5].

   A review of 500 global websites revealed that 40% of green claims are misleading, sometimes linked to controversial practices like the EU's classification of certain energy sources as sustainable. Weak sustainability certifications can further obscure harmful practices [6]. Greenwashing poses risks to consumer and investor trust, especially in markets for environmentally-friendly products and socially responsible investments [3][7]. The rise of vague environmental claims dilutes the meaning of "green" for consumers [8].
   Addressing greenwashing is key to ensuring transparency and accountability in investment practices.

1.2 Research Questions

The objective of this thesis is to analyze the behavior of key TCFD metrics, specifically Total Carbon Emissions (TCE) and Carbon Footprint (CF), within four different type of portfolios made of firms that reported emissions data for at least one year between 2011 and 2020.

The following research questions will be addressed:

1. **Research Question 1: What is the temporal trend of the two metrics? Are their trajectories similar, or do they exhibit significant differences over time?**
   To address this question, we will analyze the trends of the two metrics across four different portfolios. The analysis will be both qualitative, represented through line charts illustrating the trends, and quantitative, providing tables with statistics of the metrics and considering the percentage variations.
   Our analysis will show that Total Carbon Emissions and Carbon Footprint can exhibit either similar or divergent trends, depending on the performance of the portfolio holdings.

2. **Research Question 2: How do the metrics change when different weights are assigned to the companies? Specifically, how does their**

behavior differ between an equally weighted (EW) portfolio and a market capitalization-weighted (PW) portfolio? How do the results change between portfolios that contain only firms with 100% disclosures (Portfolio$_A^{EW}$ and Portfolio$_A^{PW}$, which we will refer to as $\mathbb{A}$ portfolios) and portfolios that allow the presence of missing data (Portfolio$_B^{EW}$ and Portfolio$_B^{PW}$, which we will refer to as $\mathbb{B}$ portfolios)?
To answer this question, the analysis will be conducted on two different types of portfolios. The first type consists of two portfolios where each company is assigned the same weight (Equally Weighted Portfolio). The second type consists of two portfolios where each company's weight is proportional to its market capitalization (Market Cap Weighted Portfolio). Two datasets will be used: one consisting of firms with 100% market cap and emissions (Scope 1 + Scope 2) disclosures, and another consisting of firms with at least one year of published market capitalization and emissions.
The data will demonstrate that the trends of the metrics can vary depending on the weightings used for the companies. The Equally Weighted portfolio tends to report higher values, especially for the Carbon Footprint, with an increase ranging from a minimum of +31.88% to a maximum of +41.29%.

3. **Research Question 3: How do these metrics vary when we apply linear interpolation to the raw data? Specifically, does the overall trend of the metrics change after interpolation? How do the variations between consecutive years change?**
To examine this question, the analysis will be conducted on $\mathbb{B}$ portfolios both before and after the linear interpolation of market capitalization and emissions. The findings will indicate that after interpolation, the trends of the metrics may change, and their values generally tend to be higher compared to the pre-interpolation values, particularly for equally weighted portfolios.

4. **Research Question 4: How do metrics change when Scope 3 emissions are also taken into account? Does the exclusion of Scope 3 emissions significantly affect their reliability, or is the impact negligible? Are these metrics an effective tool in addressing the issue of greenwashing?**
In order to investigate this question, we will analyze how emissions at the portfolio level vary when Scope 3 emissions are also considered. This analysis will be conducted on α, β, and γ portfolios.
It will become evident that Scope 3 emissions should not be disregarded, neither at the portfolio level nor at the individual company level, except in a few isolated cases. The percentage share of Scope 3 emissions within the total portfolio emissions can reach up to 76.49%, up to 99.99% at the firm level, and up to 91% at the portfolio level.

1.3 Data

We analyzed four distinct portfolios. Portfolio_A^{EW} and Portfolio_A^{PW} are composed of firms that reported their market capitalization and emissions every year from 2011 to 2020. As a result, the number of firms in these portfolios remains constant each year, totaling 288 firms.

In contrast, Portfolio_B^{EW} and Portfolio_B^{PW} include all firms that disclosed their market capitalization at least once during the 10-year period under analysis. The number of firms in these portfolios varies over time and increases progressively. Beginning in 2011 with 1,118 firms (75.08% of the total, 1,489), this number rises to 1,400 (94,02%) by 2020, as shown in Table 1.1[3]. It is important to note that while the number of firms increases from 2011 to 2020, this does not imply that a firm present in 2011 is also present in 2020. For each year, the firms included in the portfolio are assigned a weight greater than zero for that year, but their emissions may or may not be reported. Consequently, a firm could appear in the portfolio, yet if it did not report its emissions in a given year, its contribution to the metrics will be zero.

Table 1.1: This table presents the number of firms with non-zero weights (indicating that they reported their Market Capitalization) by year for Portfolio_B^{EW} and Portfolio_B^{PW}. The last column displays the percentage weight of companies with a non-zero weight relative to the total number of companies, i.e., relative to 1,489.

Year	Firms with non-zero weight	Percentage
2011	1118	75.08%
2012	1127	75.69%
2013	1147	77.03%
2014	1148	77.10%
2015	1184	79.52%
2016	1206	80.99%
2017	1257	84.42%
2018	1293	86.84%
2019	1354	90.93%
2020	1400	94.02%

Specifically, the number of firms with available emissions data decreased over

[3]All tables and figures are the result of personal work.

time, from a peak of 763 firms (68.25%) in 2011 to 580 firms (41.29%) in 2020 (Table 1.2). Based on the two datasets of firms contained in Portfolio_A and Portfolio_B,

Table 1.2: This table shows the annual firm counts and emission availability by Year for Portfolio_B^{EW} and Portfolio_B^{PW}. The second column displays the number of companies that published their Total Carbon Emissions (Scope 1 + Scope 2) for a given year. The last column presents the percentage of this number relative to the total number of companies for the same year (those with available MarkCap).

Year	Number of firms	Firms with available emissions	Percentage
2011	1118	763	68.25%
2012	1127	716	63.53%
2013	1147	668	58.15%
2014	1148	594	51.74%
2015	1184	592	50.00%
2016	1206	569	47.10%
2017	1257	586	46.46%
2018	1293	598	46.09%
2019	1354	586	43.21%
2020	1400	580	41.29%

we created three additional datasets[4]. From the one used for Portfolio_A, we created the firms' dataset that later formed the Portfolios_α, consisting of 172 firms. In contrast, the other dataset was used to create the dataset for Portfolio_β, which consists of 1,241 companies.

The final one includes only those companies that, from 2011 to 2020, reported Market Capitalization and all emissions: Scope 1, Scope 2, and Scope 3. This dataset was used to create the Portfolio_γ, which consists of 48 firms.

[4]The method used to obtain these datasets will be discussed in chapter 3.

Chapter 2

Metrics and Data Framework

Among the various metrics recommended by the TCFD (e.g., Weighted Average Carbon Intensity, Carbon Intensity), this analysis focuses on Total Carbon Emissions and Carbon Footprint. TCE, measured in tons of CO_2e, represents the portfolio's total Scope 1 and Scope 2 greenhouse gas emissions, proportionally attributed to the investor based on their ownership share in the companies' total market value. Similarly, CF expresses these emissions per million dollars invested, providing a normalized measure of the portfolio's carbon impact. It is measured in $tCO_2e/(M)\$$.

- **Scope 1** emissions are those greenhouse gas emissions that originate from sources directly controlled or owned by an organization, such as emissions from burning fuel in boilers, furnaces, or vehicles.
- **Scope 2** emissions encompass indirect greenhouse gas emissions linked to the purchase of electricity, steam, heat, or cooling.

Scope 3 emissions are excluded from these metrics due to their dependence on third-party activities (e.g., suppliers, customers), incomplete (Figure 2.1) and inconsistent data, and the risk of double-counting across supply chains. These emissions, which can represent 75–95% [17] of a company's total GHG footprint depending on the industry, cover all indirect emissions not accounted for in Scope 1 or Scope 2. Their wide scope and complexity make them unsuitable for a focused evaluation of direct corporate impacts in this study [18][19].

- **Scope 3** emissions refer to indirect emissions stemming from activities involving assets not owned or controlled by the reporting organization, yet influenced by its operations within the value chain. These emissions account for all sources outside the Scope 1 and 2 emissions boundary.

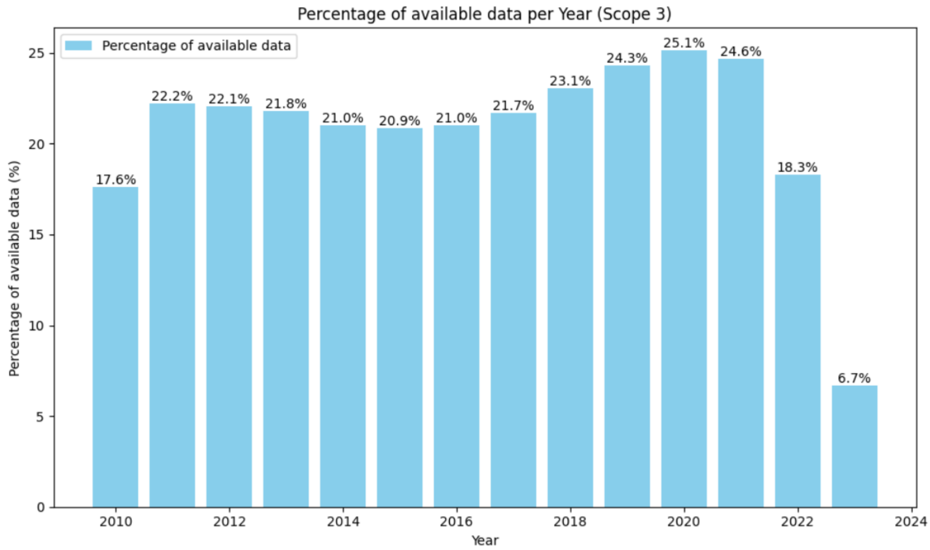

Figure 2.1: This figure shows the percentage of companies (year by year), relative to the total of 7,969, that have reported their Scope 3 emissions. On the x-axis, the years from 2011 to 2020 are represented, while the y-axis displays the percentages.

The study will compute averages, standard deviations, and medians for both metrics to better understand their typical values and variability. Temporal trends will be visualized using line charts. To evaluate the change in metrics depending on the type of weights used (market cap proportional vs. equally weighted portfolios), we will assess the year-over-year percentage change in the metrics and then examine the overall change over the entire study period.

To highlight the differences between emissions that include only Scope 1 and Scope 2 and those that also incorporate Scope 3, bar plots will be used. In this case, we will calculate the percentage weight of Scope 3 emissions at the individual firm level (statistics on these percentages, with particular attention to the maximum value) and then at the portfolio level. The percentage increase year by year will be evaluated, followed by the overall change across the ten-year period.

The methodology for calculating Total Carbon Emissions and Carbon Footprint is as follows:

A: First of all, the next two data were obtained via *Refinitiv*.

1. *Total Carbon Emissions*: The absolute greenhouse gas emissions (Scope 1

and Scope 2 GHG emissions) of the company, expressed in tons CO_2e.[1]
2. *Total Market Capitalization*: Represents the overall value of a company's outstanding shares in the stock market.

B: To calculate the metrics analyzed in this study, the following steps were performed:
First, each firm was assigned a *Weight* based on two different methodologies: one where the weight was equal to 1 divided by the total number of firms in the portfolio for a given year, and another where it was proportional to the firm's market capitalization. Using these weights, we then computed the *Holdings* of each firm.
After these steps, we were able to compute *Total Carbon Emissions* and *Carbon Footprint for each firm*[2], summing them separately to obtain *TCFD Total Carbon Emissions* and *TCFD Carbon Footprint*, respectively.

A. *Holdings*: The total value or amount of assets (such as stocks or shares) owned in the portfolio.
B. *Total Carbon Emissions*: The absolute greenhouse gas emissions associated with a portfolio (including only Scope 1 and Scope 2 Emissions), expressed in tons CO_2e [22].
C. *Carbon Footprint*: Total carbon emissions for a portfolio normalized by the market value of the portfolio, expressed in tons CO_2e/$M invested [22].

To analyze the impact of Scope 3 emissions, the same steps were followed, but instead of considering only Scope 1 and Scope 2, Scope 3 emissions were also included.

[1] This is the definition provided by Refinitiv. From this point onward, when we refer to "Total Carbon Emissions", we will be using the TCFD definition, which is as follows: The absolute greenhouse gas emissions associated with a portfolio (including only Scope 1 and Scope 2 emissions), expressed in tons of CO_2e. When referring to the total emissions of a company (always considering only Scope 1 and Scope 2 emissions), we will use the term "Total Emissions".

[2] For each firm, this refers to the portion of the total carbon emissions and carbon footprint of the portfolio that is attributable to the specific firm.

Chapter 3

Methodology

This section will first address the technical aspects, including the tools and software employed, as well as the methods used to gather the data. Subsequently, we will explore the scientific aspects, outlining the approach taken to answer the research questions initially posed.

3.1 Technical Aspects

3.1.1 Tools and Software Used

The data for this analysis was sourced from Refinitiv Eikon, a leading provider of financial market data and infrastructure. Serving over 40,000 institutions across 190 countries, Refinitiv supports global financial markets with data, trading platforms, and technology solutions in areas like trading, investment, wealth management, regulatory compliance, and risk management [20].

3.1.2 Connecting to Datasets

Since the objective was to analyze four types of portfolios over a 10-year period, Refinitiv was used to identify all companies that had reported their emissions at least once in the past 15 years. This allowed us to determine which decade had the highest number of firms. The following steps were taken to achieve this:

1. *Finding firms with Emissions' data available*:
We accessed the Refinitiv Eikon application and utilized the Screener tool via the Workspace bar. We applied a filter to generate a list of firms with available emissions data for at least one of the last 15 years. Given that Refinitiv's maximum display limit is 5,000 firms, and the filter initially yielded 9,293 firms, we modified the filter to generate a shorter list of companies. Initially, we set it

to capture companies with emissions data for at least one of the last 15 years ranging from 1 to 45,000, resulting in 4,957 firms. We then adjusted the filter to include companies with emissions (again, for at least one of the last 15 years) between 45,000 and 200,000, which resulted in 2,527 firms. Finally, we filtered for those with emissions exceeding 200,000, leading to 3,591 firms. Naturally, this approach led to lists with duplicates, increasing the total from 9,293 companies to 10,715. This issue and its resolution are addressed in the "Scientific Aspects" section.

2. *Exploring Data Tags with the Data Item Browser* (**DIB**):
We utilized the Data Item Browser to identify relevant tags, such as TR.OrganizationID and TR.CO2EmissionTotal. These tags serve as unique identifiers for specific fields within Refinitiv's database, enabling programmatic access via the Application Programming Interface (API). Through the DIB, we verified the appropriate tags for market capitalization, total shares, carbon emissions, and other essential data fields required for the analysis.

3. *Accessing Data Programmatically in Jupyter Notebook*:
A Refinitiv Desktop Session was initiated in Jupyter Notebook using the command

```
rdp.open_desktop_session(API_Key)
```

with the API key provided by our advisor. This session facilitated programmatic access to Refinitiv's database. The tags identified in **step 2** were subsequently used in API calls to retrieve the necessary data.

4. *Data Structuring*:
- The Comma-Separated Values (.csv) files were processed in **Jupyter Notebook**, where company information, including Organization ID, Company Name, NACE Classification, ISIN, GICS Sector, and GICS Industry, was compiled into a structured dataset named "*Company Info*."
- Additionally, a dataset named "*Features*" was developed to include numerical features such as Total Common Shares Outstanding, Market Capitalization, and Total Emissions, all specific to a given year. Both datasets were subsequently saved into separate Comma-Separated Values files for further analysis.

3.2 Scientific Aspects

This section presents the procedure adopted to obtain the final datasets, the metrics and the methods used to handle missing data.

To analyze the portfolio, a new Jupyter Notebook was created in VS-Code. After importing the necessary libraries (pandas, matplotlib, numpy, seaborn, interp1d and Decimal), the data files were loaded. Specifically, nine files were imported: three for each type of firm, categorized based on emissions, as obtained from Refinitiv. These files included lists of RICs, company information, and features.

Since the features file contained multiple rows for the same RIC, corresponding to different years, the DataFrame was transformed to ensure a single row for each RIC, with data from different years distributed across separate columns. Subsequently, the three files for each category of firms were merged via RIC, resulting in three consolidated datasets containing all the necessary information. These datasets were then combined into a single unified dataset.

The initial criteria required including firms that had reported emissions at least once in the past 15 years, which led to a dataset spanning from 2009 to 2024. To ensure consistency and mitigate discrepancies caused by variations in fiscal year reporting, emissions data from 2009 and 2024 were excluded, focusing the analysis on the period from 2010 to 2023. After removing duplicate RICs and excluding firms that reported emissions data only in 2009 or 2024, the final dataset comprised 7,969 firms. Another reason for omitting 2024 is that the year was still ongoing, which could have introduced potential biases due to incomplete data. After reviewing the market capitalization availability percentages (Figure 3.1), the analysis was conducted for the period 2011–2020.

3.2.1 Data Computation Techniques

Before delving into the detailed steps taken to address the various research questions, we will first outline the process of portfolio construction.

Starting from the data obtained via Refinitiv, it was necessary to assign a weight to each company in order to calculate the relevant metrics. According to the TCFD definition of Total Carbon Emissions and Carbon Footprint, each company is assigned a portion of its emissions proportional to its weight in the portfolio. We will now examine in detail the steps followed for calculating the metrics and addressing the first research question.

In addition to Total Emissions, and Total Market Capitalization (MarkCap), the following data was computed:

• **Weight**: to construct the portfolio, each firm was assigned a weight based on the portfolio type. Two weighting methods were used: For equally weighted Portfolios (denoted by the superscript 'EW'), the weight was calculated as 1 divided

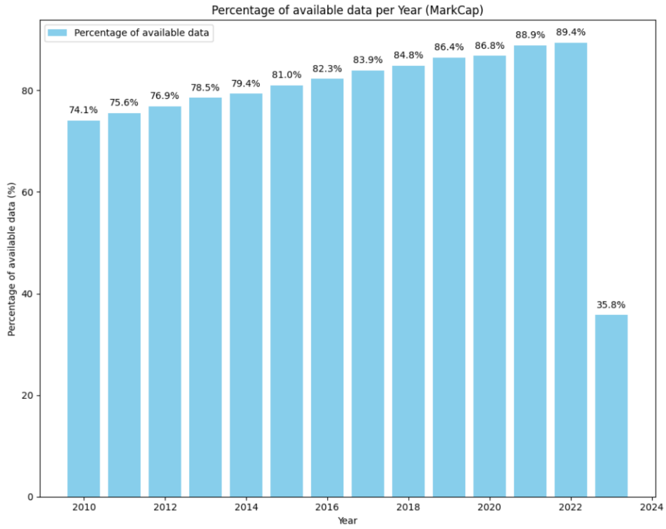

Figure 3.1: This figure shows the percentage of companies (year by year), relative to the total of 7969, that have reported their Market Capitalization. On the x-axis, the years from 2011 to 2020 are represented, while the y-axis displays the percentages.

by the total number of firms in a given year. For market cap weighted Portfolios (denoted by the superscript 'PW'), the weight was determined by dividing a firm's market capitalization by the total market capitalization of all firms in that year. In both cases, the sum of the weights must equal 1.

Equation for weight computation for equally weighted Portfolios:

$$Weight_{i,year}^{EW} = \frac{1}{Total\ number\ of\ firms_{year}} \tag{3.1}$$

Equation for weight computation for market capitalization weighted portfolios:

$$Weight_{i,year}^{PW} = \frac{MarkCap_{i,year}}{\sum_{i=1}^{N^{year}} MarkCap_{i,year}} \tag{3.2}$$

with N^{year} =Total Number of firms in the portfolio in a specific year.

- **Holdings**: The Holdings were calculated using the following formula:

$$Holdings_{i,year} = MarkCap_{i,year} \times Weight_{i,year} \tag{3.3}$$

By summing all Holdings, the *Portfolio Value* was derived:

$$Portfolio\ Value_{year} = \sum_{i}^{N^{year}} Holdings_{i,year} \tag{3.4}$$

After calculating the Holdings, we proceeded to calculate the metric values year by year for each company.
• Annual Total Carbon Emissions for each firm, as per TCFD disclosures:

$$TCE_{i,year} = Weight_{i,year} \times TE_{i,year} \tag{3.5}$$

where TE = Total Emissions (Scope 1 + Scope 2) provided by Refinitiv.
• Annual Carbon Footprint for each firm, as reported by TCFD:

$$CF_{i,year} = \frac{TCE_{i,year}}{Portfolio\ Value_{year}} \tag{3.6}$$

Finally, to address the first research question, we separately summed the contributions of each company for each year.
• **Portfolio TCE for a designated year**: The sum of all Total Carbon Emissions per firm across the portfolio:

$$TCE^{ptf}_{year} = \sum_{i}^{N^{year}} TCE_{i,year} \tag{3.7}$$

• **Portfolio CF for a specific year**:

$$CF^{ptf}_{year} = \sum_{i}^{N^{year}} CF_{i,year} \tag{3.8}$$

To answer the fourth question, we recalculated the metrics using not only Scope 1 and Scope 2 emissions but also Scope 3 emissions. From a procedural standpoint, the steps followed are the same for both weight calculation and metric calculation. The only difference lies in Equation 3.5, where *TE* will no longer refer solely to Scope 1 and Scope 2, but will also include Scope 3 emissions.

3.2.2 Missing Data Treatment

Regarding the issue of missing data, the focus must be placed on the features file, as it contains the dynamic data subject to non-reporting by companies. In contrast, the company info file primarily consists of "static" values, which do not change over time (e.g., company name, GICS Sector, etc.). The features file, however, includes "dynamic" values such as emissions and market capitalization, which vary over time.

Having clarified why the analysis must focus exclusively on the features file, let us now examine in detail how the data were processed.
We started with a dataset containing 7,969 companies: all of those that reported their emissions at least once between 2011 and 2020.

A direct examination of the .csv file obtained from Refinitiv revealed several companies with market capitalization and/or emissions values that fluctuated by a factor of 10, or even 100, from one year to the next. To address these inconsistencies, we applied a filtering process to eliminate companies that exhibited year-on-year variations greater than three times the previous year's value (either less than one-third or greater than three times the previous year's value) for both market capitalization and emissions data.

Additionally, considering that some companies had data missing in certain years (represented as NaN values), we refined the filtering process to account for these gaps. Specifically, we allowed for a company to grow or shrink by up to three times the value of the previous year. In cases where there were years separated by NaN values, the threshold for acceptable growth or decline was adjusted. The condition was that the value for a given year should not exceed the last available value, multiplied (or divided) by 3^{1+M}, where M was the number of years with NaN values. This ensured that growth or decline between non-consecutive years would follow a consistent, constrained pattern, avoiding unrealistic fluctuations due to missing data. Furthermore, of the 7,969 companies in the initial dataset, 821 had not reported their market capitalization in any of the 10 years, so they were removed.

After applying these filters, we were left with a dataset of 1,489 companies. This dataset includes the firms from both Portfolio_B^{EW} and Portfolio_B^{PW}.

In order to address the third research question, we analyzed the metrics of this dataset comprising 1,489 firms, both based on the raw data obtained from Refinitiv and through an additional analysis utilizing linear interpolation applied to the raw data. We also constructed a dataset consisting of firms with complete data availability for both Market Capitalization and Emissions with the aim of addressing the second question. The final dataset consists of 288 firms and is utilized for both Portfolio_A^{EW} and Portfolio_A^{PW}.

Finally, to address the fourth research question, we created three additional datasets. This was necessary because the previous datasets were constructed by excluding all firms that exhibited anomalous variations in market capitalization and/or total emissions (Scope 1 + Scope 2), without imposing any restrictions on the variations in Scope 3 emissions, as these were not used. To answer this question, we needed to consider this type of emission; therefore, we excluded firms that exhibited anomalous variations in Scope 3 emissions as well. The maximum variation threshold applied is the same as the one used for market capitalization and total carbon emissions.

Starting with the dataset of 1,489 firms, we created a dataset with 1,241 firms, from which Portfolio_{β} was derived. From the dataset of 288 firms, we created a dataset with 172 firms, which was then used to create $\text{Portfolio}_{\alpha}^{EW}$ and $\text{Portfolio}_{\alpha}^{PW}$.

The final dataset contains only those firms that reported Scope 1, Scope 2, and Scope 3 emissions every year, and consists of 48 firms. From this dataset, $\text{Portfolio}_{\gamma}$ was created.

Chapter 4

Portfolios Analysis

In this chapter, we will analyze the various portfolios. We will begin with $\mathbb{A}$ portfolios to examine the behavior of the metrics without the issue of missing data. Next, we will compare the trends between the equally weighted portfolio and the market-cap weighted portfolio. After doing so, we will analyze the impact of Scope 3 emissions by examining the α portfolios.

Once this initial analysis is complete, we will proceed with the analysis of the $\mathbb{B}$ and β portfolios, which contain missing data, in order to observe if and how the metrics change their behavior over time, both before and after the interpolation of the data.

Finally, we will analyze Portfolio$_\gamma$ to assess the potential weight of Scope 3 emissions in terms of portfolio emissions when all companies report these data.

The content of this chapter is the result of original work and aims to answer the four research questions presented in the introduction.

4.1 $\mathbb{A}$ Portfolios

4.1.1 Portfolio$_A^{EW}$

We begin our analysis with Portfolio$_A^{EW}$. Before delving into specific metrics, it is prudent to examine the temporal evolution of the portfolio value (Figure A.1). The observed trend exhibits an overall upward trajectory, with an absolute minimum recorded in 2011 (3.21×10^8 M\$) and an absolute maximum in 2020 (4.03×10^8 M\$). Although the portfolio's value increased only one more time than it decreased, the magnitude of these variations is of fundamental importance. Notably, the most significant decline occurred between 2013 and 2014, amounting to -4.37% as shown in Table 4.3. Conversely, the most substantial increases were recorded between 2011 and 2012, and between 2015 and 2016, reaching double-digit growth rates of +13.81% and +12.50%, respectively.

Let us now examine the trend in Total Carbon Emissions (Figure 4.1, Table 4.1). The first observation is that emissions followed an increasing trend for the initial four years, rising from a minimum of 4.79×10^6 tCO_2e in 2011 to an absolute maximum of 5.25×10^6 tCO_2e in 2015. Subsequently, the emissions decreased steadily, reaching an absolute minimum of 4.71×10^6 tCO_2e in 2020, with the exception of a slight increase (+0.16%) between 2017 and 2018. This overall pattern can be attributed not only to the fact that emissions increased only marginally more often than they decreased (five increases versus four decreases, as shown in Table 4.3), but also to the relative magnitude of these changes. Specifically, the maximum recorded growth rate, observed in the first year, did not exceed 3.31%, whereas the most pronounced decline, occurring between 2019 and 2020, amounted to -6.18%—approximately twice the magnitude of the greatest increase. Over the period from 2011 to 2020, the TCE shows a decrease of 1.67%.

Next, we investigate the relationship between the maximum, mean, and median values over the years and the overall TCE trend. Beginning with the annual maximum values, a distinct pattern emerges, differing from the behavior observed in the overall metric. The lowest maximum value was recorded in 2011 (6.55×10^5 tCO_2e), followed by a generally increasing trend over the years, with the exception of 2017 and 2020. The absolute peak was reached in 2019 (8.35×10^5 tCO_2e).

The trend in the mean value more closely resembles that of the metric. Specifically, mean values started at a relative minimum in 2011 (1.66×10^4 tCO_2e) before increasing until 2015, reaching 1.82×10^4 tCO_2e (same year of the peak in TCE). From 2016 to 2020, a continuous decline was observed, culminating in an absolute minimum of 1.63×10^4 tCO_2e in 2020 (with the exception of a slight increase in 2018).

In contrast, the trend in the median value diverges from that of TCE and maximum values. Here, a progressive increase was observed until 2016, followed by alternating periods of decline (2017 and 2019) and growth (2018 and 2020). The key difference, however, lies in the fact that, despite the median values also showing a partial decline, the final recorded value remained higher than that of 2015.

We now turn our attention to the subset of companies that contributed most significantly to total emissions. Specifically, we analyze the top 10 firms (on an annual basis) that exhibited the highest values for this metric (Table A.1). Before

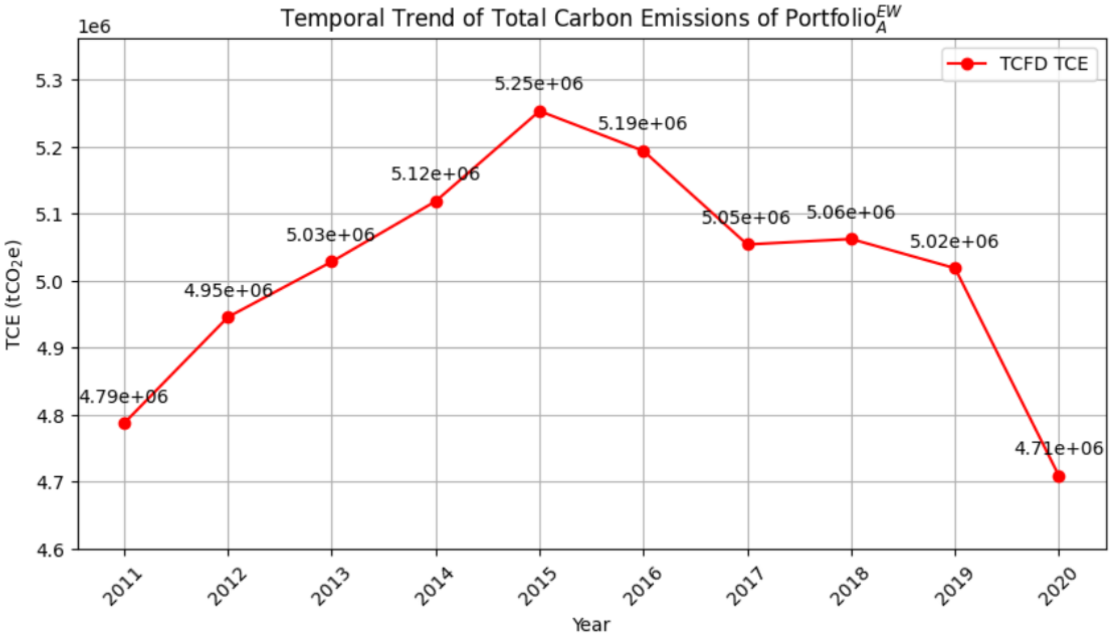

Figure 4.1: This figure shows the trend of the TCFD Total Carbon Emissions metric for Portfolio$_A^{EW}$. On the x-axis, the years from 2011 to 2020 are represented, while the y-axis displays the TCE values in tCO_2e.

Table 4.1: This table displays the TCFD Total Carbon Emissions statistics for the years 2011-2020 for Portfolio$_A^{EW}$.

Year	Total	Max	Mean	Std Dev	Median
2011	4.79×10^6	6.55×10^5	1.66×10^4	5.62×10^4	1.15×10^3
2012	4.95×10^6	6.60×10^5	1.72×10^4	5.89×10^4	1.15×10^3
2013	5.03×10^6	6.98×10^5	1.75×10^4	6.06×10^4	1.16×10^3
2014	5.12×10^6	6.98×10^5	1.78×10^4	6.20×10^4	1.17×10^3
2015	5.25×10^6	7.40×10^5	1.82×10^4	6.46×10^4	1.17×10^3
2016	5.19×10^6	8.04×10^5	1.80×10^4	6.42×10^4	1.22×10^3
2017	5.05×10^6	7.68×10^5	1.75×10^4	6.17×10^4	1.16×10^3
2018	5.06×10^6	8.06×10^5	1.76×10^4	6.31×10^4	1.19×10^3
2019	5.02×10^6	8.35×10^5	1.74×10^4	6.34×10^4	1.15×10^3
2020	4.71×10^6	7.85×10^5	1.63×10^4	6.01×10^4	1.19×10^3

addressing the details of their contribution, it is immediately evident that this group consistently accounted for no less than 52% of total emissions. This means that less than 4% of firms within the portfolio (approximately 3.47%) were responsible for more than half of total carbon emissions.

In 2011, this subset accounted for 53.03% of total emissions (2.54×10^6 tCO_2e), with their share increasing to a peak of 54.55% in 2015 (2.87×10^6 tCO_2e). Following this peak, their relative contribution declined in 2016 and 2017, reaching a minimum of 52.83% in 2017. Emissions from these top emitters increased again in 2018, before decreasing once more in 2019. Finally, in 2020, their share rebounded to 54.34%—the second highest percentage on record—despite corresponding to an absolute emission value of 2.56×10^6 tCO_2e, the second lowest value after 2011.

We now turn our attention to the analysis of the Carbon Footprint trend (Figure 4.2). First, it should be noted that, unlike the behavior observed for holdings and, particularly, TCE, the year 2011 is not characterized by a minimum, but rather a maximum, even an absolute one (1.49×10^{-2} $tCO_2e/(M)\$$), followed by an immediate decline until 2013. Subsequently, there is a rise, leading to a local maximum in 2015. A marked decrease is observed between 2015 and 2016, representing the most significant drop recorded. This downward trend continues, following a slight increase in 2017 and a more pronounced one in 2018, until 2019 and beyond. Between 2011 and 2020, the CF decreases by 21.48%. Let us now

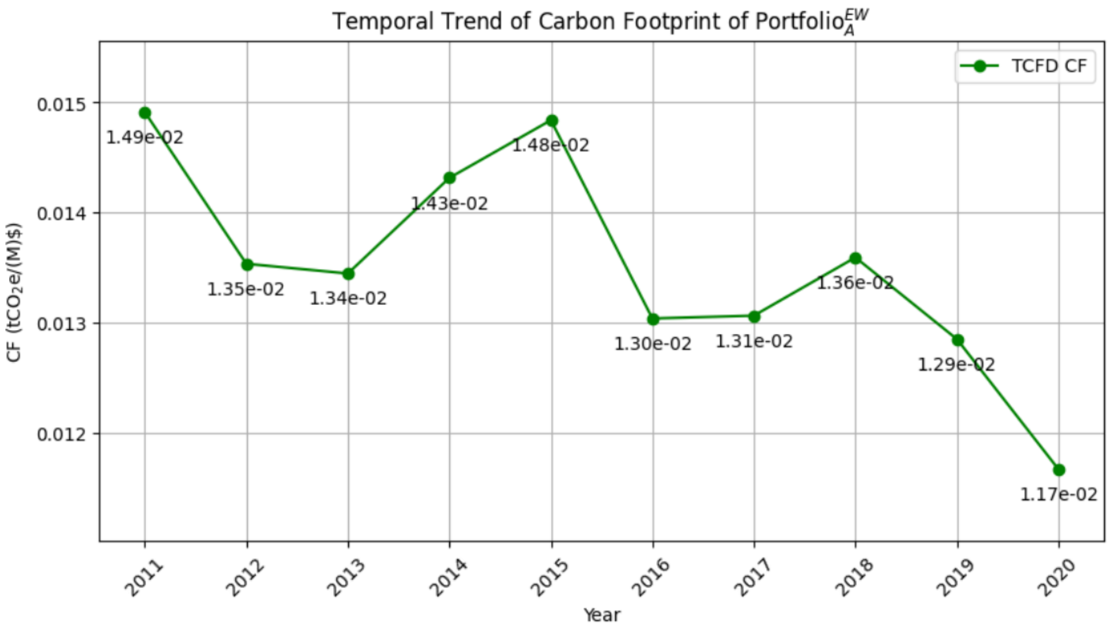

Figure 4.2: This figure shows the trend of the TCFD Carbon Footprint metric for Portfolio$_A^{EW}$. On the x-axis, the years from 2011 to 2020 are represented, while the y-axis displays the CF values in $tCO_2e/(M)\$$.

compare this trend with the behavior of the maxima, the average and the median

(Table 4.2). Analyzing the trend of the maxima, it is evident that the lowest value is recorded in 2012 (1.81×10^{-3} $tCO_2e/(M)\$$), rather than in 2020, as is the case for the metric. The second lowest value occurs in 2013, followed by an upward trend in the subsequent years, culminating in a local maximum of 2.09×10^{-3} $tCO_2e/(M)\$$ in 2015. The maxima then decrease again for two years, before rising for the final time in 2018, reaching the highest value across the entire 10-year period: 2.16×10^{-3} $tCO_2e/(M)\$$. This is followed by a decrease leading to the absolute minimum in 2020, with a value of 1.95×10^{-3} $tCO_2e/(M)\$$.

As for the average trend, it closely mirrors the behavior of the metric itself, with maxima recorded in 2011 and 2015 (5.18×10^{-5} $tCO_2e/(M)\$$ and 5.15×10^{-5} $tCO_2e/(M)\$$ respectively), and the minimum value occurring in 2020 (4.05×10^{-5} $tCO_2e/(M)\$$). Regarding the median, its trend aligns with that of the total

Table 4.2: This table displays the TCFD Carbon Footprint statistics for the years 2011-2020 for Portfolio$_A^{EW}$.

Year	Total	Max	Mean	Std Dev	Median
2011	1.49×10^{-2}	2.04×10^{-3}	5.18×10^{-5}	1.75×10^{-4}	3.59×10^{-6}
2012	1.35×10^{-2}	1.81×10^{-3}	4.70×10^{-5}	1.61×10^{-4}	3.15×10^{-6}
2013	1.35×10^{-2}	1.87×10^{-3}	4.67×10^{-5}	1.62×10^{-4}	3.10×10^{-6}
2014	1.43×10^{-2}	1.95×10^{-3}	4.97×10^{-5}	1.74×10^{-4}	3.28×10^{-6}
2015	1.48×10^{-2}	2.09×10^{-3}	5.15×10^{-5}	1.83×10^{-4}	3.30×10^{-6}
2016	1.30×10^{-2}	2.02×10^{-3}	4.53×10^{-5}	1.61×10^{-4}	3.06×10^{-6}
2017	1.31×10^{-2}	1.99×10^{-3}	4.54×10^{-5}	1.60×10^{-4}	3.00×10^{-6}
2018	1.36×10^{-2}	2.16×10^{-3}	4.72×10^{-5}	1.69×10^{-4}	3.19×10^{-6}
2019	1.29×10^{-2}	2.14×10^{-3}	4.46×10^{-5}	1.62×10^{-4}	2.94×10^{-6}
2020	1.17×10^{-2}	1.95×10^{-3}	4.05×10^{-5}	1.49×10^{-4}	2.94×10^{-6}

metric and the mean, with 2011 recording the absolute maximum (3.59×10^{-6} $tCO_2e/(M)\$$), another local peak in 2015, and the lowest values observed in 2019 and 2020 (both of 2.94×10^{-6} $tCO_2e/(M)\$$).

However, since the CF is derived from a formula that incorporates both holdings and TCE values, it is pertinent to explore how the percentage changes in these two variables interact to produce the observed behavior of the CF (Table 4.3). In essence, it is crucial to understand the underlying causes of the annual fluctuations in the CF—whether its increase or decrease.

Starting with 2012, Table 4.3 shows that despite an increase in TCE, the CF decreases (the second largest decrease, -9.22%). This is due to a significantly larger increase in holdings compared to the growth in TCE (13.81% vs. 3.31%). However, in the comparison between 2013 and 2012, it is evident that a considerable difference in the percentage growth between holdings and TCE is not required to cause a reduction in CF: a +2.34% change in holdings, versus a +1.67% increase in TCE, still results in a -0.65% reduction in CF. The two following years demonstrate that even a slight decline in holdings (-0.99%), coupled with growth in TCE, leads to an increase in CF. The greatest decrease in CF (-12.12%) occurs in 2016, with holdings growing by +12.5% while TCE decreased by -1.13%.

An intriguing case is the year 2017, when both holdings and TCE experienced a simultaneous decrease, yet the CF increased by +0.20%. In 2018, a scenario similar to the 2014-2015 period arises, where holdings decrease and TCE increases, resulting in another growth in CF. The final two years exhibit growth in holdings and a decline in TCE, which leads to a decrease in CF.

From the most straightforward observation, it is apparent that when holdings grow and TCE decreases, CF decreases as well. Conversely, when the portfolio value decreases and TCE exceeds its value from the previous year, CF increases. The most compelling cases occur when both holdings and TCE experience simultaneous growth or decline. These initial findings show that the simultaneous growth of these two variables can still result in a reduction in CF, as the magnitude of the percentage change becomes critical in determining the outcome. The same holds true when both holdings and TCE decrease simultaneously, as seen in 2016-2017, where CF increased despite these declines.

Table 4.3: This table presents the percentage variation of Holdings (Ptf value), TCE and CF over the years for $Portfolio_A^{EW}$.

Years	Ptf value	TCE	CF
2011-2012	13.81%	3.31%	-9.22%
2012-2013	2.34%	1.67%	-0.65%
2013-2014	-4.37%	1.79%	6.45%
2014-2015	-0.99%	2.63%	3.65%
2015-2016	12.50%	-1.13%	-12.12%
2016-2017	-2.88%	-2.69%	0.20%
2017-2018	-3.73%	0.16%	4.04%
2018-2019	4.85%	-0.86%	-5.45%
2019-2020	3.30%	-6.18%	-9.18%

4.1.2 Portfolio$_A^{PW}$

Let's now analyze Portfolio$_A^{PW}$. As previously done, we will briefly examine the portfolio value over time (Figure A.2). What we observe is, once again, an overall increasing trend over the 10 years, from the absolute minimum in 2011 (4.20×10^8 M$) to the absolute maximum in 2020 (5.19×10^8 M$). Despite variations in terms of percentage growth and recorded values, the trends are very similar. In both portfolios, the years of increase and decrease align, with one exception: 2017 shows growth compared to 2016, while in Portfolio$_A^{EW}$, the value was lower.

Regarding percentage changes (Table 4.6), they are generally similar. In some years, the equally weighted portfolio shows slightly higher changes, and in others, the reverse happens. It is interesting to note that the highest growth occurs in Portfolio$_A^{EW}$ (+13.81%), while the largest decrease is in Portfolio$_A^{PW}$ (-5.73%). Since the weights in this case are assigned proportionally to the market capitalization of the companies, it is unsurprising to see consistently higher values in the market cap weighted portfolio when comparing annual values. What is interesting, however, is that the maximum value of the Portfolio$_A^{EW}$ (4.03×10^8 M$) is still lower than the minimum value of the Portfolio$_A^{PW}$ (4.20×10^8 M$).

Now, let's examine the Total Carbon Emissions (Figure 4.3, Table 4.4). First, we note that there is no continuous growth in the first five years. Although 2015 again represents the absolute maximum (5.17×10^6 tCO_2e), both 2012 and 2014 show a decrease. 2017 marks another shift from the previous portfolio's trend, with its value now greater than that of 2016. 2019 and 2020 show decreasing values, as in the previous case, with 2020 once again being the year with the absolute minimum (3.65×10^6 tCO_2e). From 2011 to 2020, the TCE declines by 22.99%. In terms of overall trends, it is interesting to note that, although the years of growth and decline, as well as the periods of absolute maximum and minimum, show similarities, 2011 is no longer a year of minimum values. Instead, it marks the second highest value recorded. When comparing the values of this portfolio with the minimum value of the equally weighted portfolio (4.71×10^6 tCO_2e), it emerges that only in three years (2011, 2013, and 2015) did the Total Carbon Emissions of the market cap weighted portfolio exceed this value. In an annual comparison, however, this portfolio's emissions remain lower than the equally weighted portfolio's emissions (Figure A.4). This indicates that, in general, Portfolio$_A^{PW}$'s emissions are lower than those of Portfolio$_A^{EW}$. It is also interesting to analyze the year-over-year percentage changes (Table 4.6). While for the holdings, the changes were largely similar, this time the situation differs. The highest variation recorded by the Total Carbon Emissions of the equally weighted portfolio are +3.31% when it increases and -6.18% when it decreases. In contrast, the maximum changes in the market cap

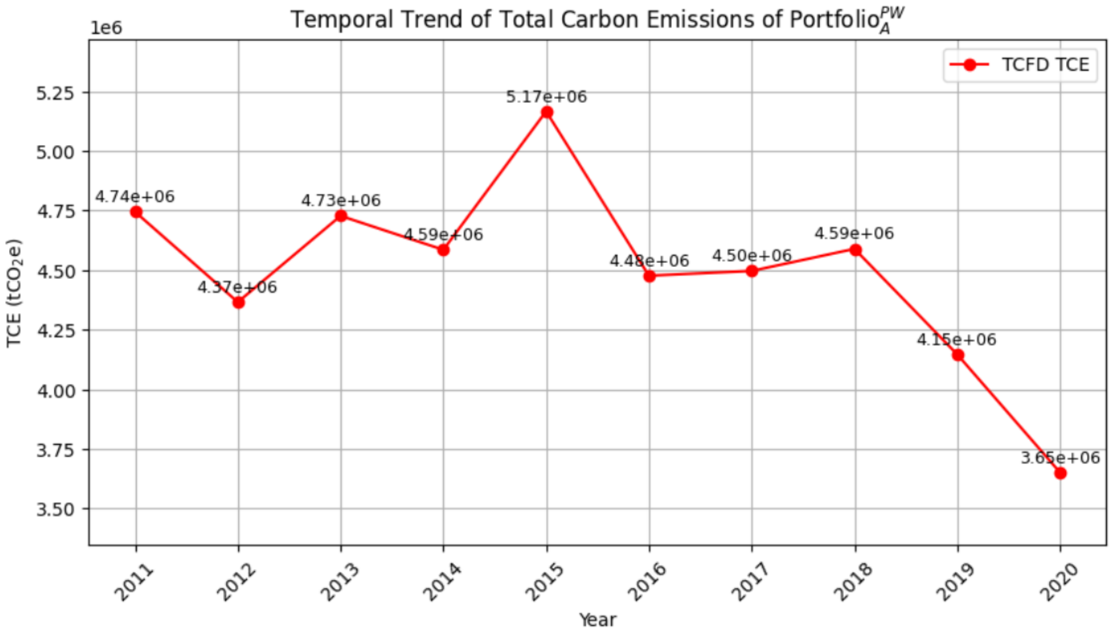

Figure 4.3: This figure shows the trend of the TCFD Total Carbon Emissions metric for Portfolio$_A^{PW}$. On the x-axis, the years from 2011 to 2020 are represented, while the y-axis displays the TCE values in tCO_2e.

weighted portfolio are -13.35%, over double the negative variation, and +12.67%, almost quadruple the positive variation. In absolute terms, only one year showed a greater percentage change in the previous portfolio: 2017, with -2.69% versus +0.98%. The greatest differences were recorded in 2015, 2016, and 2019, with the largest difference occurring in 2016, at 12.22 percentage points (-1.13% for Portfolio$_A^{EW}$ and -13.35% for Portfolio$_A^{PW}$).

Let us now look at the maxima, mean, and median values. As for the maxima, 2015 is again the absolute maximum (1.30×10^6 tCO_2e), and 2020 is the absolute minimum (2.99×10^5 tCO_2e). Years 2013-2014 and 2016-2019 are also interesting, with values higher than 2011, unlike the values of the metric, where 2011 was second only to 2015. Regarding the mean, the trend is similar to the total trend, with the absolute maximum in 2015 (1.79×10^4 tCO_2e) and the absolute minimum in 2020 (1.27×10^4 tCO_2e). Once again, 2011 is the second highest value.

The median, however, deviates from this pattern, with 2011 showing the absolute minimum (9.32×10^2 tCO_2e). Following this, there is a continuous increase up to 2015, the year of the absolute maximum. Between 2017 and 2019, the values stabilize around $1.04 - 1.05 \times 10^3$ tCO_2e and end with the third lowest value in 2020.

Table 4.4: This table displays the TCFD Total Carbon Emissions statistics for the years 2011-2020 for Portfolio$_A^{PW}$.

Year	Total	Max	Mean	Std Dev	Median
2011	4.74×10^6	5.10×10^5	1.65×10^4	5.18×10^4	9.32×10^2
2012	4.37×10^6	4.55×10^5	1.52×10^4	4.74×10^4	9.97×10^2
2013	4.73×10^6	9.13×10^5	1.64×10^4	6.50×10^4	1.08×10^3
2014	4.59×10^6	9.08×10^5	1.59×10^4	6.43×10^4	1.13×10^3
2015	5.17×10^6	1.30×10^6	1.79×10^4	8.45×10^4	1.16×10^3
2016	4.48×10^6	5.51×10^5	1.55×10^4	4.97×10^4	1.08×10^3
2017	4.50×10^6	5.23×10^5	1.56×10^4	5.01×10^4	1.04×10^3
2018	4.59×10^6	8.24×10^5	1.59×10^4	6.01×10^4	1.04×10^3
2019	4.15×10^6	5.38×10^5	1.44×10^4	4.59×10^4	1.05×10^3
2020	3.65×10^6	2.99×10^5	1.27×10^4	3.40×10^4	1.01×10^3

As was done for the previous portfolio, we now analyze the contributions of the top 10 firms (year by year) that recorded the highest values (Table A.1). The key difference that clearly emerges is that, except for 2015, where the percentage contribution was even higher than the total contribution of the top 10 firms in the equally weighted portfolio (with a contribution of 55.70%), in all other years, the top 10 firms do not exceed 52%, the minimum value for the other portfolio. In fact, excluding 2013 (51.06%), in no year do the top 10 firms contribute more than 50%. The maximum value is 49.02% (2014), with a minimum of 32.09% in 2020: compared to the previous portfolio, the contribution of the top 10 companies has decreased.

Now, let us examine the temporal trend of the Carbon Footprint (Figure 4.4). Setting aside the magnitude of percentage variations for the moment and considering only their direction, a comparison with the equally weighted portfolio shows that the overall trends are largely similar. The only two differences are observed in 2013 and 2017, which now exhibit a declining trend compared to the previous years, whereas they were increasing in the equally weighted portfolio. The years 2011 and 2015 remain peak years, but in this case, 2015 represents the absolute maximum, while 2011 is a local peak. Another local peak common to both portfolios is 2018. As for 2020, it remains the year with the absolute minimum. In this case, between 2011 and 2020 the CF decreases by -36.2%. Next, we analyze the trends in maximum, mean, and median values (Table 4.5).

Starting with the maximum values, the first similarity is in 2015, which once

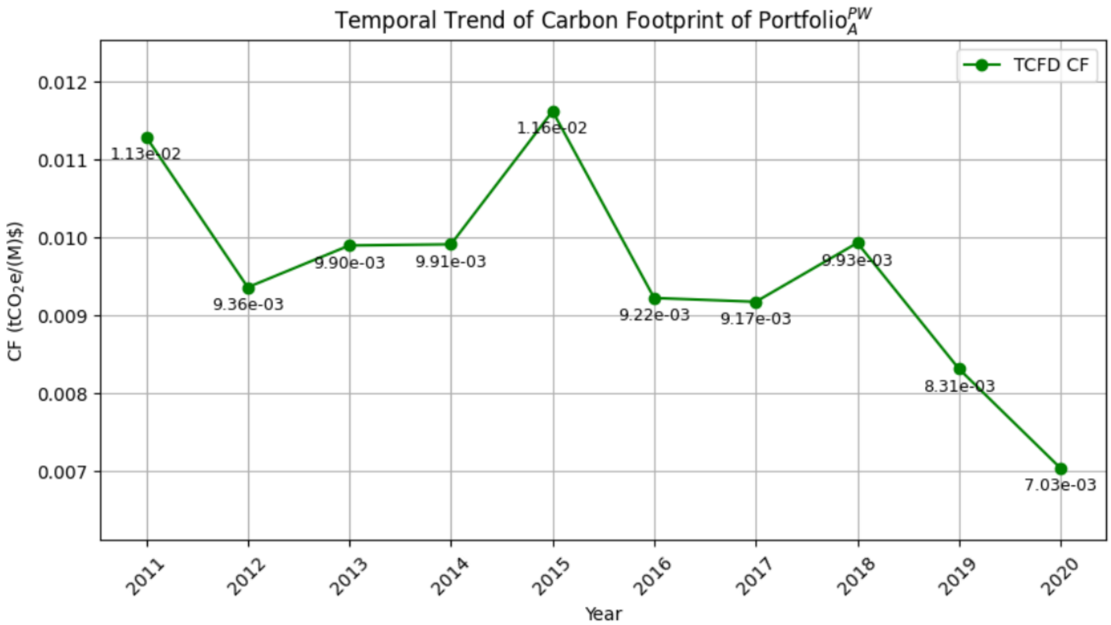

Figure 4.4: This figure shows the trend of the TCFD Carbon Footprint metric for Portfolio$_A^{PW}$. On the x-axis, the years from 2011 to 2020 are represented, while the y-axis displays the CF values in $tCO_2e/(M)\$$.

again records the highest value (2.92×10^{-3} $tCO_2e/(M)\$$). Similarly, 2020 remains the year with the absolute minimum (5.77×10^{-4} $tCO_2e/(M)\$$). The main differences concern 2011, which is no longer the second highest value but the fifth (behind 2012, 2014, 2015, and 2018). Moreover, the second-lowest value is no longer recorded in 2019 but in 2012 (9.76×10^{-4} $tCO_2e/(M)\$$).

Regarding the mean, its trend aligns with that of the total metric, both in terms of peaks (notably the absolute maximum in 2015 (4.04×10^{-5} $tCO_2e/(M)\$$) and the local maxima in 2011 and 2018, with an additional peak in 2013—differing from the total metric) and in terms of the two lowest values, which are again recorded in 2019 and 2020, with the latter representing the absolute minimum (2.38×10^{-5} $tCO_2e/(M)\$$).

Finally, examining the median, we observe that it follows the same trend as the mean and the total metric, particularly with the absolute maximum in 2015 (2.61×10^{-6} $tCO_2e/(M)\$$) and the absolute minimum in 2020 (1.95×10^{-6} $tCO_2e/(M)\$$). As previously done, we now examine the percentage variations in the holdings and the Total Carbon Emissions of this portfolio, along with the resulting percentage variation in the Carbon Footprint (Table 4.6).

Table 4.5: This table displays the TCFD Carbon Footprint statistics for the years 2011-2020 for Portfolio$_A^{PW}$.

Year	Total	Max	Mean	Std Dev	Median
2011	1.13×10^{-2}	1.21×10^{-3}	3.90×10^{-5}	1.23×10^{-4}	2.22×10^{-6}
2012	9.36×10^{-3}	9.76×10^{-4}	3.21×10^{-5}	1.02×10^{-4}	2.14×10^{-6}
2013	9.90×10^{-3}	1.91×10^{-3}	3.41×10^{-5}	1.36×10^{-4}	2.27×10^{-6}
2014	9.91×10^{-3}	1.96×10^{-3}	3.38×10^{-5}	1.39×10^{-4}	2.44×10^{-6}
2015	1.16×10^{-2}	2.92×10^{-3}	4.04×10^{-5}	1.90×10^{-4}	2.61×10^{-6}
2016	9.22×10^{-3}	1.14×10^{-3}	3.23×10^{-5}	1.02×10^{-4}	2.23×10^{-6}
2017	9.17×10^{-3}	1.07×10^{-3}	3.22×10^{-5}	1.02×10^{-4}	2.12×10^{-6}
2018	9.93×10^{-3}	1.78×10^{-3}	3.42×10^{-5}	1.30×10^{-4}	2.25×10^{-6}
2019	8.31×10^{-3}	1.08×10^{-3}	2.92×10^{-5}	9.23×10^{-5}	2.10×10^{-6}
2020	7.03×10^{-3}	5.77×10^{-4}	2.38×10^{-5}	6.59×10^{-5}	1.95×10^{-6}

While the overall trend of the CF does not change significantly when transitioning from the equally weighted to the market cap weighted portfolio, a closer analysis of the percentage variations reveals substantial differences. In the EW case, the CF trend sometimes diverged from that of the TCE—there were years in which the CF decreased despite an increase in TCE. However, in the PW portfolio, the CF generally follows the TCE trend, increasing when the TCE rises and decreasing when it falls. The only exception are in 2014 and 2017. In 2014, both holdings and TCE decreased, while there was an increase in CF. Conversely, in 2017, there was a simultaneous increase in holdings and TCE, while CF decreased. In all other years, the trends appear similar. However, this does not imply that the portfolio value is irrelevant. The observed behavior is largely due to the fact that, in this portfolio, the portfolio value often increases in years when the TCE decreases (leading to a decline in CF) and decreases in years when the TCE rises (causing the CF to increase). This pattern is evident in all years except for 2014 and 2017.

The fact that simultaneous increases or decreases in holdings and TCE occur more frequently in this portfolio, combined with the larger TCE variations compared to the EW case, results in greater fluctuations in CF in the PW portfolio than in the previous case.

Specifically, while Portfolio$_A^{EW}$ recorded a maximum increase of +6.45% in 2014 and a maximum decrease of -12.12% in 2016 (Table 4.3), Portfolio$_A^{PW}$ exhibits significantly larger variations, with a peak increase of +17.27% in 2015 and a sharp decline of -20.67% in 2016. Naturally, since the direction of changes in both holdings and TCE shifts when transitioning from the equally weighted to the market cap weighted portfolio, the CF variations also change signs accordingly, as observed in 2013 and 2017.

Table 4.6: This table presents the percentage variation of Holdings (Ptf value), TCE and CF over the years for $Portfolio_A^{PW}$.

Years	Ptf value	TCE	CF
2011-2012	11.03%	-7.99%	-17.13%
2012-2013	2.40%	8.29%	5.75%
2013-2014	-3.16%	-3.01%	0.15%
2014-2015	-3.93%	12.67%	17.27%
2015-2016	9.23%	-13.35%	-20.67%
2016-2017	0.98%	0.44%	-0.53%
2017-2018	-5.73%	2.06%	8.26%
2018-2019	7.97%	-9.65%	-16.32%
2019-2020	4.05%	-11.95%	-15.38%

4.1.3 Metrics Comparison between Portfolio$_A^{EW}$ and Portfolio$_A^{PW}$

In this section, we compare the percentage variations of the metrics between the two portfolios. We begin by analyzing the value of the holdings (Figure A.3). As we have already observed in previous sections, the portfolio with weights proportional to market capitalization consistently records higher values compared to the equally weighted portfolio, with a minimum increase of +21.90% in 2016, reaching a maximum of +30.89% in 2011 (Table 4.7). The average increase is +27.06%, and over the entire 10-year period, it amounts to +26.99%. For the sake of readability, and given that the lowest metric values are recorded by the market capitalization-weighted portfolio, we will use the values from this portfolio as reference levels. This approach will allow us to express the variations observed in the equally weighted portfolio as positive values.

Starting with the percentage change in Total Carbon Emissions (Table 4.8, Figure A.4), we observe that the smallest increase occurs in 2011, amounting to +0.89%. The highest increase is recorded in 2020 (+28.97%). Except for three years (the year of the minimum, and then 2013 and 2015), the variations consistently remain in double digits, resulting in an average variation of +12.26% and a total 10-year variation of +11.61%.

Regarding the Carbon Footprint, shown in Figure A.5, the situation differs (Table 4.8). What is observed is that all the changes in CF (with the exception of the

Table 4.7: This table illustrates the percentage change in Holdings over the years, comparing the transition from Portfolio$_A^{EW}$ to Portfolio$_A^{PW}$. A positive value indicates that the portfolio weighted by market capitalization has a higher value compared to the equally weighted portfolio.

Year	Holdings' Variations
2011	+30.89%
2012	+27.70%
2013	+27.77%
2014	+29.39%
2015	+25.55%
2016	+21.90%
2017	+26.75%
2018	+24.11%
2019	+27.81%
2020	+28.73%

Table 4.8: This table illustrates the percentage change in Total Carbon Emissions and Carbon Footprint over the years, comparing the transition from Portfolio$_A^{PW}$ to Portfolio$_A^{EW}$. A positive change indicates that the emissions of the latter portfolio are higher than those of the former.

Year	TCE	CF
2011	+0.89%	+32.05%
2012	+13.28%	+44.65%
2013	+6.36%	+35.90%
2014	+11.63%	+44.44%
2015	+1.69%	+27.67%
2016	+16.02%	+41.43%
2017	+12.40%	+42.47%
2018	+10.31%	+36.91%
2019	+21.04%	+54.69%
2020	+28.97%	+66.03%

minimum variation) are greater than the maximum variation in TCE. In 2015, the year of the minimum variation, a 27.67% increase is recorded, which is just 1.3 percentage points below the maximum TCE increase. The year with the lowest variation for CF differs from the year with the minimum variation for TCE, while the maximum variation is recorded in the same year: 2020, with a +66.03% increase. The average variation for CF is +42.62%, and the total variation over the 10 years amounts to +41.29%.

A closer examination reveals that the year 2015, which shows the minimum variation for CF, also corresponds to the year with the second lowest TCE variation (+1.69%, just 0.8 percentage points above the minimum) and the year with the third lowest variation for the holdings. The maximum variation, recorded in 2020, coincides with the year of the maximum TCE variation, and the holdings also register the third-highest variation (+28.73%, following 2011 and 2014).

4.1.4 Scope 3 Analysis: α Portfolios

In this section, we examine how the metrics change when, instead of considering only Scope 1 and Scope 2 emissions, Scope 3 emissions are also taken into account. The analysis will focus on the portfolios $\text{Portfolio}_{\alpha}^{EW}$ and $\text{Portfolio}_{\alpha}^{PW}$. While these differ from the portfolios $\text{Portfolio}_{A}^{EW}$ and $\text{Portfolio}_{A}^{PW}$ examined in the previous sections, the primary objective is to assess the impact of including Scope 3 emissions on the metrics. Therefore, although the values of holdings and TCFD metrics (considering only Scope 1 and Scope 2) differ, the changes resulting from the exclusion of firms that report anomalous variations in Scope 3 emissions will not be analyzed.

To mitigate any potential bias in the results due to portfolio modifications, we will recalculate the holdings and metrics excluding Scope 3 emissions, without delving into their analysis in such detail as previously discussed. Since the focus lies on the impact of including Scope 3 emissions in the total emissions, we will recompute the metrics incorporating these emissions and assess the percentage weight of Scope 3 emissions at the individual firm level, at the portfolio level on a yearly basis, and over the entire 10-year period. For the TCE, both a qualitative and quantitative analysis will be conducted, while for the CF, we will focus exclusively on a qualitative analysis. This is because the inclusion of Scope 3 Emissions impacts the TCE but not the holdings, so the considerations made for the TCE will also be valid for the CF. However, percentage variations may differ between the two metrics due to changes in the holdings over time, so when analyzing the CF, we will focus on how the trend changes when Scope 3 emissions are taken into account..

This analysis will initially be conducted through a comparison between TCFD Total Carbon Emissions (Scope 1 + Scope 2), and TCE that also includes Scope 3 emissions. Finally, a comparison will be made between TCE calculated without the interpolation of Scope 3 emissions and TCE after the interpolation of these emissions. It is important to note that both Market Capitalization and Scope 1 + Scope 2 emissions do not require interpolation, as the dataset used to generate this portfolio consists of companies that have published these data annually.

We begin with a comparison between metrics of Portfolio$_\alpha^{EW}$ including and excluding Scope 3 emissions, represented by the orange and blue bars, respectively (Figure 4.5). The findings reveal a markedly divergent trend. Without the inclusion of Scope 3 emissions, TCE increases from 2011 (the year of the absolute minimum) to 2016. After 2016, TCE begins to decline, with the exception of a local peak in 2018. When Scope 3 emissions are incorporated, however, the metric shows a decrease from 2011 to 2014, which is the year of the absolute minimum (6.95×10^6 tCO_2e). Subsequently, this metric experiences a steady increase until it reaches the highest value in 2020 (1.61×10^7 tCO_2e).

It is noteworthy that the year of the minimum coincides with the year in which the lowest percentage of disclosed Scope 3 emissions was recorded (2014, 38.07%, Table A.2) and the year with the lowest relative weight of Scope 3 emissions (41.15%, Table 4.9), whereas the year of maximum disclosure (2020,72.73%) corresponds to the year of maximum TCE (Pre) and the year with the highest relative weight (76.49%). From a quantitative perspective, the minimum increase from 2014 amounts to a +69.91%, while the maximum increase is a +325.39%. The average annual increase is 173.34%, with a total increase of 172.78% over the ten-year period.

Regarding the trend of the metric post-interpolation of Scope 3 emissions (red bars), the trend is similar to that observed when Scope 3 is excluded. Starting from 2011, which again is the year of the absolute minimum (1.52×10^7 tCO_2e), we observe a steady increase until 2015 (one year earlier than in the analysis excluding Scope 3), which marks the absolute maximum (2.97×10^7 tCO_2e). Following this peak, there is a continuous decline until 2020. In this case, as the results are based on interpolation, the disclosure percentage of Scope 3 emissions is the same for every year and equal to 83.52%.

Finally, a quantitative analysis reveals that, compared to the metric pre-interpolation, there have been both smaller and larger increases than those seen with or without Scope 3 emissions. It is not surprising to observe that the smallest increases occurred in the years when disclosure was already high, particularly in the last three years, when more than 50% of the companies had published this data. In these years, the increase due to interpolation ranges from a maximum of 42.71% to a minimum of 15.09%. In other years, the increase consistently exceeds 80%, and, excluding 2011, remains above 104%. The year with the maximum increase between pre- and post-interpolation is 2015, with an increase of +183.09%.

The average annual increase over the years is +99.92%, while the total increase over the ten-year period is +88.61%.

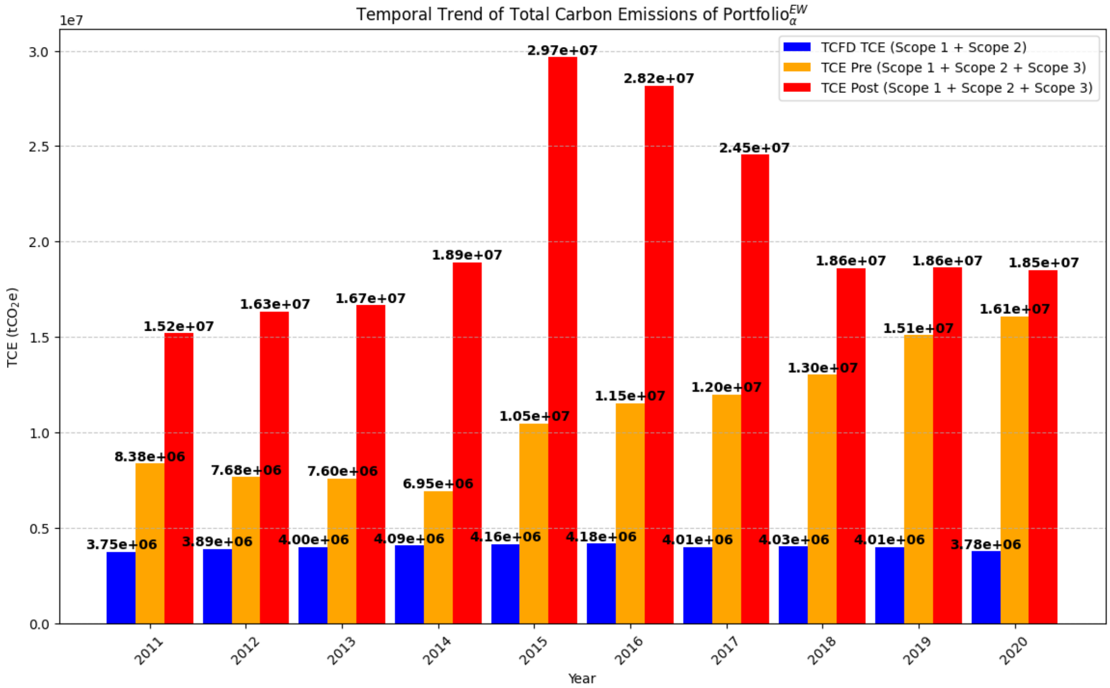

Figure 4.5: This figure shows, in blue, the TCE value for Portfolio$_\alpha^{EW}$ calculated following the TCFD guidelines, i.e., including only Scope 1 and Scope 2 emissions. In orange, the values of the metrics when Scope 3 emissions are also considered (TCE Pre). In red, the values of the metrics post interpolation of Scope 3 emissions (TCE Post). On the x-axis, the years from 2011 to 2020 are represented, while the y-axis displays the TCE values in tCO_2e.

Next, we will analyze the trend of the Carbon Footprint (Figure A.6), beginning with a comparison between the cases with and without Scope 3 emissions (represented by the blue and yellow bars, respectively). First, it is evident that, while in the absence of Scope 3 emissions the absolute minimum occurs in 2020 and the absolute maximum in 2015, the introduction of Scope 3 emissions alters the CF, initially resulting in a decreasing trend until the absolute minimum in 2014. Following this, there is a continuous increase (interrupted only by a slight decrease in 2016) until 2020, the year of the absolute maximum, demonstrating a distinctly different trend. When Scope 3 emissions are interpolated (green bars), the behavior changes again, with 2015 becoming the year of the absolute maximum, after which there is a continuous decline, contrasting sharply with the pre-interpolation trend. Post-interpolation, the trend is, in fact, more similar to the metric without Scope 3 emissions, with the absolute maximum in 2015, the absolute minimum in 2020, an initially increasing trend (with some interruptions) between 2011 and 2015, followed by a decrease.

Let us now examine how the TCE of Portfolio$_{\alpha}^{PW}$ changes following the introduction of Scope 3 emissions (Figure 4.6, Table 4.10). First and foremost, it is

Table 4.9: This table illustrates the percentage contribution of Scope 3 (S3) emissions to the total emissions (Scope 1 + Scope 2 + Scope 3), alongside the corresponding increase in the TCE metric when these emissions are incorporated (third column). The final column highlights the percentage change in TCE, comparing the post-interpolation values with the pre-interpolation metrics. These values pertain to Portfolio$_{\alpha}^{EW}$.

Year	S3 % in Emissions	TCE Increase with S3	% Increase Post
2011	55.32%	123.81%	81.42%
2012	49.32%	97.32%	112.67%
2013	47.35%	89.94%	119.21%
2014	41.15%	69.91%	172.43%
2015	60.27%	151.71%	183.09%
2016	63.74%	175.82%	144.34%
2017	66.51%	198.62%	104.83%
2018	69.12%	223.89%	42.71%
2019	73.48%	277.04%	23.38%
2020	76.49%	325.39%	15.09%

important to note once again that the trends observed with and without Scope 3 emissions differ significantly. In the case without Scope 3 emissions (represented by the blue bars), no clear upward or downward trend is identified. Specifically, 2013 marks a local maximum, 2015 represents the absolute maximum, and 2018 shows another local maximum, followed by a decreasing trend that culminates in the absolute minimum observed in 2020. Conversely, when the metric accounts for Scope 3 emissions (represented by the orange bars), an initial upward trend is observed, with 2013 also registering a local maximum. The absolute minimum is recorded in 2014 (8.70×10^6 tCO_2e), after which two of the highest values are recorded, with 2016 representing the absolute maximum (2.74×10^7 tCO_2e). Subsequently, a decline is noted, and in 2018, a local maximum occurs once again, followed by a local minimum in 2019.

Regarding the percentage changes in the with and without Scope 3 emissions periods (Table 4.10), the analysis reveals a minimum increase of +86.52% in 2014, the year of the absolute minimum for Total Carbon Emissions with Scope 3 (and also the year with the lowest publication of Scope 3 emissions). The maximum

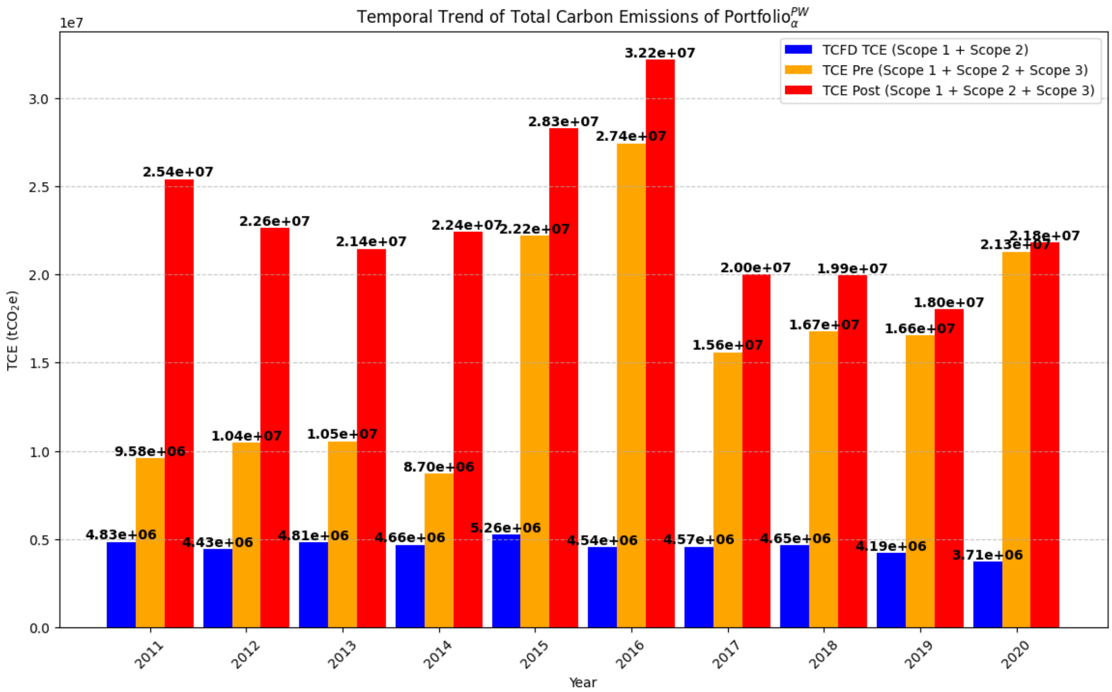

Figure 4.6: This figure shows, in blue, the TCE value for Portfolio$_{\alpha}^{PW}$ calculated following the TCFD guidelines, i.e., including only Scope 1 and Scope 2 emissions. In orange, the values of the metrics when Scope 3 emissions are also considered (TCE Pre). In red, the values of the metrics post interpolation of Scope 3 emissions (TCE Post). On the x-axis, the years from 2011 to 2020 are represented, while the y-axis displays the TCE values in tCO_2e.

increase is observed at +473.57%, recorded in a year that does not coincide with the highest value for TCE with Scope 3 (despite the highest publication of these emissions), but is still the third-highest recorded value. It also marks the year of the absolute minimum for TCFD TCE (without Scope 3). The average annual increase is +253.56%, while the total increase over the 10-year period stands at +248.43%.

When observing the trend of the metric obtained post-interpolation of Scope 3 emissions, the pattern initially differs from that observed in the absence of interpolation. The trend starts with a decline, with 2013 now marked as a local minimum rather than a local maximum. This is followed by a growth phase, where 2015 and 2016 again show the highest values, with 2016 representing the absolute maximum (3.22×10^7 tCO_2e). A continuous decline is then observed, culminating in the absolute minimum of 2019, recorded at 1.8×10^7 tCO_2e.

In terms of percentage changes, the values range from a minimum of +2.47% in 2020 to a maximum of +164.90%. The average annual increase in the pre- and post-interpolation comparison is +64.56%, while the total increase over the 10 years stands at +45.88%.

Finally, let us examine how the Carbon Footprint behaves (Figure A.7). Without Scope 3 emissions, the data reveals an immediate decrease in 2012 compared to 2011, followed by a continuous increase until the absolute maximum in 2015. After 2015, the trend becomes decreasing, interrupted only in 2018, culminating in the absolute minimum in 2020. The introduction of Scope 3 emissions brings about a shift. Initially, the decrease continues beyond 2012 until 2014, which marks the absolute minimum. Between 2015 and 2016, the second and first highest values are recorded, respectively, which also alters the year of the absolute maximum. Between 2017 and 2019, the trend mirrors that of the case without Scope 3 emissions, while in the final year, there is an increase, in contrast to the decrease observed without Scope 3 emissions. Post-interpolation, the trend remains the same, at least in terms of the years of increase and decrease, except for 2014, which now shows an increase in values compared to 2013. 2016 remains the year of the absolute maximum, while the absolute minimum is now recorded in 2019.

Table 4.10: This table illustrates the increase in the TCE metric when Scope 3 emissions are incorporated. The final column highlights the percentage change in TCE, comparing the post-interpolation values with the pre-interpolation metrics. These values pertain to Portfolio$_{\alpha}^{PW}$.

Year	**TCE Increase with S3**	**% Increase Post**
2011	98.60%	164.90%
2012	135.87%	116.62%
2013	119.29%	103.26%
2014	86.52%	157.50%
2015	322.18%	27.32%
2016	503.60%	17.31%
2017	241.36%	28.27%
2018	260.09%	19.01%
2019	294.57%	8.93%
2020	473.57%	2.47%

4.2 𝔹 Portfolios

In this section, we conduct the analysis concerning Portfolio$_B^{EW}$ and Portfolio$_B^{PW}$. Before proceeding, it is important to recall that the dataset from which these portfolios were formed includes all companies that have reported their market cap and emissions at least once. Therefore, the portfolio value and associated metrics will be influenced by missing data. For this reason, the analysis is carried out using graphs that display the performance of the metrics both before and after the interpolation of market cap and emissions data.

4.2.1 Portfolio$_B^{EW}$

As done previously, we first analyze the equally weighted case, beginning with the portfolio value. Observing Figure A.8, it is immediately noticeable that the portfolio value is higher in the pre-interpolation case[1]. Additionally, the temporal trend is almost identical. While the percentage variations differ, the years of growth, decline, maximum, and minimum values remain the same.

Overall, the trend shows growth, with 2011 representing the absolute minimum year and 2020 marking the absolute maximum. Regarding percentage variations, they exhibit the same sign both before and after interpolation (Table 4.11), with pre-interpolation showing a slightly higher maximum variation (maximum pre-interpolation = +12.26% vs. post-interpolation = +10.68% in positive terms, and -5.53% vs. -4.04% in negative terms). Only in the last two years, 2019 and 2020, the variations after interpolation are higher.

Next, we turn to the TCE. In this case as well, we plot both pre-interpolation and post-interpolation values on a single graph (Figure 4.7). What stands out immediately is that the post-interpolation metric is consistently higher than the pre-interpolation metric, both in annual comparisons and in terms of the minimum post-interpolation value (2.53×10^6 tCO_2e) compared to the maximum pre-interpolation value (2.33×10^6 tCO_2e).

In the pre-interpolation case, there is a rather discontinuous trend: starting from 2011, the absolute minimum year, the value increases for two years. 2014 marks a relative minimum, followed by two years of growth. 2017, similar to 2014, also represents a relative minimum, after which the absolute maximum is recorded. Two

[1]It is important to note that portfolio value refers to the holdings, as derived from the 3.3 and 3.4 formulas, and is not simply the sum of all market caps, which would be higher in the post-interpolation case

years later, a decline is observed.

Post-interpolation, the trend changes drastically: 2011 still represents the absolute minimum year, but the growth is continuous until 2016. The value stabilizes for three consecutive years around 2.74×10^6 tCO_2e, with a decline observed in 2019-2020. Between 2011 and 2020, the TCE for the pre-interpolation case shows an increase of +8.47%, while the post-interpolation increase is +5.53%. Regarding

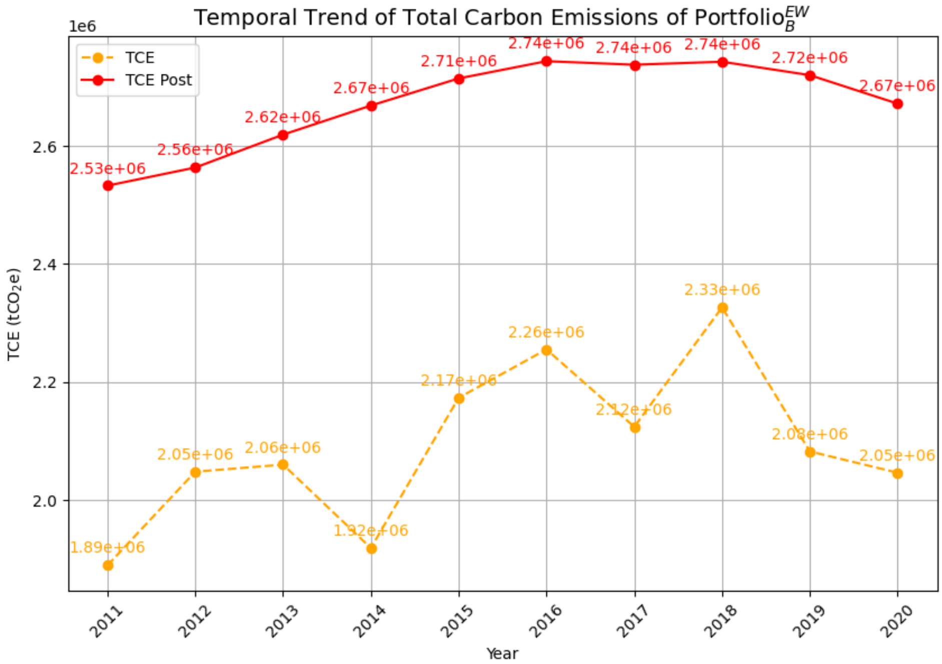

Figure 4.7: This figure shows the trend of the TCFD Total Carbon Emissions metric for Portfolio$_B^{EW}$ over the years. The dotted orange line represents the metric before interpolation, while the solid red line represents the TCE after interpolation. On the x-axis, the years from 2011 to 2020 are shown, while the y-axis displays the values in tCO_2e.

percentage variations, pre-interpolation shows far larger fluctuations (Table 4.11). The maximum decrease is recorded at -10.49% in 2019, while the maximum growth is +13.27% in 2015. Post-interpolation, however, the variations are much smaller, with a maximum increase of +2.17% in 2012 and a decrease of -1.78% in 2020. It is also worth noting that the years of maximum variation differ, and the sign may change (e.g., in 2014).

Let us now analyze the statistics of the TCE over the years (Table A.4), beginning with the maximum values. Starting with the pre-interpolation maximum values, the trend differs from that of the metric: an increasing trend is observed until 2016, which sees the highest value (1.92×10^5 tCO_2e). 2017 records a lower value, and after a slight increase in 2018, lower values are observed again until the absolute minimum in 2020 (1.62×10^6 tCO_2e).

For the average values, the trend mirrors that of the maximum values up until 2016, with the distinction that 2011 represents the absolute minimum year, and 2016 is a local maximum, not the absolute maximum, which is instead recorded in 2018 (3.57×10^3 tCO_2e). From 2016 onward, the trend is similar to that of the total metric, with the difference that the value in 2020 is higher than in 2019. Despite a decrease in 2019, the 2020 value returns to a level similar to that of 2018, with 3.54×10^3 tCO_2e being the second-highest value over the 10-year period.

Finally, let us examine the median's trend. This metric deviates from all the trends observed so far, with 2011 starting at a value higher than that of the next three years. 2013 marks the absolute minimum, after which there is a continuous increase, interrupted only in 2018. 2020 represents the absolute maximum. It is interesting to note that while 2018 is the year of the absolute maximum for the mean and total, it is a local minimum for the median.

We now proceed with the same analysis for the post-interpolation statistics.

Regarding the maximum values, the post-interpolation figures are equal (note that values are rounded to two decimal places) for the first four years. Afterward, a rise is observed until 2016. 2017 records a lower value, and in 2018, it returns to that of two years prior. 2019 marks the absolute maximum year, with 1.62×10^5 tCO_2e. The trend is similar to that of the metric, with the primary difference being that 2019 is the absolute maximum, while for the metric, the value was lower than the previous three years.

As for the average values, the trend is identical to that of the total metric, with 2011 representing the absolute minimum year, continuous growth until the 2016-2018 period, where the same values are recorded (due to rounding), and a decrease in the following two years.

Finally, the median: this metric shows a different trend. From 2011 to 2014, there is continuous growth, reaching the absolute maximum. After 2014, there is a decline until 2020, which represents the absolute minimum, only interrupted in 2018, which constitutes a local maximum.

Now, let us analyze the contribution of the top 10 companies to the TCE (Table A.3).

For the pre-interpolation contributions, the values range from a minimum of 36.48% in 2011 (where the 10 companies constitute 0.89% of the portfolio, $\frac{10}{1118}$) to a maximum of 48.18% in 2020 (where they constitute about 0.71% of the portfolio, $\frac{10}{1400}$). In general, over the years, the percentages show a steady increase, with the exception of a slight decrease in 2018 and 2019.

We now focus on the analysis of the Carbon Footprint trend (Figure 4.8). As in previous analyses, we will first examine the metric's behavior pre-interpolation and then post-interpolation. Naturally, when discussing the CF trend, we will refer to the pre-interpolation values of holdings and TCE, and the post-interpolation values of PTF and TCE, respectively. To facilitate the visualization of the graphs, we have used distinct colors, with a dashed purple line representing pre-interpolation values and a solid green line for post-interpolation values. In the pre-interpolation

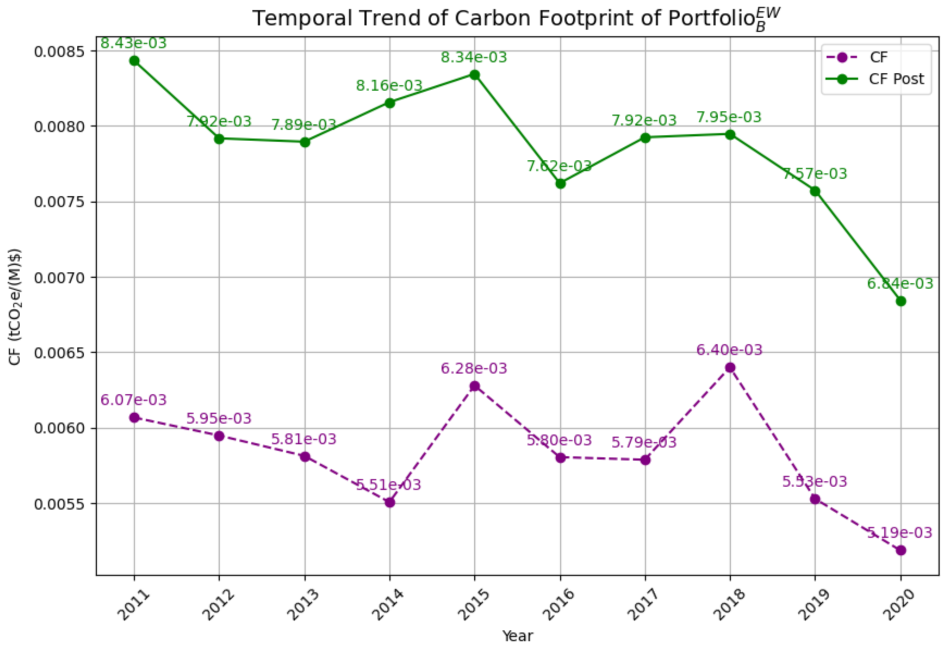

Figure 4.8: This figure shows the trend of the TCFD Carbon Footprint metric for Portfolio$_B^{EW}$ over the years. The dotted purple line represents the metric before interpolation, while the solid green line represents the CF after interpolation. On the x-axis, the years from 2011 to 2020 are shown, while the y-axis displays the values in $tCO_2e/(M)\$$.

case, the trend reveals a decline during the first three years. In 2015, however, there is an increase, which is then dampened by a decrease in the following two years.

2018 represents the absolute peak, with a value of 6.40×10^{-3} $tCO_2e/(M)\$$, after which a further decline occurs, culminating in the absolute minimum in 2020, with a value of 5.19×10^{-3} $tCO_2e/(M)\$$. This pattern, as observed for "A" Portfolios, results from variations in MarkCap and TCE from year to year. Aside from the more straightforward cases where holdings increase while TCE decreases, leading to a reduction in CF (2019 and 2020), and those with the opposite trend (2015 and 2018), we focus on the other years. Over the period from 2011 to 2020, the CF for the pre-interpolation case declines by -14.5%, compared to a -18.85% decrease post-interpolation.

For the first two years, the decrease is driven by a larger increase in portfolio value (+10.58% in 2012 and +2.92% in 2013, Table 4.11) compared to the growth of TCE (+8.4% and +0.59%). In the subsequent year, the decrease is caused by a greater reduction in TCE (-6.86%) compared to holdings (-1.67%). The dynamics for 2016 resemble those of the first two years, while 2017 is analogous to 2014.

Regarding the maximum annual values (Table A.5), 2011 emerges as the year of the absolute maximum, with a value of 5.41×10^{-4} $tCO_2e/(M)\$$. After 2012, a local minimum year, a growth trend continues until 2015, which represents a local maximum. From 2015 to 2017, a new decrease occurs, followed by the final recovery in 2018, bringing the values back to 2016 levels. After 2018, there is a continuous decline until the absolute minimum in 2020, with a value of 4.09×10^{-4} $tCO_2e/(M)\$$. Comparing this trend with the overall metric trend, it is evident that the years of maximum values (2011, 2015, 2018) remain consistent, and the year of the absolute minimum also remains unchanged.

Regarding the mean trend, it mirrors the overall metric even more closely, with correspondence in the years of maximum values, including the absolute maximum that does not change across years—2020 (while for the maxima, this was 2015). However, the year of the absolute minimum shifts from 2020 for the overall metric and maximum values to 2013 for the means.

Finally, with respect to the medians, 2011 remains a higher value compared to the subsequent two years, with 2013 marking the absolute minimum. Unlike the overall metric, a notable increase is already recorded in 2014, culminating in the local maximum of 2017. 2018 no longer constitutes the absolute maximum, instead becoming a local minimum, as 2019 shows a growth sufficient to make it the year of the absolute maximum.

Now, let us turn to the behavior of CF post-interpolation (solid green line). Upon examining the general trend, it is immediately apparent that the post-interpolation absolute minimum is still higher than the pre-interpolation absolute maximum. This trend aligns with the higher TCE and the lower PTF value in the post-interpolation scenario.

Regarding the post-interpolation trend, 2011 marks the absolute maximum (8.43×10^{-3} $tCO_2e/(M)\$$), contrasting sharply with the pre-interpolation CF, where both 2015 and 2018 had higher values. The two subsequent years show a decline, which halts in 2014, followed by a recovery in 2015, which constitutes a local maximum. From 2016 to 2018, the values increase once again, reaching another local maximum. Following this, a decline occurs, with the values ultimately reaching the absolute minimum in 2020, with a value of 6.84×10^{-3} $tCO_2e/(M)\$$.

When comparing the pre- and post-interpolation trends, a notable shift is observed in 2014, where the value moves from being lower than that of 2013 to exceeding it, and the same occurs in 2017. For the other years, however, the variations (whether positive or negative) maintain the same direction.

Given that the changes are not particularly pronounced, it is evident that the three years of maximum values remain consistent (2011, 2015, 2018). However, the years of minimum values shift: 2014 no longer marks the minimum for the pre-interpolation case but instead becomes 2013, and the local minimum from 2017 is brought forward by one year in the post-interpolation case.

The key differences, where trends are even reversed, occur in 2014 and 2017. Therefore, we will focus on the rows in Table 4.11 for the years 2013–2014 and 2016–2017.

For the 2013–2014 case, the portfolio value continues to decline, as in the pre-interpolation case, and at a similar rate (-1.67% to -1.39%). The significant change lies in the TCE, which shifts from -6.86% to +1.88%, leading to a change in CF from a decline of -5.27% to an increase of +3.32%.

In the 2016–2017 case, the holdings show little change, moving from -5.53% to -4.04%, while the TCE changes dramatically from -5.81% to just -0.22%. As a result, CF no longer decreases by -0.30%, but instead increases by +3.99%.

In terms of maximum values (Table A.5), 2011, which was the absolute maximum pre-interpolation, now represents a local maximum and ranks as the third-highest value, following 2018 and 2019. 2013 now represents a local minimum, whereas 2012 had previously held this position pre-interpolation. Growth continues until 2015, which remains a local maximum, consistent with the pre-interpolation trend.

From 2015 onwards, two years show a decrease, followed by a final rise in 2018, which represents the absolute maximum for the post-interpolation case (4.52×10^{-4} $tCO_2e/(M)\$$). A subsequent decline follows until 2020, marking the absolute minimum, with a value of 3.89×10^{-4} $tCO_2e/(M)\$$, mirroring the pre-interpolation trend.

Regarding the mean values, the trend remains identical (in terms of the increments and decrements between consecutive years) to the pre-interpolation case. However, the years of maximum and minimum absolute values shift. The first moves from 2018 to 2011 (5.67×10^{-6} $tCO_2e/(M)\$$), while the second, previously in 2013, now shifts to 2020 (4.60×10^{-6} $tCO_2e/(M)\$$).

Finally, with respect to the medians, the trend from 2011 to 2014 is comparable, with a decline until 2013, followed by a growth. However, while the pre-interpolation growth continued until 2017, a decline is already recorded in 2015, which continues into 2016, marking a local minimum. An increase follows until 2018, which represents a local maximum, followed by a decrease that ends at the absolute minimum in 2020, with a value of 1.22×10^{-7} $tCO_2e/(M)\$$ (compared to the lowest value pre-interpolation, recorded in 2013). The absolute maximum, previously in 2019, is now in 2011 1.60×10^{-7} $tCO_2e/(M)\$$.

4.2.2 Portfolio$_B^{PW}$

We now turn to the market cap weighted case. Starting from the portfolio value (Figure A.9), it is observed that the performance pre- vs post-interpolation is generally identical. The same years of growth and decline are evident, as well as the same years of maxima and minima (both absolute and local). The overall trend across the years is upward, moving from the absolute minimum in 2011 to the absolute maximum in 2020. In contrast to the equally weighted case, the interpolation has had less impact on the portfolio value.

This similarity is also observable in the table of percentage changes, Table 4.12. In general, larger absolute changes are recorded pre-interpolation, with the sole exception being 2015, where a -0.88% pre-interpolation becomes -1.46% post-interpolation.

Let us now examine the TCE (Figure 4.9). From the graph, it can be observed that the pre-interpolation case (dashed orange line) displays a very discontinuous trend. Starting from 2011, there is a slight increase followed by a peak in 2013. After a decline in 2014, the metric returns to the 2013 value, only to experience another two consecutive years of decline. In 2018, a new peak is recorded, followed by a decrease that culminates in the absolute minimum of 2020 (1.68×10^6 tCO_2e). The

Table 4.11: Percentage changes in Portfolio Value, Total Carbon Emissions, and Carbon Footprint for the periods 2011-2020 for Portfolio$_B^{EW}$. The first block represents the percentage changes for the portfolio pre-interpolation, while the second block presents the changes recorded post-interpolation.

Period	Ptf Value	TCE	CF
2011-2012	10.58%	8.40%	-1.97%
2012-2013	2.92%	0.59%	-2.26%
2013-2014	-1.67%	-6.86%	-5.27%
2014-2015	-0.67%	13.27%	14.04%
2015-2016	12.26%	3.77%	-7.56%
2016-2017	-5.53%	-5.81%	-0.30%
2017-2018	-0.96%	9.52%	10.58%
2018-2019	3.61%	-10.49%	-13.61%
2019-2020	4.73%	-1.73%	-6.17%
Post Interpolation			
2011-2012	7.79%	1.21%	-6.10%
2012-2013	2.46%	2.17%	-0.28%
2013-2014	-1.39%	1.88%	3.32%
2014-2015	-0.56%	1.72%	2.29%
2015-2016	10.68%	1.08%	-8.68%
2016-2017	-4.04%	-0.22%	3.99%
2017-2018	-0.10%	0.18%	0.29%
2018-2019	4.06%	-0.83%	-4.70%
2019-2020	8.67%	-1.78%	-9.61%

trend changes dramatically post-interpolation (solid red line). Although there are periods where the trend (upward vs. downward) remains the same (for example, from 2011 to 2016 and again from 2017 to 2019), the overall trend is upward, with 2011 marking the absolute minimum (1.57×10^6 tCO_2e) and 2018 marking the absolute maximum (2.69×10^6 tCO_2e). This stark contrast between pre- and post-interpolation was also observed in the equally weighted case. However, while in that case, emissions post-interpolation were consistently higher than pre-interpolation values, this condition does not hold for the current case, where the first three years show lower post-interpolation values. The TCE for the pre-interpolation case experiences a decline of -11.58% from 2011 to 2020, whereas the post-interpolation increase is +63.69%.

As for the percentage changes (Table 4.12), there are years where pre-interpolation values are higher (2014–2016, 2018–2020), and years where post-interpolation values are higher (the 2012–2013 period and then in 2017). The greatest decrease occurs

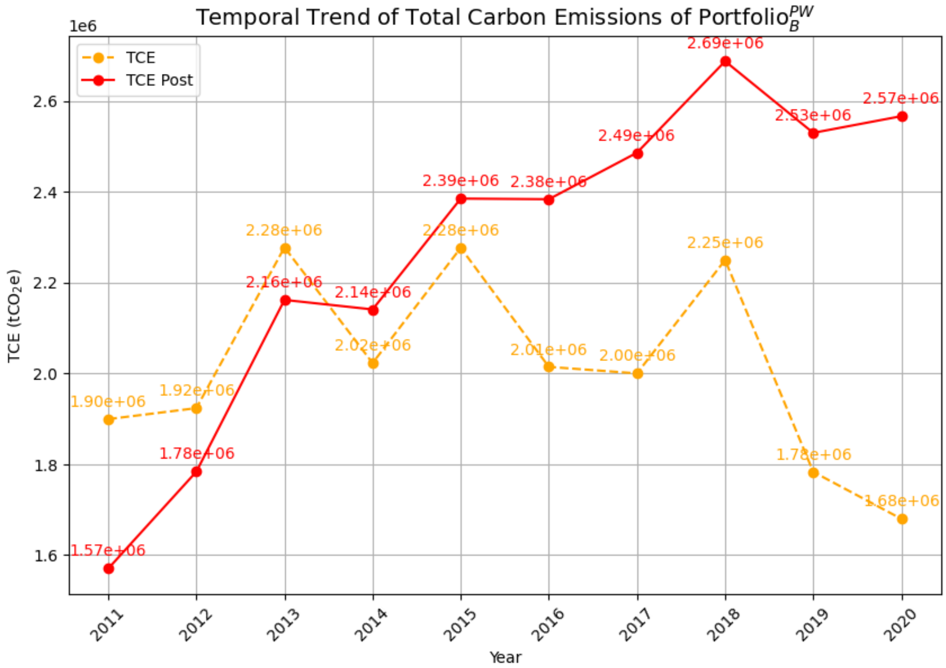

Figure 4.9: This figure shows the trend of the TCFD Total Carbon Emissions metric for Portfolio$_B^{PW}$ over the years. The dotted orange line represents the metric before interpolation, while the solid red line represents the TCE after interpolation. On the x-axis, the years from 2011 to 2020 are shown, while the y-axis displays the values in tCO_2e.

pre-interpolation in 2019 with -20.73%, while the greatest increase is recorded post-interpolation in 2013 with +21.20%.

We will now analyze the trends of the maxima, averages, and medians, starting from the pre-interpolation values (Table A.6).

Regarding the maxima, the trend is markedly different. First, 2012 shows a value lower than 2011, whereas the metric initially showed growth. Then, 2014 constitutes the absolute maximum, with 4.05×10^5 tCO_2e, whereas it was previously a local minimum. Similarly, 2017 presents a local maximum absent in the metric's previous trend, while a resemblance is found in 2020, which shows the absolute minimum with 1.26×10^5 tCO_2e.

Turning to the averages, the first three years follow a similar trend to the metric itself. However, the initial growth continues until the peak in 2015, with 3.85×10^3

tCO_2e. Thereafter, there is a decline, interrupted only by the local peak in 2017. In contrast with previous trends, 2020 is not the absolute minimum (this occurs in 2011).

As for the median, its trend mirrors that of the averages. 2011 also marks the absolute minimum. There is continuous growth until 2016, the year of the absolute maximum at 1.60×10^2 tCO_2e, followed by two years of decline, with a slight recovery in 2019.

Regarding the trends of the same metrics post-interpolation, it is observed that the maxima initially follow the metric's trend, with 2011 again marking the absolute minimum. However, growth continues in 2014, which constitutes the absolute maximum with 3.33×10^5 tCO_2e. Subsequently, there is a continuous decline, interrupted only in 2017, but it continues until the new minimum in 2020.

As for the averages, the trend is identical to the metric itself, with the same years of growth/decline, and consequently the same years of minima and maxima.

Regarding the median, 2011 constitutes the absolute maximum, in contrast to both the pre-interpolation median trend and the post-interpolation metric trend. There is continuous decline until 2020, the year of the absolute minimum, with only two interruptions: 2014 and 2018.

We now turn to the contributions of the top 10 companies that most significantly impact this metric (Table A.3, last two columns). Post-interpolation, the top 10 companies consistently have a smaller weight compared to pre-interpolation, with the exception of the last two years. While pre-interpolation, the weight ranges from a minimum of 36.3% (2011) to a maximum of 57.06% (2014), post-interpolation the minimum drops to 28.28%, while the maximum decreases to 48.29%.

Finally, we turn to the analysis of the Carbon Footprint. Starting from the pre-interpolation trend (Figure 4.10, dashed purple line), we observe the same discontinuous pattern that was present in the Total Carbon Emissions. The trend remains consistent, with the same years of growth and decline, except for 2012, which now shows a value lower than that of 2011 (whereas for TCE, it was higher), and 2017, which is now higher than 2016 (whereas for TCE, it was lower). As for the post-interpolation trend (solid green line), the pattern is similar to that of TCE. The only differences occur in 2014, which is now showing growth, and in 2020, which is decreasing compared to 2019. It is also worth mentioning 2016, as although it is decreasing as with TCE, the variation is more pronounced, with a -6.99% compared to the -0.06% for TCE (Table 4.12). In a pre vs post interpolation comparison, we observe changes in the trend only in 2012 and 2014, both of which show growth post-interpolation and decline pre-interpolation. Over the period from 2011 to 2020, the CF for the pre-interpolation case falls by -27.2%, with a +37.1% increase post-interpolation.

Now, let us analyze the percentage changes shown in Table 4.12. Starting with

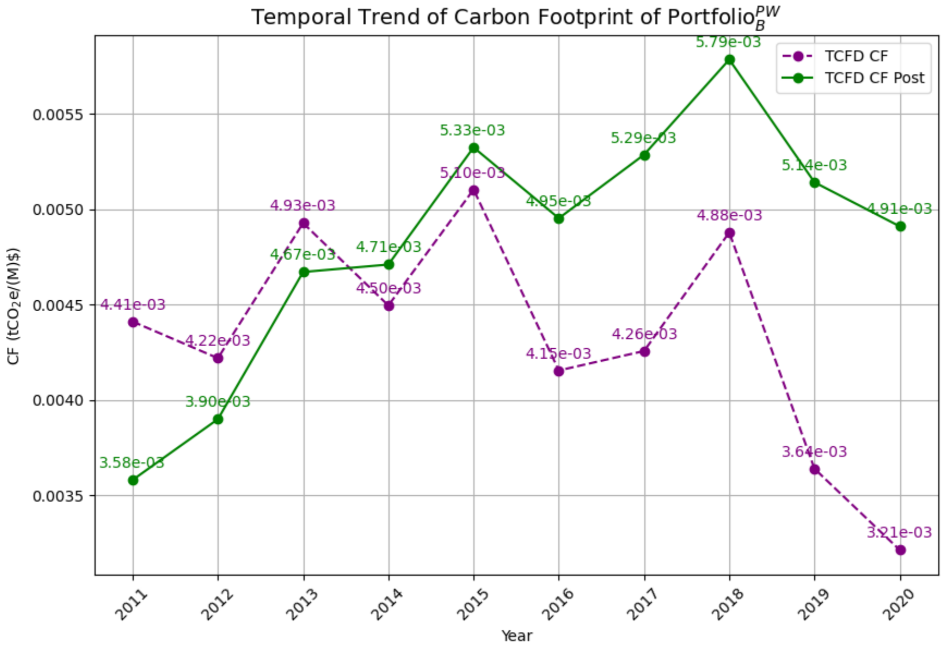

Figure 4.10: This figure shows the trend of the TCFD Carbon Footprint metric for Portfolio$_B^{PW}$ over the years. The dotted purple line represents the metric before interpolation, while the solid green line represents the CF after interpolation. On the x-axis, the years from 2011 to 2020 are shown, while the y-axis displays the values in $tCO_2e/(M)\$$.

the pre-interpolation values, several double-digit variations can be observed, both pre and post interpolation. Having analyzed the qualitative trends via the graphs, we will now focus on the quantitative variations, without discussing the signs in detail. Generally, the absolute variations pre-interpolation are larger, with only three years (2012, 2013, and 2017) showing larger variations post-interpolation. The largest variations pre-interpolation occurred in 2013 with +16.81%, and in 2019 with -25.43%. Post-interpolation, the years remain the same, but the figures are +19.81% and -11.14%, respectively.

Now, let us consider the behavior of the maximum, mean, and median values

(Table A.7). Starting with the maximum values for the pre-interpolation metric, we first notice a pattern similar to that of the metric itself, with an initial decline followed by a more significant increase. However, the maximum for 2014 exceeds that of 2013, marking a first difference, with this value being the highest over the entire 10-year period (9.00×10^{-4} $tCO_2e/(M)\$$). Similarities are found in the progressively lower values in the last three years, with 2020 recording the absolute minimum (2.40×10^{-4} $tCO_2e/(M)\$$).

Regarding the means, the trend is again different, with growth up until 2015, which marks the absolute peak at 8.62×10^{-6} $tCO_2e/(M)\$$, followed by a continuous decline, interrupted only by a local maximum in 2018. Once again, 2020 marks the absolute minimum, with 5.56×10^{-6} $tCO_2e/(M)\$$.

Finally, the median values follow a similar trend to the means, with growth until 2016 (one more year) followed by a decline, interrupted only by a local peak in 2019. The major difference is that the absolute minimum is now recorded in 2011.

Now, let us examine the post-interpolation values. Regarding the maximum values, the initial trend mirrors that of the metric, with the first four years showing progressively increasing values (except for a slight decrease in 2012). However, subsequent values never exceed that of 2014, which remains the absolute maximum at 7.32×10^{-4} $tCO_2e/(M)\$$. From 2015 onward, the values stabilize below 5×10^{-4} $tCO_2e/(M)\$$, with a fluctuating pattern between increases (2017, 2020) and decreases (2016, 2018, 2019).

Regarding the means, the trend also differs from that of the metric. Focusing on the differences, 2012 is no longer a year of growth, as is 2014. For the other years, the trend is the same, but the absolute maximum is now recorded in 2015 (4.22×10^{-6} $tCO_2e/(M)\$$) rather than in 2018, while the absolute minimum occurs in 2020 (3.31×10^{-6} $tCO_2e/(M)\$$) instead of 2011.

Finally, for the median values, the trend is even more distinct, with 2011 marking the absolute maximum. This is followed by a decline, interrupted by the isolated peak in 2014 and subsequent growth in 2017 and 2018. 2020 records the absolute minimum.

4.2.3 Metrics Comparison between Portfolio$_B^{EW}$ and Portfolio$_B^{PW}$

We now proceed with the comparison of the portfolios previously analyzed, distinguishing once again between pre- and post-interpolation trends. First, we will perform an analysis based on the trends and identify which portfolios show higher

Table 4.12: Percentage changes in Portfolio Value, Total Carbon Emissions, and Carbon Footprint for the periods 2011-2020 for Portfolio$_B^{PW}$. The first block represents the percentage changes for the portfolio pre-interpolation, while the second block presents the changes recorded post-interpolation.

Period	**Ptf Value**	**TCE**	**CF**
2011-2012	5.88%	1.28%	-4.35%
2012-2013	1.35%	18.39%	16.81%
2013-2014	-2.63%	-11.18%	-8.78%
2014-2015	-0.88%	12.54%	13.54%
2015-2016	8.72%	-11.51%	-18.61%
2016-2017	-3.09%	-0.71%	2.46%
2017-2018	-1.87%	12.48%	14.62%
2018-2019	6.29%	-20.73%	-25.43%
2019-2020	6.70%	-5.80%	-11.72%
Post Interpolation			
2011-2012	4.30%	13.59%	8.91%
2012-2013	1.16%	21.20%	19.81%
2013-2014	-1.79%	-0.97%	0.84%
2014-2015	-1.46%	11.40%	13.05%
2015-2016	7.45%	-0.06%	-6.99%
2016-2017	-2.28%	4.30%	6.73%
2017-2018	-1.23%	8.10%	9.45%
2018-2019	5.93%	-5.87%	-11.14%
2019-2020	6.22%	1.45%	-4.49%

values. Then, we will move on to the analysis of percentage variations between portfolios and between pre- and post-interpolation periods.

Starting with the holdings (Figure A.10)), it is immediately evident that, regardless of whether interpolation is applied or not, the market cap weighted portfolio consistently shows higher values compared to the equally weighted portfolio. For the latter, post-interpolation values are higher, while for Portfolio$_B^{PW}$, values are very similar, with post-interpolation values tending to be higher, except for the years 2016 and 2018, which show lower values, and for 2017 and 2020, which show identical values (rounded to two decimal places).

Moving on to the percentage variations (Table 4.13) between the EW and PW cases, we observe that the post-interpolation values are consistently higher. Pre-interpolation, the variations range from a minimum of +24.81% in 2016 to a maximum of +38.29% in 2011. Post-interpolation, although the years with the minimum and maximum variations remain the same, the values increase, with the minimum variation rising to +33.65%, and the maximum variation reaching +46.03%. On average, the pre-interpolation annual variation is +30.16%, while over the entire 10-year period, the variation is +30.02%. Post-interpolation, these percentages rise to +37.86% and +37.65%, respectively.

Next, we examine the TCE (Figure A.11). Here, the situation changes. In a

Table 4.13: Comparison of Holdings (Pre vs Post) for $\mathbb{B}$ Portfolios. A positive variation indicates that Portfolio$_B^{PW}$ exhibits higher values than Portfolio$_B^{EW}$.

Year	Holdings - Pre	Holdings - Post
2011	38.29%	46.03%
2012	32.42%	41.30%
2013	30.41%	39.50%
2014	29.14%	38.93%
2015	28.88%	37.67%
2016	24.81%	33.65%
2017	28.03%	36.10%
2018	26.85%	34.57%
2019	30.14%	36.97%
2020	32.58%	33.89%

comparison of pre-interpolation metrics, we observe that in some years, the EW portfolio presents higher values (2012, 2016-2020), while in others (2011, 2013-2015), it shows lower values compared to the PW portfolio. However, when we examine the post-interpolation values, the EW portfolio consistently records higher values than the PW portfolio. Another distinction between the two portfolios is how interpolation affects them. In the case of the equally weighted portfolio, the values—whether in an annual comparison or in the "minimum recorded post-interpolation vs. maximum post-interpolation" comparison—are always higher post-interpolation. This does not hold true for the PW portfolio, where the first three years show higher values in the pre-interpolation metric.

In terms of percentage variations (Table 4.14), for the pre-interpolation case, the negative variations range from a minimum of -0.53% in 2011 to a maximum of -9.55% in 2013. The positive variations range from a minimum of +3.41% in 2018 to a maximum of +21.82% in 2020. Post-interpolation, as seen in the graph, the values for the EW portfolio are consistently higher, with variations ranging from a minimum of +2.06% in 2018 to a maximum of +61.29% in 2011. The average pre-interpolation variation is +4.69%, while the total variation over the 10 years is +3.96%. Post-interpolation, these percentages rise to +20.35% and +17.71%, respectively.

Finally, we conclude with the analysis of the Carbon Footprint, shown in Figure A.12. As with the holdings, in this case as well, the values for one portfolio are

Table 4.14: Comparison of TCE and CF (Pre vs Post) for $\mathbb{B}$ Portfolios. A positive variation indicates that Portfolio$_B^{EW}$ exhibits higher values than Portfolio$_B^{PW}$.

Year	**TCE - Pre**	**TCE - Post**	**CF - Pre**	**CF - Post**
2011	-0.53%	61.29%	37.56%	135.53%
2012	6.47%	43.71%	40.98%	103.06%
2013	-9.55%	21.15%	17.96%	69.01%
2014	-5.15%	24.64%	22.50%	73.16%
2015	-4.53%	13.81%	23.03%	56.68%
2016	11.95%	15.10%	39.73%	53.84%
2017	6.20%	10.12%	35.97%	49.88%
2018	3.41%	2.06%	31.18%	37.33%
2019	16.77%	7.52%	51.96%	47.28%
2020	21.82%	4.10%	61.51%	39.38%

always higher than those for the other. In this instance, however, the EW portfolio shows higher values, analogous to the behavior observed with the post-interpolation TCE values. A key observation is that, for the PW portfolio, the CF values in the first three years are higher pre-interpolation than post-interpolation, similar to the pattern observed with the TCE values.

Regarding the percentage variations (Table 4.14), there is a clearer increase in percentage when transitioning from PW to EW, compared to the TCE, both pre- and post-interpolation. Pre-interpolation, all variations are positive, ranging from a minimum of +17.96% in 2013 to a maximum of +61.51% in 2020. Post-interpolation, the variations range from a minimum of +37.33% in 2018 to +135.53% in 2011. The average variations before interpolation are +34.26%, which becomes +31.88% over the total of the 10 years. After interpolation, these values become +66.51% and +62.96%, respectively. It is interesting to note that both the TCE and CF percentages tend to decrease from 2011 to 2020.

4.2.4 Scope 3 Analysis: β Portfolio

In this section, as in Section 4.1.4, we focus on the variation of the metrics when Scope 3 emissions are also considered. It is important to note that Portfolio$_\beta$ is an equally weighted portfolio. The corresponding PW portfolio was not created because the goal of this analysis is to observe the impact of Scope 3 emissions on a broader dataset of companies compared to the 188 companies in the α portfolios (in this case, 1,241 firms), specifically how the percentage weight of Scope 3 emissions changes. In particular, we aim to assess whether even a percentage lower than 25% of companies reporting such data (the minimum for the α portfolios is 38.07%, as shown in Table A.2) can lead to significant changes in the trends of the metrics. In this portfolio, the percentage of data availability ranges from a minimum of 15.79% to a maximum of just 21.51% in 2011 (see Table A.8).

As with the α portfolios compared to the $\mathbb{A}$ portfolios, Portfolio$_\beta$ includes fewer firms than the $\mathbb{B}$ portfolios, as firms exhibiting abnormal variations in their Scope 3 emissions reports have been excluded. The analysis will follow the same procedure as that used in Section 4.1.4: calculating holdings, calculating metrics without Scope 3, calculating metrics with Scope 3, and finally recalculating with Scope 3 interpolation.

We begin with the analysis of the TCE (Figure 4.11). Regarding the trend of the TCFD TCE (i.e., the one without Scope 3, represented by the blue bars), we observe an increasing trend over the years. 2011 represents the absolute minimum, followed by two local maxima in 2013 and 2016, an absolute maximum in 2018, and another increase in 2020, which marks the second-highest value of the 10-year period.

However, when Scope 3 emissions are included without interpolation (represented by the orange bars), the trend changes. Overall, the trend remains upward, with 2013 and 2016 still representing local maxima. However, the absolute minimum occurs in 2014 (1.97×10^6 tCO_2e), while the absolute maximum is recorded in 2020 (4.97×10^6 tCO_2e). As in the case of the α portfolios, the minimum TCE with Scope 3 emissions occurs when the minimum Scope 3 emissions are recorded (Table 4.15, 53.34%), and consequently, the minimum increase (+35.38%) is observed. Similarly, the maximum is recorded when the maximum percentage of Scope 3 emissions is reached, along with the maximum increase (65.64% and 141%, respectively). The average annual increase when Scope 3 emissions are added is 77.57%, while over the entire 10-year period, it is 80.33%.

Regarding the trend post-interpolation (red bars, 59.71% of availability every year as shown in Table A.8), the trend changes further. The series starts with an

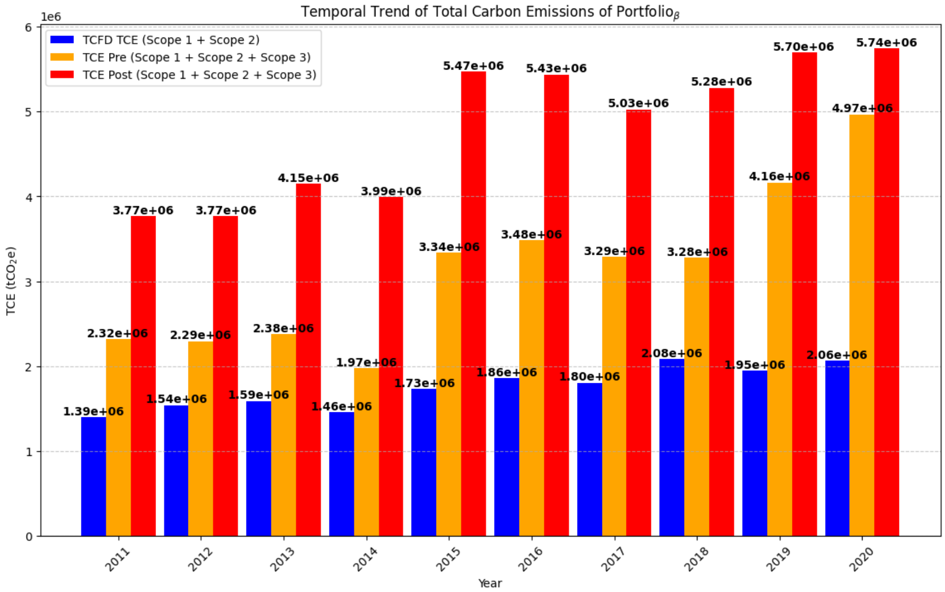

Figure 4.11: This figure shows, in blue, the TCE value for Portfolio$_\beta$ calculated following the TCFD guidelines, i.e., including only Scope 1 and Scope 2 emissions. In orange, the values of the metrics when Scope 3 emissions are also considered (TCE Pre). In red, the values of the metrics post interpolation of Scope 3 emissions (TCE Post). On the x-axis, the years from 2011 to 2020 are represented, while the y-axis displays the TCE values in tCO_2e.

absolute minimum (2011 and 2012 both record the same value, 3.77×10^6 tCO_2e). 2013 records a local maximum, while another local maximum appears in 2015 rather than in 2016. Finally, the absolute maximum occurs again in 2020, with 5.74×10^6 tCO_2e. The fact that 2014 no longer constitutes the absolute minimum can be explained by the lower data availability before interpolation, which results in the largest increase being recorded post-interpolation, at 102.18% (Table 4.15). The minimum increase is recorded in 2020, the year with the highest data availability, at +15.68%. With interpolation, the average annual increase compared to the non-interpolated data is 59.03%, which, over the entire 10-year period, results in a +53.56% increase.

For the Carbon Footprint (Figure 4.12), as done for the α portfolios, we will focus on qualitative analysis, as the quantitative analysis is similar to that performed for the TCE. However, changes in the TCE may lead to different outcomes for the CF. Starting with the CF without Scope 3 emissions (blue bars), we observe that the trend tends to decrease over the years. The initial value is 5×10^{-3} $tCO_2e/(M)\$$, followed by the absolute minimum in 2014, with 4.55×10^{-3} $tCO_2e/(M)\$$. This

Table 4.15: This table illustrates the percentage contribution of Scope 3 (S3) emissions to the total emissions (Scope 1 + Scope 2 + Scope 3), alongside the corresponding increase in the TCE metric when these emissions are incorporated (third column). The final column highlights the percentage change in TCE, comparing the post-interpolation values with the pre-interpolation metrics. These values pertain to Portfolio$_\beta$.

Year	S3 % in Emissions	TCE Increase with S3	% Increase Post
2011	57.87%	66.05%	62.80%
2012	55.54%	49.17%	64.31%
2013	55.85%	49.71%	74.42%
2014	53.34%	35.38%	102.18%
2015	62.91%	92.80%	64.03%
2016	62.48%	87.80%	55.96%
2017	62.11%	82.17%	52.96%
2018	57.16%	57.52%	61.16%
2019	62.49%	114.11%	36.80%
2020	65.64%	141.00%	15.68%

is followed by a peak, a decline over the next two years, and after reaching the maximum value in 2018 (5.52×10^{-3} $tCO_2e/(M)\$$), the value in 2020 is lower than the initial value, at 4.65×10^{-3} $tCO_2e/(M)\$$.

When Scope 3 emissions are added, the trend changes. From 2011 to 2017, the trend remains the same, but in 2018, a value lower than 2017 is recorded, followed by a growth that reaches the maximum value in 2020, with 1.12×10^{-2} $tCO_2e/(M)\$$. Therefore, the years of the absolute maximum change (from 2018 to 2020), while the absolute minimum remains the same (2014).

Finally, when Scope 3 emissions are interpolated, a greater difference is observed. Starting from 2013, the value is higher than that of 2012 (the year of the absolute minimum), marking a local maximum. The absolute maximum is then recorded not in 2018 or 2020, but in 2015, with 1.67×10^{-2} $tCO_2e/(M)\$$. This is followed by a decrease in values, with the last local maximum appearing in 2018.

4.3 Portfolio$_\gamma$

The final analysis of this study focuses on Portfolio$_\gamma$. This portfolio consists of 48 companies: all and only those companies that, each year from 2011 to 2020, have published data on market capitalization, Total Emissions (Scope 1 + Scope

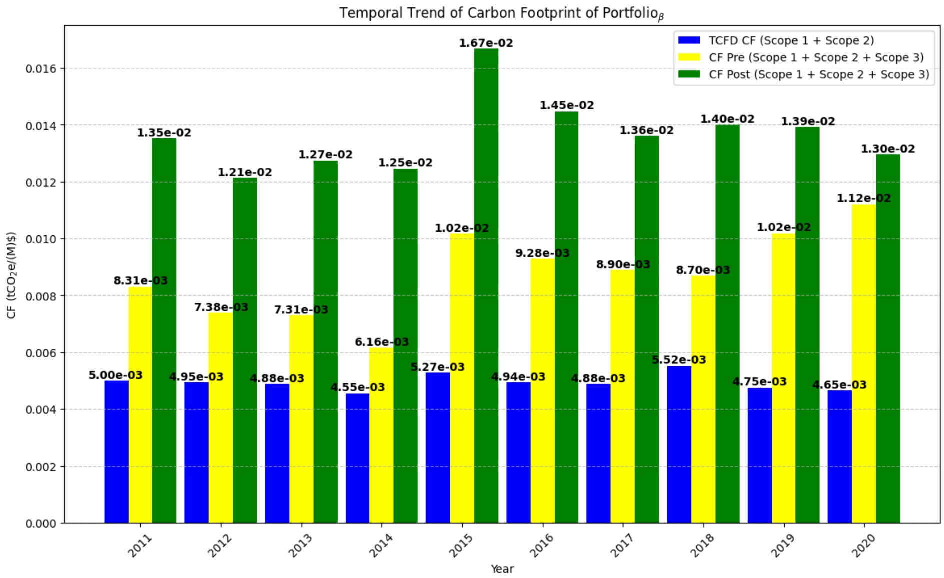

Figure 4.12: This figure shows, in blue, the CF value for Portfolio$_\beta$ calculated following the TCFD guidelines, i.e., including only Scope 1 and Scope 2 emissions. In yellow, the values of the metrics when Scope 3 emissions are also considered (CF Pre). In green, the values of the metrics post interpolation of Scope 3 emissions (CF Post). On the x-axis, the years from 2011 to 2020 are represented, while the y-axis displays the CF values in $tCO_2e/(M)\$$.

2), and Scope 3 Emissions. This analysis, which does not focus on the TCE/CF analysis, was conducted because it was considered important to have a counterpart to Portfolio$_A$ (the one containing companies with 100% disclosure of market capitalization and Total Emissions) that also had 100% disclosure for Scope 3 emissions. This way, we can observe once again whether the trends accounting for these emissions differ from those that only consider Scope 1 and Scope 2 emissions and, here lies the novelty, whether a 100% disclosure leads to different results, specifically in terms of trends, compared to trends with missing data.

The following behaviors are observed (Figure 4.13):

1. In the absence of Scope 3 emissions, total emissions (blue bars) reach their absolute maximum in 2011 (3.09×10^8 tCO_2e), with a decreasing trend until 2014. There is a slight uptick in the following two years, with 2016 marking a local maximum, after which the decline continues until the absolute minimum in 2020 (2.65×10^8 tCO_2e).

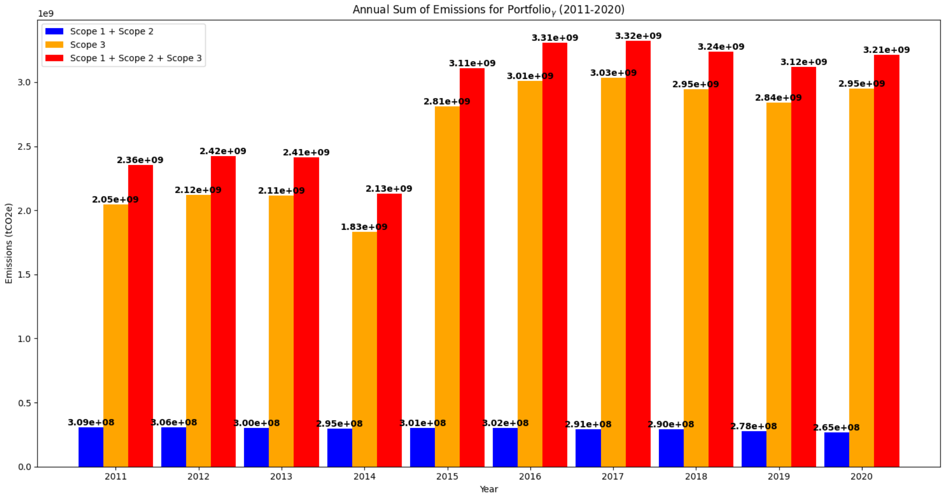

Figure 4.13: This figure shows, in blue, the TCE value for Portfolio$_\gamma$ calculated following the TCFD guidelines, i.e., including only Scope 1 and Scope 2 emissions. In orange, the values of the metrics when Scope 3 emissions are also considered (TCE Pre). In red, the values of the metrics post interpolation of Scope 3 emissions (TCE Post). On the x-axis, the years from 2011 to 2020 are represented, while the y-axis displays the TCE values in tCO_2e.

2. Scope 3 emissions (orange bars) exhibit a different trend. 2012 represents a local maximum, while 2019 marks a local minimum. The absolute maximum occurs in 2017 (3.03×10^9 tCO_2e), while the absolute minimum coincides with the year of the local minimum for Total Emissions (Scope 1 + Scope 2): 1.83×10^9 tCO_2e. Given the significantly higher contribution of Scope 3 emissions, the total emissions (Scope 1 + Scope 2 + Scope 3, red bars) follow the trend of these emissions.

3. As for the percentage of Scope 3 emissions relative to total emissions at the individual company level (Table 4.16), it ranges from a minimum of 0.00% (values are rounded to two decimal places) to a maximum of 99.99%. On average, these emissions account for values ranging from approximately 30% (30.81% in 2011) to about 62% (61.75% in 2020). The median weight starts below the average (15.57%) and remains lower until 2017. From 2018 onward, the median percentage exceeds the average, reaching 73.62%.

4. These percentages, when applied to individual companies, lead to the following results for the entire portfolio (Table 4.17): the percentage of Scope 3 emissions within total emissions ranges from a minimum of 86.14% in 2014 to a maximum of 91.77% in 2020.

Table 4.16: This table presents the statistics of the percentages of Scope 3 emissions relative to the total emissions (Scope 1 + Scope 2 + Scope 3) for individual firms in Portfolioγ.

Year	Max	Min	Mean	Median
2011	99.67%	0.00%	30.81%	15.57%
2012	99.54%	0.00%	31.38%	17.00%
2013	99.52%	0.07%	33.90%	21.25%
2014	99.60%	0.07%	37.87%	31.29%
2015	99.84%	0.01%	39.74%	31.68%
2016	99.93%	0.04%	44.93%	37.47%
2017	99.92%	0.35%	47.09%	43.33%
2018	99.94%	0.23%	52.71%	53.57%
2019	99.94%	0.05%	56.89%	63.84%
2020	99.99%	0.29%	61.75%	73.62%

Table 4.17: This table shows the percentage of Scope 3 emissions relative to the total emissions (Scope 1 + Scope 2 + Scope 3) for Portfolio$_\gamma$.

Year	Percentage of Scope 3
2011	86.89%
2012	87.38%
2013	87.56%
2014	86.14%
2015	90.33%
2016	90.89%
2017	91.25%
2018	91.04%
2019	91.10%
2020	91.77%

Chapter 5

Conclusions

In this thesis, we have analyzed two TCFD metrics, namely Total Carbon Emissions and Carbon Footprint. Our analysis focuses on comparing the temporal trends of these two metrics, identifying any similarities and/or differences in their behaviors, both qualitatively (by examining the trends in a line graph) and quantitatively (by analyzing the percentage changes). By comparing the results obtained for four distinct portfolios, we have addressed the first three research questions. Subsequently, we introduced Scope 3 emissions to answer the fourth and final research question. All the results presented in this section are the result of personal contribution.

Our findings reveal the following key insights:

1. **Answer to the first research question**[1].
   Regarding $\mathbb{A}$ portfolios, the trend in TCE results in final values lower than those of 2011 (Figure A.4). The same pattern is observed for CF (Figure A.5). As for $\mathbb{B}$ portfolios, the TCE value in 2020 is higher than in 2011 for the EW case, while it is lower for the PW case (Figure A.11). For CF, however, 2020 records values lower than 2011 in both cases (Figure A.12).
   The analysis revealed that the trends of the metrics can either be similar or different, depending on the portfolio being considered. Generally, there are periods—whether short or long—where the growth or decline of the metrics coincides (for example, the years 2013-2016, 2017-2020 for Portfolio_A^{EW}, 2011-2013, 2014-2016, 2017-2020 for Portfolio_A^{PW}). However, over the entire period, the trend may either be similar (e.g., Portfolio_B^{PW} - Pre-interpolation, showing a generally decreasing trend for both metrics) or different (e.g., Portfolio_B^{EW} - Pre-interpolation, with an overall increasing trend for TCE and a decreasing

[1] To answer this question and the second one, we used only the analyses conducted on $\mathbb{A}$ and $\mathbb{B}$ portfolios without interpolation. Post interpolation results are addressed in Research Question 3.

trend for CF).
In addition to the clearer results, where significant variations in TCE (or Holdings), if present in a year of small variations in Holdings (or TCE), had a stronger impact on CF, it emerged that even a slightly larger variation (in absolute value) in holdings (Table 4.6) could lead to either an increase (2013-2014) or a decrease (2016-2017) in CF. Similarly, it also occurred that a slightly larger decrease in TCE compared to the holdings could cause CF to decrease (Table 4.11, period 2016-2017, pre-interpolation).
Regarding the percentage changes between consecutive years, it was observed across all portfolios that the Carbon Footprint exhibited higher maximum values compared to the Total Carbon Emissions, as shown in Tables 4.3, 4.6 and 4.11 (Pre-Interpolation results). The only exception was the Portfolio$_B^{PW}$, which recorded higher negative changes (in absolute value) in the CF, as did the other portfolios. However, the maximum positive change was found to be higher for the TCE (Table 4.12, Pre-Interpolation results).

2. **Answer to the second research question**.
In a comparison of the performance of metrics between equally weighted portfolios and market capitalization-weighted portfolios, the following findings emerged:

    (a) Regarding Total Carbon Emissions, $\mathbb{A}$ portfolios exhibit a trend that, in an annual comparison, can differ in specific years (2012, 2014, 2017, Figure A.4). However, both portfolios reach their absolute maximum in 2015 and their absolute minimum in 2020. Notably, the percentage decrease over the entire 10-year period is significantly different, with a 22.99% decrease for PW and only a modest 1.67% decrease for EW. The most interesting observation, however, is that the EW portfolio consistently reports higher values, in an annual comparison, than the PW portfolio.
    When turning to $\mathbb{B}$ portfolios , the trends diverge. Firstly, the condition of having the same relative minimum and maximum years is no longer met (2015-2016, Figure A.11). Additionally, over the 10-year period, the equally weighted portfolio shows a growth of +8.74%, while the market cap weighted one experiences a decline of -11.58%. Moreover, unlike in the previous case, there are years (2011, 2013–2015) where the TCE of the PW portfolio exceeds that of the EW portfolio.

    (b) Regarding Carbon Footprint, the observations for $\mathbb{A}$ portfolios are consistent with those made for TCE. Some years show differing trends (e.g., 2013, 2017, Figure A.5), but overall, the trend is downward for both portfolios. Furthermore, as with TCE, the values for the equally weighted portfolio are consistently higher than those for the market cap weighted one, a result of higher TCE and lower value in holdings.

As for $\mathbb{B}$ portfolios, similar to what was observed with TCE, the years of relative minimum and maximum do not always align (e.g., 2012 and 2013, Figure A.12). However, unlike in the TCE case, the CF values for the two portfolios no longer intersect, with the CF of the EW portfolio consistently higher than that of the PW portfolio, mirroring the trend seen in $\mathbb{A}$ portfolios.

(c) Over the 10-year period, transitioning from Portfolio_A^{PW} to Portfolio_A^{EW}, there is a recorded increase in Total Carbon Emissions of +11.61%. However, for $\mathbb{B}$ portfolios (pre-interpolation), this value decreases to +3.96%. In terms of Carbon Footprint, the respective values are +41.29% and +31.88%. It is noteworthy that higher values are observed in portfolios consisting of firms with 100% of emissions data available, despite these portfolios containing less than one-fifth of the companies found in $\mathbb{B}$ portfolios (288 versus 1,489).

3. **Answer to the third research question**.
Analyzing the $\mathbb{B}$ portfolios both before and after the linear interpolation of market capitalization and emissions, the following results emerge:

(a) Regarding the Total Carbon Emissions of the Equally Weighted portfolio, the overall trend remains similar, with only one year showing a reversal (2014, Figure 4.7). Post-interpolation, values are higher, with a difference of 2.10×10^5 tCO_2e between the maximum value pre-interpolation and the minimum post-interpolation. Growth continued until 2016-2018, with the last two years ending at levels lower than the previous three years but still higher than the starting point. However, the percentage variations changed drastically, moving from double-digit values, such as in 2015 and 2019 (+13.27% and -10.49%, respectively, as shown in Table 4.11), to values that do not exceed 2.17% in absolute terms.
When examining TCE for the Market Cap Weighted Portfolio (Figure 4.9), a markedly different behavior emerges. Pre-interpolation, the 2020 value is lower than that of 2011, showing a percentage decrease of -11.58%. However, post-interpolation, the trend is upward, leading to an increase of +63.69%. The two metrics intersect, with the pre-interpolation values being higher than the post-interpolation values for the first three years. When analyzing the annual variations, the overall behavior is similar in terms of growth and decline, with only two years showing a trend reversal (2017 and 2020). The differences were influenced by fewer years of decline (three post-interpolation versus five pre-interpolation), as well as lower decline values (Table 4.12, rows 2013-2014, 2015-2016, 2018-2019) and higher positive variations (especially in 2011-2012, as well as the years

transitioning from decline to growth).

(b) Regarding the Carbon Footprint, starting with Portfolio$_B^{EW}$, a similar trend to that of TCE is observed in both cases. However, an additional year shows a reversal of trend (2014 and 2017, Figure 4.8). The year of the absolute maximum changes (2011 post-interpolation vs. 2018 pre-interpolation), while the absolute minimum year remains 2020. As with TCE, the values post-interpolation are always higher than those pre-interpolation, with a difference between the post-interpolation minimum and the pre-interpolation maximum of 4.4×10^{-4} $tCO_2e/(M)\$$. When examining the percentage variations (Table 4.11), the pre-interpolation values are again higher, with a maximum decrease of -13.61% and a maximum increase of +14.04%. Post-interpolation, these values decrease to -9.61% and +3.99%, respectively.
Turning to the Portfolio$_B^{PW}$, there are many similarities between CF and TCE. First, the post-interpolation CF intersects with the pre-interpolation one. The overall trend also changes, shifting from a decrease of -27.2% pre-interpolation to an increase of +37.1% post-interpolation. A reversal in trend is observed in two years (2012 and 2014), with three years of decline post-interpolation compared to five pre-interpolation, as seen in the TCE data. Regarding the percentage variations, the maximum decrease is recorded pre-interpolation (-25.43%, Table 4.12), while the maximum increase is recorded post-interpolation (+19.81%).

4. **Answer to the fourth research question**.
When Scope 3 emissions are included in the calculation of the metrics, their behavior significantly. This is particularly evident for the Carbon Footprint, both with and without the interpolation of Scope 3 emissions, as well as for the Total Carbon Emissions, which shows a greater change prior to the interpolation of Scope 3 emissions.

(a) Concerning TCE, we observe that a declining trend that takes into account only Scope 1 and Scope 2 emissions may shift to an increasing trend upon the introduction of Scope 3 emissions (see Figures 4.5, 4.6). After interpolation, the trend then reverts to one that is more in line with the metric excluding Scope 3 emissions, particularly in Portfolio$_\alpha^{EW}$. The PW portfolio, on the other hand, initially exhibits a different trend from the others, but from 2015 onward, its behavior closely resembles that of the pre-interpolation trend. In the case of Portfolio$_\beta$, the changes were less pronounced, with variations in the timing of maximum and minimum values, but overall, the trend remained increasing in all three cases.

(b) Moving on to the Carbon Footprint, in addition to the α portfolios, which follow the same trend as TCE, the β portfolio also reverses its trend from a decreasing to an increasing one when Scope 3 emissions are introduced. However, similar to the TCE, post-interpolation, the trend differs from the previous one for the first three years. From 2014 onward, the trend aligns more closely with that of the metric excluding Scope 3 emissions.

(c) A critical element observed, especially in the α portfolios (which are characterized by a greater availability of Scope 3 emissions compared to Portfolio$_\beta$), is that TCE increases by an order of magnitude, rising from values in the range of $3-5 \times 10^6$ tCO_2e to values reaching up to $1-2 \times 10^7$ tCO_2e. It is noteworthy that the percentage of Scope 3 emissions within total emissions can reach up to 76.49% (Table 4.9), with an increase in Total Carbon Emissions of up to +473.59% (Table 4.10) upon the introduction of these emissions, and +183.09% following their interpolation.

(d) Finally, when analyzing the percentage weight of Scope 3 emissions within total emissions (see Table 4.16), we observe that this weight can range from a minimum of 0% to a maximum of 99.99%, further emphasizing the impossibility of disregarding these emissions, except in the case of certain individual companies for which the weight is negligible. Additionally, in a comparison between Scope 1 + Scope 2 versus Scope 3 emissions alone, the latter consistently represents a much larger share of emissions each year. Specifically, Scope 1 + Scope 2 emissions reach a maximum of 3.09×10^8 tCO_2e, while Scope 3 emissions reach a minimum of 1.83×10^9 tCO_2e.

(e) Based on the observed findings, it is clear that these metrics are significantly influenced by the inclusion of Scope 3 emissions, with the exception of a few isolated cases where companies exhibit negligible Scope 3 emissions. At the level of individual firms and portfolios, therefore, neglecting these emissions leads to different results, which may be subject to misinterpretation and potential greenwashing by companies. Furthermore, the fact that the Carbon Footprint may decrease while the portfolio's Total Carbon Emissions still increases, further strengthens the potential for companies to manipulate this metric in a way that could mislead readers of the graphs, as well as potential investors and consumers.

The main findings of this study can be summarized as follows:

(a) Total Carbon Emissions and Carbon Footprint can exhibit either similar or divergent trends, depending on the performance of the portfolio holdings.

(b) The trends of the metrics can vary depending on the weightings used for the companies. The Equally Weighted portfolio tends to report higher values, especially for the Carbon Footprint, with an increase ranging from a minimum of +31.88% to a maximum of +41.29%.

(c) After interpolation, the trends of the metrics may change, and their values generally tend to be higher compared to the pre-interpolation values, particularly for equally weighted portfolios.

(d) Scope 3 emissions should not be disregarded, neither at the portfolio level nor at the individual company level, except in a few isolated cases. The percentage share of Scope 3 emissions within the total portfolio emissions can reach up to 99.99% at the firm level, and up to 91% at the portfolio level. The findings show that Scope 3 emissions significantly impact metrics, and ignoring them can lead to misinterpretation or greenwashing. Additionally, a decrease in Carbon Footprint while Total Emissions rise could be manipulated, misleading investors and consumers.

The results obtained in this study have two main limitations. Firstly, portfolios such as $\mathbb{A}$ and α ones are somewhat unrealistic, as they were created ad hoc using companies with 100% disclosures for each year. In this sense, the results obtained from the $\mathbb{B}$ and β portfolios are more realistic. Similarly, the results derived from Portfolio$_\gamma$ are subject to the same restriction. The main limitation, however, lies in the fact that the datasets used are essentially hierarchical, where datasets from the γ, β, α, and $\mathbb{A}$ portfolios are subsets of the dataset used to create the $\mathbb{B}$ portfolios. This means that they are not independent of one another.

5.1 Future Developments

Future research could focus on analyzing a greater number of portfolios using independent datasets. This would help address the limitations identified in this study and provide a more accurate representation of how emission metrics behave across a diverse range of portfolios. In addition to the analyses conducted in this study, future work could examine the firms' effect, specifically how the emissions of a portfolio evolve over time when fixed weightings are maintained. Additionally, the rebalancing effect could be explored, which would involve studying the emissions of a portfolio while keeping the emissions of the firms at their initial levels and adjusting the weights of the companies over time.

Future studies could also explore the impact of sectoral and geographic diversification on emission profiles. By categorizing companies according to industry sectors or countries, researchers could assess how the emission patterns of portfolios differ across various sectors (e.g., energy, technology, finance) or regions (e.g., developed versus emerging markets). This could offer valuable insights into how specific industries or geographic regions contribute to overall carbon footprints and allow for a more nuanced understanding of emissions trends.

For example, certain sectors may inherently have higher emissions due to their operational nature, such as energy-intensive industries, while others may benefit from green innovation or more stringent environmental regulations. Similarly, geographic factors, such as the presence of national climate policies, can significantly affect the emissions profiles of companies within those regions. Understanding these dynamics would enable more tailored strategies for sustainable investing, accounting for both the environmental impact and the regulatory environment in which companies operate.

These future studies could significantly enrich the findings of this work and contribute to the further development of green finance and sustainable investing, particularly in the context of improving data transparency, reducing greenwashing, and enabling more informed investment decisions.

Chapter 6

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Appendix A

Additional Figures and Tables

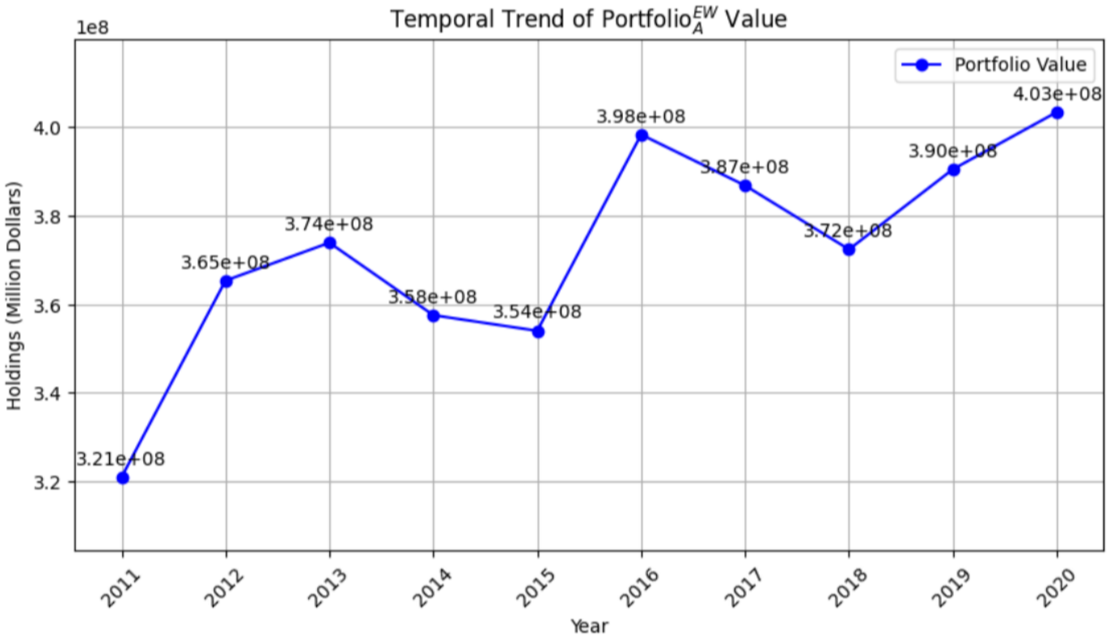

Figure A.1: This figure shows the trend of the Holdings for Portfolio$_A^{EW}$. On the x-axis, the years from 2011 to 2020 are represented, while the y-axis displays the Portfolio values in Million Dollars.

Table A.1: This table shows the percentage weight in Total Carbon Emissions of the top 10 contributors from 2011 to 2020. The values are relative to the $\mathbb{A}$ portfolios. Column "Weight A^{EW}" represents the EW portfolio, while column "Weight A^{PW}" represents the PW portfolio.

Year	Weight A^{EW}	Weight A^{PW}
2011	53.03%	48.58%
2012	53.60%	43.88%
2013	53.75%	51.06%
2014	53.61%	49.02%
2015	54.55%	55.70%
2016	53.88%	42.00%
2017	52.83%	43.61%
2018	53.42%	46.71%
2019	53.10%	38.55%
2020	54.34%	32.09%

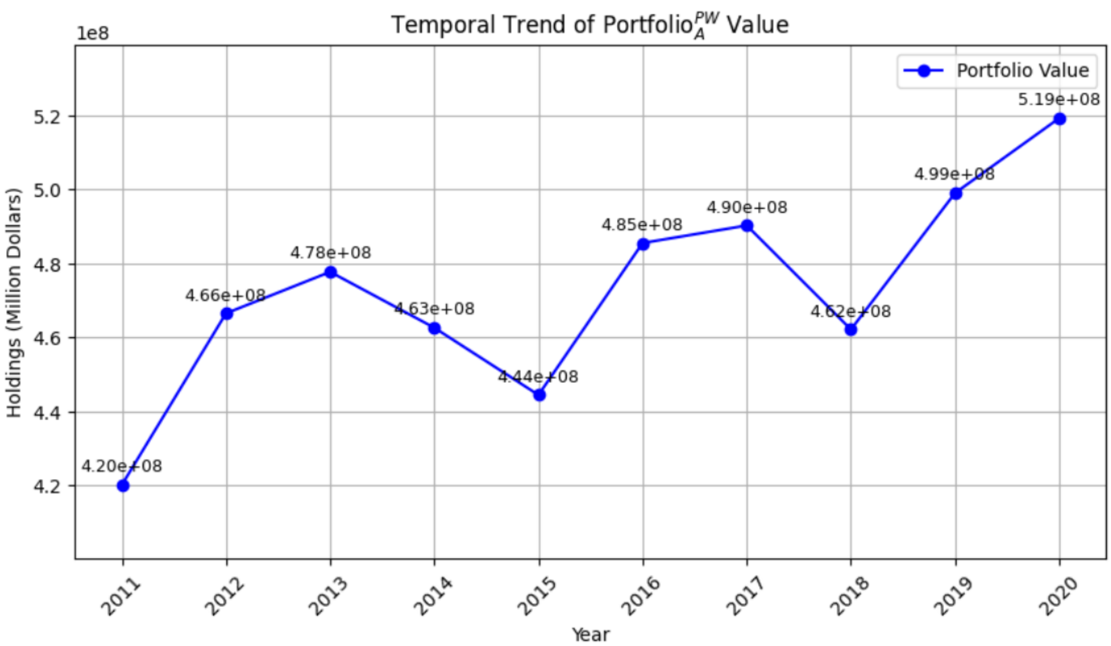

Figure A.2: This figure shows the trend of the Holdings for Portfolio$_A^{PW}$. On the x-axis, the years from 2011 to 2020 are represented, while the y-axis displays the Portfolio values in Million Dollars.

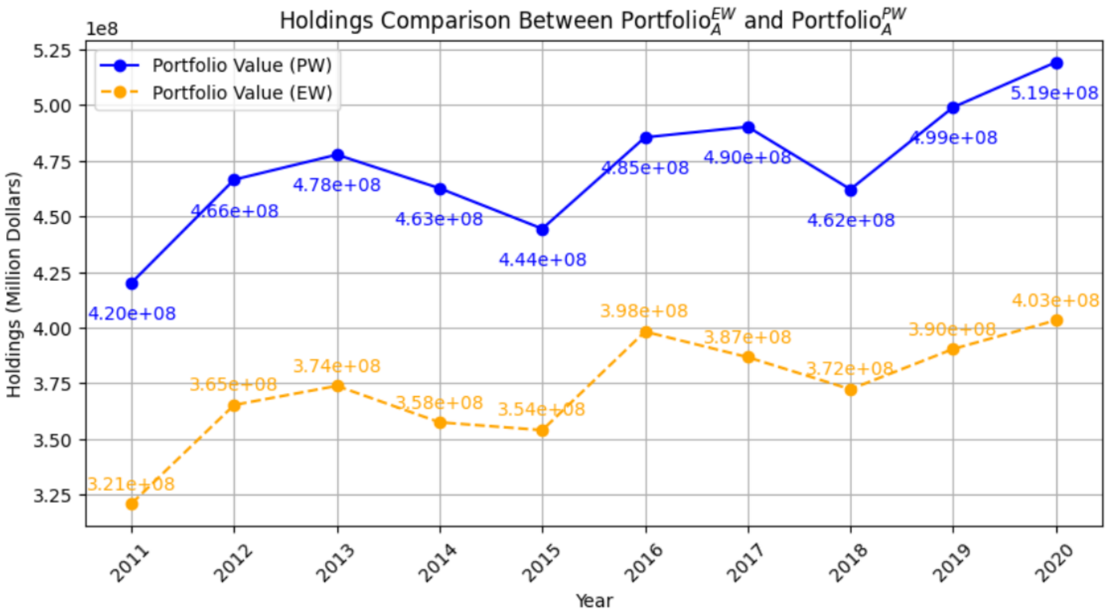

Figure A.3: This figure illustrates the trend of the holdings for Portfolio$_A^{EW}$ and Portfolio$_A^{PW}$ over the years. The dotted yellow line represents the values for the EW portfolio, while the solid blue line represents the values for the PW portfolio. The x-axis displays the years from 2011 to 2020, and the y-axis shows the values in Million Dollars.

Table A.2: The table presents the percentage of companies within Portfolio$_\alpha^{EW}$ and Portfolio$_\alpha^{PW}$, in relation to the total of 176 companies, that have disclosed their Scope 3 emissions over the years. "Pre" refers to the percentage of Scope 3 availability Pre Interpolation. "Post" refers to the same percentage Post Interpolation.

Year	**Percentage of Scope 3 - Pre**	**Percentage of Scope 3 - Post**
2011	46.02%	83.52%
2012	43.75%	83.52%
2013	43.75%	83.52%
2014	38.07%	83.52%
2015	39.77%	83.52%
2016	45.45%	83.52%
2017	47.16%	83.52%
2018	56.82%	83.52%
2019	65.34%	83.52%
2020	72.73%	83.52%

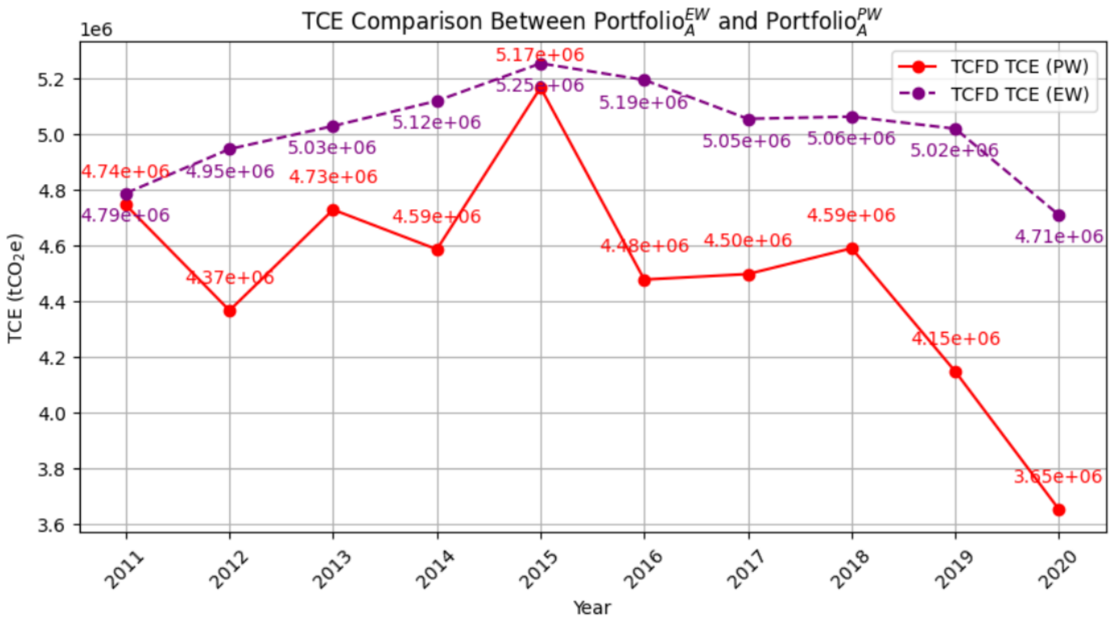

Figure A.4: This figure illustrates the trend of the Total Carbon Emissions for Portfolio$_A^{EW}$ and Portfolio$_A^{PW}$ over the years. The dotted purple line represents the values for the EW portfolio, while the solid red line represents the values for the PW portfolio. The x-axis displays the years from 2011 to 2020, and the y-axis shows the values in tCO_2e.

Table A.3: Percentage weight in Total Carbon Emissions of the top 10 contributors to this metric by year. The first two columns show the weight relative to Portfolio$_B^{EW}$, pre-interpolation (B^{EW} Pre) and post-interpolation (B^{EW} Post). The last two columns represent the weights for Portfolio$_B^{PW}$ (B^{PW} Pre and B^{PW} Post).

Year	B^{EW} Pre	B^{EW} Post	B^{PW} Pre	B^{PW} Post
2011	36.48%	50.17%	36.30%	28.28%
2012	40.25%	47.63%	38.99%	31.63%
2013	40.80%	48.38%	54.36%	44.97%
2014	43.83%	52.62%	57.06%	48.29%
2015	45.46%	46.39%	56.63%	47.96%
2016	47.65%	44.84%	40.64%	39.38%
2017	46.52%	46.48%	43.55%	43.31%
2018	47.18%	43.08%	49.07%	46.39%
2019	46.10%	47.88%	38.57%	46.23%
2020	48.18%	48.74%	35.05%	46.74%

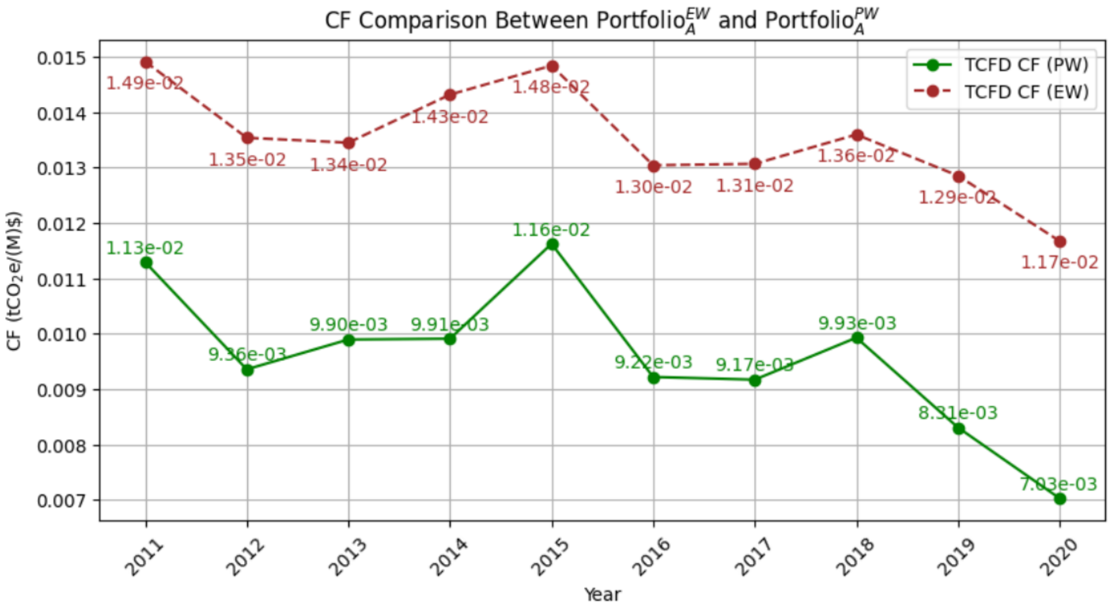

Figure A.5: This figure illustrates the trend of the Carbon Footprint for Portfolio$_A^{EW}$ and Portfolio$_A^{PW}$ over the years. The dotted red line represents the values for the EW portfolio, while the solid green line represents the values for the PW portfolio. The x-axis displays the years from 2011 to 2020, and the y-axis shows the values in $tCO_2e/(M)\$$.

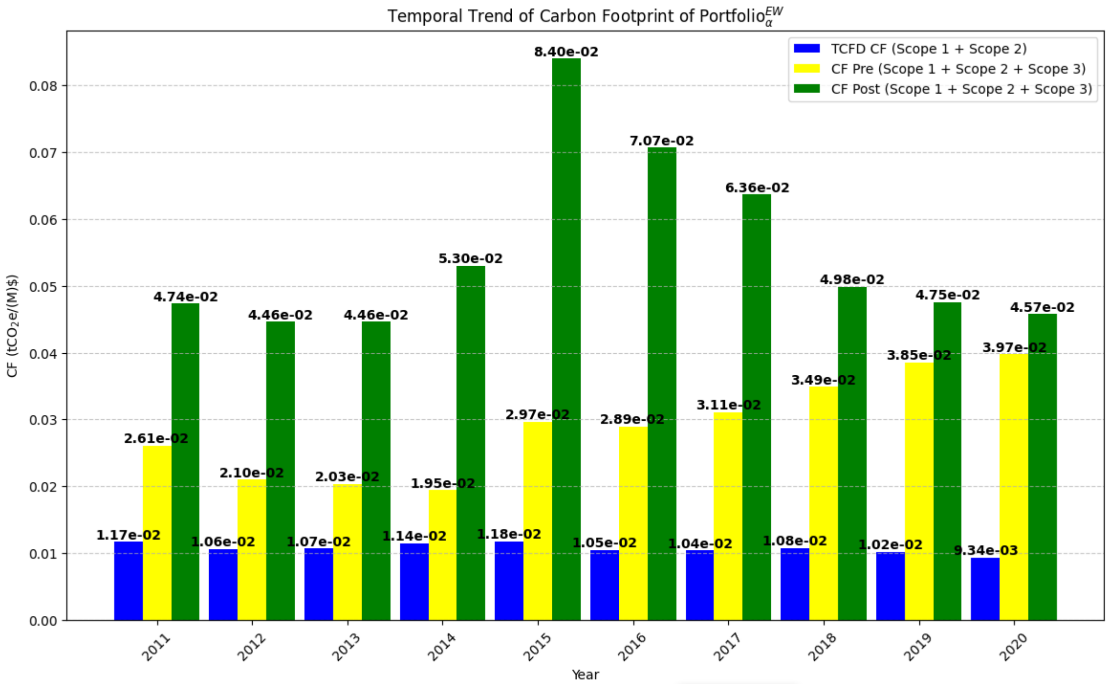

Figure A.6: This figure shows, in blue, the Carbon Footprint values for Portfolio$_\alpha^{EW}$ calculated following the TCFD guidelines, i.e., including only Scope 1 and Scope 2 emissions. In yellow, the values of the metrics when Scope 3 emissions are also considered. In green, the values of the metrics post interpolation of Scope 3 emissions. The x-axis displays the years from 2011 to 2020, and the y-axis shows the values in $tCO_2e/(M)\$$.

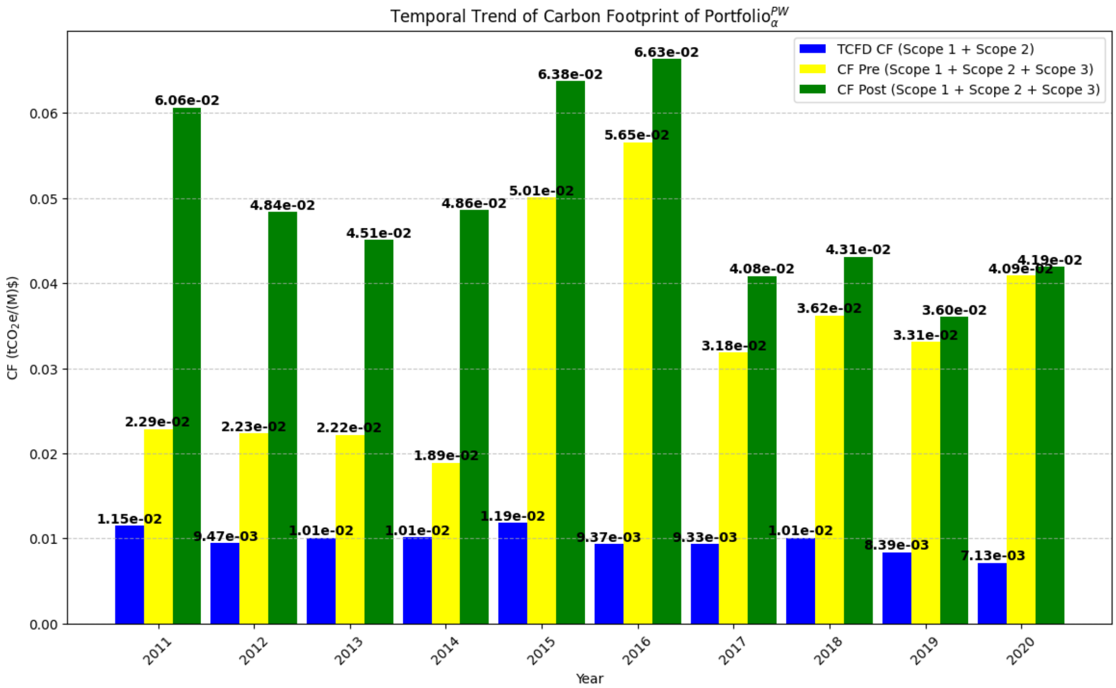

Figure A.7: This figure shows, in blue, the CF values for Portfolio$_\alpha^{PW}$ calculated following the TCFD guidelines, i.e., including only Scope 1 and Scope 2 emissions. In yellow, the values of the metrics when Scope 3 emissions are also considered. In green, the values of the metrics post interpolation of Scope 3 emissions. The x-axis displays the years from 2011 to 2020, and the y-axis shows the values in $tCO_2e/(M)\$$.

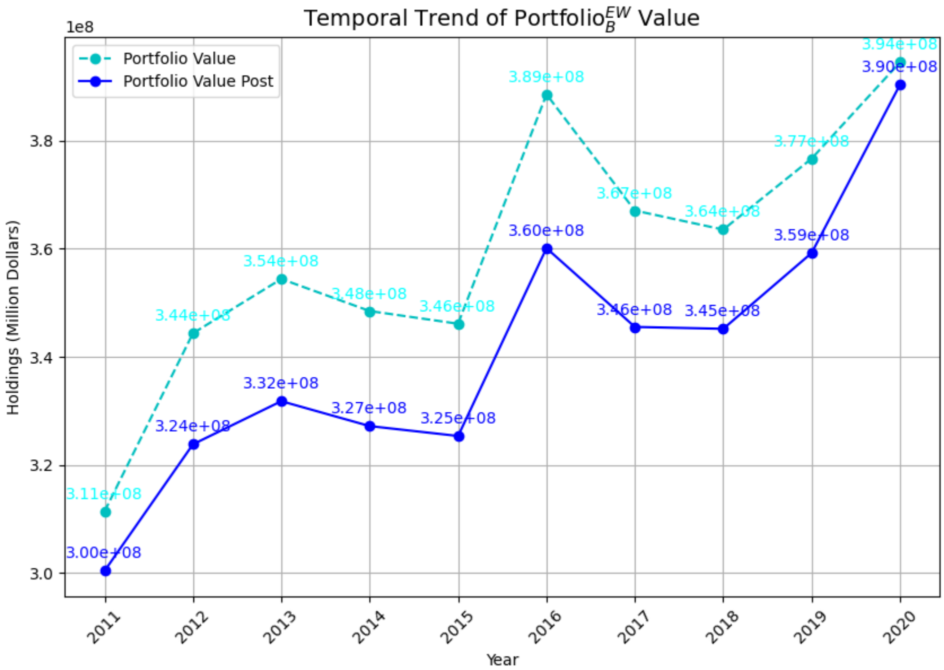

Figure A.8: This figure illustrates the trend of Portfolio$_B^{EW}$ value over the years. The dotted cyan line represents the portfolio value before interpolation, while the solid blue line represents the holdings after interpolation. On the x-axis, the years from 2011 to 2020 are represented, while the y-axis displays the Holdings values in Million Dollars.

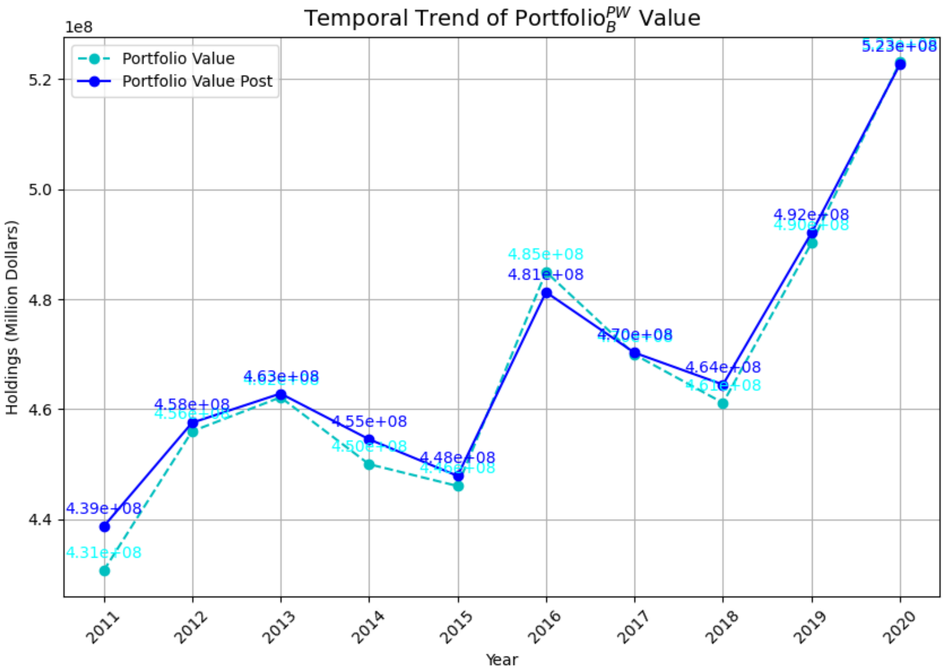

Figure A.9: This figure shows the trend of Portfolio$_B^{PW}$ value over the years. The dotted cyan line represents the Holdings before interpolation, while the solid blue line represents the Portfolio Value after interpolation. On the x-axis, the years from 2011 to 2020 are shown, while the y-axis displays the values in Million Dollars.

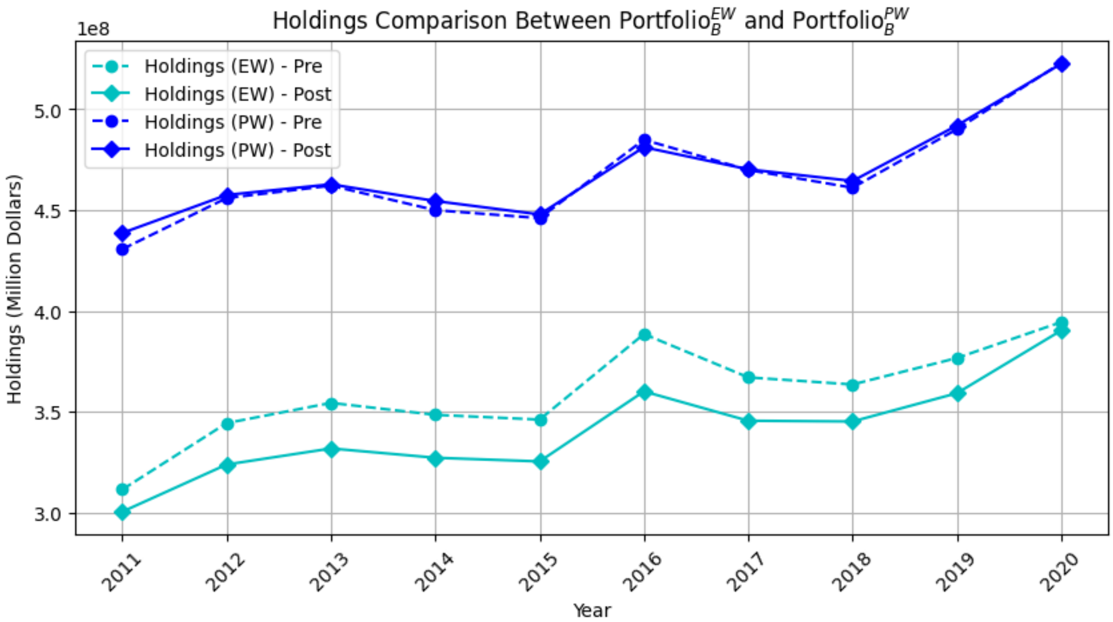

Figure A.10: This figure illustrates the trend of the holdings for Portfolio$_B^{EW}$ and Portfolio$_B^{PW}$ over the years, both before and after interpolation. The dotted lines represent the values before interpolation, while the solid lines represent the values after interpolation. Cyan lines are used for Portfolio$_B^{EW}$, while blue lines are used for Portfolio$_B^{PW}$. The x-axis displays the years from 2011 to 2020, and the y-axis shows the values in Million Dollars.

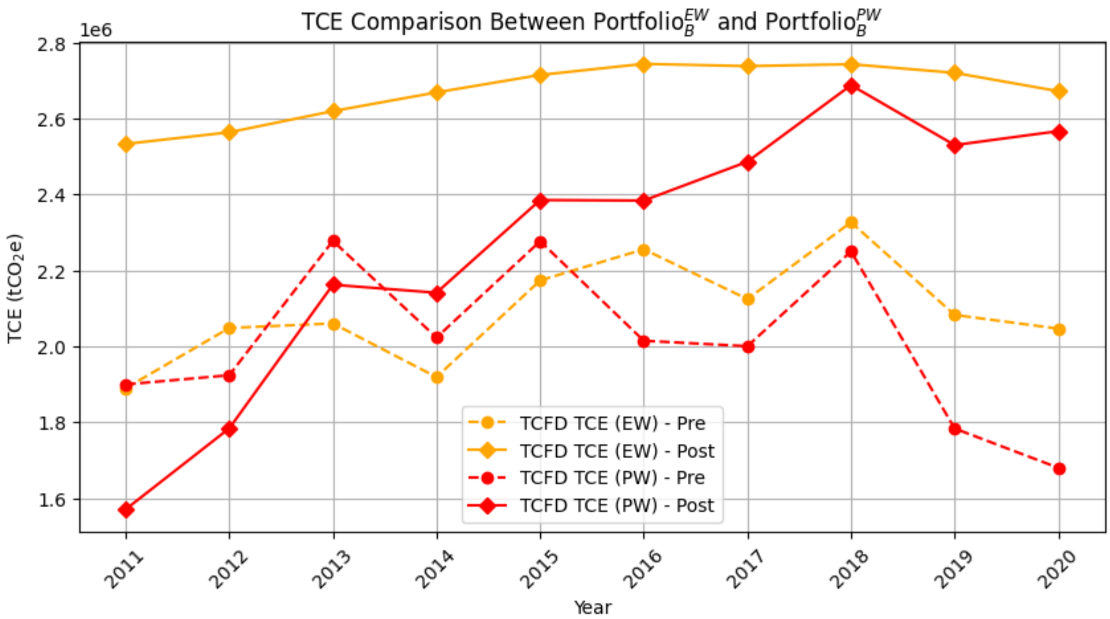

Figure A.11: This figure illustrates the trend of the Total Carbon Emissions for Portfolio$_B^{EW}$ and Portfolio$_B^{PW}$ over the years, both before and after interpolation. The dotted lines represent the values before interpolation, while the solid lines represent the values after interpolation. Orange lines are used for Portfolio$_B^{EW}$, while red lines are used for Portfolio$_B^{PW}$. The x-axis displays the years from 2011 to 2020, and the y-axis shows the values in tCO_2e.

Table A.4: Total Carbon Emissions statistics for Portfolio$_B^{EW}$. The first block presents the TCE statistics pre-interpolation, while the values in the second block refer to the post-interpolation data.

Year	**Total**	**Max**	**Mean**	**Std Dev**	**Median**
2011	1.89×10^6	1.69×10^5	2.25×10^3	9.33×10^3	1.10×10^2
2012	2.05×10^6	1.69×10^5	2.46×10^3	1.08×10^4	1.04×10^2
2013	2.06×10^6	1.75×10^5	2.51×10^3	1.12×10^4	9.22×10^1
2014	1.92×10^6	1.75×10^5	2.54×10^3	1.16×10^4	9.55×10^1
2015	2.17×10^6	1.80×10^5	2.89×10^3	1.32×10^4	1.11×10^2
2016	2.26×10^6	1.92×10^5	3.22×10^3	1.48×10^4	1.24×10^2
2017	2.12×10^6	1.76×10^5	3.15×10^3	1.40×10^4	1.31×10^2
2018	2.33×10^6	1.79×10^5	3.57×10^3	1.54×10^4	1.27×10^2
2019	2.08×10^6	1.78×10^5	3.43×10^3	1.43×10^4	1.47×10^2
2020	2.05×10^6	1.62×10^5	3.54×10^3	1.47×10^4	1.49×10^2
Post Interpolation					
2011	2.53×10^6	1.35×10^5	1.70×10^3	8.99×10^3	4.81×10^1
2012	2.56×10^6	1.35×10^5	1.72×10^3	9.13×10^3	4.98×10^1
2013	2.62×10^6	1.35×10^5	1.76×10^3	9.31×10^3	5.01×10^1
2014	2.67×10^6	1.35×10^5	1.79×10^3	9.44×10^3	5.09×10^1
2015	2.71×10^6	1.43×10^5	1.82×10^3	9.52×10^3	5.04×10^1
2016	2.74×10^6	1.56×10^5	1.84×10^3	9.66×10^3	4.93×10^1
2017	2.74×10^6	1.49×10^5	1.84×10^3	9.47×10^3	4.84×10^1
2018	2.74×10^6	1.56×10^5	1.84×10^3	9.62×10^3	4.97×10^1
2019	2.72×10^6	1.62×10^5	1.83×10^3	9.59×10^3	4.77×10^1
2020	2.67×10^6	1.52×10^5	1.79×10^3	9.57×10^3	4.76×10^1

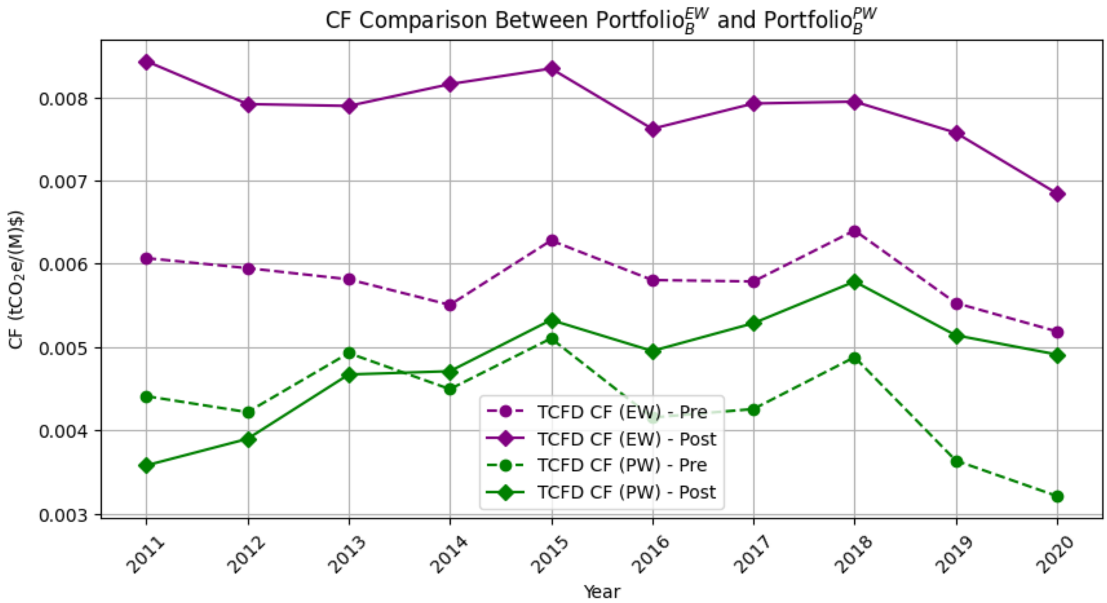

Figure A.12: This figure illustrates the trend of the Carbon Footprint for Portfolio$_B^{EW}$ and Portfolio$_B^{PW}$ over the years, both before and after interpolation. The dotted lines represent the values before interpolation, while the solid lines represent the values after interpolation. Purple lines are used for Portfolio$_B^{EW}$, while green lines are used for Portfolio$_B^{PW}$. The x-axis displays the years from 2011 to 2020, and the y-axis shows the values in $tCO_2e/(M)\$$

Table A.5: Statistics for Carbon Footprint in Portfolio$_B^{EW}$. The first block presents the CF statistics pre-interpolation, while the values in the second block refer to the post-interpolation data.

Year	**Total**	**Max**	**Mean**	**Std Dev**	**Median**
2011	6.07×10^{-3}	5.41×10^{-4}	7.21×10^{-6}	3.00×10^{-5}	3.53×10^{-7}
2012	5.95×10^{-3}	4.90×10^{-4}	7.14×10^{-6}	3.14×10^{-5}	3.01×10^{-7}
2013	5.81×10^{-3}	4.94×10^{-4}	7.07×10^{-6}	3.15×10^{-5}	2.60×10^{-7}
2014	5.51×10^{-3}	5.03×10^{-4}	7.30×10^{-6}	3.33×10^{-5}	2.74×10^{-7}
2015	6.28×10^{-3}	5.20×10^{-4}	8.35×10^{-6}	3.81×10^{-5}	3.20×10^{-7}
2016	5.81×10^{-3}	4.94×10^{-4}	8.28×10^{-6}	3.80×10^{-5}	3.20×10^{-7}
2017	5.79×10^{-3}	4.79×10^{-4}	8.59×10^{-6}	3.80×10^{-5}	3.57×10^{-7}
2018	6.40×10^{-3}	4.94×10^{-4}	9.82×10^{-5}	4.23×10^{-5}	3.49×10^{-7}
2019	5.53×10^{-3}	4.71×10^{-4}	9.11×10^{-6}	3.79×10^{-5}	3.90×10^{-7}
2020	5.19×10^{-3}	4.09×10^{-4}	8.98×10^{-6}	3.73×10^{-5}	3.77×10^{-7}
Post Interpolation					
2011	8.43×10^{-3}	4.48×10^{-4}	5.67×10^{-6}	3.00×10^{-5}	1.60×10^{-7}
2012	7.92×10^{-3}	4.16×10^{-4}	5.32×10^{-6}	2.82×10^{-5}	1.54×10^{-7}
2013	7.90×10^{-3}	4.07×10^{-4}	5.31×10^{-6}	2.81×10^{-5}	1.51×10^{-7}
2014	8.16×10^{-3}	4.13×10^{-4}	5.48×10^{-6}	2.88×10^{-5}	1.56×10^{-7}
2015	8.34×10^{-3}	4.40×10^{-4}	5.61×10^{-6}	2.93×10^{-5}	1.55×10^{-7}
2016	7.62×10^{-3}	4.32×10^{-4}	5.12×10^{-6}	2.68×10^{-5}	1.37×10^{-7}
2017	7.92×10^{-3}	4.30×10^{-4}	5.33×10^{-6}	2.74×10^{-5}	1.40×10^{-7}
2018	7.95×10^{-3}	4.52×10^{-4}	5.34×10^{-6}	2.79×10^{-5}	1.44×10^{-7}
2019	7.57×10^{-3}	4.50×10^{-4}	5.01×10^{-6}	2.67×10^{-5}	1.33×10^{-7}
2020	6.84×10^{-3}	3.89×10^{-4}	4.60×10^{-6}	2.45×10^{-5}	1.22×10^{-7}

Table A.6: Total Carbon Emissions statistics for Portfolio$_B^{PW}$. The first block presents the TCE statistics pre-interpolation, while the values in the second block refer to the post-interpolation data.

Year	Total	Max	Mean	Std Dev	Median
2011	1.90×10^6	1.35×10^5	2.49×10^3	9.67×10^3	8.92×10^1
2012	1.92×10^6	1.33×10^5	2.69×10^3	1.10×10^4	9.51×10^1
2013	2.28×10^6	3.84×10^5	3.41×10^3	1.93×10^4	1.02×10^2
2014	2.02×10^6	4.05×10^5	3.41×10^3	2.06×10^4	1.25×10^2
2015	2.28×10^6	3.22×10^5	3.85×10^3	1.99×10^4	1.45×10^2
2016	2.01×10^6	1.93×10^5	3.55×10^3	1.41×10^4	1.60×10^2
2017	2.00×10^6	2.36×10^5	3.43×10^3	1.46×10^4	1.44×10^2
2018	2.25×10^6	1.88×10^5	3.77×10^3	1.67×10^4	1.28×10^2
2019	1.78×10^6	1.58×10^5	3.05×10^3	1.21×10^4	1.40×10^2
2020	1.68×10^6	1.26×10^5	2.91×10^3	1.11×10^4	1.23×10^2
Post Interpolation					
2011	1.57×10^6	1.06×10^5	1.71×10^3	6.91×10^3	5.14×10^1
2012	1.78×10^6	1.07×10^5	1.73×10^3	7.59×10^3	4.78×10^1
2013	2.16×10^6	3.16×10^5	1.91×10^3	1.24×10^4	4.35×10^1
2014	2.14×10^6	3.33×10^5	1.78×10^3	1.22×10^4	4.38×10^1
2015	2.39×10^6	2.73×10^5	1.89×10^3	1.18×10^4	4.26×10^1
2016	2.38×10^6	1.69×10^5	1.82×10^3	9.20×10^3	4.24×10^1
2017	2.49×10^6	2.12×10^5	1.86×10^3	9.63×10^3	4.19×10^1
2018	2.69×10^6	1.72×10^5	1.95×10^3	1.06×10^4	4.31×10^1
2019	2.53×10^6	1.56×10^5	1.80×10^3	9.46×10^3	3.99×10^1
2020	2.57×10^6	1.43×10^5	1.73×10^3	9.88×10^3	3.51×10^1

Table A.7: Carbon Footprint statistics for Portfolio$_B^{PW}$. The first block presents the CF statistics pre-interpolation, while the values in the second block refer to the post-interpolation data.

Year	Total	Max	Mean	Std Dev	Median
2011	4.41×10^{-3}	3.15×10^{-4}	5.78×10^{-6}	2.44×10^{-5}	2.07×10^{-7}
2012	4.22×10^{-3}	2.93×10^{-4}	5.89×10^{-6}	2.41×10^{-5}	2.09×10^{-7}
2013	4.93×10^{-3}	8.32×10^{-4}	7.39×10^{-6}	4.19×10^{-5}	2.21×10^{-7}
2014	4.50×10^{-3}	9.00×10^{-4}	7.57×10^{-6}	4.59×10^{-5}	2.78×10^{-7}
2015	5.10×10^{-3}	7.23×10^{-4}	8.62×10^{-6}	4.46×10^{-5}	3.25×10^{-7}
2016	4.15×10^{-3}	3.99×10^{-4}	7.31×10^{-6}	2.91×10^{-5}	3.31×10^{-7}
2017	4.26×10^{-3}	5.02×10^{-4}	7.29×10^{-6}	3.12×10^{-5}	3.06×10^{-7}
2018	4.88×10^{-3}	4.08×10^{-4}	8.19×10^{-6}	3.62×10^{-5}	2.77×10^{-7}
2019	3.64×10^{-3}	3.23×10^{-4}	6.22×10^{-6}	2.48×10^{-5}	2.85×10^{-7}
2020	3.21×10^{-3}	2.40×10^{-4}	5.56×10^{-6}	2.11×10^{-5}	2.35×10^{-7}
Post Interpolation					
2011	3.58×10^{-3}	2.41×10^{-4}	3.89×10^{-6}	1.58×10^{-5}	1.17×10^{-7}
2012	3.90×10^{-3}	2.35×10^{-4}	3.78×10^{-6}	1.66×10^{-5}	1.05×10^{-7}
2013	4.67×10^{-3}	6.84×10^{-4}	4.13×10^{-6}	2.68×10^{-5}	9.39×10^{-8}
2014	4.71×10^{-3}	7.32×10^{-4}	3.91×10^{-6}	2.69×10^{-5}	9.64×10^{-8}
2015	5.33×10^{-3}	6.09×10^{-4}	4.22×10^{-6}	2.64×10^{-5}	9.52×10^{-8}
2016	4.95×10^{-3}	3.52×10^{-4}	3.79×10^{-6}	1.91×10^{-5}	8.81×10^{-8}
2017	5.29×10^{-3}	4.50×10^{-4}	3.95×10^{-6}	2.05×10^{-5}	8.91×10^{-8}
2018	5.79×10^{-3}	3.71×10^{-4}	4.19×10^{-6}	2.29×10^{-5}	9.27×10^{-8}
2019	5.14×10^{-3}	3.18×10^{-4}	3.67×10^{-6}	1.92×10^{-5}	8.11×10^{-8}
2020	4.91×10^{-3}	4.49×10^{-4}	3.31×10^{-6}	1.89×10^{-5}	6.71×10^{-8}

Table A.8: The table presents the percentage of companies within Portfolio$_\beta$, in relation to the total of 1,241 companies, that have disclosed their Scope 3 emissions over the years. "Pre" refers to the percentage of Scope 3 availability Pre Interpolation. "Post" refers to the same percentage Post Interpolation.

Year	**Percentage of Scope 3 - Pre**	**Percentage of Scope 3 - Post**
2011	21.51%	59.71%
2012	20.23%	59.71%
2013	18.86%	59.71%
2014	17.00%	59.71%
2015	17.81%	59.71%
2016	16.12%	59.71%
2017	15.79%	59.71%
2018	17.41%	59.71%
2019	17.49%	59.71%
2020	19.18%	59.71%