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Decomposition of Greenhouse Gas Emissions Associated with an Equity Portfolio

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The authors can be contacted at contact@scientificportfolio.com.

About the Author

Vincent Bouchet is Scientific Portfolio's Director of ESG and Climate research. After a master's degree in finance, he obtained a PhD in management science from École polytechnique (France) in partnership with the Caisse des Dépôts group, where he spent three years working on the integration of climate risks. He then worked for the French Ministry of Economy and Finance on public policies related to climate and biodiversity.

Abstract

While methodologies to measure the alignment of a financial portfolio with climate objectives develop rapidly, historical and cross-sectional analysis of greenhouse gas emissions associated with a portfolio has received little attention. Yet understanding the factors that influence these emissions is essential to identifying the levers of a portfolio manager to set ambitious but realistic reduction targets and avoid the phenomenon of "portfolio greenwashing". This paper introduces a decomposition method inspired by those used in environmental economics which enables to disentangle five factors that influence portfolio emissions. To illustrate our model, we analyze a climate impact index and its benchmark over the period 2014-2019. We show that the index reaches a similar decarbonization rate (-35%) to its benchmark by selecting the least emissions intensive companies within the sectors and the companies that structurally reduce their emissions intensity. In contrast, the benchmark achieves this decarbonization mainly through sector allocation, the most emissive sectors being less represented.

Key Takeaways

- This paper introduces a decomposition method that enables to disentangle five factors that influence the emissions of a portfolio: the sector allocation, the intra-sectoral allocation, the emissions intensity of the firms on scope 1+2 and 3, the sales and the market capitalization.
- The method can be applied to different performance metrics such as emissions intensity, footprint, or absolute emissions. The analysis can be historical or cross-sectional and can thus help a portfolio manager to achieve reduction targets compatible with climate objectives.
- We illustrate the method by analyzing a climate impact index and its benchmark. We show that despite similar emission reduction rates, the index decarbonization is due to intra-sector allocation and to companies whose carbon intensity structurally decreases, whereas the benchmark decarbonization is mostly due to sector allocation.

Keywords: greenhouse gas, carbon intensity, climate finance.
JEL codes: G11, G23, Q54

1. Introduction

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Investors are increasingly looking to manage the greenhouse gas emissions of their portfolios (portfolio emissions thereafter) to meet new regulatory and stakeholders' expectations. Since the Paris Agreement (2015), many initiatives have emerged to structure these practices. On the one hand, regulators are standardizing the extra-financial information that financial and non-financial companies must communicate (e.g., in EU through the sustainable finance disclosure regulation). On the other hand, collective investor initiatives are proposing frameworks to align portfolios with climate objectives (e.g., the Net-Zero Asset Owner Alliance and the Paris Aligned Investment Initiative). While early requirements have focused on reporting, frameworks increasingly include target setting related to emissions performance metrics, including absolute and asset-level value chain emissions. However, popular climate metrics, either assessing current or forward-looking performance, give investors limited understanding and control of the factors influencing the evolution of portfolio emissions over time in the absolute or relative to other portfolios.

Over the last 25 years, research in environmental economics has been confronted by similar issues at the macroeconomic level and has developed decomposition methods to understand the different drivers of global emissions. One of the most famous is the "Kaya identity" (Exhibit 1), that expresses global emissions as the product of four factors: population, GDP per capita, energy intensity, and carbon intensity (Kaya, 1990).

We propose to adapt these decomposition methods to the variables of interest and factors relevant for analyzing and controlling equity portfolio emissions. The proposed decomposition model makes it possible to distinguish between five factors that influence these emissions: sector allocation (weight of a given sector in portfolio), intra-sectoral allocation (weight of a stock in the sector), emissions intensity of the firms (expressed as tons of CO2e per million dollars of sales), sales and market capitalization. The model can be applied to analyze the different performance metrics recommended by the regulator and investor initiatives (intensity, footprint, or absolute emissions), and can be used for both historical and cross-sectional analysis.

To illustrate our model, we analyze a climate impact index and its benchmark over the period 2014-2019. From a cross-sectional perspective, we show that the allocation within each sector factor explains nearly 70% of the difference between the emissions intensity of the index and its benchmark. This confirms the ability of the climate impact index to be less emissions intensive while limiting sector exposure bias. From a historical perspective, both the index and its benchmark emissions have been reduced by about 35% over the period. However, the decomposition shows that the climate impact index achieves this decarbonization mainly through intra-sectoral allocation and the selection of stocks that reduce their emissions intensity, while the benchmark achieves this decarbonization mainly through sector allocation (the most emissive sectors being less and less represented).

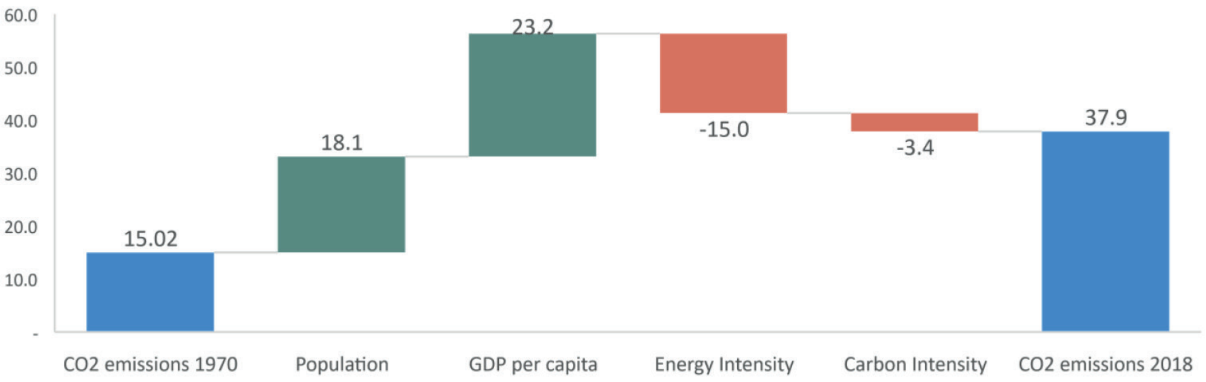
By revealing the factors underlying the decarbonization of a portfolio, this framework allows investors to control the extent to which emissions and emissions trends are explained by i) sector biases, which will potentially increase the portfolio's active risk with arguably a limited effect on climate

1. Introduction

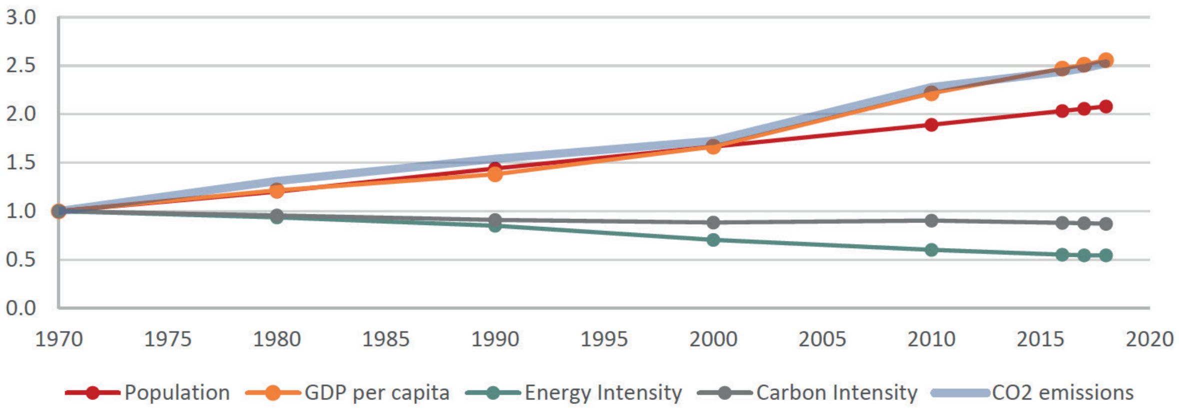
mitigation (Edmans et al., 2022), or ii) by selection of companies within sectors with lower and structurally decreasing emissions. This makes it possible to gain a more qualitative view into the decarbonization of a portfolio, and hence to limit the risk of "portfolio greenwashing" in the sense of Amenc et al. (2022).

Exhibit 1: Historical analysis of global CO2 emissions with the Kaya identity

(a) Additional



(b) Multiplicative



Note: the evolution of emissions is decomposed into four factor effects: population, GDP per capita, energy intensity (energy per unit of GDP), and carbon intensity (emissions per unit of energy). In the additional decomposition (a) emissions are expressed in billion tons of CO2, while they are normalized to 1 in the multiplicative decomposition (b). This decomposition highlights that despite an improvement in energy efficiency (energy intensity) and a reduction in carbon intensity, emissions are increasing mainly due to the increase in wealth per capita and population. Data retrieved from Our World in Data[1].

The rest of the article is organized as follows. Section 2 introduces the new expectations towards investors regarding climate change and the need to better understand the factors influencing the portfolio emissions; section 3 presents an adaptation of the decomposition developed in environmental economics to the analysis of an equity portfolio; and section 4 presents the results of an analysis of a climate impact index and its benchmark.

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[1] - Source: https://ourworldindata.org/grapher/kaya-identity-co2

2. Limitations of Existing Emissions Metrics in Finance

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Climate metrics have been developed to help investors comply with regulatory reporting requirements, track progress against their goals (such as reaching net-zero emissions) and manage climate-related risks associated with their portfolios. Focusing on emissions, we present in this section *current performance metrics* that highlight the current emissions associated with a portfolio and *forward-looking metrics* that focus on potential future emissions. We then show how the expectations towards investors, initially focused on reporting, have evolved into setting and monitoring reduction targets, and how understanding the factors that explain portfolio emissions can enable them to meet these new expectations.

2.1 Current Performance Metrics

Current performance metrics at the level of financial portfolios are generally constructed by aggregation from metrics defined at the company level. The starting point is emissions, which is expressed in tons of carbon dioxide equivalent (CO_{2e}) to allow the addition of emissions of gases with different global warming potentials[2].

At the company level, the Greenhouse Gas Protocol, established in 1998, is the main framework for accounting and reporting. A central parameter is the scope of the emissions considered. Scope 1 corresponds to direct emissions by the company in the manufacture of its products and/or the production of its services, scope 2 to indirect emissions linked to the consumption of purchased energy, and scope 3 to other indirect emissions in the product/service value chain (upstream and downstream). The choice of a relevant scope first depends on the question that the metric must help answer. If the objective is to sum emissions, as it is the case for example for the Inventory of U.S. greenhouse gas Emissions[3], only scope 1 should be used to avoid double counting. On the other hand, to review the impact of a company on global warming, a wider scope may be relevant. Moreover, the breakdown of emissions between the different scopes depends strongly on the sectors (Le Guenedal & Roncalli, 2022). For example, the Utilities sector has most of its emissions in scope 1, while the Consumer Staples sector has most of its emissions in scope 3 (upstream). Finally, the choice of a scope depends on the availability and the consistency of the data: while scope 1 and 2 are increasingly reported and consistent, scope 3 emissions are still often estimated and vary widely depending on data-providers (Busch et al., 2022) or the emissions accounting choices made by reporting companies (Ducoulombier, 2021).

Although emissions accounting and reporting standards may not have been intended to compare companies with one another (see Ducoulombier, 2021, in respect of scope 3 emissions), the reporting of aggregated performance metrics at the level of a financial portfolio typically assumes that such uses are acceptable. At the company level, comparability is usually achieved by normalizing absolute emissions (on a given scope) by the size of the activities or the company. The three most used denominators are "sales", "enterprise value" and "market capitalization", each of which has its advantages and disadvantages (Ducoulombier & Liu, 2021). At the portfolio level, the resulting aggregate metric is the average of these intensities (or footprints),

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2 - The global warming potential is a measure of how much the emissions of one ton a gas will contribute to global warming compared to one ton of carbon dioxide (over a given period, usually of 100 years). Methane has for example a global warming potential of 27-30 over 100 years, i.e., the emission of one ton of methane is "equivalent" to about thirty tons of carbon dioxide.

3 - See https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks for more information.

2. Limitations of Existing Emissions Metrics in Finance

weighted by the share of the different companies (stocks) in the portfolio. By considering the asset under management, it is also possible to calculate the absolute emissions financed by the portfolio (PCAF, 2022).

This article only addresses metrics related to emissions. Other metrics such as the share of revenues, operating expenses or investments related to "green" activities (following regulatory taxonomies or taxonomies elaborated by data providers), fossil fuel reserves and energy mix are increasingly used to monitor the climate impact and risks associated with a portfolio. However, emissions have the advantage of a more mature accounting system and a common unit, which makes it easier to compare and aggregate them.

2.2 Forward-Looking Metrics

Measuring the portfolio emissions associated with a portfolio or its average emissions intensity is a necessary first step in monitoring its climate impact. However, current performance metrics give little indication of the alignment of a portfolio with climate mitigation scenarios. Forward-looking metrics have therefore been developed to measure a portfolio's alignment with the temperature change goals of the Paris Agreement, or specific climate scenarios. Based on a review of eleven forward-looking methodologies, ILB (2020) identifies four common steps to build such metrics: 1) measuring the climate performance at the portfolio level (as discussed above), 2) choose one or several scenarios, 3) convert macro emissions trajectories from these scenarios to portfolio trajectories, and 4) compare the results of step 1 and step 3. These steps can lead to different metrics: binary statement (aligned/ not aligned), score, percentage of (mis)alignment, or implied temperature rise (ITR).

ILB (2020) highlights a wide disparity of results from different methodologies applied to a same portfolio. For example, the ITR of the Euronext Low-Carbon 100 index, which is designed to reflect price level trends of companies in Europe that have the best climate scores, vary between 1.5 and 3°C, depending on the methodology. These strong disparities therefore limit the interest of such metrics to communicate on the alignment of a portfolio. Most importantly, these metrics are difficult to use for monitoring portfolio emissions. Principles for Responsible Investment therefore recommend that ITR metrics should not be viewed in isolation but considered alongside a range of additional climate metrics including emissions (PRI, 2021, 2022).

2.3 From Reporting to Target-Setting and Monitoring Emissions

While expectations toward investors have so far focused on transparency of current and past portfolio performance, they are moving towards future objectives. Since the Paris Agreement, many voluntary and mandatory frameworks have been developed to support and structure investor practices in terms of reporting, target setting and monitoring related to climate change. The purpose of this subsection is to look at emissions metrics used by five of the recent accounting, disclosure and target setting frameworks (Exhibit 2). Two of the selected frameworks are regulatory: the sustainable finance

2. Limitations of Existing Emissions Metrics in Finance

disclosure regulation (SFDR) defines climate reporting requirements at the market participants and financial products levels; the EU climate transition and Paris-aligned benchmarks delegated regulation (BMR) defines rules for benchmarks to use these official labels. Two other frameworks are developed by coalitions of institutional investors: the target setting protocol of the Net-Zero Asset Owner Alliance (NZAO), and the net-zero investment framework developed by the Paris Aligned Investment Initiative (PAII). The fifth and oldest framework comes from the task force on climate-related financial disclosure (TCFD). This framework is on the border between a regulatory and a voluntary framework; while it was initially developed as a voluntary initiative, it is increasingly mandated by regulators.

Exhibit 2: Emissions metrics across five frameworks

	SFDR	BMR	TCFD	NZAOA	PAII
Scope 1 absolute emissions	R		R+T	R+T	R+T
Scope 1+2 absolute emissions	R		R+T	R+T	R+T
Scope 1+2+3 absolute emissions	R		(R)	R+T*	
Scope 1 footprint (/ M€ invested)	R	R+T	(R)		R+T
Scope 1+2 footprint (/ M€ invested)	R	R+T	(R)		R+T
Scope 1+2+3 footprint (/ M€ invested)	R	R+T*	(R)		
Scope 1 intensity (/ M€ sales)	R		R	R+T	
Scope 1+2 intensity (/ M€ sales)	R		R	R+T	
Scope 1+2+3 intensity (/ M€ sales)	R		(R)	R+T*	

*Note: footprint represents the emissions divided by the enterprise value or by the market capitalization. R: Reporting; T: Target setting; () optional; *initially only on most material sectors.*

The analysis of these five frameworks highlights three points. First, while the early requirements focused on reporting, the frameworks increasingly include target setting related to emissions performance metrics. Second, several initiatives require absolute emissions targets to be set. Third, including asset-level scope 3 emissions is becoming increasingly mandatory, both in reporting and in the development of targets, particularly for those sectors making the largest contribution to global emissions.

The decomposition model we propose in the rest of this article aims to help investors meet these new expectations regarding the management of their emissions by analyzing the factors that explain changes in the relative or absolute emissions of a portfolio, including asset-level scope 3. On one hand, understanding the role of each factor makes it possible to control whether a portfolio's emissions have been reduced effectively, i.e., without relying solely on sector allocation (by divesting from the most emitting sectors) and therefore to avoid the risk of "portfolio greenwashing". On the other hand, it helps to assess a portfolio's potential to achieve reduction targets.

3. A Decomposition Method for Portfolio Emissions

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In this section, we introduce the principles of the decomposition methods developed in environmental economics and propose a decomposition model to analyze different emissions performance metrics of an equity portfolio, from a cross-sectional and historical perspective.

3.1 Theoretical Principles of the Index Decomposition Analysis

A series of works on environmental economics identify the drivers of observed changes on environmental variables such as energy consumption or emissions (two examples are provided in Appendix A). The decomposition methods used in environmental economics have origins in index number theory, which is about decomposing the difference of an aggregated value (e.g., the value of a basket of products) over a period into two factors: a price factor (e.g., consumer price index) and a quantity factor. Methods used in environmental economics are extensions of index number theory methods to more than two factors (De Boer and Rodrigues, 2020). This sub-section introduces the index decomposition analysis (IDA) principles as it is the most easily applicable method for a financial portfolio[4].

Let us consider G as an aggregate value of sub-categories h (e.g., the sum of emissions associated with different instruments), and n factors contributing to these sub-categories' emissions x_1, x_2,… , x_n (e.g., weight in portfolio, carbon intensity, sales, etc.).

$$G = \sum_h x_{1,h} . x_{2,h} \dots x_{n,h}$$

The goal of IDA is to understand historical aggregate change from G^0 to G^T as an (1) *additive* or (2) *multiplicative* operation between factors.

$$(1)\ G^T - G^0 = \Delta G_{x_1} + \Delta G_{x_2} + \cdots + \Delta G_{x_n} \qquad (2)\ \frac{G^t}{G^0} = I_{x_1} . I_{x_2} \dots I_{x_n}$$

The reasoning behind the IDA is to derive the aggregate value formula over time and isolate the contribution of the n factors. As developed in Ang (2015), the additional effects of the k^{th} factor is given by

$$(1)\ \Delta G_{x_k} = \textstyle\sum_h L(g_h^T, g_h^0) . \ln\left(\frac{x_{k,h}^T}{x_{k,h}^0}\right) \qquad (2)\ I_{x_k} = exp\left(\textstyle\sum_h \frac{L(g_h^T, g_h^0)}{L(g_\square^T, g_\square^0)} . \ln\left(\frac{x_{k,h}^T}{x_{k,h}^0}\right)\right)$$

where $L(a,b) = \frac{a-b}{\ln a - \ln b}$ and g_h is in our case the emissions of the instrument h (proof in Appendix B).

The reason to choose the additive or multiplicative method is a matter of presentation and it's possible to shift from one to the other. Additive decomposition is preferred for aggregate analysis of multi-year periods, while multiplicative decomposition is preferred to identify changes in trends.

3.2 Identity for Portfolio Emissions

We present the identity for absolute emissions below (the identity for emissions intensity and footprint are presented in Appendix C).

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4 - The structural decomposition analysis, the other main method, relies on the same mathematical principles but adds the input-output analytical framework developed by Wassily Leontief to the approach.

3. A Decomposition Method for Portfolio Emissions

$$G_p = \sum_{H}\sum_{S} w_{sp} \,.\, w_{hs}.\,(CIs1_h + CIs2_h + CIs3_h).\,Sales_h.\frac{1}{Mktcap_h}.\,MktValue_p$$

The factors can be grouped into three categories:

- **Portfolio management choices.** The portfolio manager can have a direct impact on the two following factors: w_{sp}, the sector allocation (weight of sector s in portfolio *p*), and w_{hs} the intra-sectoral allocation (weight of holding *h* in sector *s*). The control of the sector allocation factor is particularly important. Firstly, from a climate impact point of view, it can be seen to some extent as an artifice, allowing to reduce emissions simply by reducing exposure to emissive sectors. Secondly, from a financial risk perspective, inappropriate sectoral deviations from a benchmark can cause large tracking errors.

- **Emissions intensity.** Companies can reduce their emissions intensity on the three scopes: $CIs1_h$ (scope 1), $CIs2_h$ (scope 2), and $CIs3_h$ (scope 3). The selection of companies that improve their intensity can be the result of portfolio management choices. In the rest of the article, scope 1+2 emissions are reported emissions when available (either directly by companies or through the Carbon Disclosure Project) while scope 3 emissions are systematically estimated emissions (estimates from Bloomberg). This choice is motivated by the lack of comparability of scope 3 reported emissions (Ducoulombier, 2021) and by our goal to provide historical analysis. Historical analysis requires consistent data over time, however, the coverage of companies reporting scope 3 data reported in 2014 was very low and the reporting methodologies have changed significantly since then. Estimated data is more stable because it is adjusted in line with methodological developments and was therefore preferred.

- **Economic factors.** These factors provide a link between relative emissions (intensity or footprint) and absolute emissions. As discussed in the previous section, more and more frameworks recommend setting absolute targets and monitoring the absolute emissions of a portfolio. Environmental economics have confirmed that demographic and economic factors (population and growth of GDP per capita) are the main drivers of global emissions (Appendix A). It is therefore essential to analyze absolute emissions and to understand the economic factors that influence them.
  -> Sales : the absolute emissions of a company might be explained from a change in its emissions intensity or its sales.
  -> $\frac{1}{Mktcap_h}$ the share of emissions attributed to an investor depends on the market value of a company (for a fixed amount invested in this company). Capital market volatility can contribute to significant short-term effects.
  -> $MktValue_p$: as the market value of a portfolio increases, the investor's responsibility in terms of emissions increases.

3.3 Cross-Sectional and Historical Analysis

Although emissions decomposition methods are mainly used for historical analyses in environmental economics, they can also be used for cross-sectional (e.g., between two countries) and forward-looking (e.g., between two energy scenarios) analyses (Ang and Goh, 2019). For an equity portfolio, it may also

3. A Decomposition Method for Portfolio Emissions

be relevant to carry out a historical decomposition together with a cross-sectional decomposition, for example against a benchmark. Depending on this choice and the type of metric analyzed, only some factors will influence the decomposition model (Exhibit 3).

Exhibit 3: Factors influencing the decomposition model by type of analysis and metrics

Analysis		Cross-sectional			Historical		
Metrics		Absolute	Intensity	Footprint	Absolute	Intensity	Footprint
Allocation	Sector allocation	✓	✓	✓	✓	✓	✓
	Intra-sectoral allocation	✓	✓	✓	✓	✓	✓
Emissions intensity	Intensity scope 1				✓	✓	✓
	Intensity scope 2				✓	✓	✓
	Intensity scope 3				✓	✓	✓
Economic variables	Sales				✓		
	1 / Market cap				✓		
	Value	✓			✓		

4. Results

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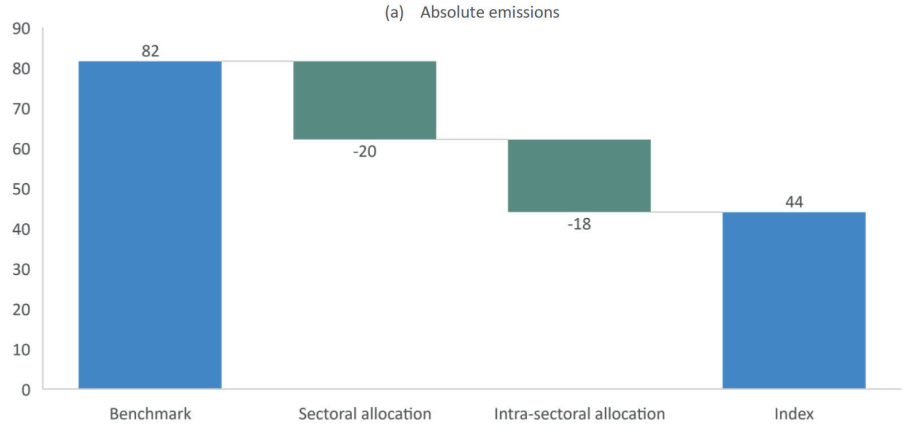
In this section, we illustrate the decomposition model by comparing two portfolios: a conventional index representative of the US equity universe (500 stocks) (the "benchmark" thereafter) and a climate impact index[5] built on the same universe (the "index" thereafter). According to the index provider, the objective of the climate impact index is to contribute to climate mitigation through "*the appropriate weighting of stocks, while at the same time complying with the Paris-Aligned Benchmark criteria set forth by the European Union*[6]".

4.1 Cross-Sectional Analysis

The performance of a portfolio, whether financial or non-financial, can first be assessed in relation to a reference. For example, the BMR requires for an index to be considered as "Paris-aligned" that its "*GHG [Greenhouse gas] intensity or, where applicable, absolute GHG emissions […], including scope 1, 2 and 3 GHG emissions, shall be at least 50 % lower than the GHG intensity or absolute GHG emissions of the investable universe*[7]".

As discussed previously, the cross-sectional decomposition will only be influenced by two factors: sector allocation and intra-sectoral allocation. Exhibit 4 (a) shows the factors explaining the difference between the absolute emissions of the benchmark (left) and the climate impact index (right). How should the results be interpreted? The lower decarbonization of the climate impact index can be explained by the fact that it is less exposed to high emitting sectors (notably the energy sector owing to regulatory criteria excluding companies involved in fossil fuels). The second factor, intra-sectoral allocation, shows, however, that even with similar exposure to these sectors, the index would have lower emissions because it is less exposed (within these sectors) to the most emissions intensive companies. All in all, sector and intra-sectoral allocation have a relatively similar effect when considering absolute emissions.

Exhibit 4: Cross-sectional analysis on emissions



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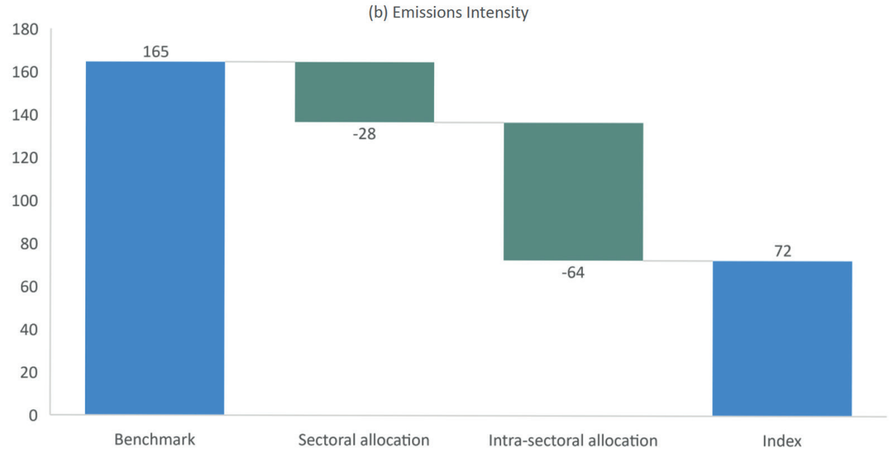
[5] -Scientific Beta's United States Climate Impact Consistent EU PAB Compliant index.
[6] - Scientific Beta Equity Strategy Construction Rules, Scientific Beta United States Climate Impact Consistent EU PAB Compliant (17 June 2022).
[7] - From the Commission delegated regulation (EU) 2020/1818.

4. Results

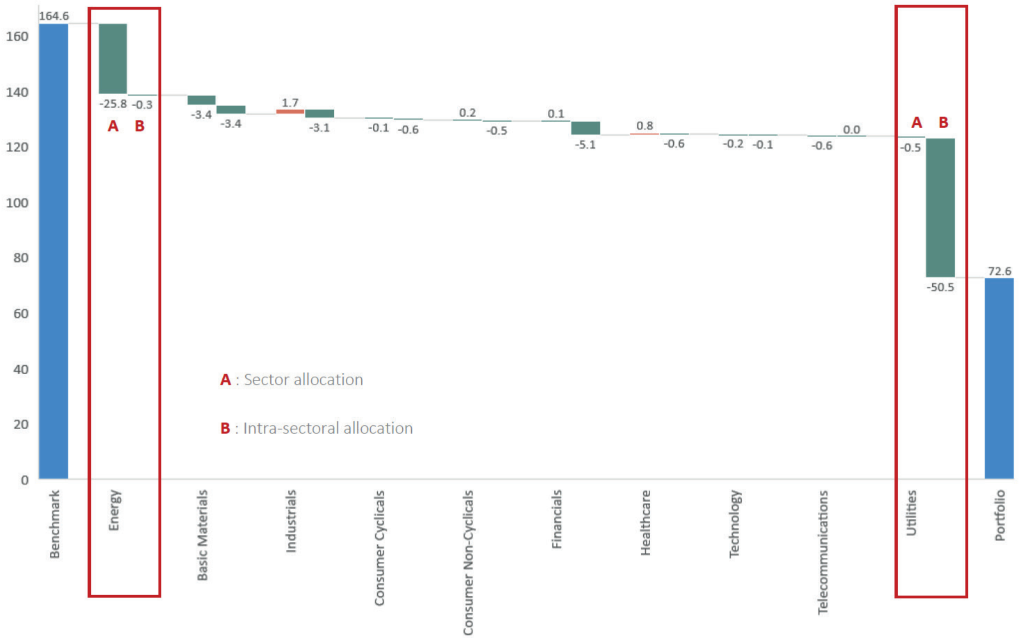


Note: the absolute emissions correspond to the emissions on scope 1+2 associated with an investment of 1 million dollars in each instrument for the fiscal year 2019. The emissions intensity corresponds, for each instrument, to the average greenhouse gas emissions on scope 1+2 divided by 1 million dollars of sales of the underlying companies.

However, the weight of the two factors in explaining the cross-sectional decarbonization of the index depends on the metric considered. When analyzing emissions intensity instead of absolute emissions, the results are quite different: the intra-sectoral allocation factor now explains nearly 70% of the decarbonization (Exhibit 4 (b)). The choice of a metric to set and monitor targets is therefore not neutral and should be considered carefully both by the asset manager and by stakeholders who wish to assess the performance of a financial instrument.

From this initial cross-sectional analysis, we want to understand which sectors are affecting the two (sector and intra-sectoral allocation) factors. In other words, which sectors have been over/underweighted by the climate impact index compared to the benchmark, and for which sectors the index manager has been successful in reducing emissions compared to the benchmark (at constant exposure). This can be done by rearranging the decomposition model by summing the effects per sector (Exhibit 5).

Exhibit 5: Cross-sectional analysis on emissions intensity by sector



Note: the emissions intensity corresponds, for each instrument, to the average greenhouse gas emissions on scope 1+2 divided by 1 million dollars of sales of the underlying companies. For each sector, the left bar corresponds to the "sector allocation" factor and the right bar to the "intra-sectoral allocation" factor.

4. Results

This new decomposition shows that the cross-sectional difference is mainly explained by two sectors: the "Energy" and the "Utilities" sectors. However, the factors are not the same for each sector. Within the "Energy" sector, the main effect is the sector allocation (left bar), while for the "Utilities" sector, it is the intra-sectoral allocation (left bar). This result is consistent with the minimum criteria of Paris-aligned benchmarks, that require the exclusion of "companies that derive 10% or more of their revenues from the exploration, extraction, distribution or refining of oil fuels; *companies that derive 50% or more of their revenues from the exploration, extraction, manufacturing or distribution of gaseous fuels*[8]". These results allow to confirm on the one hand that the index provider has taken into account the exclusion criteria of the EU Benchmarks regulation, and, on the other hand, that he selected the "best in class" within the other emissions intensive sectors, in particular the Utilities sector.

4.2 Historical Analysis

We have just analyzed the factors explaining the difference between the emissions performance of the climate impact index at a given time compared to its benchmark. However, targets needed to achieve decarbonization objectives must be set over time. For example, the BMR sets a minimum decarbonization compared to a reference, but also set a minimum decarbonization rate of 7% per year (in terms of emissions intensity or absolute emissions). It is therefore essential to complement the cross-sectional analysis by a historical analysis.

This historical analysis brings new factors into the model. While sector allocation and intra-sectoral allocation remain, emissions intensity of companies (on scope 1,2 and 3), and economic factors (sales and market capitalization) will now have an effect on the decomposition. These factors can be interpreted as the decarbonization "trend" of companies. Their contribution can be interpreted as the decarbonization that the portfolio would have experienced if the weights of its constituents had remained unchanged during the period. These factors depend primarily on the evolution of the emissions intensity of the companies.

When analyzing absolute emissions, we must also take into account the economic factors, i.e., sales and market capitalization. As demonstrated in the cross-sectional analysis, the choice to analyze absolute or relative emissions leads to different results. To better understand these differences, we propose a simplified and amplified example that illustrates some counter-intuitive effects of these factors. Consider a portfolio consisting of two equally weighted stocks. If emissions intensity increases for one company, all of the portfolio performance metrics will increase (Exhibit 6, column (1)). Now, if the change comes from a sales increase, the impact on footprint and absolute emissions is the same as in the previous scenario but the intensity remains unchanged (column (2)). A market capitalization increase has more counter-intuitive effects and can be analyzed in three steps (columns (3) (a), (b) and (c)).
(a) If the market capitalization of company A doubles (from 20 to 40), the AUM of the portfolio will increase and the weights of companies A and B in the portfolio will change. While the average emissions intensity will increase (because of the larger weight in company A which is more intensive), the footprint of the portfolio will decrease (because absolute emissions are constant while the portfolio AUM is larger).

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[8] - Refer to Commission delegated regulation (EU) 2020/1818 Article 12 for further details.

(b) If we take the hypothesis of an equally weighted portfolio, the AUM should be redistributed in the two companies. Such a change has no impact on the average intensity, but it does have an impact on footprint and absolute emissions. Although the AUM is now 50% *higher* than in the initial state, the absolute emissions of the portfolio have *decreased* by almost 20%!
(c) The effect is amplified if we simulate an outflow of AUM from the portfolio to come back to a level similar to the initial situation.

Exhibit 6: Illustration of factors influence on a simplified portfolio of two stocks

	Reference		(1) Emissions intensity increase		(2) Sales increase		(3) Market capitalization increase					
							(a)		(b)		(c)	
Companies	A	B	A	B	A	B	A	B	A	B	A	B
(1) Portfolio weight	50%	50%	50%	50%	50%	50%	67%	33%	50%	50%	50%	50%
(2) AUM (MUSD)	5.0	5.0	5.0	5.0	5.0	5.0	10.0	5.0	7.5	7.5	5.0	5.0
(3) Market capitalization (MUSD)	20	20	20	20	20	20	**40**	20	**40**	20	40	20
(4) Share of market capitalization (2)/(3)	25%	25%	25%	25%	25%	25%	25%	25%	19%	38%	13%	25%
(5) Emissions intensity (TCO2e/MUSD)	100	10	**200**	10	100	10	100	10	100	10	100	10
(6) Sales (MUSD)	10	10	10	10	**20**	10	10	10	10	10	10	10
(7) Emissions (TCO2e) (5)*(6)	1000	100	2000	100	2000	100	1000	100	1000	100	1000	100
(8) Emissions of portfolio (TCO2e) (4)*(7)	250.0	25.0	500.0	25.0	500.0	25.0	250.0	25.0	187.5	37.5	125.0	25.0
Portfolio												
AUM (MUSD)	10		10		10		15		15		10	
Avg emissions intensity (TCO2e/MUSD) (1A)*(5A)+(1B)*(5B)	55		105		55		70		55		55	
Avg emissions footprint (TCO2e/MUSD) (1A)*(7A)/(3A)+(1B)*(7B)/(3B)	27.5		52.5		52.5		18.3		15.0		15.0	
Absolute emissions (TCO2e) (8A)+(8B)	275		525		525		275		225		150	

Note: the first column (Reference) represents the portfolio at the beginning of the period, while the four following columns represent the portfolio at the end of the period with different hypothesis. Figures in bold blue underlined represent the initial change in one factor, and figures in blue represent the indirect effects of this change.

This example illustrates on the one hand the importance of considering several metrics (absolute and relative) to analyze a portfolio, and on the other hand, the importance of considering the effects of economic factors (sales and market capitalization). The market capitalization factor is in particular difficult to control for a portfolio manager but has important short-term effects (financial shocks). It may therefore be relevant to neutralize it when comparing the emissions performance of different instruments.

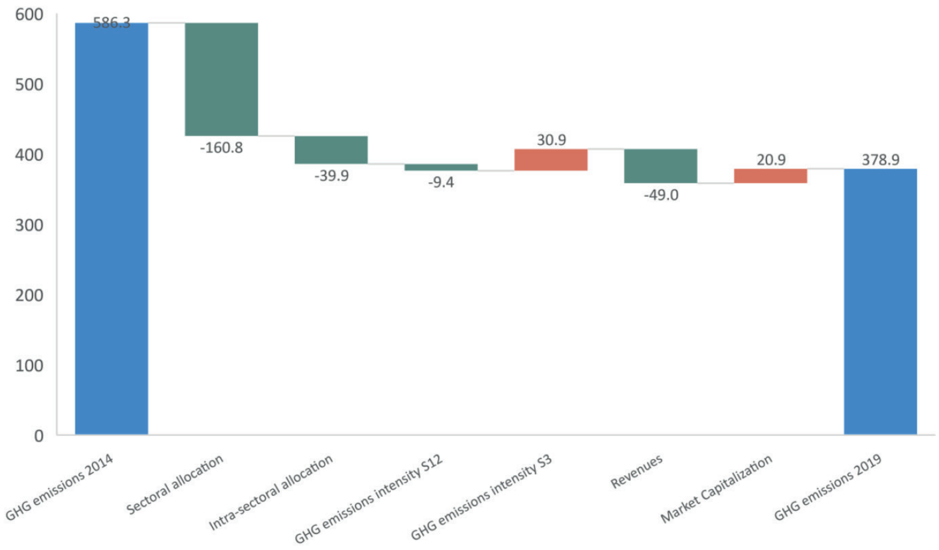
When analyzing the benchmark over the period 2014-2019 (Exhibit 7 (a)), we show that most of the historical decarbonization comes from sector allocation. The emissions intensity factor, which reflects the global rhythm of decarbonization of the region (US), on the opposite, contributes positively to the absolute emissions (on scope 1+2+3). If we now analyze the climate impact index, we observe that the main factor contributing to the historical reduction is the intra-sectoral allocation (Exhibit 7 (b)). Furthermore, the emissions intensity factor has also contributed to reducing emissions, while

4. Results

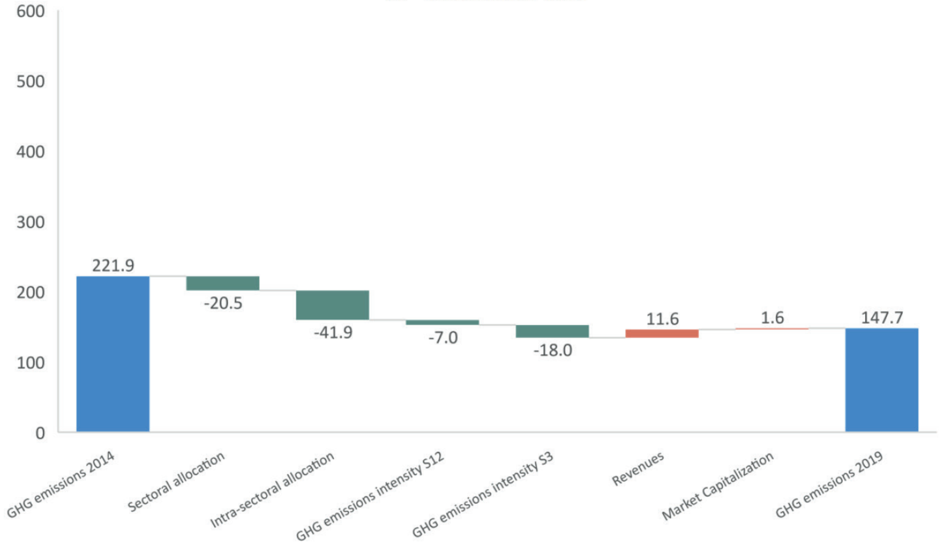
the sales factor tended to increase them. This historical perspective shows how two seemingly similar decarbonization rates (-35% for the benchmark and -33% for the index) can be achieved through very different factors.

Exhibit 7: Historical analysis on absolute emissions

(a) Benchmark



(b) Climate Impact Index



Note: The absolute emissions correspond to the greenhouse gas emissions in TCO2e (tons of CO_2 equivalent) per 1 million dollars invested in each instrument. They are calculated considering a scope 1+2+3.

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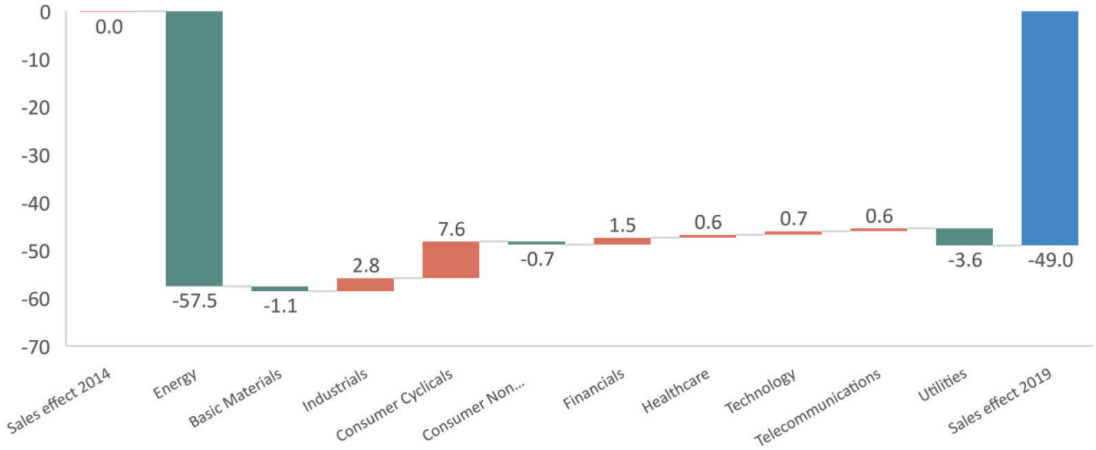
One may be surprised by the sales effect on the benchmark, which is negative. Indeed, the total sales of all companies of the benchmark during the period increases. However, if we focus on the sectors that contribute the most in terms of emissions (e.g., the energy sector), their sales decrease, which influences the aggregate effect. This can be verified by rearranging the decomposition of the Sales factor effect by sector (Exhibit 8).

Exhibit 8: Sector analysis of the historical sales effect on the absolute emissions (benchmark)



Note: The absolute emissions correspond to the greenhouse gas emissions in TCO2e (tons of CO_2 equivalent) per 1 million dollars invested in each instrument. They are calculated considering a scope 1+2+3.

The further decomposition provides a synthetic view of the factors that contributed most to the decarbonization of the climate impact index and its benchmark over the 2014-2019 period. However, the effects of each factor might not be stable over time. The multiplicative decomposition allows for a better understanding of the historical trends of each factor. We observe for example that, for the benchmark, the sector and intra-sectoral allocation effects are stable over time while the emission intensity, sales and market capitalization are more volatile (Exhibit 9 (a)). Furthermore, we note that while the index has, on average, over the period experienced a similar rate of decarbonization to its benchmark, its emissions increased between 2014 and 2016 (Exhibit 9 (b)). From a portfolio management perspective, this multiplicative decomposition thus makes it possible to monitor the evolution of the various factors over shorter periods of time (provided that the data, in particular the emissions intensity, can be updated at the corresponding frequency).

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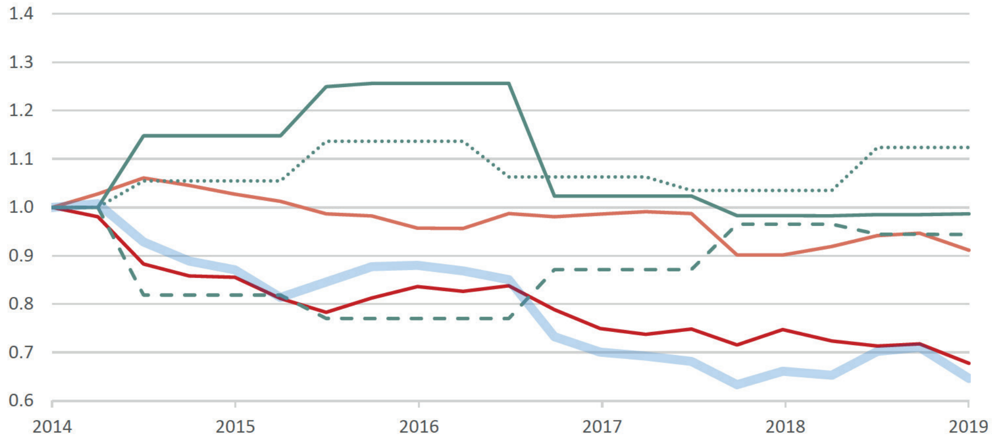
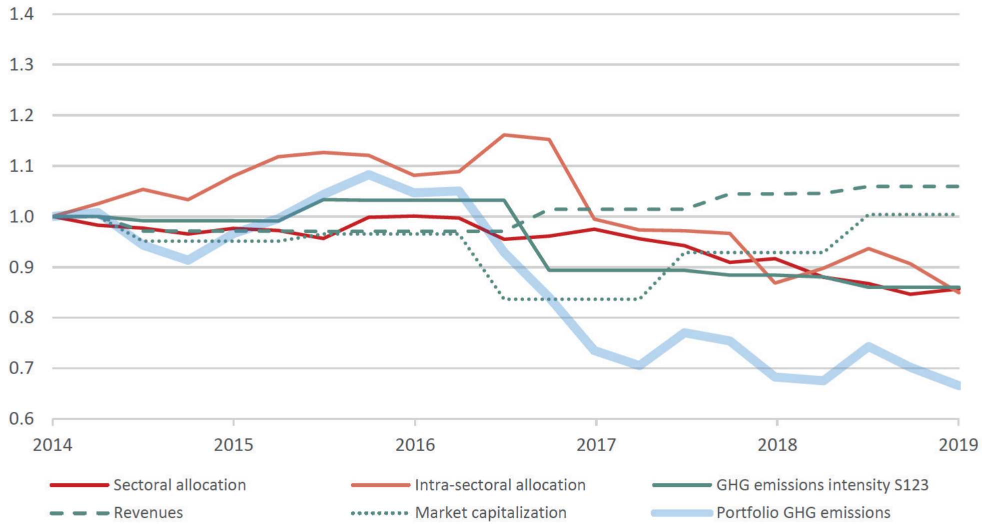
Exhibit 9: Multiplicative analysis on absolute emissions

(a) Benchmark



(b) Climate Impact Index



Note: each factor is normalized to 1.

5. Conclusion

5. Conclusion

In response to the growing expectations of regulators and stakeholders for investors to manage the greenhouse gas emissions associated with their portfolios, this article proposes a method for decomposing these emissions. This method, inspired by those used in environmental economics, allows for cross-sectional analysis (of a portfolio compared to a benchmark at a given time) and historical analysis.

The model proposed enables us to distinguish the effect of three types of factors: i) those linked to the portfolio manager's allocations, ii) those linked to the emissions intensity of the companies, and iii) economic factors (sales and market capitalization) that influence absolute emissions. We illustrate this model by analyzing an index with a climate objective and its benchmark. We show, for example, that although both observe a rate of decarbonization of 35% between 2014 and 2019, the climate impact index achieves this decarbonization mainly through intra-sectoral allocation and the reduction of companies' emissions intensity, while the benchmark achieves this decarbonization mainly through sector allocation (the Energy sector being less and less represented, which is not possible in the index as this sector is essentially excluded by BMR constraints). Understanding the role of each factor makes it possible to control whether a portfolio's emissions have been reduced effectively, i.e., without relying solely on sector allocation and therefore to avoid the risk of "portfolio greenwashing".

This approach is thus complementary to existing forward-looking approaches. Metrics such as implied temperature rise may be relevant for communication but are limited for managing emissions associated with a portfolio (PRI, 2021). It is therefore important to separate forward looking methods for setting long-term alignment targets, including greenhouse gas emission reduction targets, from methods for assessing and monitoring the achievement of these targets. The decomposition method proposed in this article is part of this assessment objective and, to be as relevant as possible, it is necessary to have previously defined targets at the portfolio level that are compatible with global emissions pathways. Based on this initial model, several avenues of research can be explored.

From a technical perspective, as discussed by Ang & Liu (2007) in environmental economics, particular attention should be paid to the treatment of zero values in the decomposition, as they might bias the decomposition results (in our case, when weights for a given stock at a given date is equal to zero). It could also be interesting to add a factor allowing the sales effect to be broken down into a price effect and a quantity effect. In certain sectors where prices are very volatile, such as the energy sector, the latter generally has a strong impact on the emissions intensity of companies. Finally, since institutional investors are generally exposed to several asset classes, including equities and bonds, it would be relevant to extend this method to other asset classes and to consider the aggregate analysis of portfolios containing several asset types. In this respect, the use of a common denominator for equity and bond portfolio allocation factors such as EVIC (PCAF, 2022) could be relevant (a preliminary model is proposed in Appendix C).

From a practitioner perspective, it is possible to derive a synthetic metric that reflects a portfolio manager's ability to decarbonize its portfolio. This metric could focus on the following factors: intra-

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sectoral (this corresponds to the ability of the portfolio manager to pick the best-in-class stocks within the sectors), and the intensity (this corresponds to the ability of the portfolio manager to track and select the companies with a decreasing emissions intensity). On the other hand, the metric could neutralize the sector effect that might be considered as "portfolio greenwashing", and sales and market capitalization effects over which a portfolio manager has little control.

Appendix

Appendix

Appendix A - Empirical Applications in Environmental Economics

Ang (2015) identifies more than 550 studies that rely on index decomposition analysis. While early work focused on energy consumption, the growing importance of climate change has led to more papers on trends in emissions. This sub-section highlights two articles from environmental economics that inspired our model and that could inspire future applications in climate finance. Wang et al. (2020) analyze for example the driving forces behind the United States CO_2 emissions between 1997 (5 703 $MtCO_2$) and 2016 (5 310 $MtCO_2$[9]) using an extension of the four factor Kaya identity (Kaya,1990). They show that during the first period, from 1997 to 2007 (where emissions reached their highest level at 6 130 $MtCO_2$), the main influencing factors were demographic (population) and economic (income per capita). During this period, while energy intensity decreases, it was compensated by the two former drivers and led to a CO_2 emissions increase. Between 2007 and 2016, the decrease in energy intensity and the decrease in population growth and GDP per capita led to an overall emissions reduction.

Over a similar period, Dong et al. (2020) find similar results at the global level, focusing on worldwide CO2 emissions between 1997 (c. 22 100 $MtCO_2$) and 2015 (c. 32 200 $MtCO_2$[10]). As Wang et al. (2020), their model extends the four factors of the Kaya identity with different types of energy and countries. They show that economic growth (GDP per capita) is responsible for 72.5% of the total emission growth over the period while population growth contributed to an additional 17.7 % and energy intensity allowed to reduce CO2 emissions by 47.7%. They show that these results differ greatly according to the income level of the countries. In low-income countries, population is the main driver of emissions, while it is GDP per capita in middle-income countries, and carbon intensity in high-income countries (that allows to observe a global reduction).

How can this work in environmental economics help financial actors manage their portfolio emissions? First, the underlying decomposition methods can be adapted to analyze the emissions of an equity portfolio. Moreover these "macro" results show the importance of the demographic and economic factors compared to the technological factors (energy and carbon intensity). For a financial portfolio, it means that it would be relevant to analyze the absolute emissions instead of the intensity, i.e., to consider the economic growth of companies (e.g., the increase of sales) as a factor increasing emissions instead of neutralizing it.

Appendix B - Proof of the Logarithmic Mean Divisia Index Decomposition Formula

The reasoning behind index decomposition analysis is to derive the aggregate value formula over time and isolate the contribution of the *n* factors. We can illustrate with the following decomposition.

$$G_t = \sum_i V_t \,.\, w_{it} . \frac{G_{it}}{V_{it}} = \sum_i V_t \,.\, w_{it} . F_{it}$$

Where G_t are the absolute emissions of the portfolio, V_t is the monetary value of the portfolio, w_{it} is the weight of the holding in the portfolio, $\frac{G_{it}}{V_{it}}$ or Fi_t is the emissions footprint of the company (emissions divided by the market capitalization).

---

[9] - These value are from the EPA inventory. Link: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2016

[10] - These values are extracted from the International Energy Agency. Link: https://www.iea.org/reports/global-energy-review-2021/co2-emissions

Appendix

The derivative of I with respect to time is

$$\frac{dG}{dt} = \sum_i w_i\, F_i \frac{dV}{dt} + \sum_i V\, F_i \frac{dw_i}{dt} + \sum_i V\, w_i \frac{dF_i}{dt} \tag{5}$$

We now consider the growth rate of the intensity by dividing by *G*.

$$\frac{1}{G} \cdot \frac{dG}{dt} = \frac{d\ln G}{dt} \tag{6}$$

Because $\ln(u)' = \frac{u\prime(x)}{u(x)}$

$$\frac{1}{G} \cdot \frac{dG}{dt} = \frac{1}{G} \cdot \left(\sum_i w_i\, F_i V \frac{d\ln V}{dt} + \sum_i V\, F_i w_i \frac{d\ln w_i}{dt} + \sum_i V\, w_i F_i \frac{dF_i}{dt} \right) \tag{7}$$

$$\frac{d\ln G}{dt} = \Sigma \frac{g_i}{G} \left[\frac{d\ln V}{dt} + \frac{d\ln w_i}{dt} + \frac{d\ln F_i}{dt} \right] \tag{8}$$

where g_i represents the absolute emissions of the company *i* associated with the portfolio. Then we need to integrate over a discrete time period $[0,T]$

$$\begin{aligned} \int_0^T \frac{d\ln G}{dt} dt \quad &= \ln(G_T) - \ln(G_0) = \ln(\frac{G_T}{G_0}) \\ &= \int_0^T \sum_i \frac{g_i}{G} \cdot \frac{d\ln V_i}{dt} dt + \\ &\int_0^T \sum_i \frac{g_i}{G} \cdot \frac{d\ln w_i}{dt} dt + \\ &\int_0^T \sum_i \frac{g_i}{G} \cdot \frac{d\ln F_i}{dt} dt \end{aligned} \tag{9}$$

The exponential of this equation gives us the multiplicative form where

$$\frac{G_T}{G_0} = I_V . I_w . I_F \tag{10}$$

where

$$\begin{aligned} I_V \quad &= \exp\left(\int_0^T \sum_i g_i \cdot \frac{d\ln V_i}{dt} dt \right) \\ I_w \quad &= \exp\left(\int_0^T \sum_i g_i \cdot \frac{d\ln w_i}{dt} dt \right) \\ I_F \quad &= \exp\left(\int_0^T \sum_i g_i \cdot \frac{d\ln F_i}{dt} dt \right) \end{aligned} \tag{11}$$

Appendix

For the additive decomposition, we just need to integrate the following expression

$$\frac{dG}{dt} = \sum g_i \left[\frac{d\ln V}{dt} + \frac{d\ln w_i}{dt} + \frac{d\ln F_i}{dt}\right] \tag{12}$$

To obtain

$$\int_0^T \frac{dG}{dt} dt = G_T - G_0$$
$$= \int_0^T \sum_i g_i . \frac{d\ln V_i}{dt} dt + \int_0^T \sum_i g_i . \frac{d\ln w_i}{dt} dt + \int_0^T \sum_i g_i . \frac{d\ln F_i}{dt} dt \tag{13}$$

The next step is to find a discrete approximation of these equations (as empirical data are in discrete time).

$$\frac{G_t}{G_0} = \exp\left(\sum_i \frac{g_i}{G}(t*). \ln\left(\frac{V_{iT}}{V_0}\right)\right) + \exp\left(\sum_i \frac{g_i}{G}(t*). \ln\left(\frac{w_{iT}}{w_{i0}}\right)\right)$$
$$+ \exp\left(\sum_i \frac{g_i}{G}(t*). \ln\left(\frac{F_{iT}}{F_{i0}}\right)\right) \tag{14}$$

$$G_t - G_0 = \sum_i g_i\,(t*). \ln\left(\frac{V_{iT}}{V_{i0}}\right) + \sum_i g_i\,(t*). \ln\left(\frac{w_{iT}}{w_{i0}}\right) + \sum_i g_i\,(t*). \ln\left(\frac{F_{iT}}{F_{i0}}\right) \tag{15}$$

Different approximations can be done for the "weights" ($\frac{g_i}{G}$) in the case of the multiplicative decomposition, g_i for the additive decomposition). The first option is based on the arithmetic average of two consecutive weight function (arithmetic mean divisia index method):

$$\frac{g_i}{G}(t*) = \frac{\frac{g_{i0}}{G_0} + \frac{g_{iT}}{G_T}}{2} \tag{16}$$

But this solution still leads to residuals.

$$\frac{G_T}{G_0} = I_V . I_w . I_F . I_{residuals} \tag{17}$$

The logarithmic mean Divisia index (LMDI) method aims to solve this issue by replacing $\frac{g_i}{G}$ (t *) by:

$$\frac{g_i}{G}(t*) = L(g_{iT}, g_{i0})/L(G_T, G_0) \tag{18}$$

where:

$$L(a,b) = \frac{a-b}{\ln x - \ln b} \tag{19}$$

For the additive decomposition, we just replace g_i (t *) by:

$$g_i(t*) = L(g_{iT}, g_{i0}) \tag{20}$$

Appendix

Proof of perfect decomposition (for the additive decomposition)

$$
\begin{aligned}
&(G_T - G_0) - \left[\sum_i L\left(g_{iT}, g_{i0}\right) \cdot \ln\left(\frac{V_{iT}}{V_{i0}}\right) + \sum_i L\left(g_{iT}, g_{i0}\right).\ln\left(\frac{w_{iT}}{w_{i0}}\right) + \sum_i L\left(g_{iT}, g_{i0}\right).\ln\left(\frac{F_{iT}}{F_{i0}}\right)\right] \\
&= (G_T - G_0) - \left[\sum_i L\left(g_{iT}, g_{i0}\right).\ln\left(\frac{V_{iT}.\,w_{iT}.\,F_{iT}}{V_{i0}.\,w_{i0}.\,F_{i0}}\right)\right] \\
&= (G_T - G_0) - \left[\sum_i \frac{g_{iT} - g_{i0}}{\ln(\frac{g_{iT}}{g_{i0}})}.\ln\left(\frac{V_{iT}.\,w_{iT}.\,F_{iT}}{V_{i0}.\,w_{i0}.\,F_{i0}}\right)\right] \\
&= (G_T - G_0) - \left[\sum_i \frac{g_{iT} - g_{i0}}{\ln(\frac{g_{iT}}{g_{i0}})}.\ln\left(\frac{g_{iT}}{g_{i0}}\right)\right] \\
&= (G_T - G_0) - \left[\sum_i \left(g_{iT} - g_{i0}\right)\right] \\
&= 0
\end{aligned}
\tag{21}
$$

Appendix C - Emissions Intensity and Footprint Decompositions

Emissions intensity of a portfolio

$$I_p = \sum_H \sum_S w_{sp}\,.\,w_{hs}.\,(CIs1_h + CIs2_h + CIs3_h)$$

Emissions footprint of a portfolio

$$F_p = \sum_H \sum_S w_{sp}\,.\,w_{hs}.\,(CIs1_h + CIs2_h + CIs3_h).\,Sales_h.\,\frac{1}{Mktcap_h}$$

Absolute emissions of a portfolio containing different asset classes (limited to assets which correspond to companies, i.e., assets that can be associated with Sales).

$$G_p = \sum_H \sum_{AC} \sum_S w_{acp}.\,w_{sac}\,.\,w_{hs}.\,(CIs1_h + CIs2_h + CIs3_h).\,Sales_h.\,\frac{1}{EVIC_h}.\,MktValue_p$$

Where

- w_{acp}, would be the strategic allocation factor (weight of asset class *ac* in portfolio *p*),

- w_{sac}, would be the sector allocation (weight of sector *s* in asset class *ac*).

The "market capitalization" factor used previously would become the "enterprise value including cash (EVIC)" factor to ensure alignment with similar asset classes (PCAF, 2022).

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- Bouchet, V., Vaucher, B., Herzog, B. Look up! A Market-Measure of the Long-Term Transition Risks in Equity Portfolios. (December).

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