Climate Finance : limitations of Current Indicators and Implications for Emerging Markets

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Abstract

Do portfolio strategies of climate finance contribute to the decarbonization of the economy? This study examines climate investment strategies, focusing on Carbon Intensity (**CI**) and Implied Temperature Rise (**ITR**) indicators, as well as Best-in-Universe (BiU) and Best-in-Class (BiC) strategies. The findings reveal that while these strategies are effective according the two mentionned climate metrics, they exhibit significant sectoral and geographical biases. Notably, they reduce investments in emerging markets and essential sectors like electricity, potentially hindering the global energy transition. The study also highlights the limitations of current criteria used to assess the climate performance of portfolios, which can be insufficient or even misleading. Pure exclusion strategies, such as BiU and BiC, risk delaying the transition if not accompanied by targeted investments in renewable energy and green bonds.

Keywords: Climate finance, Climate metrics, Portfolio choice, decarbonization.

JEL codes: G10, G11, Q54, Q56

1 Introduction

In response to climate regulations and their Environmental, Social, and Governance (ESG) commitments[1], institutional investors are revising their investment allocation and selection criteria, such as ESG ratings and climate impact materiality indicators. Historically, exclusionary strategies have been popular, involving the removal of assets that do not meet certain sustainability criteria from the investment universe. In terms of portfolio construction, this means excluding companies with a high environmental impact, particularly in terms of greenhouse (GHG) gas emissions. However, the Intergovernmental Panel on Climate Change (IPCC) highlights the need for investment in the most polluting sectors to transition to a low-carbon economy. In this context, does the traditional practice of exclusion contradict the necessary energy transition?

Following the Paris Agreement (2015), the financial industry decided to implement investment strategies aimed more explicitly at reducing the GHG emissions of the companies in which it invests. These strategies, referred to as sustainable finance or climate finance strategies, have been the subject of active research by both asset management companies, financial indices providers and academic researchers. The literature aims notably to address three specific research questions. First, what metrics should be employed to gauge the carbon efficiency of investments? Second, how can portfolios be effectively decarbonized? Thirdly, does the rise of sustainable finance influence the performance of high-GHG emitters and their cost of capital? These research questions are currently at the forefront of attention for investors, policymakers, and stakeholders. While the development of climate portfolio strategies appears to be a rapidly expanding field of literature, the macroeconomic implications and their alignment with macro-climatic objectives have not, to our knowledge, been extensively researched. This represents a significant research gap.

Additionally, the world is experiencing demographic aging, which will primarily affect developed countries. From an intertemporal general equilibrium perspective, a resource transfer must occur between developed and developing countries to support this aging process. Essentially, developed countries should to invest in emerging markets today to receive a share of the wealth produced by these countries in the future. Given their industrial structure, developing countries have a higher carbon intensity of energy, as illustrated by the Environ-

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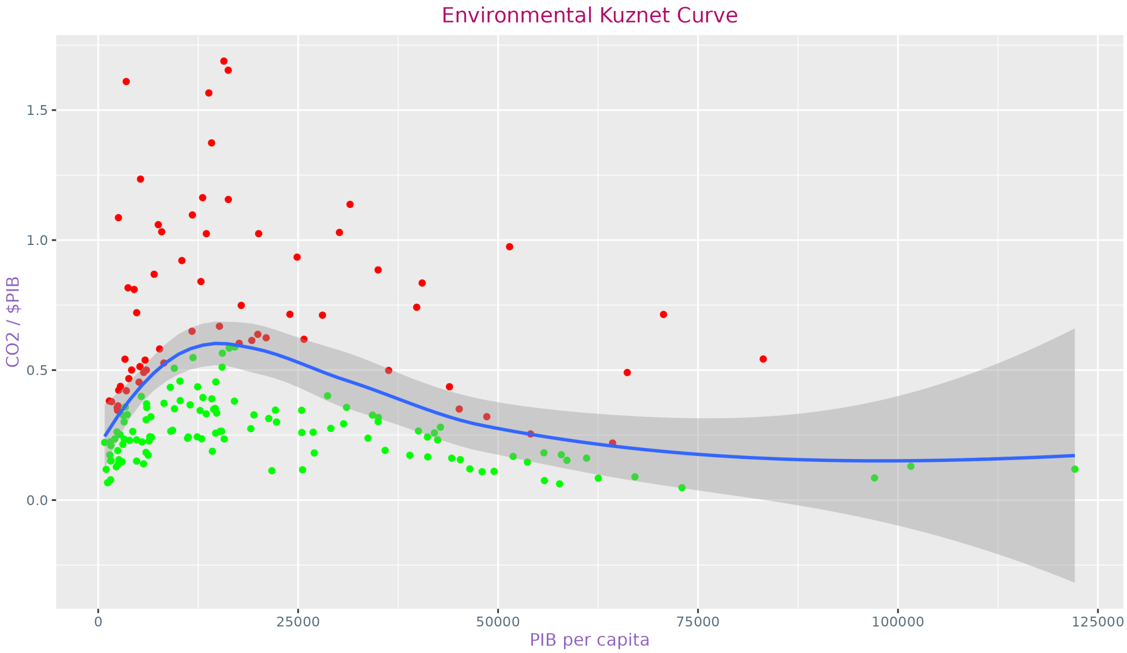
[1] including the United Nations Principles for Responsible Investment (PRI)

mental Kuznets Curve in Figure 1. Do exclusion criteria also contradict this necessary wealth transfer? While both the energy transition and demographic transition are subjects of active research, the implications of one on the other and the potential conflicts between these two transitions appear to have received little attention. This lack of exploration highlights a significant research gap that warrants further investigation.



source: World Bank, Climate Watch

Figure 1: Environmental Kuznets Curve

In this paper, we evaluate the impacts of two classic exclusion strategies: Best in Universe and Best in Class. We demonstrate that both strategies result in under-allocation in the electricity and energy sectors, where the most virtuous actors are crucial for the energy transition. Furthermore, these strategies lead to underinvestment in emerging and developing countries, resulting in a suboptimal equilibrium in the context of demographic aging.

This article is organized as follows. Section 2 presents a review of the literature on portfolio decarbonization. Section 3 outlines the theoretical framework used to assess the relevance of Best-in-Class and Best-in-Universe strategies. Section 4 describes the data employed in the analysis, while Section 5 details our empirical findings. The implications of these results are discussed in Section 6, and concluding remarks are provided in Section 7.

2 Literature Review

Our paper is related to the literature developing climate evaluation metrics for investments. Developments in this area are progressing rapidly, with extra-financial data providers offering increasingly detailed data. However, the integration of this data into portfolio construction remains imperfect in both operational and academic research. These measures are primarily collected from issuers or estimated by the internal models of ESG data providers, such as MSCI, Trucost, Sustainalytics, Moody's Vigeo, and ISS Oekom. Giese et al. (2023) define a taxonomy of climate metrics along two axes: climate impact/risk measures and static/dynamic measures. A climate impact measures reflects the deterioration of the climate linked to the company, and climate risk measures, which correspond to the probable financial risk the company could face, notably due to the carbon intensity of its activities, i.e. transition risk. On the second axis, a static climate metric measures the contribution to global warming or a transition risk based on the company's activity at the measurement date. On the other hand, a dynamic climate metric measures the impact or risk taking into account for the company's transformation and adaptation plans.

Le Guenedal et al. (2022) introduces a novel carbon metric, called carbon momentum, which measures the efforts of an issuer or a sector. To do so, the authors propose estimating the decarbonization trend using the linear model $CE(t) = \beta_0 + \beta_1 \cdot t + \epsilon(t)$. Barahhou et al. (2022) observes that the model can be analyzed in a logarithmic version $\ln(CE(t)) = \beta_0 + \beta_1 \cdot t + \epsilon(t)$. The carbon momentum $CM(t)$ is then the ratio between the current emissions and the estimated coefficient $\hat{\beta}_1$, quantifying the decrease in emissions for the issuer.

$$CM(t) = \frac{CE(t)}{\hat{\beta_1}(t)}$$

Barahhou et al. also points out that the adoption of the European taxonomy allows for the definition of green revenue or green capex intensity. However, data remains scarce, particularly regarding CAPEX, and the taxonomy includes highly heterogeneous activities. To our knowledge, no published papers have integrated these indicators.

The article by Andersson et al. (2016) pioneered a portfolio decarbonization method, particularly for developing climate indices. The authors proposed minimizing the tracking error using a benchmark, subject to an x% reduction in the portfolio's carbon footprint compared to its index. Andersson et al. demonstrated that tracking error can be very low even with a 50% reduction in carbon footprint. At this date, they considered this a "free option" on the price of carbon, as performance remains similar to the benchmark until carbon costs are accounted for, at which point the index should outperform the market.

The main global index providers, such as MSCI (2022), Standard and Poor's (2023), and Bloomberg (2022), publish methodologies for constructing their Paris Aligned Benchmark (PAB) indices. While these methodologies share similarities due to European regulatory compliance, notable differences exist. Some methodologies use mathematical optimization programs, constituting operational research models. For instance, Bloomberg (2022) minimizes the sum of squared deviations of the PAB index weights relative to the parent benchmark, whereas MSCI (2022) minimizes the ex-ante tracking error based on component weights and a covariance matrix. PAB indices, due to carbon intensity targets and exclusion criteria, often reduce allocations in certain sectors. To mitigate this, European legislation mandates that PAB indices maintain constant exposure to high carbon intensity sectors relative to the benchmark. Roncalli and Le Guenedal (2022) have highlighted that the definition of High Carbon Intensity Sector ("HICS") is too broad to be effective.

Hodges et al. (2022) embed PAB requirements in a multi-asset portfolio containing developed and emerging market equities, sovereign bonds, corporate bonds, listed real estate, and commodities, designed to limit average global temperature increases to 1.5°C. Bolton et al. (2022) propose a model allowing to align a financial portfolio with a consistent carbon budget with maintaining temperatures below 1.5°C above the pre-industrial level, with a high confidence threshold of 86%, as defined by the IPCC (2018). Barahhou et al. (2022) propose several decarbonization strategies, including different constraints, on stock portfolios and on bond portfolios. Barahhou et al. test the impact of several levels of immediate decarbonization on the optimal portfolio, based on the 1600 MSCI World securities, as well as on different levels of "carbon momentum", i.e. by no longer segmenting the securities according to of their carbon intensity but according to their speed of decarbonization.

Giese et al. (2021) highlights the crucial role of investors in aligning their portfolios with IPCC (2018) budgets, by reallocating capital away from high-carbon entities, engaging with industry laggards, investing in climate solutions, and advocating for supportive policies. Giese et al. (2021) offer three approaches to portfolio construction to help transition to a net-zero strategy : tilting the portfolios towards the lowest carbon issuers and periodically rebalancing the portfolios, "tilting toward decarbonization leaders" consists of favoring companies that reduce their emissions the most, particularly on a prospective basis, and mixed strategy. This paper evaluates the unintended impacts of the first type of strategy and, indirectly, the third type.

This paper illustrates that traditional metrics for assessing the climate impact of a portfolio vary significantly between sectors, leading to mechanical penalization of some sectors and favoring others. Geographic disparities between emerging and developed countries are also significant, with emerging countries being penalized despite their relatively low historical contribution to global warming. This approach appears inconsistent from an economic equilibrium perspective, as it leads to underfinancing essential sectors like energy.

Current research and regulations add constraints to optimization programs at aggregated sectoral levels. Our alternative approach proposes a new method for aggregating climate metrics to discourage portfolio allocation effects that reduce investment in high carbon intensity sectors necessary for the transition. Unlike weighted averages, this method penalizes portfolios that do not invest in sectors crucial for the transition, such as utilities, materials, oil & gas, and industrials.

Traditional methods for aggregating carbon metrics at the portfolio level are typically weighted averages. Adding constraints for sector-neutral portfolios penalizes the carbon performance of a portfolio. An unconstrained and optimized portfolio ($P^{NC}OPT$) generally performs better than a constrained and optimized portfolio ($P^{C}OPT$), based on climate metrics. It is also common for an unoptimized and unconstrained portfolio to outperform an optimized constrained portfolio (P^{C}_{OPT}) in terms of carbon performance.

We introduce two new metrics: CI^* [2] to avoid underweighting crucial decarbonizing sectors, and ITR^* [3] to penalize portfolios that underinvest in energy-intensive sectors or emerging countries. Additionally, we test two non-optimized but robust ESG indexing strategies: Best-in-class and Best in Universe. We evaluate their climate performance relative to various metrics and their exposure to essential economic sectors, complementing the work of Jondeau et al. (2021). Finally, we perform statistical tests to measure reductions in sector exposures, adding to the literature on the impact of portfolio strategies on asset prices and the cost of

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[2] derived from carbon intensity

[3] derived from Implied Temperature Rise

capital.

3 Theory

3.1 Capitalization weighted strategy

The Capitalization weighted ("cap-weighted" or **CW** thereafter) strategy is the standard benchmark in the portfolio construction literature supported by the CAPM (Sharpe (1964); Lintner (1965); Mossin (1966)) and the Efficient Market Hypothesis (Fama (1970)). Indeed, weights defined by the market capitalization replicate the market for an investor, as if she invests in the overall market proportionally to her wealth. To define the cap-weighted portfolio as weighting portfolio construction strategy for which the market capitalization for each security i $MC(i)$ is divided by the aggregate capitalization of the market $\sum_{j=1}^{J} MC(j)$.

$$w_i^{cap} = \frac{MC_i}{\sum_{j=1}^{J} MC_j}$$

3.2 Best-in-Universe strategies

The Best-in-Universe (BiU) strategy prioritizes investments with the lowest carbon emissions, evaluated based on their Carbon Emissions to EVIC intensity (CI). The carbon intensity metric is presented in detail in Appendix B. Companies with lower CI or those actively reducing it are preferred, focusing on minimizing GHG emissions and mitigating climate change. This approach is consistent with the first strategy proposed by Giese et al. (2021).

To do so, the strategy exclude several securities, for which the carbon footprint, denoted CI_i is above a given threshold $\bar{CI}$. The market capitalization is reduced to 0 if $CI_i \geq \bar{CI}$. Otherwise, the capitalization is maintained.

$$MC_i^{BIC} = \begin{cases} MC_i & \text{if} \quad CI_i < \bar{CI} \\ 0 & \text{else} \end{cases}$$

The threshold $\bar{CI}$ is generally defined as a quantile of the empirical distribution:

$$P\left(CI(t) \leq \bar{CI}\right) = \alpha$$

The weight of the remaining securities is then proportional to their capitalization in the total capitalization of the remaining stocks.

$$w_i^{BIU} = \frac{MC_i^{BIU}}{\sum_{j=1}^{J} MC_j^{BIU}}$$

3.3 Best-in-Class strategies

A Best-in-Class (BiC) strategy involves selecting the top securities within each sector or region based on a specific climate criterion, such as the scope 1-2 carbon footprint. By evaluating securities relative to their sector rather than the entire investment universe, a BiC strategy is likely to have a lower sector bias compared to a Best-in-Universe (BiU) strategy. For a BiC strategy based on carbon intensity (CI_i), descriptive statistics are calculated by sector, with the median ($\alpha = 0.5$) used as the selection level in this study.

$$P\left(CI(t) \leq CI_i^S\right) = \alpha \quad \forall s \in S$$

This approach is consistent with the second strategy proposed by Giese et al. (2021). As a consequence, 50% of issuers from each sector have been removed from the BiC sample when their metric CI_i is higher than the median for their sector $\bar{CI}_i^S$. Mathematically, this corresponds to the definition of the following Boolean variable.

$$S_i^{BIC} = \begin{cases} 1 & \text{if } CI_i \leq \bar{CI}_i^S \\ 0 & \text{else} \end{cases}$$

The market capitalization is reduced to 0 if $CI_i > \bar{CI}_i^S$. Otherwise, the capitalization is maintained.

$$MC_i^{BIC} = \begin{cases} MC_i & \text{if } CI_i \leq \bar{CI}_i^S \\ 0 & \text{else} \end{cases}$$

Or:

$$MC_i^{BIC} = MC_i \cdot S_i^{BIC}$$

The weight of the remaining securities is then proportional to their capitalization in the total capitalization of the remaining values.

$$w_i^{BIC} = \frac{MC_i^{BIC}}{\sum_{j=1}^{J} MC_j^{BIC}} = \frac{S_i^{BIC} \cdot MC_i}{\sum_{j=1}^{J} S_j^{BIC} \cdot MC_j}$$

3.4 Modified WACI and Modified ITR

We provide a new aggregation formula for assessing the climate quality of an investment portfolio. Currently, it is a weighted average, such as the Weighted Average Carbon Intensity to EVIC (WACI), defined as:

$$\text{WACI} = \frac{\sum_{i=1}^{n}(w_i \cdot \text{CI}_i)}{\text{EVIC}}$$

This aggregation formula penalizes certain essential sectors (e.g., utilities, electricity) and countries (emerging markets). To address these issues, PAB indices add constraints, but this can result in less favorable climate performance compared to funds practicing pure exclusion. Therefore, we propose an indicator that ensures better climate performance for an index maintaining sector-neutral exposures than a fund practicing exclusion, all else being equal.

To evaluate investment strategies, a modified WACI indicator, denoted $WACI_P^*$, is proposed. It is calculated as the classic WACI of the portfolio $WACI_P$ minus the allocation effect AE_P:

$$WACI_P^* = WACI_P - AE_P = w_{S,P}^T \cdot CI_{S,P} + [w_{S,P} - w_{S,B}]^T \cdot CI_{S,B}$$

With :

- $w_{S,P}$ is the vector of the weights of each sector s in the portfolio P,
- $w_{S,B}$ is the vector of the weights of each sector s in the benchmark B
- $CI_{S,P}$ is the vector of weighted average carbon intensity of sector s in the portfolio P
- $CI_{S,B}$ is the vector of weighted average carbon intensity of sector s in the benchmark

Similarly, the Modified Implied Temperature Rise ITR_P^* takes into account the allocation effect by reintegrating the emissions projections and the carbon budget of the sectors in which the investor is under-allocated.

$$ITR_P^* = 2\% + \frac{w_{S,P}^T \cdot E_{S,P} + [w_{S,B} - w_{S,P}]^T \cdot E_{S,B}}{w_{S,P}^T \cdot B_{S,P} + [w_{S,B} - w_{S,P}]^T \cdot B_{S,B}} \times TCRE \times GB$$

Where:

- $E_{S,P}$ is the vector of weighted average emissions projections of companies in sector s in the portfolio P
- $E_{S,B}$ is the vector of weighted average emissions projections of companies in sector s in the benchmark B
- $B_{S,P}$ is the vector of the weighted average carbon budgets of companies in sector s in the portfolio P
- $B_{S,B}$ is the vector of the weighted average carbon budgets of companies in sector s in the benchmark B.

3.5 Investors preferences

The key point is that this new aggregation method penalizes portfolios that do not invest in sectors that need to organize the transition, notably in scope 1 (utilities and electricity sectors). As a consequence, this aggregation method can be used directly in a Utility function U taking into account both a given risk profile σ, reward profile μ and carbon intensity CI of a given portfolio.

Let's assume that an investor has to choose between the four following portfolios the following portfolio as follows:

- an risk-reward optimized sector-neutral portfolio $P_{\text{OPT}}^{\text{SN}}$
- a non-optimized sector-neutral portfolio $P_{\text{NO}}^{\text{SN}}$
- an optimized portfolio without sector constraints $P_{\text{OPT}}^{\text{CF}}$
- a low carbon intensity non-optimized non-sector-neutral portfolio (typically a Best-in-Universe portfolio) $P_{\text{NO}}^{\text{CF}}$

Let's also assume that:

- The risk-return profile of an optimized portfolio is superior to that of a non-optimized portfolio. Then:

  $$\frac{\mu}{\sigma}\left(P_{\text{OPT}}^{\text{SN}}\right) > \frac{\mu}{\sigma}\left(P_{\text{NO}}^{\text{SN}}\right)$$

  And:

  $$\frac{\mu}{\sigma}\left(P_{\text{OPT}}^{\text{CF}}\right) > \frac{\mu}{\sigma}\left(P_{\text{NO}}^{\text{CF}}\right)$$

- The risk-return profile of a sector-neutral portfolio is inferior to that of an unconstrained portfolio due to the reduction in the feasible set. Then:

  $$\frac{\mu}{\sigma}\left(P_{\text{OPT}}^{\text{SN}}\right) < \frac{\mu}{\sigma}\left(P_{\text{OPT}}^{\text{CF}}\right)$$

  And:

  $$\frac{\mu}{\sigma}\left(P_{\text{NO}}^{\text{SN}}\right) < \frac{\mu}{\sigma}\left(P_{\text{NO}}^{\text{CF}}\right)$$

- The WACI of a sector-neutral portfolio is higher than that of an unconstrained portfolio. Then:

  $$WACI(P_{\text{OPT}}^{\text{SN}}) \equiv WACI(P_{\text{NO}}^{\text{SN}}) > WACI(P_{\text{OPT}}^{\text{CF}}) \equiv WACI(P_{\text{NO}}^{\text{CF}})$$

- The modified WACI of a sector-neutral portfolio is lower than that of an unconstrained portfolio.

  $$WACI^{*}(P_{\text{OPT}}^{\text{SN}}) \equiv WACI^{*}(P_{\text{OPT}}^{\text{SN}}) < WACI^{*}(P_{\text{OPT}}^{\text{CF}}) \equiv WACI^{*}(P_{\text{NO}}^{\text{CF}})$$

Finally, let us assume that an investor's portfolio choice is defined by utility function U containing three criteria: return, risk, and carbon intensity. The utility function is an increasing function of return $\frac{\partial U}{\partial \mu} > 0$ and a decreasing function of risk $\frac{\partial U}{\partial \sigma} < 0$ and carbon intensity $\frac{\partial CI}{\partial \sigma} < 0$.

If the utility function is defined using the WACI, then :

$$U\left(P_{\text{OPT}}^{\text{CF}}\right) > U\left(P_{\text{OPT}}^{\text{SN}}\right)$$

And:

$$U\left(P_{\text{NO}}^{\text{CF}}\right) > U\left(P_{\text{NO}}^{\text{SN}}\right)$$

And for an investor sufficiently averse to the carbon footprint of their portfolio, we even have:

$$U\left(P_{\mathrm{NO}}^{\mathrm{CF}}\right) > U\left(P_{\mathrm{OPT}}^{\mathrm{SN}}\right)$$

This leads to the following pre-order:

$$U\left(P_{\mathrm{OPT}}^{\mathrm{CF}}\right) > U\left(P_{\mathrm{NO}}^{\mathrm{CF}}\right) > U\left(P_{\mathrm{OPT}}^{\mathrm{SN}}\right) > U\left(P_{\mathrm{NO}}^{\mathrm{SN}}\right)$$

This results in a preference for portfolios that do not invest in carbon-intensive sectors but make efforts towards decarbonization. Conversely, using the modified WACI, the investor prefers :

$$U\left(P_{\mathrm{OPT}}^{\mathrm{SN}}\right) > U\left(P_{\mathrm{OPT}}^{\mathrm{CF}}\right)$$

And:

$$U\left(P_{\mathrm{NO}}^{\mathrm{SN}}\right) > U\left(P_{\mathrm{NO}}^{\mathrm{CF}}\right)$$

Therefore, we obtain the following preference order:

$$U\left(P_{\mathrm{OPT}}^{\mathrm{SN}}\right) > U\left(P_{\mathrm{NO}}^{\mathrm{SN}}\right) > U\left(P_{\mathrm{OPT}}^{\mathrm{CF}}\right) > U\left(P_{\mathrm{NO}}^{\mathrm{CF}}\right)$$

Using a modified WACI in the utility function prioritizes portfolios that are decarbonizing while maintaining sector neutrality, thereby effectively financing the entire energy transition in line with IEA recommendations.

3.6 Hypothesis Testing

The empirical study of carbon strategies leads to testing the following hypotheses.

Hypothesis 1: The BiU decarbonization strategy performs significantly better than the BiC decarbonization strategy both in terms of Carbon Emissions to EVIC intensity and ITR.

The BiC and BiU strategies can be understood as non-random sampling of a population that would be the MSCI ACWI. Consequently, the validation test of hypothesis H1 amounts to carrying out a hypothesis test on the average carbon intensity of the strategy's securities against that of the population. The statistical test commonly employed to compare two empirical means is the Student's t-test.

Hypothesis 2: The BiU decarbonization performance is more driven by allocation effects than the BiC decarbonization performance.

The study compares the BiU and BiC strategies, which are non-random samples from the initial population, by testing the empirical means of these samples using the Student's t-test. This test determines if the means of two independent samples differ significantly. Initial tests suggest that the BiU strategy generally shows better climate performance than the BiC strategy, but this does not guarantee a lower carbon footprint for BiU.

To validate this, a resampling method (bootstrap) is used, generating 2000 random samples of 300 securities each. The BiU and BiC strategies are applied to these samples to calculate variables like carbon intensity, ITR, and sector weights. This bootstrap method allows for hypothesis testing on the strategy parameters, reducing sampling error.

If the resampled parameters follow a normal distribution, standard tests are used; otherwise, critical values are adjusted. This approach is useful when traditional statistical assumptions are violated or sample sizes are small.

Hypothesis 3: BiU and BiC strategies significantly reduce investors' exposure to the electricity sector compared to an equivalent market portfolio.

To test this hypothesis, a two empirical frequencies Z-test is performed. To use these test, sufficiently large sample sizes are necessary to ensure that the normal distribution is a fair approximation of the empirical one.

Hypothesis 4: BiU strategy has lower exposure to the electricity sector than BiC strategy.

Hypothesis 5: BiU and BiC strategies significantly reduce investors' exposure to emerging markets

In hypotheses 4 and 5, the objective is to compare the weight of the electricity sector or emerging countries between two samples of the population, the BiU and BiC samples.

4 Data

4.1 Universe

The current study utilizes a dataset from MSCI Inc., encompassing all companies within the MSCI All Countries World Index (MSCI ACWI). This dataset includes both static and dynamic metrics of climate impact and risk, as well as financial indicators such as market capitalization and enterprise value including cash (EVIC).

To ensure data quality, observations missing essential carbon metrics were systematically removed from the dataset. This data curation was crucial to maintain the integrity and reliability of the analyses. By excluding incomplete data, potential biases and inaccuracies were mitigated. Only 4% of the data was removed, minimally impacting the dataset's integrity while ensuring the reliability of the analyses. The table 1 describes this data cleaning process[4].

	Step	Obs.	% init.
1	Total dataset	8968	100.00
2	GHG/EVIC unavailable removed	8644	96.39
3	ITR unavailable removed	8596	95.85
4	GHG projections unavailable removed	8593	95.82
5	GHG budget removed	8593	95.82

Table 1: Data cleaning process
Source: MSCI, author's calculations

Table 2 provides an overview of the dataset by geographic regions, revealing an overrepresentation of developed countries, especially North America, which accounts for 53% of the total market capitalization. In contrast, Africa and Latin America are underrepresented, with market caps of 0.3% and 1.3%, respectively. This imbalance may introduce biases in analyses and interpretations, highlighting the need to improve data collection from underrepresented regions to enhance inclusivity and comprehensiveness in research and policymaking.

Table 3 provides an overview of market capitalization across various industrial sectors. The manufacturing sector is prominently represented due to its diverse sub-sectors. Technology and finance sectors also show significant representation, reflecting their importance in the

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[4] Such stringent data filtering practices are needed to robust empirical research. While this deletion inevitably resulted in a reduction in sample size, the preservation of data integrity and the maintenance of analytical rigor take precedence, safeguarding the credibility and validity of research outcomes.

	Region	n	Market Cap (bn USD)	Weight (%)
1	Africa	80	345.29	0.31
2	Developed Asia / Pacific	2045	12,030.92	10.84
3	Emerging Asia	2121	18,984.13	17.10
4	Europe	1455	18,996.10	17.11
5	Latin America	198	1,457.32	1.31
6	North America	2474	59,206.48	53.33

Table 2: Market Cap of the sample by region
Source: MSCI, author's calculations

equity market. In contrast, the agriculture sector is underrepresented. This imbalance may introduce biases, affecting the generalizability of findings and requiring careful consideration in analyses.

	Sector	n	Market Cap (bn USD)	Weight (%)
1	Basic materials	1026	7,227.68	6.51
2	Communications	525	9,392.19	8.46
3	Consumer cyclical	1325	15,199.06	13.69
4	Consumer non-cyclical	336	4,040.39	3.64
5	Energy	264	6169.46	5.56
6	Financial	1112	18,723.57	16.87
7	Healthcare	431	6,866.63	6.19
8	Industrial	1670	13,657.52	12.30
9	Real estate	453	2,460.55	2.22
10	Technology	948	24,044.10	21.66
11	Utilities	283	3,239.08	2.92

Table 3: Market Cap of the sample by sector (GICS classification)
Source: MSCI, author's calculations

4.2 Carbon Intensity by sector

An analysis of Carbon Intensity to EVIC (CI) statistics across sectors reveals notable variations in GHG emissions in the dataset. Given the limited availability of data for Scope 3, we have focused on Scopes 1 and 2. Figure 2 and Table 8 in the appendix present descriptive statistics for each GICS sector (level 1) and highlight significant disparities in carbon emissions intensity across sectors.

Remarkably, the average carbon footprints of three specific sectors (Energy, Materials, and Utilities) markedly exceed those of others from both the median and the average perspectives. The energy and utilities sectors are particularly polluting, as are basic materials, primarily due to sub-sectors like steel and cement. This observation underscores the significance of targeted interventions and policies aimed at mitigating emissions within these sectors. Integrating Scope 3 carbon emissions would alter the sector rankings, particularly for materials, utilities, and industrials. However, the electricity sub-sector within Utilities remains one of the most polluting. Conversely, some sectors, such as financials, telecommunications, healthcare, and technology, exhibit low pollution levels. These substantial intersectoral disparities can lead to biases in exclusion policies based on this criterion.

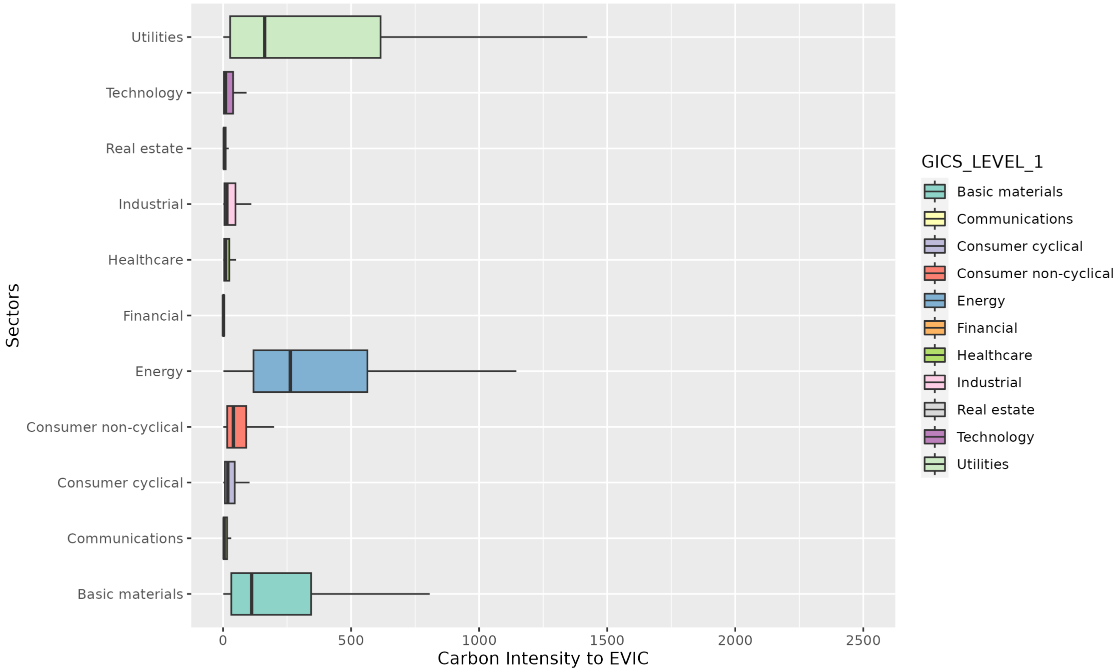

Figure 2: Carbon intensity (Scope 1-2) by sector as of 12/31/2024

4.3 Carbon Intensity contribution by sectors

Figure 3 and Table 9 in appendix present the contribution of carbon emissions by sector to the index carbon footprint, classified according to the Global Industry Classification Standard (GICS). It reveals that certain sectors, such as basic materials, energy, and utilities, have a disproportionately high contribution to carbon emissions relative to their weight. For instance, the basic materials sector, with a weight of 6.51%, contributes 30.40% of the total emissions, while the energy sector, with a weight of 5.56%, contributes 21.02% of the emissions. Conversely, sectors like communications and financials, despite their significant weight (8.46% and 16.87% respectively), have a much lower contribution to carbon emissions (0.71% and 1.39%).

Figure 3 and Table 9 indicates that portfolio managers aiming to improve their carbon footprint, as measured by the Weighted Average Carbon Intensity (WACI), may be inclined to reduce the allocation of certain sectors within their portfolios. However, this strategy might be reconsidered if sectoral emissions are concentrated among a few issuers that represent a negligible portion of the index.

4.4 Carbon Intensity by regions

The assessment of **CI** (scope 1 and 2) across diverse economic regions on Table 10 reveals noteworthy disparities. Notably, Emerging countries, including Africa, Latin America and Emerging Asia, exhibit higher **CI** compared to Europe and North America. The observed variance underscores the influence of regional energy compositions. In these regions, the reliance on carbon-intensive energy sources for electricity generation contributes significantly to the elevated **CI**. In contrast, Europe and North America, with a greater emphasis on renewable energy and cleaner technologies, demonstrate lower **CI**.

A potential risk is that investors may divest from emerging countries due to their elevated **CI**. This poses a significant challenge as these nations necessitate additional capital expenditures to effectively implement and achieve their climate agenda. The paradoxical scenario of increased capital withdrawal in tandem with heightened capital requirements exacerbates the financial constraints faced by emerging economies striving to align with global decarbonization objectives. This underscores the intricate interplay between environmental sustainability goals and economic considerations, requiring nuanced policy interventions and international

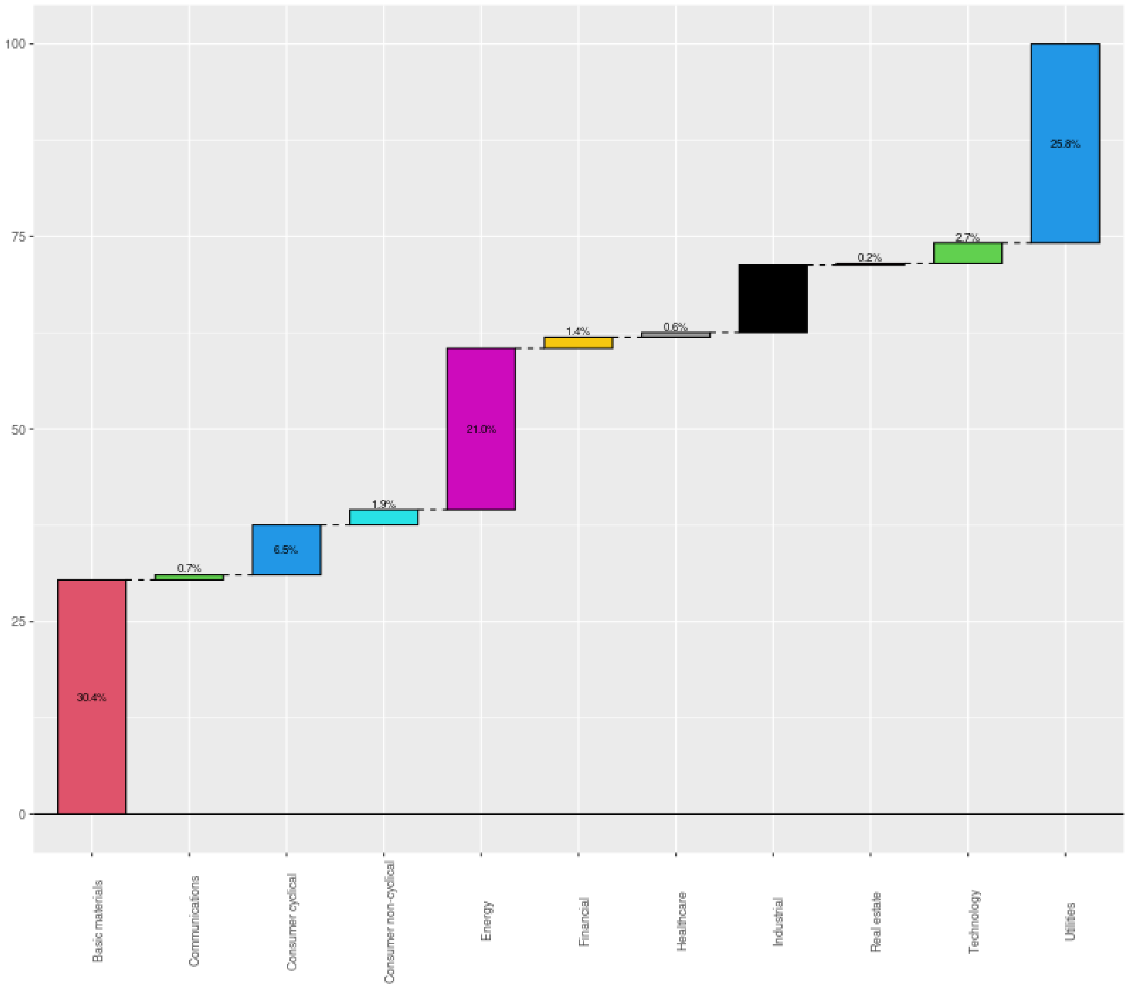

Figure 3: Carbon intensity (Scope 1-2) contribution by sector as of 12/31/2024

collaboration to address the potential adverse impacts on emerging economies' climate efforts.

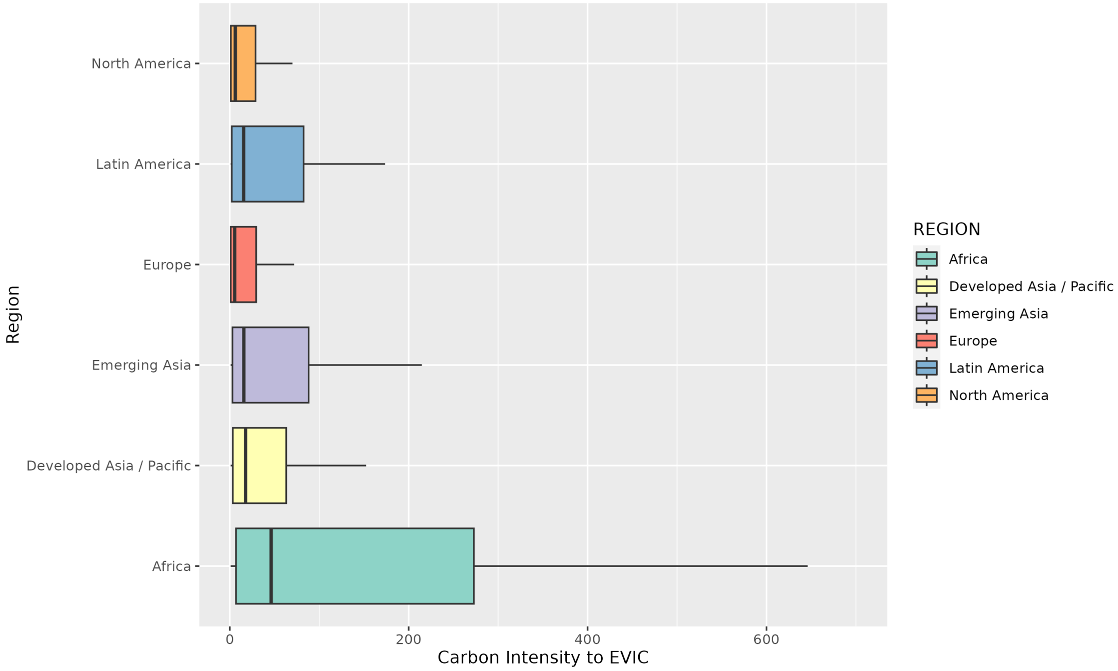

Figure 4: Carbon intensity (Scope 1-2) by region as of 12/31/2024

Table 11 provides the contribution of major world regions to the carbon footprint of the index, and reveals significant disparities in carbon contributions relative to market capitalization. Emerging Asia, for instance, contributes nearly 45% of the index's carbon footprint despite representing only 18% of global market capitalization. This disproportionate contribution underscores the outsized impact of emerging Asian economies on the **WACI** of the index as a lot of GHG emission moved from developed countries to Asian emerging countries in the context of globalization. Conversely, Africa's contribution is modest, accounting for only 0.73% of the index's carbon footprint. However, this figure is 2.3 times greater than Africa's weight in the index, highlighting a relative overrepresentation of GHG emissions from the region. In contrast, North America contributes 24% to the index's carbon footprint, despite equities from the region representing 52% of the index. This incongruity suggests a potential risk whereby investors seeking to reduce **WACI** of their portfolio may divert investments away from emerging markets towards developed ones. Paradoxically, developed regions often "import" carbon-intensive production from emerging economies (see Barahhou et al. (2023)).

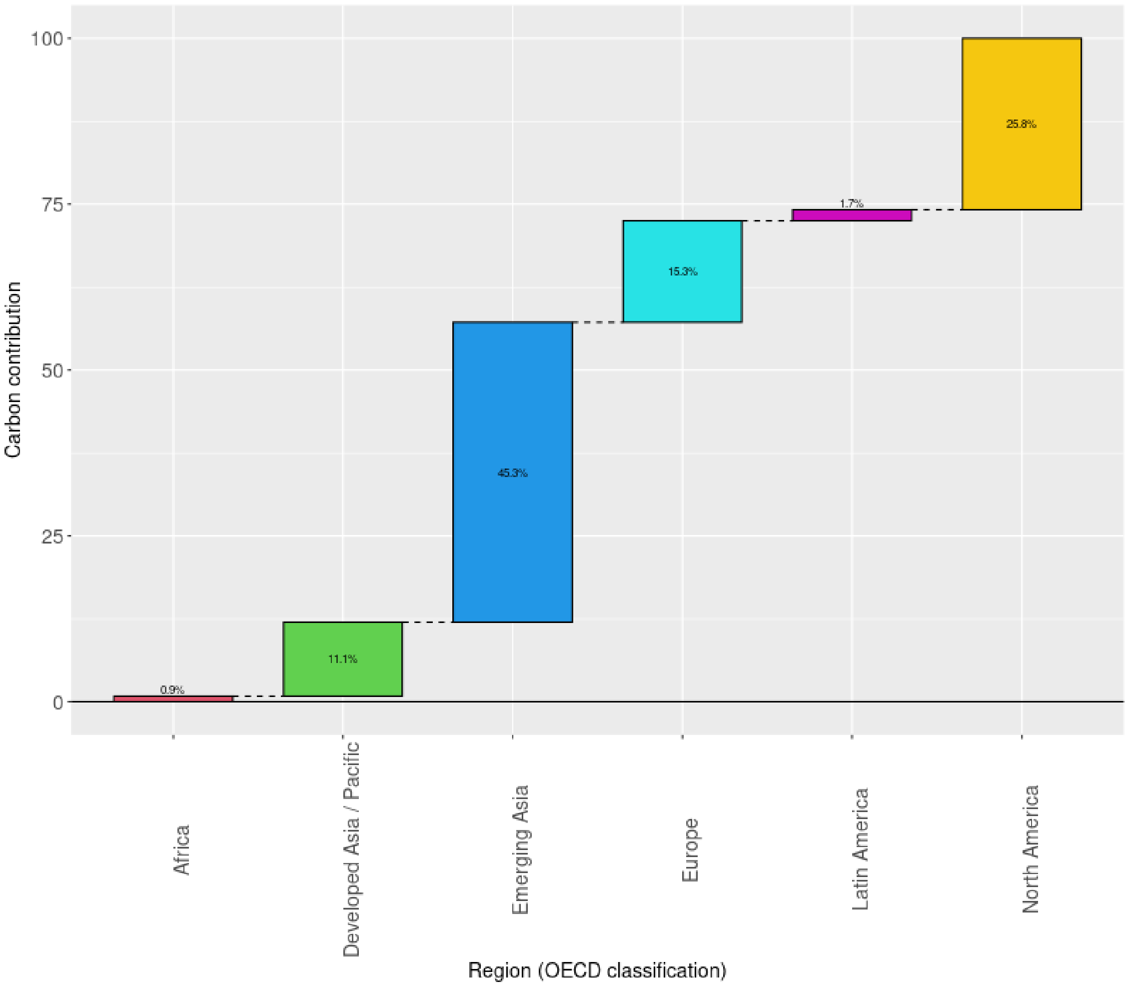

Figure 5: Carbon intensity (Scope 1-2) contribution by region as of 12/31/2024

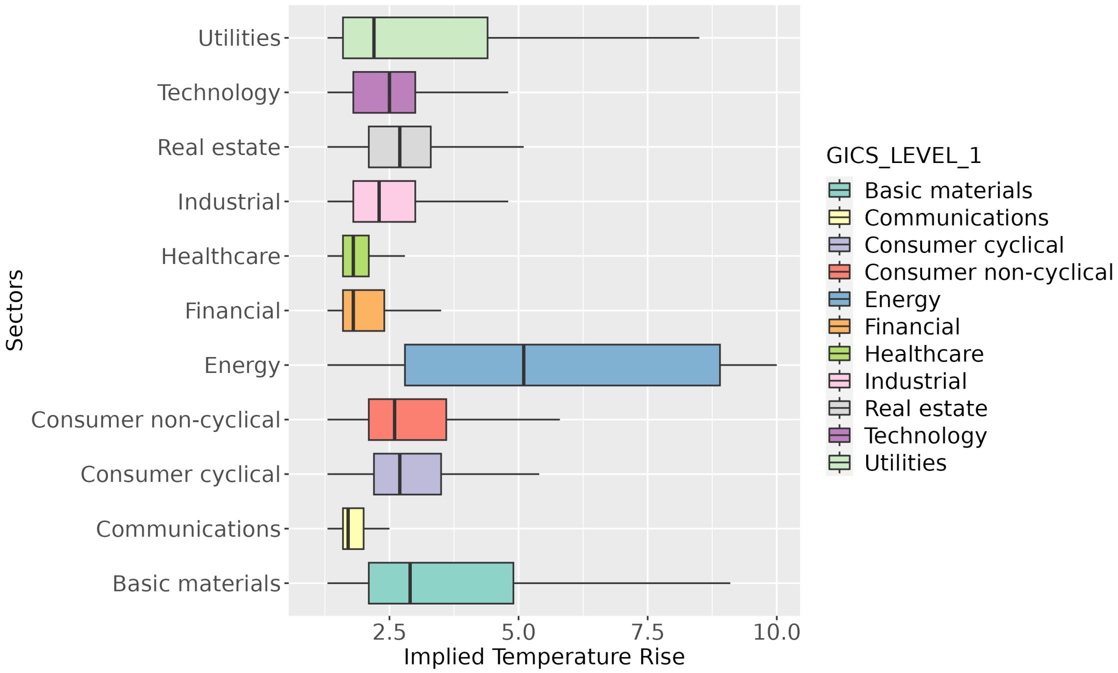

Figure 6: Implied Temperature Rise by sectors as of 2024/12/31

4.5 ITR by sector

Figure 6 and Table 12 present descriptive statistics of the ITR stratified by sectors, providing insights into the distribution of data across different industrial sectors. Notably, the data range for the variable is bounded between 1.3 and 10, a measure implemented by the data provider to mitigate extreme values.

Upon examination, it becomes apparent that the three sectors (energy, basic materials and utilities), characterized by intensive industrial activities, higher **CI** and substantial utilization of carbon-intensive energy sources, exhibit mean and median values greater than 2.

In contrast, sectors characterized by less energy-intensive operations demonstrate mean values below 2. This disparity in mean values suggests varying levels of energy consumption and **ITR** across industrial sectors, highlighting potential distinctions in environmental impact and resource utilization practices.

In the context of portfolio optimization, the integration of this variable could introduce sectoral biases, underscoring the importance of careful consideration and mitigation strategies to ensure the robustness and integrity of the optimization process.

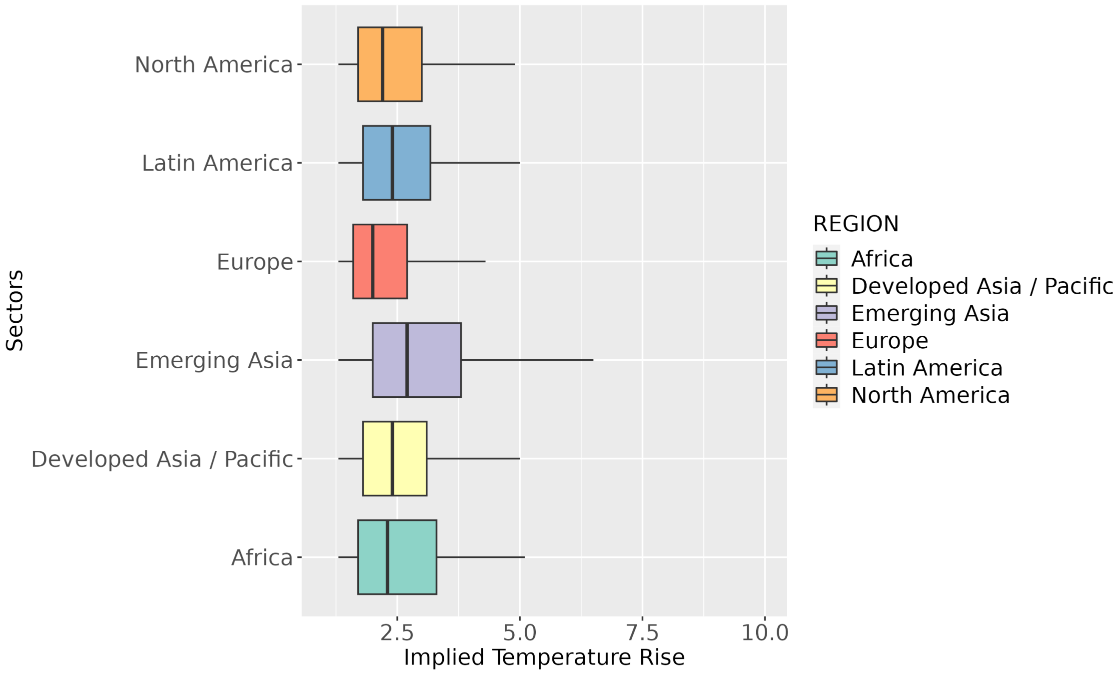

Figure 7: Implied Temperature Rise by region as of 2024/12/31

4.6 ITR by region

Figure 7 and Table 13 present descriptive statistics of the ITR stratified by regions, providing insights into the distribution of data across different geographical areas. Regions like Africa, Emerging Asia, and Latin America show higher mean ITR values, indicating greater implied temperature rises. These regions often have higher industrial activity and energy mix based on fuels. Conversely, Europe and North America have lower mean ITR values, suggesting less energy-intensive operations. This variation highlights differences in environmental impact and resource use across regions. In portfolio optimization, incorporating this variable could introduce regional biases.

5 Results

5.1 Allocations by strategy on full sample

Table 14 presents the allocations and contributions by sector for our three different strategies: Capital Weighted, Best in Universe (BiU), and Best in Class (BiC).

The Best in Universe (BiU) strategy focuses on reducing carbon emissions by selecting the least emitting companies within each sector. Compared to the Capital Weighted strategy, the allocation to the Basic Materials sector is significantly reduced from 6.51% to 1.92%, with a substantial drop in **CI** from 319.56 to 4.05, and contribution from 20.80 to 0.08. In the Communications sector, the allocation increases from 8.46% to 10.64%, while the **CI** decreases from 5.73 to 2.25, and contribution from 0.48 to 0.24. For the Consumer Cyclical sector, the allocation decreases slightly from 13.69% to 12.04%, with a drop in **CI** from 32.24 to 4.68, and contribution from 4.41 to 0.56. The Consumer Non-Cyclical sector sees a decrease in allocation from 3.64% to 2.24%, with a reduction in **CI** from 36.30 to 4.38, and contribution from 1.32 to 0.10. The Energy sector experiences a drastic reduction in allocation from 5.56% to 0.16%, with a significant drop in **CI** from 258.86 to 3.95, and contribution from 14.39 to 0.01. In the Financial sector, the allocation increases from 16.87% to 23.69%, with a decrease in **CI** from 5.65 to 0.88, and contribution from 0.95 to 0.21. The Healthcare sector sees an increase in allocation from 6.19% to 7.88%, with a reduction in **CI** from 6.96 to 2.37, and contribution from 0.43 to 0.19. The Industrial sector's allocation decreases from 12.30% to 10.36%, with a drop in **CI** from 48.67 to 4.12, and contribution from 5.99 to 0.43. The Real Estate sector's allocation increases from 2.22% to 2.75%, with a reduction in **CI** from 6.35 to 2.86, and contribution from 0.14 to 0.08. In the Technology sector, the allocation increases from 21.66% to 27.74%, with a decrease in **CI** from 8.52 to 1.27, and contribution from 1.84 to 0.35. The Utilities sector sees a reduction in allocation from 2.92% to 0.57%, with a significant drop in **CI** from 605.74 to 2.77, and contribution from 17.67 to 0.02. Overall, the BiU strategy significantly reduces the **CI** by lowering allocations to high-emission sectors like Energy and Utilities, while increasing allocations to low-emission sectors like Financials and Technology.

The Best in Class (BiC) strategy selects the best-performing companies in terms of environmental impact within each sector. Compared to the Capital Weighted strategy, the allocation to the Basic Materials sector is slightly reduced from 6.51% to 6.14%, with a drop in **CI** from 319.56 to 33.93, and contribution from 20.80 to 2.08. In the Communications sector, the allocation is reduced from 8.46% to 4.09%, with a decrease in **CI** from 5.73 to 0.54, and contribution from 0.48 to 0.02. For the Consumer Cyclical sector, the allocation increases from 13.69% to 14.97%, with a drop in **CI** from 32.24 to 5.88, and contribution from 4.41 to 0.88. The Consumer Non-Cyclical sector sees an increase in allocation from 3.64% to 4.67%, with a reduction in **CI** from 36.30 to 11.90, and contribution from 1.32 to 0.56. The Energy sector's allocation is slightly increased from 5.56% to 6.14%, with a drop in **CI** from

258.86 to 118.33, and contribution from 14.39 to 7.27. In the Financial sector, the allocation decreases from 16.87% to 13.44%, with a reduction in **CI** from 5.65 to 0.31, and contribution from 0.95 to 0.04. The Healthcare sector sees an increase in allocation from 6.19% to 8.04%, with a drop in **CI** from 6.96 to 2.21, and contribution from 0.43 to 0.18. The Industrial sector's allocation decreases slightly from 12.30% to 11.88%, with a drop in **CI** from 48.67 to 4.74, and contribution from 5.99 to 0.56. The Real Estate sector's allocation decreases from 2.22% to 2.07%, with a reduction in **CI** from 6.35 to 1.44, and contribution from 0.14 to 0.03. In the Technology sector, the allocation increases from 21.66% to 26.65%, with a drop in **CI** from 8.52 to 0.79, and contribution from 1.84 to 0.21. The Utilities sector sees a reduction in allocation from 2.92% to 1.90%, with a significant drop in **CI** from 605.74 to 42.44, and contribution from 17.67 to 0.81. The BiC strategy aims to balance sector allocations while selecting the best-performing companies in terms of environmental impact, resulting in a more moderate reduction in carbon footprint compared to the BiU strategy.

5.2 Carbon intensity by strategy on full sample

The BiU strategy significantly reduces the **WACI** to 2.26 tCO2eq/USD million, compared to 68.44 tCO2eq/USD million in the Capital Weighted strategy. This represents a reduction of approximately 96.7%. High-emission sectors like Energy and Utilities see drastic reductions in their allocations.

The BiC strategy also reduces the overall carbon intensity, achieving 12.64 tCO2eq/USD million, which is an 81.5% reduction compared to the Capital Weighted strategy. While the reduction is less dramatic than that of the BiU strategy, the BiC strategy maintains a more balanced sector representation.

5.3 Carbon attribution by strategy on full sample

Table 4 attributes the drop in scope 1-2 **WACI** to three effects: allocation, selection, and interaction, based on the principles of performance attribution as described by Brinson et al. (1986). At the full sample level, the allocation effect accounts for a significant portion of decarbonization of the BiU strategy, while the selection effect is also substantial, though partially offset by the interaction effect.

A detailed examination of Table 4 reveals that a large part of the observed allocation effect stems from the underweighting of sectors such as Basic Materials, Energy, and Utilities. Similarly, the selection effect is predominantly driven by these sectors, indicating that the strategy reduces carbon footprint by divesting from high-emission sectors with minimal presence in the stock market.

The table also presents the carbon performance attribution of the Best in Class strategy. In this strategy, sector weight deviations remain significant. For instance, the Utilities sector represents a smaller portion of the portfolio compared to the benchmark, due to the substantial size of some highly carbon-intensive players within the sector. Conversely, the Energy sector sees an increase in weight, as major players in this sector have a lower carbon footprint than smaller ones.

The allocation effect is less significant in the Best in Class strategy compared to the Best in Universe strategy. In the former, the allocation effect increases the carbon footprint, whereas it reduces it in the latter. The combined selection and interaction effects lead to a substantial reduction in carbon intensity, highlighting the importance of selecting the least energy-intensive securities within sectors.

However, a paradox arises in the Best in Class strategy, where the portfolio leads to an increased allocation to high-emission sectors at the expense of essential sectors like Utilities. This is due to the fact that the least polluting issuers in the Energy sectors (mainly including the oil and gas sector) are typically larger, while those in Utilities (including the essential subsector of electricity production) sectors are smaller. To mitigate this issue, investors should consider neutralizing sectoral allocation discrepancies or incorporating market capitalization in defining thresholds. The intra-sectoral Best-in-Class exclusion strategy, when combined with a market capitalization-based portfolio construction, proves to be suboptimal due to its unintended side effects on the allocation to the oil sector.

5.4 Hypothesis testing results

Table 5 illustrates the results of the primary statistical tests, based on the full sample, at the security level. This analysis is crucial for understanding the efficacy and robustness of the evaluated decarbonization strategies, namely BiU and BiC, compared to the cap-weighted strategy.

The **WACI** of the BiU strategy ($CI_{BiU} = 2.26$) is significantly lower than that of the

	Sector	$Weight_B$	CI_B	$Weight_S$	CI_S	Alloc.	Selec.	Inter.
	Best in universe strategy							
1	Communications	8.46	5.73	10.64	2.25	0.12	-0.29	-0.08
2	Industrial	12.30	48.67	10.36	4.12	-0.95	-5.48	0.87
3	Financial	16.87	5.65	23.69	0.88	0.39	-0.80	-0.33
4	Consumer non-cyclical	3.64	36.30	2.24	4.38	-0.51	-1.16	0.45
5	Consumer cyclical	13.69	32.24	12.04	4.68	-0.53	-3.77	0.45
6	Real estate	2.22	6.35	2.75	2.86	0.03	-0.08	-0.02
7	Basic materials	6.51	319.56	1.92	4.05	-14.67	-20.54	14.48
8	Energy	5.56	258.86	0.16	3.95	-13.98	-14.17	13.76
9	Utilities	2.92	605.74	0.57	2.77	-14.21	-17.59	14.15
10	Technology	21.66	8.52	27.74	1.27	0.52	-1.57	-0.44
11	Healthcare	6.19	6.96	7.88	2.37	0.12	-0.28	-0.08
12	Total	100.00	68.44	100.00	2.26	-43.66	-65.74	43.22
	Best in class strategy							
1	Communications	8.46	5.73	4.09	0.54	-0.25	-0.44	0.23
2	Industrial	12.30	48.67	11.88	4.74	-0.20	-5.40	0.18
3	Financial	16.87	5.65	13.44	0.31	-0.19	-0.90	0.18
4	Consumer non-cyclical	3.64	36.30	4.67	11.90	0.37	-0.89	-0.25
5	Consumer cyclical	13.69	32.24	14.97	5.88	0.41	-3.61	-0.34
6	Real estate	2.22	6.35	2.07	1.44	-0.01	-0.11	0.01
7	Basic materials	6.51	319.56	6.14	33.93	-1.18	-18.60	1.06
8	Energy	5.56	258.86	6.14	118.33	1.51	-7.81	-0.82
9	Utilities	2.92	605.74	1.90	42.44	-6.16	-16.43	5.73
10	Technology	21.66	8.52	26.65	0.79	0.43	-1.67	-0.39
11	Healthcare	6.19	6.96	8.04	2.21	0.13	-0.29	-0.09
12	Total	100.00	68.44	100.00	12.64	-5.14	-56.16	5.50

Table 4: Carbon performance attribution of the two strategies

BiC strategy ($CI_{BiC} = 12.64$) and the cap-weighted strategy ($CI_{CW} = 68.44$). The p-value of the Student tests indicate that both BiU and BiC strategies effectively reduce the carbon footprint of selected securities, as they are less than 0.05, confirming that the reduction in carbon intensity is statistically significant. Furthermore, the comparison between BiU and BiC strategies also yields a p-value less than 0.05, indicating that the BiU strategy performs significantly better in terms of carbon intensity reduction.

The average ITR of securities selected by the BiU strategy stands at $ITR^{BiU} = 1.3^{o}C$, whereas the average ITR for the BiC strategy is $ITR^{BiC} = 1.69^{o}C$, which is lower than the ITR of the full sample ($ITR^{pop} = 2.92^{o}C$). The Student's p-values suggest that it is virtually certain that the selected securities have a significantly lower ITR than the full sample, with p-values less than 0.05. Additionally, the difference between BiC and BiU strategies also indicates a p-value less than 0.05, concluding that ITR of BIC stratgy ITR^{BiC} is very likely higher than the one of BiU strategy ITR^{BiU}. This finding implies that the BiU strategy is more effective in reducing the ITR compared to the BiC strategy. As a consequence, **hypothesis 1** (the BiU decarbonization strategy performs significantly better than the BiC decarbonization strategy both in terms of Carbon Emissions to EVIC intensity and ITR), is validated by our analysis.

The sector weights reveal significant differences between the strategies. For instance, the BiU strategy has higher weights in the communications and financial sectors compared to the cap-weighted strategy, while the BiC strategy shows lower weights in these sectors. The p-values for the chi-square tests indicate that these differences are statistically significant, with values less than 0.05 for most sectors. This suggests that the sectoral composition of the portfolios is substantially altered by the decarbonization strategies. Notably, the utilities sector (mainly comprising the electricity sub-sector) is significantly underweighted in both BiU and BiC strategies compared to the cap-weighted strategy, validating **hypothesis 3** (BiU and BiC strategies significantly reduce investors' exposure to the electricity sector compared to an equivalent market portfolio). The p-values for the chi-square tests for these sectors are less than 0.05, confirming the statistical significance of this underweighting. Furthermore, the BiU strategy has a lower exposure to the electricity (utilities) sector than the BiC strategy, as indicated by the chi-square test results, supporting **hypothesis 4** (BiU strategy has lower exposure to the electricity sector than BiC strategy).

The geographic exposures highlight variations in the representation of different regions. The BiU and BiC strategy shows a higher weight in North America and lower weights in Emerging Asia (13.1 and 13.4 respectively vs 17.1) and Africa (0.23 and 0.1 respectively vs 0.31) compared to the cap-weighted strategy. The p-values for the chi-square tests confirm that these differences are statistically significant, with values less than 0.05 for most regions. This indicates that the geographic distribution of investments is significantly influenced by the decarbonization strategies. Specifically, the significant underweighting of Emerging Asia and Africa in both BiU and BiC strategies supports **Hypothesis 5** , which posits that these strategies significantly reduce investors' exposure to emerging markets.

These results provide valuable insights into the performance and robustness of the BiU and BiC strategies. The statistically significant p-values underscore the efficacy of these strategies in reducing carbon intensity and ITR, as well as their impact on sector weights and geographic exposures. Further validation through resampling methods, such as bootstrap, is recommended to ensure the robustness of these findings.

	CW	BiU	BiC	BiU-CW	p-value	BiC-CW	p-value	BiU-BiC	p-value
Obs.	8 373	4 186	4 184	-4 187	n.a.	-4 189	n.a.	2	n.a.
Sector weights									
Communications	8.46	10.64	4.09	2.18	0	-4.37	0	6.55	0
Industrial	12.3	10.36	11.88	-1.94	0	-0.42	0.52	-1.52	0.03
Financial	16.87	23.69	13.44	6.82	0	-3.43	0	10.25	0
Consumer non-cyclical	3.64	2.24	4.67	-1.4	0	1.03	0.01	-2.43	0
Consumer cyclical	13.69	12.04	14.97	-1.65	0.01	1.28	0.06	-2.93	0
Real estate	2.22	2.75	2.07	0.53	0.08	-0.15	0.63	0.68	0.05
Basic materials	6.51	1.92	6.14	-4.59	0	-0.37	0.45	-4.22	0
Energy	5.56	0.16	6.14	-5.4	0	0.58	0.2	-5.98	0
Utilities	2.92	0.57	1.9	-2.35	0	-1.02	0	-1.33	0
Technology	21.66	27.74	26.65	6.08	0	4.99	0	1.09	0.27
Healthcare	6.19	7.88	8.04	1.69	0	1.85	0	-0.16	0.82
Climate metrics									
Carbon intensity	68.44	2.26	12.64	-66.18	0	-55.8	0	-10.38	0
Modified Carbon Intensity	68.44	45.92	17.78	-22.52	0	-50.66	0	28.14	0
ITR	2.92	1.3	1.69	-1.62	0	-1.23	0	-0.39	0
Modified ITR	2.92	1.45	1.7	1.47	0	1.22	0	-0.25	0
Geographic exposures									
Emerging Asia	17.1	13.09	13.36	-4.01	0	3.46	0	-0.27	0.74
Europe	17.11	17.68	19.7	0.57	0.44	4.42	0	-2.02	0.02
Developed Asia / Pacific	10.84	7	7.39	-3.83	0	5.2	0	-0.39	0.52
North America	53.33	61.14	58.3	7.81	0	-13.94	0	2.84	0.01
Latin America	1.31	0.86	1.15	-0.45	0.03	1.08	0.5	-0.29	0.22
Africa	0.31	0.23	0.1	-0.08	0.54	-0.22	0.04	0.13	0.23

Table 5: Main Statical tests

5.5 Robustness check

Table H presents a comprehensive examination of key descriptive statistics derived from resampled data, encompassing variables pertinent to carbon intensity, ITR metrics, carbon performance decomposition, emerging countries weights and utilities sector weights. These statistics are avalable across Cap-weighted, BiU and BiC strategy. The dataset under scrutiny offers insights into the central tendencies, dispersion, shape, and quartile distributions characterizing the resampling outcomes.

The results from Table 18 consistently reject the normality assumptions across variables, as indicated by the Shapiro-Wilk, Jarque-Bera, and Kolmogorov-Smirnov tests. This rejection is largely attributed to the presence of outliers within various sectors, which persistently distort the data distributions even after resampling attempts. Additionally, the pervasive rejection of normality assumptions highlights the limitations of relying solely on parametric techniques, necessitating consideration of alternative non-parametric approaches or transformations to ensure the validity of statistical inferences. The results from Table 18 are corroborated by two series of graphs, 8 and 11, displaying Q-Q plots and density plots of the resampled variables. These graphical representations further underscore the departure of the data distributions from normality, aligning with the findings of the normality tests. The Q-Q plots reveal systematic deviations from the diagonal line, indicative of non-normal distributions, while the density plots exhibit skewed or multi-modal distributions, further confirming the presence of outliers and non-Gaussian behavior. These visualizations provide additional support for the need to employ robust statistical techniques and outlier detection strategies in analyzing results.

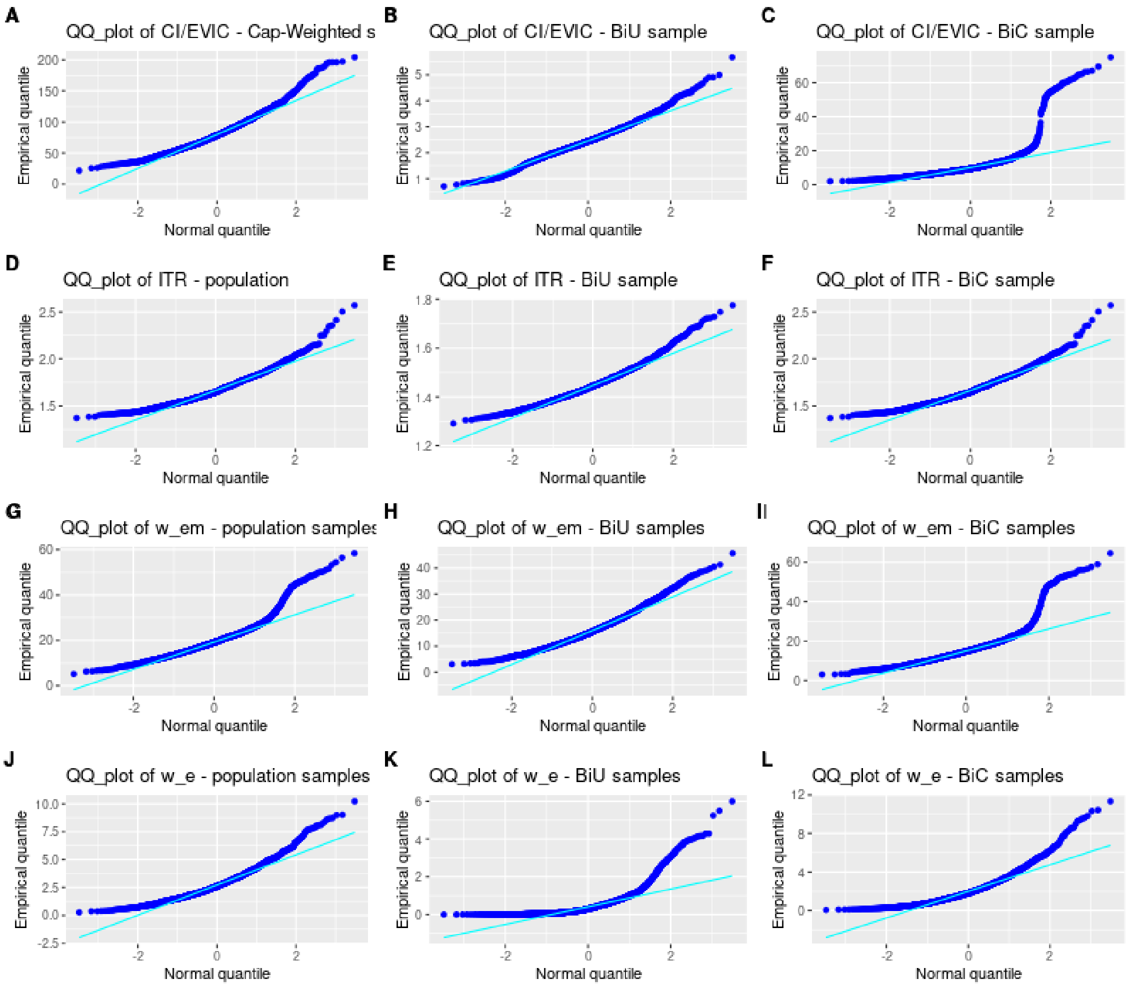

Figure 8: QQ plots of bootstrapped metrics
Source: author's calculations

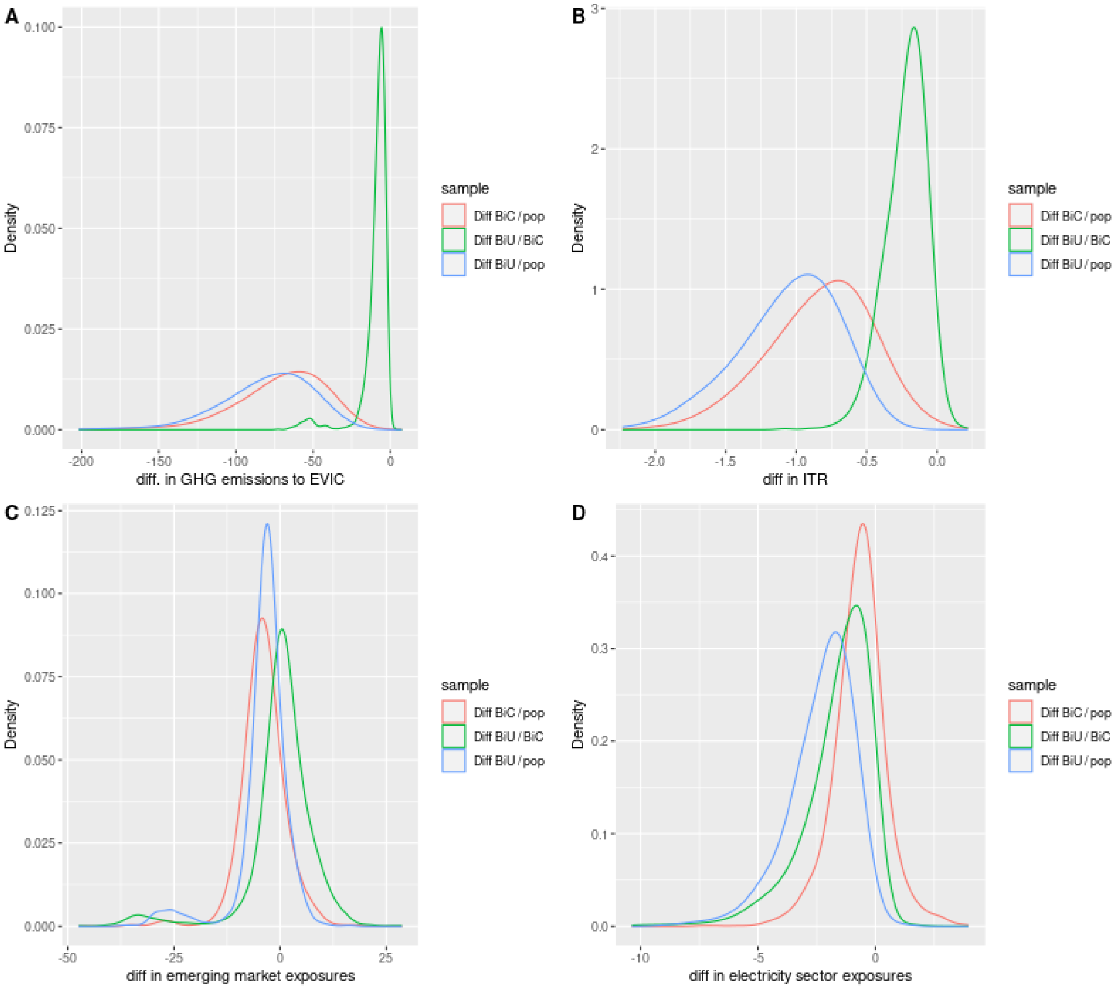

Figure 9: Density of differences metrics

Table 6 presents the carbon metric differences in terms of quartiles (median, P95, P99, P99.5). The median **CI** gap between the BiU strategy and the CW strategy is -66.1 tCO_2/M\$ invested. The gap is lower than -23.8 tCO_2/M€ in only 0.5% of cases. By construction, the BiU strategy consistently exhibits a lower **CI** compared to the CW strategy. The median **CI** gap between the BiC and CW strategies is -55.4 tCO_2/M\$ invested. This gap falls below -16.4 tCO_2M\$ in only 0.5% of cases. By design, the BiC strategy consistently maintains a lower **CI** compared to the CW strategy. The **CI** difference between the BiU and BiC strategies is -10.3 tCO_2/M\$ invested and is never positive by design. This order is maintained for the results in terms of ITR. The ITR of the BiC strategy is lower than that of the BiU strategy in only 3% of the samples.

Table 7 allows for testing whether the mean of the resampled **CI** from the BiU strategy

	mean	sd	$Q_{0.5}$	$Q_{0.90}$	$Q_{0.95}$	$Q_{0.99}$	$Q_{0.995}$	$P(X>0)$
ΔCI_{BiU}	-69.83	25.15	-66.13	-41.61	-36.06	-26.07	-23.79	0.00
ΔCI_{BiC}	-59.57	24.00	-55.42	-32.92	-27.05	-19.39	-16.42	0.00
$\Delta CI_{BiUvsBiC}$	-10.26	9.33	-6.89	-3.08	-2.43	-1.49	-1.23	0.00
ΔITR_{BiU}	-1.64	0.59	-1.53	-1.01	-0.90	-0.72	-0.62	0.00
ΔITR_{BiC}	-1.32	0.63	-1.23	-0.65	-0.45	-0.17	-0.05	0.00
$\Delta ITR_{BiUvsBiC}$	-0.32	0.34	-0.19	-0.04	-0.00	0.02	0.04	0.01
Δw_e^{BiU}	-0.02	0.02	-0.02	-0.01	-0.01	-0.00	0.00	0.01
Δw_e^{BiC}	-0.01	0.01	-0.01	0.00	0.01	0.02	0.02	0.17
$\Delta w_e^{BiUvsBiC}$	-0.02	0.01	-0.01	-0.00	-0.00	0.00	0.00	0.02
Δw_{EM}^{BiU}	-0.04	0.06	-0.03	0.01	0.02	0.06	0.08	0.16
Δw_{EM}^{BiC}	-0.04	0.04	-0.04	0.01	0.03	0.10	0.12	0.13
$\Delta w_{EM}^{BiUvsBiC}$	0.09	8.13	0.75	10.23	15.04	16.18	0.58	

Table 6: Quantiles of differences metrics

is significantly lower than that of the BiC strategy. The Student's t-statistic stands at -49.1, while the critical value of $F_{0.99} = -3.8$ was obtained from the empirical centered reduced distribution of resampled data. As the t-statistic is lower than the critical value, the null hypothesis of equal means is rejected with a 99% confidence level. Similarly, for the ITR, the t-statistic is -41.6, significantly lower than the resampled critical value of -3.5. Thus, the null hypothesis of equal means is rejected. Therefore, Hypothesis 1 is validated by our various statistical tests: the BiU strategy outperforms the BiC strategy in terms of **CI** and ITR.

The analysis of the Table H reveals a notable disparity between the mean and median values of allocation effects associated with the BiU and BiC strategies. Specifically, it is observed that both the mean and median allocation effects of the BiC strategy surpass those of the BiC counterpart, standing at respectively -47.03 tCO_2/M\$ and -42.80 tCO_2/M\$ for the BiU strategy, while standing at -11.85 tCO_2/M\$ and -10.60 tCO_2/M\$ for the BiC strategy. The interquartile range is between $[-58.4; -32.6]$ for the BiU strategy, compared to $[-18.8; -3.3]$ for the BiC strategy. This observation suggests distinct characteristics in the allocation and selection strategies employed by the two approaches. The statistics observed indeed validate **Hypothesis 2** (The BiU decarbonization performance is more driven by allocation effects than the BiC decarbonization performance).

In Table 16, the exposure to utilities sector (i.e. mainly the electricity sector) is also lower in both the BiU and BiC strategies compared to the CW strategy, in mean and median.

The average exposure to utilities sector for the cap weighted strategy stands at 3.11% in the bootstrap sample, with an interquartile range of $[1.90\%; 3.97\%]$. On the contrary, the BiU and BiC strategy have an average exposure to the electricity sector respectively of 0.66% and 2.19%, with interquartile ranges respectively of $[0.11\%; 0.86\%]$ and $[1.01; 2.97]$. According to Table 7, these underexposures are statistically significant when testing on the resampled data. The z-stat for the difference in weight for the electricy sector relative to the CW strategy is $z - stat = -72.72$, for the BiU strategy, well below the resampled critical value of -3.0, for a $\alpha = 1\%$ confidence level. Conversely, the $z - stats = -33.9$ for the BiC strategy is well below the resampled critical value of -2.96, with a confidence level $\alpha = 1\%$. We reject the null hypothesis of equal weights of electricity sector between the CW strategy and the BiU strategy and between the CW strategy and the BiC strategy. Overall, the **Hypothesis 3** (BiU and BiC strategies significantly reduce investors' exposure to the electricity sector compared to an equivalent market portfolio) is verified.

According to Table 7, the difference in weights of utilities / electricity sector between the BiU strategy and the BiC strategy is significant. The t-stat stands at -48.54 with a resampled critical value of -3.47 for a confidence level $\alpha = 1\%$, rejecting the null hypothesis of equality of weights in mean. As a consequence, the **Hypothesis 4** (BiU strategy has lower exposure to the electricity sector than BiC strategy) is validated: the BiU sampling strategy as significantly lower exposure to the electricity sector than the BiC sampling strategy.

In Table 17, the exposure to emerging markets is lower in both the BiU and BiC strategies compared to the cap-weighted strategy, in mean and median. The average exposure to emerging markets for the cap weighted strategy stands at 19.6% in the bootstrap sample, with an interquartile range of $[14.9; 22.9]$. On the contrary, the BiU and BiC strategy have an average exposure to emerging market respectively of 15.7% and 15.4%, with interquartile ranges respectively of $[10.7; 19.7]$ and $[10.0; 18.2]$. According to the Table 7, these underexposures are statistically significant when testing on the resampled data. The z-stat for the difference in weight of emerging markets relative to the benchmark is $z - stats = -31.8$, for the BiU strategy, well below the resampled critical value of -3.9, for a confidence level $\alpha = 1\%$. We reject the null hypothesis of equal weights of emerging market between the CW strategy and the BiU strategy. Conversely, the $z - stats = -41.9$ for the BiC strategy is well below the resampled critical value of -2.5, for a confidence level $\alpha = 1\%$. As a consequence, the null hypothesis of **Hypothesis 5** is accepted : BiU and BiC strategies significantly reduce investors' exposure to emerging markets. Moreover, the difference in weight of emerging markets between the BiU strategy and the BiC strategy is not significant. The t-stat stands at 1.46 with a critical value at 4.01.

Conversely, the Modified Carbon Intensity statistic is calculated on the two substets. The BiU strategy ($CI^*_{BiU} = 49.4$) is penalized compared to the BiC ($CI^*_{BiC} = 24.5$). The statistic aims to penalize allocations effects by the BiC strategy and under-investment in the electricity sector. Hence, one clearly observe the limitations of the two major indicators currently used, namely carbon footprint and ITR, as these two climate impact assessment metrics favor exclusionary strategies targeting specific sectors over a systematic transition toward a low-carbon economy.

	t-stat	p-value	w-stat	p-value	$F_{0.95}$	$F_{0.975}$	$F_{0.99}$	$F_{0.995}$
$\Delta CI_{BiU,CW}$	-124.17	0.00	0.00	0.00	-1.90	-2.38	-2.83	-3.31
$\Delta CI_{BiC,CW}$	-111.01	0.00	0.00	0.00	-1.87	-2.37	-2.96	-3.27
$\Delta CI_{BiU,BiC}$	-49.15	0.00	0.00	0.00	-2.22	-2.92	-3.78	-4.31
$\Delta ITR_{BiU,CW}$	-124.27	0.00	0.00	0.00	-1.80	-2.51	-3.49	-4.10
$\Delta ITR_{BiC,CW}$	-94.08	0.00	807.00	0.00	-1.75	-2.35	-3.21	-3.76
$\Delta ITR_{BiU,BiC}$	-41.64	0.00	5608.00	0.00	-2.19	-2.56	-3.53	-3.80
$\Delta Weight^{utilities}_{BiU,CW}$	-72.72	0.00	2694.00	0.00	-1.84	-2.42	-3.04	-3.53
$\Delta Weight^{utilities}_{BiC,CW}$	-33.88	0.00	210787.00	0.00	-1.79	-2.33	-2.96	-3.57
$\Delta Weight^{utilities}_{BiU,BiC}$	-48.54	0.00	10686.00	0.00	-1.82	-2.60	-3.47	-4.76
$\Delta Weight^{Emerging}_{BiU,CW}$	-31.81	0.00	181708.00	0.00	-2.44	-3.29	-3.89	-4.26
$\Delta Weight^{Emerging}_{BiC,CW}$	-41.94	0.00	174004.00	0.00	-1.48	-1.94	-2.43	-2.64
$\Delta Weight^{Emerging}_{BiC,CW}$	1.46	0.14	1319770.00	0.00	-2.48	-3.52	-4.01	-4.24

Table 7: Hypothesis Testing on differences

6 Discussion

This study highlights concerns about current indicators, focusing on **CI** and **ITR**, and investment strategies, focusing on the Best-in-Universe and Best-in-Class strategies, in climate finance. It examines whether these strategies show sectoral and geographical biases and if the indicators contribute to these biases.

BiU and BiC strategies not only impact investors but also have broader economic effects. Reducing **CI** in portfolios has costs for both investors and the economy. One major effect is the reduced presence of emerging markets in investment portfolios, along with a decrease in the electricity sector's importance.

This shift in investment strategies aims to align portfolios with sustainability goals. By prioritizing lower **CI**, investors move capital away from high-carbon sectors and regions, including many emerging markets. This can limit these markets' access to capital, hindering their development and increasing global inequalities.

The BiU strategy tends to exclude several sectors, especially the electricity sector, which is crucial for economic activity. This sector is also underweighted in the BiC strategy compared to a Cap Weighted strategy. This suggests that exclusionary strategies, while aiming for sustainability, may encourage superficial tactics rather than genuine efforts.

The decline in the electricity sector's prominence shows the impact of sustainability-driven investment strategies. As investors move towards low-carbon alternatives, traditional electricity providers, especially those using fossil fuels, may reduce their investments in cleaner energy sources. While necessary for climate change, these transitions have costs and socioeconomic implications, especially for regions relying on legacy energy infrastructure.

Due to underinvestment in the energy sector, usual metrics like carbon intensity and ITR are not relevant for portfolio construction based on exclusions. Corrections reduce carbon performance but still outperform the market. Therefore, it's essential to evaluate investment portfolios not only on these criteria but also on their ability to invest in green CAPEX, as highlighted by the European taxonomy (2020).

However, this may not be enough. Regulators must encourage renewable and decarbonized energy actors to raise funds from investors. This includes facilitating market access, especially through IPOs, and possibly spinning off renewable energy subsidiaries of carbon-intensive companies to attract investors.

Reducing investments in emerging markets contradicts the goal of transition given their energy mix, as well as the Sustainable Development Goals (SDG) of the United Nations. However, these markets are a small part of global capitalization. To support the transition, investments in emerging markets must be encouraged. This requires facilitating investment flows from northern to southern countries and overcoming the Lucas paradox. Emerging countries need more ambitious strategies, and European institutional investors must adapt their rules. Facilitating the issuance of securities by companies from emerging markets on developed markets would improve their financial integration.

Markets alone may not solve these issues due to currency risks and institutional constraints. Public authorities must also be involved. Development banks and state-sponsored funds can raise more funds than the market. This requires fair risk-sharing between investors, public authorities, and actors in emerging markets.

Blended finance, defined as the strategic use of development finance and philanthropic funds to mobilize private capital flows to emerging and frontier markets, can increase investment leverage. It ensures attractive returns for investors, equitable risk-sharing, and aligned interests. However, these strategies need more assets under management and stronger incentives from public authorities, especially through taxation.

The Environmental Kuznets Curve explains these trends. Emerging economies often use high-pollution energy technologies, leading to high **CI**. Investors aiming for environmental considerations may reduce financing to these countries instead of supporting their transition.

Historically, developed nations have emitted more GHGs than emerging ones. Reducing financial support to emerging economies based on their high **CI** raises fairness questions. Climate short-termism may lead emerging economies to ignore Paris Agreement commitments, arguing that developed nations, major historical contributors to climate change, are now withdrawing financial support.

From a theoretical perspective, the aging population and slowing growth in northern countries require increased investment in southern countries, where birth rates are high. For optimal intergenerational balance, developing these financial flows would improve the economic situation in a Pareto sense. Simplistic climate criteria could reduce these flows, moving the global economy away from an optimal situation. Increased focus on environmental criteria can negatively impact social criteria, affecting both the development of southern countries and the financing of pensions in northern countries.

The highly efficacious strategies of BiU and BiC in terms of **CI** inadvertently engender externalities, particularly evident in the diminished financial allocations to pivotal sectors and emerging economies. Forward-looking metrics such as the Intensity Transition Ratio (ITR) have been conceptualized to calibrate the pace of decarbonization across sectors and economies, employing the Sector Decarbonization Approach. Empirical findings reveal that short-termist BiU and BiC strategies, anchored in **CI**, exhibit notable proficiency in terms of ITR. Paradoxically, sectors characterized by heightened **CI** encounter challenges in securing commensurate budgets for decarbonization initiatives. Thus, the ITR emerges as a flawed metric, failing to internalize the external costs associated with BiU and BiC strategies.

The study questions the effectiveness of environmental criteria integration by private actors and the market. While integrating climate criteria is a significant step in holding financial actors accountable, there is no guarantee that the resulting price signal will lead to a Pareto-improving situation without substantial changes in the investment supply. The usual criteria used (carbon intensity and ITR) can therefore be very insufficient, even misleading, and pure exclusion strategies (BiU and BiC) can delay the transition if not accompanied by ad-hoc investments in renewable energy companies and targeted investments, such as green bonds or sustainability-linked bonds.

In essence, while the pursuit of lower **CI** represents a commendable endeavor towards sustainability, it necessitates a nuanced understanding of its broader economic ramifications. Efforts to mitigate carbon emissions within investment portfolios must be accompanied by strategies to mitigate adverse socioeconomic impacts, ensuring a just transition towards a sustainable future. Thus, while the observed reduction in **CI** signifies progress towards environmental objectives, it also underscores the imperative for holistic approaches that reconcile sustainability imperatives with broader economic considerations.

7 Conclusion

Private and public initiatives have strongly emphasized Carbon Emissions to EVIC (**CI**) intensity as a benchmark indicator, and this metric of climate performance is now widely used as a reference indicator, both for communication with institutional investors and for products aimed at private investors such as ETFs. This article has highlighted the limitations of **CI**, both in terms of financing essential sectors and for emerging countries that will need to play an active role in the decarbonization of the global economy.

Both Best-in-Class and Best-in-Universe strategies exhibit excellent climate performance in terms of **CI**. However, far from aiding in financing the transition, these two exclusion strategies pose a risk to energy transition. On the one hand, they reduce funding for the most polluting sectors that require significant investment to transition. On the other hand, they reduce funding for emerging countries, which have accounted for global emissions during the globalization of the last thirty years. Concentrating portfolios on sectors and countries that have little effort to make to align their emissions with the Paris Agreement seems entirely counterproductive in the face of the climate warming challenge.

The Implied Temperature Rise aims to be a forward-looking indicator of impact materiality. This metric was developed based on the work of the IPCC, evaluating companies' decarbonization trajectories. It corresponds to the global temperature increase if the entire global economy were to over- or under-emission greenhouse gases compared to the budget defined by the IPCC in the same way as the company's trajectory exceeds its $1.5°C$ budget. Each company's budget depends on its sector and geographical location. By doing so, proponents of the ITR hoped to limit the sector-based exclusion induced by short-term measures such as **CI**.

This article has demonstrated that the ITR is a highly imperfect indicator of climate performance since short-termist strategies, such as BiU and BiC, are not penalized. They maintain excellent performance in terms of ITR. Far from internalizing the externalities of these strategies, the ITR provides additional comfort to investors implementing them by suggesting that their portfolio would effectively transition if the entire economy followed their example. This is obviously not the case for our BiU and BiC strategies, which underinvest in sectors at the forefront of the transition.

To support a just and effective transition, more ambitious investment strategies are needed, along with facilitating financial flows from northern to southern countries. Blended finance initiatives can play a key role in mobilizing private capital for emerging markets but require stronger incentives and better integration of social and environmental criteria.

Two indicators have been proposed to correct the limitations of the Carbon intensity and the ITR. They involve penalizing the effects of sectoral and geographical allocation by correcting **CI** and the ITR. The climate performance of BiU and BiC strategies is then widely questioned by these indicators. These indicators would encourage the implementation of sector-neutral and country-neutral strategies to avoid the external costs of exclusion strategies. Further research is needed on the quality of these indicators, particularly in terms of parameterization. Some under-allocations, such as in the oil sector, could, for example, be tolerated, and over-exposure to renewable energy sectors favored.

Another area of further research is portfolio optimization using these indicators. The literature review has shown that many additional constraints are imposed by quantitative finance researchers to address the limitations of **CI**. Sectoral weight limits are notably integrated into optimization programs. It will be necessary to verify whether CI and ITR can do without multiple constraints to more effectively define investment portfolios favoring energy transition.

The study does not evaluate the impact of these allocation strategies on market returns/prices. In theory, the capital cost for the most polluting actors should increase as these climate-related extra-financial criteria are considered. This topic is covered in the second chapter of the thesis. Additionally, the criteria used are impact criteria of portfolios on the environment, not financial materiality criteria: the impact of warming on portfolio performance. These two topics are covered in the other chapters of the thesis.

A GHG definitions

Giese et al. (2023) have proposed a taxonomy of climate related metrics. First, several definitions regarding greenhouse gas emissions mean at company level are provided.

Definition A.1 (Green House Gases Emissions)**.** GHG emissions of a given company refer to the release of gases into the atmosphere that contribute to the greenhouse effect, trapping heat and causing global warming. GHG emission may result from its operations, including manufacturing, transportation, and other activities.

These emissions can come from a variety of sources, such as burning fossil fuels for energy, industrial processes, and transportation of goods and people. The main types of GHG emissions include carbon dioxide (CO_2), methane (CH4), nitrous oxide (N2O), and fluorinated gases. Measuring and reducing GHG emissions is an important part of corporate sustainability, as it helps to mitigate climate change and its impacts on the environment and society.

Moreover, GHG emissions are generally divided into three different scopes, depending on the direct or indirect production by the company.

Definition A.2 (Scope 1 GHG Emission)**.** Scope 1 emissions are direct emissions, generated by own activities and operations of a given firm.

As burning fossil fuels to generate heat or power in their facilities, operating their own vehicles, or releasing process emissions from their manufacturing processes are considered as Scope 1 GHG Emissions.

Definition A.3 (Scope 2 GHG Emission)**.** Scope 2 are indirect GHG emissions, resulting from the generation of purchased electricity, heating, or cooling consumed by a firm. As a consequence, scope 2 emissions are generated by third-party entities, supplying energy to a firm.

These companies notably includes electricity utilities and are often reported using location-based or market-based emission factor. Despite they rely on a model, scope 2 emissions are quite robust, because electricity mix are rather stable.

Definition A.4 (Scope 3 GHG Emission)**.** Scope 3 emissions refer to all other indirect emission occuring during the value chain of the firm, including upstream and downstream activities.

For example, on the upstream, the extraction, production and transportation of raw materials necessary to the production of outputs are considered as Scope 3 emission. On the downstream scope 3 include the the transportation of outputs and emissions due to the use of the products by customers. For most companies, it is the largest source of GHG emissions. For instance, automobile makers have a large Scope 3 due to the gasoline used by the buyers of their cars. There is a large double counting of in scope 3 emissions. For instance, the gasoline used by cars are counted for automobile makers and oil and gas companies.

B Carbon Intensity to EVIC : a static climate impact metric

Giese et al. define Carbon Emissions to EVIC Intensity (in short "carbon intensity" or "**CI**") as

> "The current climate impact metric which indicates the amount of GHG emissions (in metric tons) an investor would be responsible for per USD 1 million of financing of a company. Depending on the use case, a company's GHG emissions can be based on Scopes 1, 2 or 3, either individually or on a combined basis."

The metric at time t $CI_i(t)$ is computed as the GHG emissions of company i at time t $GHG_i(t)$ divided by the EVIC of company i at time t denoted $EVIC_i(t)$. EVIC stands for "Enterprise Value Including Cash," a measure of a company's total value aggregating both its market capitalization (the value of its outstanding shares) and its gross debt. Therefore, the GHG or Carbon Emissions to EVIC intensity ("CI"), denoted CI_i is generally expressed in tonnes of CO_2 emitted per million dollars invested.

$$CI_i(t) = \frac{GHG_i(t)}{EVIC_i(t)}$$

The carbon footprint makes it possible to determine the financed emissions of a portfolio P at time t, denoted $FE_P(t)$, i.e. the carbon emissions attributable to the portfolio as a whole, by multiplying the carbon footprint of each asset i by the exposure of the portfolio $EX_i(t)$ to the given asset. By denoting EX, the vector of exposure at time t and CI the vector of CI.

$$FE_P = CI \cdot EX$$

Consequently, the **CI** of the portfolio is written directly as the average of the **CI** weighted by the weight of each asset/issuer in the portfolio w_i, as is refered as the Weighted Average Carbon Intensity or WACI_P. By denoting w the vector of asset weights in the portfolio, the formula of WACI is the following:

$$\text{WACI}_P = w^T \cdot CI$$

Giese et al. suggests the **CI** is one of the most widely used and popular measures of climate impact for several reasons. On the one hand, it is recommended by several regulatory bodies and private initiatives. This is therefore the key metric according to the Net Zero initiative, in terms of commitments. In addition, it is possible to make a carbon performance attribution of a portfolio against its benchmark, using this metric.

However, the measure is not free from criticism. On the one hand, it is sensitive to changes in market values: when the EVIC increases (rise in market capitalization), the **CI** decreases. This element should therefore be corrected to dynamically compare two **CI**. In its 2019 report, the group of technical experts on sustainable finance (TEGSF (2019)), recommends correcting the **CI** measurement of the portfolio by taking into account the ratio between the average EVIC of the period $E\bar{V}IC(t)$ with the average EVIC of the reference period $E\bar{V}IC(0)$.

$$\text{WACI}_P = w^T \cdot CI \, \frac{E\bar{V}IC(t)}{E\bar{V}IC(0)}$$

Moreover, **CI** is a static measure, it does not take into account the climate scenario and the carbon footprint reduction trajectories set by companies or States.

C Implied Temperature Rise : a dynamic climate impact metric

The Implied Temperature Rise (”ITR” thereafter) measures a company’s climate impact based on the validated and modeled carbon trajectory of its consumption / production of GHG by 2050. The ITR calculates the probable rise in temperatures over global level if the entire global economy achieved the same carbon budget overrun as the emitter. The ITR is therefore based on carbon emission projections, known as the carbon trajectory. This can be presented by the issuer, possibly validated by third-party organizations such as the Science Based Target Intiative (or ”SBTI”), or even modeled by the data provider.

In addition, the ITR requires the definition of a carbon budget specific to each emitter which is consistent with the 2°C scenarios of the IPCC (2018). If the cumulative GHG emissions projected by 2050 are lower than the budget, then there is a carbon trajectory is said to be undershooting, otherwise it is said to be overshooting.

$$\text{Absolute Overshoot/Undershoot} = \text{Projected GHG emissions} - \text{Carbon Budget}$$

$$\text{Relative Overshoot/Undershoot} = \frac{\text{Projected GHG emissions}}{\text{Carbon budget}} - 1$$

The ITR of the emitter is then calculated around the budget of a 2° warming using the Transient Climate Response to Cumulative Carbon Emissions (TCRE) established by the IPCC (2018) at 0.000545°C, which corresponds to the increase in temperature due to each gigatonne of CO_2e emitted around the 2°C budget. The global carbon budget retained by MSCI is 1491 GtCO_2 between 2020 and 2050 to limit global warming to 2°C. This budget is based on the work of the IPCC.

$$ITR_i = 2\% + \text{Relative Overshoot/Undershoot} \times TCRE \times \text{Global Carbon Budget}$$

The ITR of a portfolio cannot be calculated as the average ITR of the assets weighted by their weight in the portfolio. Indeed, the aggregated overshoot/undershoot is not equal to the average overshoot of the portfolio. The overshoot used for the calculation of the ITR is a relative overshoot, whereas the calculation of the ITR of a portfolio must be done on the basis of the weighted absolute overshoot.

In addition, the absolute overshoot/undershoot of an issuer must be broken down between the different types of contributors of capital, creditors or shareholders. In the classic case, the excess CO_2e emission is allocated proportionally to the weight of the exposure in the financial structure. It should be specified that this means that an equity exposure of an amount K will have the same share of the excess issue as a debt exposure of an amount K, regardless of the maturity of the debt. Implicitly, this amounts to considering that debt exposures will be rolled over and reinvested in the same issuers and that the allocation proportions between issuers will be maintained perpetually until 2050.

Giese et al. (2023) provide the following formula to compute the ITR of a portfolio:

$$ITR_P = 2\% + \frac{\sum_{i=1}^{I} \ E(i) \ \frac{O(i)}{EVIC(i)}}{\sum_{i=1}^{I} \ E(i) \ \frac{B(i)}{EVIC(i)}} \times TCRE \times GB$$

With:

- $E(i)$ the exposure of the portfolio to the i^{th} issuer
- $O(i)$ the absolute overshoot (undershoot) of the issuer i
- $EVIC(i)$ is the Enterprise Value Including Cash of the issuer i
- $B(i)$ is the given carbon budget of the issuer i, defined according to the guidelines of the NGFS, taking into account for the country and the sector of the issuer
- $TCRE$ the Transient Climate Response to Cumulative Carbon Emissions (TCRE) established by the IPCC (2018) at 0.000545°C
- GB the Global Carbon Budget is the sum of carbon emissions to limit the global warming at 2°C, defined by the IPCC (2018) at 1,491 GtCO_2e.

D Carbon Performance Attribution

By design, an underexposure of BiU and BiC strategies to the most carbon-intensive sectors could be anticipated, while these strategies favor the least carbon-intensive sectors. This outcome poses a problem from the perspective of economic agents' welfare, because highly carbon-intensive sectors are sometimes vital to the economy, as is the case with the energy sector. An effective transition requires significant investments in the electricity sector, as emphasized by the International Energy Agency. As a consequence, if the carbon outperformance of a strategy stems from under-allocation to a vital sector, the investor following this kind of strategy could be considered as acting as a free-rider, because this kind of investors benefits from the production of a sector without contributing to its financing and the investments necessary for its decarbonization. To evaluate this item, a carbon performance attribution analysis of the portfolio has been untertaken.

The carbon performance attribution approach draws inspiration from the financial performance attribution framework proposed by Brinson et al. (1986). It serves to elucidate performance differentials among various factors, primarily the sectoral allocation of the portfolio, intra-sector security selection, and a residual effect termed interaction effect. Within the context of a portfolio's carbon footprint analysis, performance differentials are discerned based on the relative sectoral allocation within the investment universe and security selection within each sector. A residual factor persists, referred as the interaction effect.

$$E_C^P - E_C^B = \underbrace{[w_P - w_B]^T \cdot E_B}_{\text{allocation}} + \underbrace{[E_P - E_B]^T \cdot w_B}_{\text{selection}} + \underbrace{[E_P - E_B]^T \cdot [w_P - w_B]}_{\text{interaction}}$$

The performance attribution has been simplified into two components: an allocation effect and a selection effect, aiming to isolate, on one hand, the deviation in sectoral allocation, and on the other hand, the effect of reducing the carbon footprint through security selection within each sector. In this context, our interaction effect vanishes.

$$E_C^P - E_C^B = \sum_{j=1}^{J} w_j^P E_i - w_j^B E_j$$

$$E_C^P - E_C^B = \sum_{s=1}^{S} w_s^P E_s^P - w_j^B E_s^B$$

$$E_C^P - E_C^B = w_P^T E_P - w_B^T E_B$$

$$E_C^P - E_C^B = \underbrace{[w_P - w_B]^T \cdot E_B}_{\text{allocation}} + \underbrace{[E_P - E_B]^T \cdot w_P}_{\text{selection}}$$

The **WACI** of each sector is defined as follows.

$$CI_{sector} = \frac{\sum_{i=1}^{J} w_i^{BIC} \cdot CI_i}{\sum_{i=1}^{J} w_i^{BIC}}$$

Likewise, the carbon contribution of each sector s corresponds to the share of the carbon footprint of the strategy attributable to sector s. It is calculated by summing the contributions of each title i of sector S, product of the weight of title i and its **CI**.

$$Contrib_{sector} = \sum_{i=1}^{J} w_i^{BIC} \cdot CI_i$$

E Statistical tests used

$$T - test = \begin{cases} H_0: & \mu_{strat} = \mu_{pop} \\ H_1: & \mu_{strat} \neq \mu_{pop} \end{cases}$$

The Student's t-test statistic is calculated using the formula:

$$\text{T-stat} = \frac{\bar{\mu}_{strat} - CI_{pop}}{\sigma_{pop}\sqrt{\frac{1}{n_{strat}}}}$$

The Student's t-test operates on the null hypothesis that the means of the two samples are equal and generates a p-value indicating the probability that the observed differences are due to chance. If the p-value falls below a pre-defined threshold (typically 0.05), the null hypothesis is rejected, and it is concluded that there exists a significant difference between the means of the two samples.

If the p-value falls below a pre-defined threshold (typically 0.05), the null hypothesis is rejected, and it is concluded that there exists a significant difference between the means of the two samples. The equality of means across multiple carbon performance metrics have been tested, such as the Carbon Emissions to EVIC intensity and the ITR. To test these hypotheses, statistical tests have been performed on our entire sample, comprised of the stocks in the MSCI ACWI index. The statistical test commonly employed to compare two empirical means is the Student's t-test.

In the hypothesis 3, the test assess the difference between two observed proportions $F_{sample} = F_{strat}$ from two samples (BiU and BiC) relative to the population $F_{pop} = F_{CW}$. The test is as follows.

$$Z - test = \begin{cases} H_0: & F_{sample} = F_{pop} \\ H_1: & F_{sample} \neq F_{pop} \end{cases}$$

The test statistic for the Z-test is calculated using the following formula:

$$Z_{stat} = \frac{F_{sample} - F_{pop}}{\sqrt{(F_{pop}(1 - F_{pop})\frac{1}{n_{sample}}}}$$

where:

- $F_{sample} = F_{strat}$ is the sample proportion of the sample, i.e. the weight in the tested strategy

- $F_{pop} = F_{CW}$ is the sample proportion of the full sample, i.e. the weight in the tested strategy (Cap Weighted in MSCI ACWI)

- $n_{strat} = n(sample)$ is the sample size of the tested strategy strategy

This Z-statistic approximately follows a standard normal distribution under the null hypothesis of no difference between the two proportions. If the absolute value of the test statistic exceeds the quantile of the standard normal distribution at a given confidence level of $1-\alpha/2$, then the null hypothesis is rejected.

The usual statistical test for this type of hypothesis is a test of equality of proportions between two samples, described below.

$$Z - test = \begin{cases} H_0 : & F_{strat} = F_{CW} \\ H_1 : & F_{strat} \neq F_{CW} \end{cases}$$

Frequency denotes the weight of sectors within each strategy, as well as the weight of emerging countries. Emerging countries encompass the cumulative weights of Emerging Asia, Latin America, and Africa. The test statistic for the Z-test is calculated using the following formula:

$$Z_{stat} = \frac{F_{strat} - F_{CW}}{\sqrt{\left(\frac{F_{strat}(1-F_{strat})}{n_{strat}}\right) + \left(\frac{F_{CW}(1-F_{CW})}{n_{CW}}\right)}}$$

where:

- F_{strat} is the sample proportion of the tested strategy

- F_{CW} is the sample proportion of the benchmark strategy

- n_{strat} is the sample size of the tested strategy

- n_{CW} is the sample size of the benchmark strategy

F Descriptive statistics

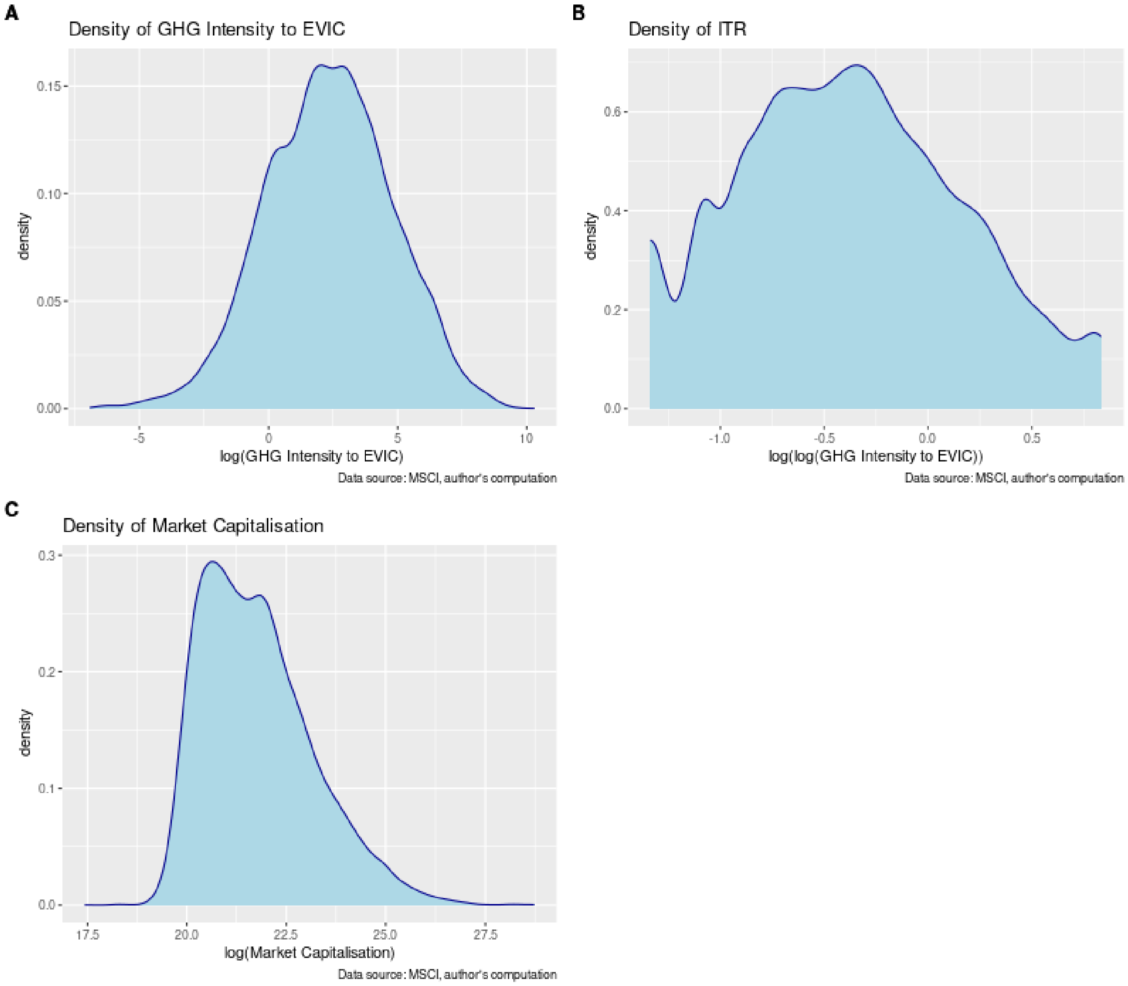

Figure 10: Density of financial and carbon metrics (full sample)

	GICS LEVEL 1	n	min	q1	median	mean	q3	max	sd
1	Basic materials	1026.00	0.00	31.45	115.62	451.91	389.68	11097.58	992.90
2	Communications	525.00	0.00	0.51	1.78	9.47	7.55	377.92	25.92
3	Consumer cyclical	1325.00	0.00	5.90	17.03	48.80	42.84	3919.36	158.55
4	Consumer non-cyclical	336.00	0.09	15.02	40.37	94.65	90.41	3190.32	227.07
5	Energy	264.00	0.03	112.62	260.00	470.09	566.74	11636.64	866.25
6	Financial	1112.00	0.00	0.27	0.70	2.74	1.41	417.31	19.03
7	Healthcare	431.00	0.03	3.58	8.61	22.80	22.00	885.45	57.75
8	Industrial	1670.00	0.00	3.93	12.41	72.57	42.53	3940.42	211.89
9	Real estate	453.00	0.00	1.45	3.71	9.75	9.29	406.95	28.62
10	Technology	948.00	0.00	1.30	4.85	33.02	28.15	1703.13	97.91
11	Utilities	283.00	0.02	19.53	171.07	783.71	757.09	8471.09	1478.41
12	Total	8373.00	0.00	1.78	10.15	129.08	52.07	11636.64	521.84

Table 8: Carbon Emissions to EVIC (scope 1-2) by sectors as of 12/31/2024

	GICS LEVEL	n	weight	contribution	contribution (%)	$\frac{contribution}{Weight}$
1	Basic materials	1026	6.51	20.80	30.40	4.67
2	Communications	525	8.46	0.48	0.71	0.08
3	Consumer cyclical	1325	13.69	4.41	6.45	0.47
4	Consumer non-cyclical	336	3.64	1.32	1.93	0.53
5	Energy	264	5.56	14.39	21.02	3.78
6	Financial	1112	16.87	0.95	1.39	0.08
7	Healthcare	431	6.19	0.43	0.63	0.10
8	Industrial	1670	12.30	5.99	8.75	0.71
9	Real estate	453	2.22	0.14	0.21	0.09
10	Technology	948	21.66	1.84	2.70	0.12
11	Utilities	283	2.92	17.67	25.82	8.85

Table 9: Carbon Emissions contribution by sectors (GICS classification)

	REGION	n	min	q1	median	mean	q3	max	sd
1	Africa	80.00	0.09	6.95	46.28	236.67	272.89	4128.23	550.26
2	Developed Asia / Pacific	2045.00	0.00	3.38	17.67	100.37	63.11	5916.55	324.77
3	Emerging Asia	2121.00	0.00	3.05	15.75	245.15	88.17	11636.64	858.33
4	Europe	1455.00	0.00	1.08	5.56	96.38	29.52	8074.55	425.28
5	Latin America	198.00	0.01	2.23	15.51	129.25	82.58	2048.85	296.42
6	North America	2474.00	0.00	1.19	6.17	69.03	28.86	4786.52	251.58
7	Total	8373.00	0.00	1.78	10.15	129.08	52.07	11636.64	521.84

Table 10: Carbon Emissions to EVIC (scope 1-2) by region as of 12/31/2024

Sector	Obs.	Weight	Contribution	Contrib.(%)	$\frac{Contrib.}{Weight}$
Africa	80	0.31	0.59	0.86	2.77
Developed Asia / Pacific	2045	10.84	7.61	11.12	1.03
Emerging Asia	2121	17.10	30.97	45.26	2.65
Europe	1455	17.11	10.44	15.26	0.89
Latin America	198	1.31	1.17	1.71	1.30
North America	2474	53.33	17.66	25.80	0.48

Table 11: Carbon Emissions to EVIC by World regions (scope 1-2) as of 12/31/2024

	Sector	Obs.	min	q1	median	mean	q3	max	sd
1	Basic materials	1 026	1.30	2.10	2.90	3.93	4.90	10.00	2.54
2	Communications	525	1.30	1.60	1.70	1.86	2.00	9.30	0.52
3	Consumer cyclical	1 325	1.30	2.20	2.70	3.32	3.50	10.00	2.06
4	Consumer non-cyclical	336	1.30	2.10	2.60	3.07	3.60	10.00	1.50
5	Energy	264	1.30	2.80	5.10	5.52	8.90	10.00	3.05
6	Financial	1 112	1.30	1.60	1.80	2.08	2.40	10.00	0.90
7	Healthcare	431	1.30	1.60	1.80	2.08	2.10	10.00	1.23
8	Industrial	1 670	1.30	1.80	2.30	2.85	3.00	10.00	1.81
9	Real estate	453	1.30	2.10	2.70	2.80	3.30	7.50	0.90
10	Technology	948	1.30	1.80	2.50	2.74	3.00	10.00	1.49
11	Utilities	283	1.30	1.60	2.20	3.68	4.40	10.00	3.02
12	Total	8 373	1.30	1.80	2.30	2.96	3.20	10.00	1.97

Table 12: ITR by sector

	Region	Obs.	min	q1	median	mean	q3	max	sd
1	Africa	80	1.30	1.70	2.30	3.15	3.30	10.00	2.39
2	Developed Asia / Pacific	2 045	1.30	1.80	2.40	2.87	3.10	10.00	1.71
3	Emerging Asia	2 121	1.30	2.00	2.70	3.49	3.80	10.00	2.34
4	Europe	1 455	1.30	1.60	2.00	2.47	2.70	10.00	1.54
5	Latin America	198	1.30	1.80	2.40	3.02	3.18	10.00	1.97
6	North America	2 474	1.30	1.70	2.20	2.85	3.00	10.00	1.95
7	Total	8 373	1.30	1.80	2.30	2.96	3.20	10.00	1.97

Table 13: ITR by region

G Allocations by strategy

	Sector	Obs	Market Cap.	Weight	CI^{EVIC}_{1+2}	$Contrib_{1+2}$
	Capital weighted strategy					
1	Basic materials	1 026	7 227.68	6.51	319.56	20.80
2	Communications	525	9392.19	8.46	5.73	0.48
3	Consumer cyclical	1 325	15199.06	13.69	32.24	4.41
4	Consumer non-cyclical	336	4040.39	3.64	36.30	1.32
5	Energy	264	6 169.46	5.56	258.86	14.39
6	Financial	1 112	18 723.57	16.87	5.65	0.95
7	Healthcare	431	6 866.63	6.19	6.96	0.43
8	Industrial	1 670	13 657.52	12.30	48.67	5.99
9	Real estate	453	2 460.55	2.22	6.35	0.14
10	Technology	948	2 4044.10	21.66	8.52	1.84
11	Utilities	283	3 239.08	2.92	605.74	17.67
12	Total	8373	111 020.23	100.00	68.44	68.44
	Best in Universe strategy					
1	Basic materials	121	1 424.91	1.92	4.05	0.08
2	Communications	413	7 895.58	10.64	2.25	0.24
3	Consumer cyclical	498	8 936.31	12.04	4.68	0.56
4	Consumer non-cyclical	61	1 662.91	2.24	4.38	0.10
5	Energy	17	117.01	0.16	3.95	0.01
6	Financial	1 082	17 578.48	23.69	0.88	0.21
7	Healthcare	234	5 849.81	7.88	2.37	0.19
8	Industrial	761	7 687.41	10.36	4.12	0.43
9	Real estate	356	2 043.29	2.75	2.86	0.08
10	Technology	585	20 588.12	27.74	1.27	0.35
11	Utilities	58	423.96	0.57	2.77	0.02
12	Total	4186	74 207.79	100.00	2.26	2.26
	Best in Class strategy					
1	Basic materials	513	4359.22	6.14	33.93	2.08
2	Communications	262	2900.07	4.09	0.54	0.02
3	Consumer cyclical	662	10627.54	14.97	5.88	0.88
4	Consumer non-cyclical	168	3315.94	4.67	11.90	0.56
5	Energy	132	4359.99	6.14	118.33	7.27
6	Financial	556	9539.48	13.44	0.31	0.04
7	Healthcare	215	5710.47	8.04	2.21	0.18
8	Industrial	835	8436.57	11.88	4.74	0.56
9	Real estate	226	1470.07	2.07	1.44	0.03
10	Technology	474	18919.75	26.65	0.79	0.21
11	Utilities	141	1349.25	1.90	42.44	0.81
12	Total	4184	70988.34	100.00	12.64	12.64

Table 14: Allocations and contributions by strategy

H Resampling tables

	mean	sd	skew.	kurt.	$Q_{0.25}$	$Q_{0.5}$	$Q_{0.75}$	Min	Max
Carbon attribution									
Allocation BiU	-47.03	20.38	-1.11	1.84	-58.35	-42.80	-32.56	-157.38	-4.20
Allocation BiC	-11.85	14.10	-0.58	2.50	-18.78	-10.60	-3.28	-78.00	59.79
Selection BiU	-69.48	25.15	-0.87	1.06	-83.55	-65.82	-51.48	-191.70	-17.72
Selection BiC	-59.06	22.98	-1.00	1.44	-71.61	-54.76	-42.75	-175.67	-14.09
Interaction BiU	46.68	20.37	1.12	1.86	32.20	42.47	57.98	4.61	157.43
Interaction BiC	11.34	11.92	0.79	3.06	4.24	9.70	16.90	-50.57	70.02
Carbon metrics									
Carbon footprint CW	72.20	25.35	0.86	1.04	54.03	68.59	86.42	19.45	195.21
Carbon footprint BiU	2.37	0.83	1.20	2.48	1.89	2.24	2.72	0.41	5.98
Carbon footprint BiC	12.63	9.44	2.16	5.65	6.83	9.38	14.89	1.34	75.22
ITR CW	2.95	0.59	1.33	3.05	2.55	2.84	3.24	1.79	6.51
ITR BiU	1.32	0.06	4.48	22.29	1.30	1.30	1.30	1.30	1.87
ITR BiC	1.64	0.34	1.86	3.90	1.41	1.51	1.72	1.30	3.67
CI^*_{CW}	72.20	25.35	0.86	1.04	54.03	68.59	86.42	19.45	195.21
CI^*_{BiU}	49.41	20.49	1.11	1.85	34.85	45.28	60.62	8.68	160.94
CI^*_{BiC}	24.49	14.06	0.64	1.81	15.44	22.95	31.92	-39.16	88.41
ITR^*_{CW}	2.95	0.59	1.33	3.05	2.55	2.84	3.24	1.79	6.51
ITR^*_{BiU}	1.50	0.17	1.40	2.50	1.38	1.46	1.58	1.30	2.49
ITR^*_{BiC}	1.67	0.33	1.78	3.67	1.45	1.56	1.78	1.30	3.58

Table 15: Resampled carbon metrics

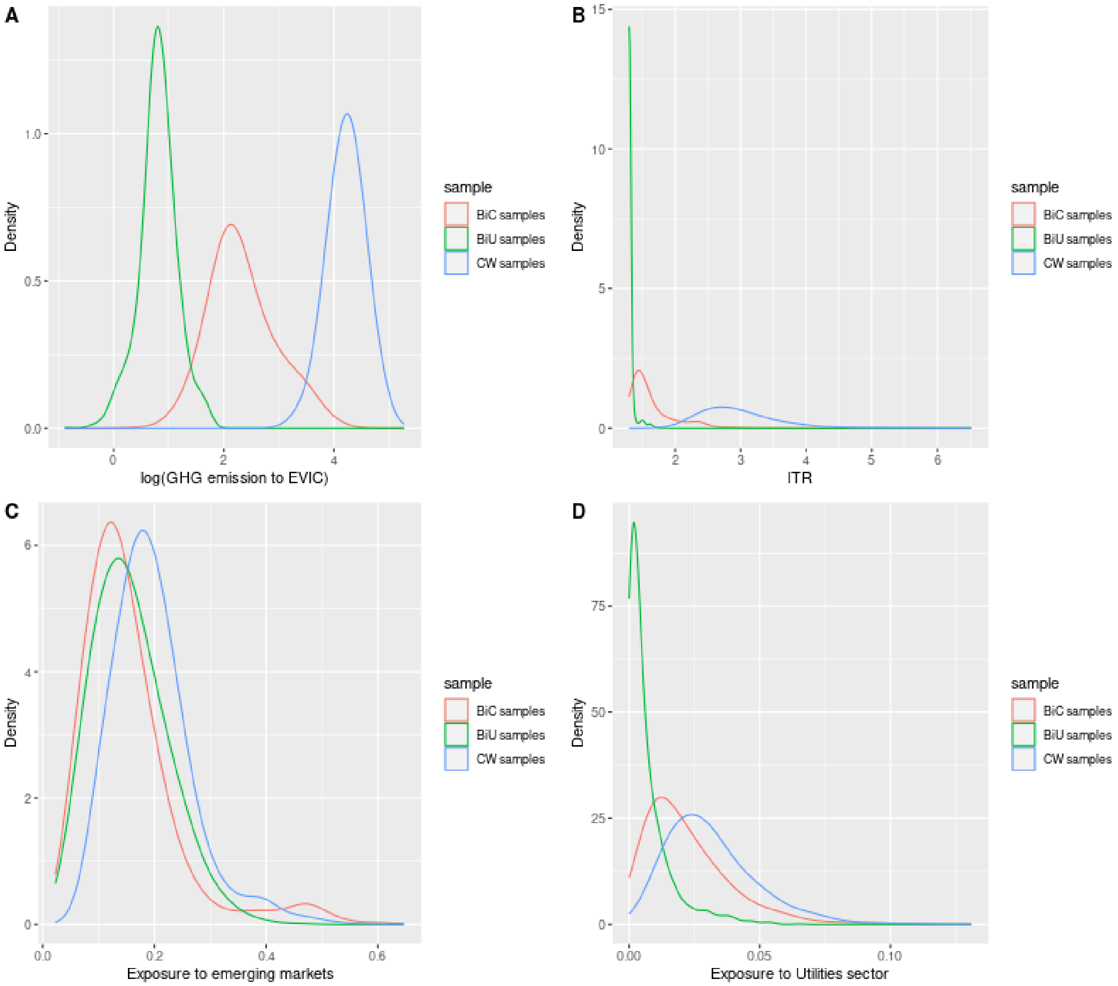

Figure 11: Density of bootstrapped metrics

	mean	sd	skew.	kurt.	$Q_{0.25}$	$Q_{0.5}$	$Q_{0.75}$	Min	Max
Cap weighted									
CW Communications	7.77	7.84	3.26	11.35	3.79	5.62	8.72	0.60	59.37
CW Consumer cyclical	13.94	7.24	1.44	2.33	8.94	12.14	16.99	2.50	46.71
CW Industrial	13.06	4.28	0.50	0.05	9.85	12.71	15.77	3.22	28.72
CW Energy	5.35	6.08	2.71	7.99	1.92	3.35	5.95	0.26	49.47
CW Technology	19.65	12.84	1.27	0.87	10.63	15.29	24.59	2.46	69.62
CW Basic materials	6.92	3.02	1.02	1.27	4.74	6.41	8.53	1.22	20.40
CW Consumer non-cyclical	3.84	2.54	1.21	1.38	1.93	3.07	5.13	0.31	17.00
CW Utilities	3.11	1.66	1.10	1.57	1.90	2.81	3.97	0.23	11.55
CW Financial	17.65	6.84	0.73	0.48	12.68	16.73	21.68	2.87	47.36
CW Healthcare	6.35	5.00	1.45	2.23	2.57	4.73	8.77	0.38	33.39
CW Real estate	2.37	1.20	1.16	1.81	1.49	2.11	3.01	0.29	9.16
Best in Universe									
BiU Communications	9.34	10.29	3.17	10.63	4.03	6.29	10.21	0.56	72.41
BiU Consumer cyclical	12.03	8.90	1.88	4.14	6.08	9.46	15.07	0.85	53.74
BiU Industrial	11.36	5.27	0.74	0.48	7.27	10.68	14.47	1.45	34.37
BiU Energy	0.19	0.42	3.90	16.11	0.00	0.07	0.16	0.00	3.67
BiU Technology	24.21	16.44	1.15	0.39	12.42	18.82	31.08	1.38	80.31
BiU Basic materials	2.41	2.69	2.29	6.98	0.65	1.49	3.07	0.00	24.28
BiU Consumer non-cyclical	2.51	3.08	1.88	3.64	0.44	1.23	3.32	0.00	18.95
BiU Utilities	0.66	0.86	2.48	7.42	0.11	0.34	0.86	0.00	6.50
BiU Financial	25.93	9.93	0.34	-0.39	18.44	25.31	32.52	3.42	55.98
BiU Healthcare	8.23	7.41	1.38	1.71	2.59	5.70	12.06	0.12	43.05
BiU Real estate	3.13	1.86	1.33	2.49	1.78	2.73	4.08	0.26	13.22
Best in Class									
BiC Communications	5.38	7.05	4.96	28.87	2.31	3.63	5.75	0.40	66.61
BiC Consumer cyclical	15.08	9.93	1.61	2.86	8.19	12.25	19.03	1.90	59.08
BiC Industrial	12.63	5.66	0.69	0.25	8.32	11.96	16.06	2.05	36.38
BiC Energy	5.18	8.36	3.15	9.89	1.17	2.34	4.75	0.01	58.57
BiC Technology	22.48	16.63	1.25	0.58	10.75	16.62	28.81	1.88	79.54
BiC Basic materials	6.54	4.00	1.50	3.07	3.71	5.58	8.23	0.84	32.33
BiC Consumer non-cyclical	4.94	3.92	1.32	1.68	1.99	3.65	7.05	0.18	24.83
BiC Utilities	2.19	1.63	1.65	4.25	1.01	1.81	2.97	0.05	13.09
BiC Financial	15.15	7.23	0.92	0.90	9.89	14.02	19.27	1.67	48.02
BiC Healthcare	8.21	7.48	1.43	1.93	2.48	5.77	11.98	0.17	42.60
BiC Real estate	2.22	1.48	1.67	4.22	1.18	1.84	2.84	0.20	12.86

Table 16: Resampled allocations by sector

	mean	sd	skew.	kurt.	$Q_{0.25}$	$Q_{0.5}$	$Q_{0.75}$	Min	Max
Cap weighted									
CW Emerging Asia	17.80	6.95	1.40	3.05	13.24	16.75	20.77	5.47	56.29
CW Europe	18.04	6.05	0.49	0.16	13.57	17.55	21.90	3.93	43.48
CW Developed Asia / Pacific	11.44	4.42	1.21	2.58	8.41	10.78	13.73	3.30	39.24
CW North America	50.93	11.38	0.26	-0.51	42.38	49.90	58.72	19.91	82.76
CW Latin America	1.44	1.03	1.46	2.98	0.68	1.17	1.92	0.03	7.63
CW Africa	0.34	0.28	1.51	2.73	0.13	0.25	0.47	0.00	1.69
Best in Universe									
BiU Emerging Asia	14.39	6.36	0.77	0.61	9.58	13.47	18.35	2.79	44.84
BiU Europe	19.56	8.41	0.54	-0.07	13.02	18.61	24.96	2.91	50.76
BiU Developed Asia / Pacific	8.11	3.72	0.79	0.67	5.25	7.55	10.28	1.24	25.99
BiU North America	56.69	13.36	0.17	-0.75	46.40	55.46	66.78	21.13	89.62
BiU Latin America	0.99	1.00	2.38	9.49	0.31	0.69	1.31	0.00	10.59
BiU Africa	0.27	0.38	1.90	3.53	0.01	0.09	0.36	0.00	2.33
Best in class									
BiC Emerging Asia	13.98	8.75	2.23	6.07	8.68	12.08	16.32	1.90	64.43
BiC Europe	20.73	8.86	0.59	0.06	14.02	19.73	26.40	3.22	57.66
BiC Developed Asia / Pacific	8.19	4.02	0.95	0.92	5.17	7.51	10.41	1.45	25.91
BiC North America	55.70	13.90	0.04	-0.55	45.79	55.16	65.63	15.84	88.01
BiC Latin America	1.31	1.21	1.89	5.01	0.46	0.94	1.76	0.00	10.08
BiC Africa	0.10	0.27	3.79	16.66	0.00	0.00	0.05	0.00	2.91
Emerging Markets									
CW Emerging	19.58	7.16	1.24	2.52	14.85	18.71	22.91	5.52	56.88
BiU Emerging	15.65	6.60	0.70	0.50	10.70	14.85	19.73	2.99	46.64
BiC Emerging	15.38	8.88	2.06	5.40	9.97	13.47	18.16	2.29	64.62

Table 17: Resampled allocations by region

	SW_{stat}	$SW_{p-value}$	JB_{stat}	$JB_{p-value}$	KS_{stat}	$KS_{p-value}$
$Alloc_{BiU}$	0.94	0.00	696.76	0.00	0.08	0.00
$Alloc_{BiC}$	0.96	0.00	630.09	0.00	0.07	0.00
$Selec_{BiU}$	0.96	0.00	347.62	0.00	0.07	0.00
$Selec_{BiC}$	0.95	0.00	506.30	0.00	0.08	0.00
$Inter_{BiU}$	0.94	0.00	703.58	0.00	0.08	0.00
$Inter_{BiC}$	0.94	0.00	988.18	0.00	0.08	0.00
CI_{CW}	0.96	0.00	335.00	0.00	0.06	0.00
CI_{BiU}	0.93	0.00	991.85	0.00	0.10	0.00
CI_{BiC}	0.77	0.00	4210.95	0.00	0.19	0.00
ITR_{CW}	0.92	0.00	1361.34	0.00	0.08	0.00
ITR_{BiU}	0.36	0.00	48088.62	0.00	0.38	0.00
ITR_{BiC}	0.80	0.00	2422.88	0.00	0.19	0.00
$CIstar_{CW}$	0.96	0.00	335.00	0.00	0.06	0.00
$CIstar_{BiU}$	0.94	0.00	694.40	0.00	0.08	0.00
$CIstar_{BiC}$	0.96	0.00	410.90	0.00	0.07	0.00
$ITRstar_{CW}$	0.92	0.00	1361.34	0.00	0.08	0.00
$ITRstar_{BiU}$	0.89	0.00	1173.59	0.00	0.11	0.00
$ITRstar_{BiC}$	0.82	0.00	2177.67	0.00	0.17	0.00
$w_{Emerging}^{CW}$	0.93	0.00	1037.36	0.00	0.08	0.00
$w_{Emerging}^{BiU}$	0.97	0.00	182.30	0.00	0.05	0.00
$w_{Emerging}^{BiC}$	0.82	0.00	3837.41	0.00	0.13	0.00
$\Delta w_{Emerging}^{BiU,CW}$	0.81	0.00	4527.18	0.00	0.17	0.00
$\Delta w_{Emerging}^{BiC,CW}$	0.96	0.00	797.00	0.00	0.07	0.00
$\Delta w_{Utilities}^{BiU,CW}$	0.94	0.00	612.92	0.00	0.08	0.00
$\Delta w_{Utilities}^{BiC,CW}$	0.94	0.00	1524.74	0.00	0.08	0.00
$\Delta w_{Emerging}^{BiU,BiC}$	0.77	0.00	5564.38	0.00	0.21	0.00
$\Delta w_{Utilities}^{BiU,BiC}$	0.85	0.00	3650.28	0.00	0.12	0.00

Table 18: Normality test on resampled variables

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