Building Benchmarks Portfolios with Decreasing Carbon Footprints*

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Abstract

In this paper, we build portfolios with decreasing carbon footprint, which passive investors can use as new Paris-consistent (PC) benchmarks and have the same risk-adjusted returns as business as usual (BAU) benchmarks. As the distribution of firms' carbon intensity is very skewed, excluding a small fraction of highly polluting firms can massively reduce the carbon footprint of a portfolio of corporate stocks. We identify the worst polluters globally, exclude them from the portfolio, and re-allocate the proceeds so as to keep sectoral and regional exposures similar to those of the business as usual (BAU) benchmark. This approach limits divestment from corporates in Emerging Countries that would result from implementing exclusions and reinvestment without the objective of preserving regional exposures. We show that reducing the carbon footprint of the portfolio by 64% in 10 years would be obtained by excluding sequentially up to 11% of the corporates, which together amount to less than 6% of the global market portfolio. While this reallocation preserves regional and sectoral exposures similar to those of the BAU benchmark, it does not change its risk-adjusted return. We define PC benchmark portfolios at the global level, for Emerging Countries, Europe, North America, and the Pacific.

Keywords: Portfolio carbon footprint, Green and brown assets, Alignment with Paris Agreement
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1 Introduction

Intergovernmental Panel on Climate Change (IPCC) reports compelling evidence that mitigating climate change requires limiting greenhouse gas emissions (IPCC, 2021). Climate-related risks become increasingly important for investors, financial intermediaries, and their regulators. Bolton *et al.* (2020) foresee an epistemological change in risk management techniques, integrating climate change-related risks as global, irreversible, massive and systemic, called "Green Swans." One way to both foster greener means of production and ways of life and hedge against climate risk is to reallocate investment towards greener corporates. On the one hand, the financial sector and especially asset managers have to hedge against climate risks to ensure the preservation of their portfolio value. On the other hand, they need to assess what this reallocation would imply in terms of financial performance.

To decarbonize a portfolio such that its carbon footprint is compatible with a 1.5°C temperature increase above pre-industrial levels, the first obvious route is to exclude the most polluting firms. Large institutional investors and financial authorities are already taking this road. The Network for Greening the Financial System promotes best practices and contributes to the development of environment and climate risk management in the financial sector (NGFS, 2020). BlackRock and the Norway's Government Pension Fund Global have established exclusion lists based on environmental criteria. Several asset managers have already realized that the claim in Andersson *et al.* (2016) that portfolios can be hedged against climate risk with little to no damage to performance through exclusion restrictions is both accurate and easy to implement. As a small number of firms contribute disproportionately to carbon emissions, marginal reallocation of the market portfolio that excludes such firms would have strikingly smaller carbon footprint than a portfolio that includes all firms. Bolton and Kacperczyk (2020) provide evidence that institutional investors already implement exclusionary screening based on direct emission intensity in a few salient industries.

The exclusion approach is in principle very effective because corporates' carbon emissions are extremely right skewed. More precisely, we build a decarbonized portfolio by excluding firms based on their carbon intensity, which measures the amount of carbon emitted per million dollars of revenue. This approach allows us to identify firms that are the most polluting for a given revenue generation. The exclusion threshold is chosen so that excluded firms represent a given fraction of the market value of the portfolio. On average, excluding firms with the highest carbon intensity representing 10% of the market value of the worldwide passive portfolio would reduce the carbon emissions of the resulting portfolio by 50%.

A drawback of this pure exclusion approach is that the excluded firms often belong to the same sectors (utilities, energy, and materials) and to the same regions (Emerging Countries). For an otherwise passive investor, this approach introduces severe undesirable regional and sectoral biases compared to the business-as-usual (BAU) benchmark portfolio. To circumvent this problem and still substantially reduce the carbon footprint of the portfolio, we propose the following approach. As before, we exclude the firms with the highest carbon intensity. But then we reinvest the proceeds of the exclusion in the very same region and sector as the excluded firms. In doing so, we preserve the same regional and sectoral exposures as the BAU benchmark. We demonstrate that this approach is very effective and easy to implement.

In a second step, we implement this overall exclusion and regional/sectoral reinvestment strategy in a dynamic fashion to target a drastically decarbonized Paris-consistent (PC) portfolio in a 10 year time horizon. By targeting a carbon footprint reduction of 10% per annum every year, we reduce the carbon footprint of the portfolio by 64% within 10 years. This can be achieved by excluding approximately an additional 1% of the corporates per annum, representing less than 1% of the market value of the portfolio on average. Precisely, we show that such a reduction of the carbon footprint would be obtained by excluding sequentially up to 11% of the corporates, which together amount to less than 6% of the global market portfolio. In addition, we reinvest the proceeds of the excluded firms in the same region and sector where they belong. Therefore, the resulting portfolio preserves the regional and sectoral exposures of the BAU benchmark. This is particularly important for passive investors and to maintain the flow of capital to corporates based in Emerging Countries. We show that, if the strategy had been implemented in the period 2010–2019, the performance of the decarbonized portfolio would have been nearly identical to that of the stock market BAU benchmark, in terms of risk-adjusted returns. Only the tracking error is impacted. Reducing the carbon footprint would have induced a tracking error equal to 0.06% per annum for an objective of 41% in 5 years and to 0.2% per annum for an objective of 64% in 10 years. We define the benchmark green portfolio at the world level, while maintaining regional exposures in Emerging Countries, Europe, North America, and the Pacific.

It is worth noting that our goal is to design PC benchmark portfolios that are well suited for large passive institutional investors. Such portfolios aim to be compatible with a minimal carbon footprint in 2050. By excluding most polluting firms, investors renounce to directly change the way these firms operate through the "voice" channel. However, if it is implemented at a large scale (for instance, in the context of an investors' alliance such as the Glasgow Financial Alliance for Net-Zero, which Mark Carney chairs, a consortium of over 450 financial firms across 45 nations whose assets under management add up to $130 trillion), this coordinated action would move funding from most polluting to least polluting firms in the same region and sector and therefore it would reduce the cost of the transition. It is unlikely that such a strategy will suffer from lower financial performance because it precisely excludes firms that are the most at risk and the most likely to suffer from the transition.

Several papers have investigated the consequences on financial performance of introducing environmental objectives into the investment process and found mixed empirical evidence. Pastor *et al.* (2021a) find that in equilibrium, green assets have low expected returns because investors enjoy holding them and because green assets hedge climate risk. Pedersen *et al.* (2021) describe a theoretical framework that could explain why the relation between an environmental score and financial performance of firms may actually switch from positive to negative. If the market is driven by investors using the environmental score only as an indicator of high future performance, high-environmental-score stocks should deliver high expected returns. However, as soon as the market is driven by investors with environmental preferences, these investors are willing to pay a premium to hold high-environmental-score stocks, which therefore deliver lower expected returns. Interestingly, this model may explain why empirical studies have found contradicting evidence over time or across regions or industries. We discuss the expected financial performance of our strategy in this context in Section 5.

Görgen *et al.* (2020) construct a carbon risk factor-mimicking portfolio and find that stock returns are positively affected by this factor, indicating that brown firms have to generate higher returns on average. Bolton and Kacperczyk (2020) find that investors are already demanding a compensation for their exposure to carbon emission risk. In contrast, consistent with Andersson *et al.* (2016), Garvey *et al.* (2018) find that reducing the carbon footprint of a portfolio is associated with a stronger future profitability and a positive stock returns in a global universe of stocks. In *et al.* (2019) also report evidence that an investment strategy of "long carbon-efficient firms and short carbon-inefficient firms" would earn positive abnormal returns. A possible interpretation of these apparently contradictory results is that they reflect the transition in investors' preferences. As investors switch their preferences toward environment-friendly firms, there is a short-term selling pressure and low-carbon firms outperform the market (see Rohleder *et al.*, 2022). In the long term, as most of investors have rebalanced their portfolio, the valuation effect vanishes and investors pay a premium for holding low-carbon firms. This interpretation is consistent with Pastor *et al.* (2021a). It should be noted however that in the long run, if the transition is effective, high-carbon firms will have changed their production process or will have disappeared.

Our paper is closely related and complementary to Bolton *et al.* (2021). They also implement exclusion restrictions to reduce the carbon emission of the portfolio and attain net zero emissions in 2050. They emphasize minimizing the tracking error while we explore simpler reinvestment rules. In particular, in our PC portfolios, most firms have the same weights as in the BAU benchmark.

The remainder of the paper is organized as follows. In Section 2, we present the data that we use in our empirical analysis. In Section 3, we describe the construction of a decarbonized portfolio based on an exclusion of firms with high carbon intensity and discuss the implications for the sectoral and regional exposures of this portfolio. We investigate the impact on the carbon footprint of restricting the sectoral and regional exposures to be the same as in the benchmark. In Section 4, we consider dynamic exclusion approach, which allows investors to reach a massive decarbonization of their portfolio while not suffering from regional and sectoral biases. In Section 5, we discuss some aspects of the approach. Finally, we provide our main conclusions in Section 6.

2 Data

Our analysis relies on annual data from S&P Trucost (S&P Global Trucost, 2019). This dataset covers a large number of firms (above 15,500 in 2019) and provides information on the three scopes of carbon emissions. Scope 1 refers to the emissions generated from burning fossil fuels and production processes which are owned or controlled by the company (direct emissions). Scope 2 relates to the emissions from consumption of purchased electricity, heat or steam by the company (first-tier indirect emissions). Scope 3 relates to other upstream indirect emissions, such as from the extraction and production of purchased materials and fuels, transport-related activities in vehicles not owned or controlled by the reporting entity, electricity-related activities not covered in Scope 2.[1] Data are provided in terms of emissions (in tonnes CO_2e) and intensity (in tonnes CO_2e/$ million of revenue).

At the company level, there is a consensus that Scope 3 emissions need to be included to measure carbon intensity. Scope 3 metrics are particularly relevant for some sectors, such as fossil energy producers and car manufacturers. When Scope 1 to 3 emissions are aggregated at portfolio level, this may lead to double counting, however, because the

[1] All the analysis in this paper is based on Scope 3 upstream emissions. Trucost also provides Scope 3 downstream emissions but over a much shorter sample period.

same tonne of carbon may be counted multiple times. For this reason, we have controlled for the use of Scope 1, 1–2, or 1–3 intensity metrics to select firms. Results are essentially unaltered when exclusion is based on one measure or another.[2] In the following, we report results based on the Scope 1–3 metric.

For assessing the performance of investment strategies, we use a well-established benchmark that gives us a reference level for carbon metrics and financial performance. We therefore reduce the pool of firms to those belonging to MSCI standard indexes. We consider the All Country World Index (ACWI), which covers large- and mid-cap stocks across 23 developed markets and 24 emerging markets. We classify its constituent corporates into four large zones, Emerging Countries, Europe, North America, and the Pacific. We use the corresponding MSCI indexes as regional benchmark portfolios in Section 4.2.

In Table 1, we report the coverage of Trucost numbers with those of the benchmark index. The number of firms in Trucost dataset increases substantially over time, from $3,756$ in 2005 to $15,663$ in 2019. In relation to MSCI indexes, we report the coverage of Trucost data in terms of number of firms and in percentage of the market capitalization. We also provide a distinction between all countries (ACWI), developed markets, and emerging markets. The coverage of the ACWI index was below 90% until 2007 for the number of firms and until 2006 for the market capitalization. The coverage exceeds 96% since 2013. We also observe that the coverage was slightly lower in emerging markets until 2008 but it is now as high as in developed markets.

For all these firms, we also collect accounting and financial data from Refinitiv. Accounting data are used for identifying some properties of the firms that are found to have a high carbon intensity. Financial data are used for measuring the performance of a portfolio based on excluding firms with a high carbon intensity. The last rebalancing of the portfolio is done at the beginning of 2020, based on emission data at the end of 2019, and the performance is evaluated for 2020.

[Insert Table 1 here]

[2]The correlations between Scopes 1, 1–2, and 1–3 intensity measures are high for all years. In fact, they are all above 98%. In the following, we focus on Scope 1–3 but adopting another scope would barely affect the analysis.

3 Excluding the Most Polluting Corporates

We first describe some cross-section characteristics of firms' carbon intensity. Then, we discuss the construction of portfolios based on excluding firms with the highest carbon intensity.

3.1 Cross-section Distribution of Firms' Carbon Intensity

We consider all firms belonging to the MSCI ACWI index with a measure of carbon intensity and valid market capitalization. Figure 1 displays the histogram in 2019 of the Scope 1–3 carbon intensity of these firms, which is expressed in tonnes of CO_2 equivalents per million dollar of revenue ($tCO_2e/m\$$). The distribution of firms' carbon intensity (represented in log-scale) is extremely skewed to the right, with a few firms generating very high carbon intensity levels. The figure also represents the 75%,90%, and 99% quantiles with vertical lines. The 1% of firms with the highest carbon intensity (above $7,580$ $tCO_2e/m\$$) contributes to 16.8% of the total carbon intensity of the index. The 10% and 25% of firms with the highest carbon intensity contribute to 52.7% and 74.4% of the index carbon intensity, respectively.

Figure 2 displays some characteristics of the distribution of firms' carbon emissions over time. Panel A displays the temporal evolution of the high quantiles corresponding to probabilities from 75% to 99%. On average, the 75% quantile of the distribution is close to 500 $tCO_2e/m\$$, whereas the 90% and 99% quantiles are equal to $1,200$ and $7,700$ $tCO_2e/m\$$, respectively. Over time, the threshold for $\theta = 99\%$ ranges between $6,400$ and $10,300$ $tCO_2e/m\$$ in our sample.[3]

Panel B reports the average of carbon intensity for all firms above the selected quantile. As expected for a highly skewed distribution, the average is substantially larger than the

[3]These numbers are smaller than the threshold of $17,000$ $tCO_2e/m\$$ reported by Ehlers *et al.* (2020) for the same quantile. The reason is twofold. First, we restrict our analysis to firms belonging to the ACWI index, which is a much smaller set of firms than the full set of firms available in Trucost dataset. Even if other firms are likely to be smaller, they may have higher carbon intensity. Second, the computation made by Ehlers *et al.* (2020) include both upstream and downstream Scope 3 data, which clearly increases the threshold.

quantile itself for high probabilities. The average above the 75% quantile is equal to $1,960$ $tCO_2e/m\$$, whereas the average is equal to $3,770$ and $12,470$ $tCO_2e/m\$$ above the 90% and 99% quantiles, respectively. The average carbon intensity of the most polluting firms substantially decreased in the first years of the sample until 2012. Since then, there is an upward trend, in particular for higher quantiles. For the firms above the 99% quantile, the carbon intensity has decreased by 50% between 2005 and 2012, but increased by 48% between 2012 and 2019, for an overall reduction of 26% over the sample period.

Panel C of the figure reveals that the average of carbon emissions above high quantiles tends to increase over time since 2005, with a maximum of 154 million tCO_2e. This trend, which is particularly pronounced for high quantiles reflects the increasing coverage of the data. The 2019 sample includes 3,050 firms against 2,460 in 2010. And some of the firms that enter the sample are among the worst polluters. The total emissions of firms above the 99% threshold has increased by 84% between 2012 and 2019, while the number of firms in the ACWI index with a carbon measure has increased by 29% only.[4]

[Insert Figures 1 and 2 here]

3.2 Metrics of Portfolio's Carbon Intensity

We compute three metrics of the carbon quality of the portfolio. The first one is the weighted-average carbon intensity. It follows the recommendation of the Task Force on Climate-related Financial Disclosures to evaluate the carbon exposure of a portfolio (TCFD, 2017): The weighted-average carbon intensity measures the portfolio's exposure to carbon-intensive companies (in $tCO_2e/m\$$). It is defined as:

$$WACI_t^{(p)} = \sum_{i=1}^{N_t} w_{i,t}^{(p)} \frac{E_{i,t}}{Rev_{i,t}}, \tag{1}$$

[4] Firms with a high intensity are not necessarily firms with the highest carbon emissions. Yet, the 15 firms (over 2,630) with the highest intensity contribute to almost 5% of total carbon emissions in 2005. In 2019, the carbon intensity is usually slightly lower but the emissions are higher on average. The emissions of the 15 firms with the highest intensity contribute to more than 10% of total emissions.

where $E_{i,t}$ represents the amount of carbon emitted by firm i in year t, $Rev_{i,t}$ represents the revenues generated by the firm, and $w_{i,t}^{(p)}$ is the weight of firm i in the portfolio. The portfolio weight is defined as $w_{i,t}^{(p)} = V_{i,t}^{(p)}/V_t^{(p)}$, where $V_{i,t}^{(p)}$ is the dollar value invested in firm i and $V_t^{(p)} = \sum_{i=1}^{N_t} V_{i,t}^{(p)}$ is the dollar value of the portfolio, with N_t the number of firms available in year t.

The second metric is the carbon intensity. It measures the volume of carbon emissions per million dollars of revenue (carbon efficiency of the portfolio), again expressed in tCO_2e/m$ of revenue. This metric is adjusted for company size and is therefore a measure of how carbon-efficient the portfolio is in generating revenue through its investee companies. This measure accounts for the fraction of the equity of the firm held in the portfolio, which we denote by $o_{i,t}^{(p)} = V_{i,t}^{(p)}/Cap_{i,t}$, where $Cap_{i,t}$ represents the market capitalization of the firm. It is measured as:

$$CI_t^{(p)} = \frac{\sum_{i=1}^{N_I} o_{i,t}^{(p)} E_{i,t}}{\sum_{i=1}^{N_I} o_{i,t}^{(p)} Rev_{i,t}}.$$

Finally, our third metric we consider is the carbon footprint. It measures the total carbon emissions for a portfolio normalized by the market value of the portfolio. It expresses the amount of annual carbon emissions that can be allocated to the investor per million dollar invested in the portfolio (in tCO_2e/m$). It is defined as:

$$CF_t^{(p)} = \sum_{i=1}^{N_t} w_{i,t}^{(p)} \frac{E_{i,t}}{Cap_{i,t}} = \frac{1}{V_t^{(p)}} \sum_{i=1}^{N_t} o_{i,t}^{(p)} E_{i,t}. \tag{2}$$

All three metrics can be compared to those of the MSCI index benchmark. As carbon emissions are not recorded for a few firms in the MSCI index, we define a new BAU benchmark with only the firms with a carbon emission measure available in the Trucost dataset. The impact is marginal in the recent period as the coverage is large. Indeed, the available firms cover at least 95% of the market capitalization of the ACWI index since 2007.

We now turn to characterizing portfolios based on excluding firms with high carbon intensity. We exclude all firms whose carbon intensity is above a worldwide quantile of the cross-section distribution.[5] Importantly, we use a value-weighted approach: we sort all firms by increasing carbon intensity. For a given probability θ (say, $\theta = 99\%$), we sum the market weights (i.e., the relative market capitalizations) until this sum is equal to θ, which defines the carbon intensity threshold, above which a firm should be excluded from the portfolio. The firms with a carbon intensity above this quantile represent 1% of the BAU benchmark market value. We implement the same approach by excluding 10% and 25% of the portfolio value. The exclusion is implemented annually on the basis of the carbon emission data as reported for the previous year. This way, a firm that may have been excluded a given year can re-enter the portfolio if it reduced its emissions to no longer end up among the worst emitters.

We consider three different strategies for reinvesting the proceeds of selling the excluded corporates. In the first approach (proportionate reinvestment), we reinvest the proceeds in all the remaining firms proportionately to their weight in the BAU benchmark. In the second approach (symmetric reinvestment), we reallocate the proceeds corresponding to excluded firms by investing in firms with the lowest overall carbon intensity, representing $(1 - \theta)$ of the market value of the BAU benchmark. In other words, we double the weight of these firms in the new portfolio. In the third approach (regional/sectoral reinvestment), we reinvest a fraction $(1 - \theta)$ of the market value in the $100(1-\theta)\%$ least polluting firms in the region-sector where the excluded firms are located. For instance, if we exclude the most polluting European utilities that amount to 1% of the portfolio value, this 1% is reinvested in the least polluting firms among European utilities that add up to 1% of the market value of the BAU benchmark. This third approach brings two major complementary benefits: Investors can keep the same regional and sectoral exposure as the benchmark, and corporates from Emerging Countries are not penalized as an asset class.

[5] See the discussion in Ehlers *et al.* (2020) on determining the threshold.

3.3 Proportionate Reinvestment

We define the list of firms to be excluded from the BAU benchmark portfolio as the firms with the highest carbon intensity $CI_{i,t}$, i.e., $I_{H,t} = \{1_{\{CI_{i,t} > q_{\theta,t}\}}\}_{i=1}^{N_t}$, where $q_{\theta,t}$ is the carbon intensity threshold corresponding to probability θ. This threshold is defined such that the sum of the market weights of excluded firms is equal to the targeted probability: $1 - \theta = \sum_{i=1}^{N_t} w_{i,t}^{(b)}\ 1_{\{CI_{i,t} > q_{\theta,t}\}}$, where $w_{i,t}^{(b)}$ is the weight of firm i in the benchmark. We also define the number of excluded firms as $N_{H,t} = \sum_{i=1}^{N_t} 1_{\{CI_{i,t} > q_{\theta,t}\}}$. The proceeds, which represent a fraction $(1-\theta)$ of the BAU benchmark market value, are reallocated proportionately to all stocks remaining in the portfolio. The vector of weights in the pure exclusion portfolio is given by:

$$
\begin{aligned}
w_{i,t}^{(p)} &= 0 \quad \text{for } i \in I_{H,t} \quad \text{with} \sum_{i \in I_{H,t}} w_{i,t}^{(b)} \approx 1 - \theta \\
w_{i,t}^{(p)} &= w_{i,t}^{(b)} \left(\frac{1}{\sum_{i \in I_{H,t}} w_{i,t}^{(b)}} \right) \quad \text{for } i \in I_{I,t},
\end{aligned}
$$

where $I_{I,t}$ is the list of firms included in the portfolio (set of firms complementary to $I_{H,t}$).[6]

Table 2 (Panel A) reports results for the carbon metrics of portfolios based on the 75%, 90%, and 99% exclusion thresholds. We start our analysis by considering the quantile $\theta = 99\%$, so that we exclude the firms with the highest carbon intensity until they cover 1% of the BAU benchmark market value. On average, the weighted-average intensity, the carbon intensity, and the carbon footprint of the portfolio after exclusion are reduced by 16.9%, 20.3%, and 15.6%, respectively.[7] As Figure 3 also reveals, the reduction in the carbon metrics of the portfolio is considerable relative to the BAU benchmark, even when excluding highest carbon emitters until they represent only 1% of the market value.

[6] We use the "$\approx$" operator to indicate that we exclude the list of firms with the sum of market weights that is the closest below $1 - \theta$. This approximation occurs because the distribution of market weights is not perfectly continuous.

[7] Excluding 1% of the firms instead of 1% of the market value would result in a more modest reduction in the three carbon metrics, ranging between 9% and 10.2%. The difference is due to the fact that firms with high carbon intensity are relatively small relative to the average firm's size in the benchmark.

Excluding a larger proportion of corporates also results in massive improvements of the carbon footprint, although returns are decreasing: the reduction is equal to 48.1% and 70% with excluding highest carbon emitters until they represent 10% and 25% of the market value, respectively.

[Insert Table 2 and Figure 3 here]

The financial performance of portfolios based on excluding firms with high carbon intensity is also reported in the table. We assume that the investment takes place at the end of year t based on carbon emitted in year t and the performance is measured over year $t+1$. The performance includes dividend payments and is expressed in dollar. We compare the portfolios based on the 75%, 90%, and 99% exclusion thresholds to the BAU benchmark (based on all firms of the ACWI index with a carbon intensity) and the ACWI index itself.

As the table clearly demonstrates, exclusion does not reduce the ex-post performance of the portfolio compared to the BAU benchmark portfolio. This result is consistent with the empirical evidence on decarbonization reported by Bolton and Kacperczyk (2020) and Rohleder *et al.* (2022) and with the literature on ESG investing (Alessandrini and Jondeau, 2020). First, the portfolio based on the 99% quantile threshold results in the same risk-adjusted performance as the portfolio based on the firms of the ACWI index with a carbon intensity. This result suggests that the correlation between firms' financial performance and carbon emissions is sufficiently low to have no material effect on portfolio performance. In addition, the annual tracking error is as low as 0.1% over the sample period. Second, even for lower selection thresholds, the exclusion portfolios produce an annualized compounded return that is at least equal to the BAU benchmark performance. The Sharpe ratio actually increases for lower exclusion thresholds. The only cost for asset managers that are benchmarked is that the tracking error increases to 0.71% and 1.77% for the 90% and 75% thresholds.

3.4 Symmetric Reinvestment

In the second strategy, the proceeds from selling the firms with the highest carbon intensity are reinvested in the firms with the lowest carbon intensity, which we define as the set $I_{L,t} = \{1_{\{CI_{i,t}<q_{1-\theta,t}\}}\}_{i=1}^{N_t}$:[8]

$$
\begin{aligned}
w_{i,t}^{(p)} &= 0 \quad \text{for } i \in I_{H,t} \quad \text{with} \sum_{i \in I_{H,t}} w_{i,t}^{(b)} \approx 1-\theta \\
w_{i,t}^{(p)} &= w_{i,t}^{(b)} \quad \text{for } i \in I_{I,t} \\
w_{i,t}^{(p)} &= w_{i,t}^{(b)} \left(1 + \frac{\sum_{i \in I_{H,t}} w_{i,t}^{(b)}}{\sum_{i \in I_{L,t}} w_{i,t}^{(b)}}\right) \quad \text{for } i \in I_{L,t} \quad \text{with} \sum_{i \in I_{L,t}} w_{i,t}^{(b)} \approx 1-\theta,
\end{aligned}
$$

where $I_{I,t}$ is the list of included firms but not in $I_{L,t}$. The term in parentheses in the last equation ensures that the proceeds are entirely reinvested in firms with the lowest carbon intensity and proportionately to their market weights. One advantage of this approach is that the resulting portfolio is invested as the BAU benchmark for $100(1-2(1-\theta))\%$ of its market value (the proportion of firms in $I_{I,t}$).

Table 2 (Panel B) provides results with the rebalancing strategy. As expected, the gain in carbon metrics is even higher than the gain obtained with the pure exclusion strategy. For the 99% threshold, the weighted average intensity, the carbon intensity, and the carbon footprint of the portfolio are reduced on average by 18%, 21%, and 16.6%. The carbon footprint is also reduced by 52.6% and 75.9% when the threshold is set at 90% and 75%, respectively.

We observe that the financial performance is barely affected for the 99% quantile, with a Sharpe ratio equal to 0.47 and an annual tracking error equal to 0.2%. However, the risk-adjusted return is reduced to 0.44 for the 75% quantile. This result relative to the proportionate reinvestment case can be interpreted by an asymmetry in the relation between firm's carbon intensity and stock performance. As discussed above, firms with high carbon intensity are often utilities and materials firms in Emerging Countries, which

[8] This strategy is close to the investment strategy often called "ESG integration," which consists in over-weighting firms with high ESG scores and down-weighting firms with low ESG score. In our strategy, the down-weighting is extreme, as firms with high carbon intensity are excluded.

have had relatively low performance on average. In contrast, firms with low carbon intensity are mostly financial firms in Europe, which also experienced low performance in the sample period.[9] Interestingly, the proportionate reinvestment strategy benefits from sectoral and regional biases to improve its financial performance, while the symmetric reinvestment strategy suffers from these very same biases and obtains lower risk-adjusted performance. The tracking error increases substantially to 1.05% for the 90% quantile and 2.57% for the 75% quantile.

We now analyze the impact of exclusion strategies on the sectoral and regional exposures. In Table 3, we report the proportion of excluded firms in major sectors and countries. For the least aggressive portfolio (excluding only 1% of the BAU benchmark market value), we find that firms with the highest carbon intensity are concentrated in utilities and materials (57% and 37% of the excluded firms on average, respectively), whereas these sectors only represent 5.3% and 10.1% of the BAU benchmark on average. The proportion of excluded firms in the energy sector has increased from 2.1% in 2005 to 5.1% in 2019. In contrast, financials represent 16.6% of the BAU benchmark but not a single financial firm is excluded. This result is expected as financial firms have low Scope 1–3 carbon emissions.

[Insert Table 3 here]

Regarding the regional pattern, the first three countries represented in the list of firms with high carbon intensity (above the 1% threshold) are the United States, China, and India (20.3%, 14.3%, and 13.6% on average, respectively). The weight of China has jumped to 30.4% in 2019, while the weight of the United States is down to 15.2%. The impact of exclusion on the regional exposure of the portfolios is substantial. On average over the period, 10.3% of excluded firms (in market value) have a European headquarter, while they represent 24.5% of the BAU benchmark. In contrast, 23.5% of excluded firms (in market value) are located in Emerging Countries, while they represent 10.7% of the BAU benchmark.

[9] In the 99% exclusion portfolio, 96% of firms that benefited from a weight increase are financials and are mostly firms from Europe and Emerging Countries.

If we consider the 90% quantile of the carbon intensity distribution, we find that most firms with high carbon intensity are concentrated in three sectors, materials, utilities, and industrials (37.5%, 23.2%, and 14.1% on average, respectively). The energy sector has increased from 8.1% in 2005 to 12.7% in 2019. In contrast, only 1.3% of excluded firms are financial firms. Regarding regional exposures, the first three countries in the list of excluded firms are now the United States, Japan, and China (16.7%, 9.7%, and 8.5% on average, respectively). The weight of China has increased to 22.7% in 2019, while the weight of Japan is reduced to 7.5% in the same year.

These results raise two main issues. First, portfolios based on excluding firms with the highest carbon intensity have sectoral exposures that can substantially differ from the exposures of the BAU benchmark. In particular, they have larger exposures to financial and information technology firms and lower exposures to firms in material, utility, and energy sectors. Second, exclusion portfolios are exposed to country or regional risk. The main effect of the exclusion process is to increase the weights of firms in North America, where information technology firms account for a very large share of the market capitalisation, to decrease the weights of firms in Emerging Countries.

Addressing these issues related to the exposure to risk factors is fundamental to render portfolio exclusion acceptable to passive investors. As a large part of the asset management industry relies on benchmarking, it is of great importance that the portfolio does not depart too much from the BAU benchmark, not only in terms of tracking error, but also with respect to geographical and sectoral diversification. Regional and sectoral exposures are also crucial for authorities in several countries. Excluding a large fraction of firms from a given country or a given sector may have detrimental effects for this country or sector, as the exclusion process would raise the financing costs of these firms. This would be particularly challenging for the Emerging Countries whose sectoral specialization and choice of production technology imply higher levels of carbon emissions than is the case on average across the globe. Such economies may be severely affected by exclusion strategies. We now consider a portfolio strategy that addresses these issues, by maintaining the exposures to sectors and regions.

3.5 Regional/Sectoral Reinvestment

The section above illustrates that excluding and reinvesting the same proportion of the portfolio value in each region and sector to maintain the same regional and sectoral exposures as the BAU benchmark could be challenging. We now consider a reinvestment strategy that avoids reducing the effectiveness of the exclusion approach. This approach is similar to the one implemented in Fahlenbrach and Jondeau (2021). It can be viewed as a "best-in-class" strategy, as firms with low carbon intensity are over-weighted in a given region-sector.

We denote by R_i and S_i the region and sector of firm i. Therefore, the indicator variable $1_{\{R_i=r,S_i=s\}}$ is equal to 1 if the firm belongs to region r and sector s and to 0 otherwise. We also denote the set of firms in a given region r and sector s by $I_t(r,s) = \{1_{\{R_i=r,S_i=s\}}\}_{i=1}^{N_t}$, for any r and s. In the list of firms to be excluded ($I_{H,t}$), the sub-set of firms in a given region r and sector s is defined by $I_{H,t}(r,s) = \{1_{\{R_i=r,S_i=s,CI_{i,t}>q_{\theta,t}\}}\}_{i=1}^{N_t}$, for any r and s. In this region-sector, a proportion $\theta_t(r,s) = \sum_{j\in I_{H,t}(r,s)} w_{j,t}^{(b)} / \sum_{j\in I_t(r,s)} w_{j,t}^{(b)}$ of the market value is excluded. The proceeds are reinvested in the same region-sector in the set of firms with the lowest carbon intensity and a cumulative market value approximately the same. The set of firms to be overweighted is defined as $I_{L,t}(r,s) = \{1_{\{R_i=r,S_i=s,CI_{i,t}<q_{\theta_t(r,s),t}\}}\}_{i=1}^{N_t}$. The overall set of firms to be overweighted is given by $I_{L,t} = \{I_{L,t}(r,s)\}_{r,s}$.

The exclusion and reinvestment strategy is defined as follows:

$$
\begin{aligned}
w_{i,t}^{(p)} &= 0 \quad \text{for } i \in I_{H,t} \quad \text{with } \sum_{i\in I_{H,t}} w_{i,t}^{(b)} \approx 1-\theta \\
w_{i,t}^{(p)} &= w_{i,t}^{(b)} \quad \text{for } i \in I_{I,t} \\
w_{i,t}^{(p)} &= w_{i,t}^{(b)} \left(1 + \frac{\sum_{j\in I_{H,t}(R_i,S_i)} w_{j,t}^{(b)}}{\sum_{j\in I_{L,t}(R_i,S_i)} w_{j,t}^{(b)}}\right) \quad \text{for } i \in I_{L,t},
\end{aligned}
$$

where $\sum_{j\in I_{L,t}(R_i,S_i)} w_{j,t}^{(b)} \approx \sum_{j\in I_{H,t}(R_i,S_i)} w_{j,t}^{(b)}$. The term in parentheses in the last equation ensures that the regional and sectoral exposures of the resulting portfolio are exactly equal to the exposures of the BAU benchmark at the beginning of the year. The over-weighting is the same for all firms in the same region-sector ($I_{L,t}(r, s)$) but it may be different across regions and sectors.

For the exclusion process, we exclude the firms with the overall highest carbon intensity. We reinvest the proceeds into the same sectors and regions as the excluded firms. Precisely, if excluded firms in utilities in Emerging Countries represent 1% of the BAU benchmark market value because of their high carbon intensity, we reinvest 1% of the market value in the firms with the lowest carbon intensity in the same sector and same region.[10] Contrary to the symmetric reinvestment case, this approach does reinvest in regions-sectors in which firms with the lowest carbon intensity may contribute to the carbon footprint of the portfolio.[11]

Table 4 provides carbon metrics and financial performance of such portfolios for different values of the exclusion threshold. Figure 4 displays the impact of exclusion on the temporal evolution of the portfolio's carbon metrics. The table reveals that indeed such a strategy results in a reduction of the carbon intensity of the portfolio that is similar to the overall exclusion strategy, while at the same time maintaining the same regional and sectoral exposures of the BAU benchmark. When the portfolio is based on the 99% threshold with reinvestment at the region-sector level, the reduction in the carbon footprint is equal to 15.6% on average, only slightly lower than the reduction by 15.8% with the proportionate reinvestment. For all exclusion thresholds, the reduction in carbon metrics is almost the same compared to the overall exclusion. The reason for this result is that the exclusion is very effective (because it targets the most polluting firms) and the reinvestment is not too costly (because it involves the firms that are the least polluting in the same region-sector).

[10] For instance, we may exclude Chinese firms producing electricity based on coal and reinvest in Chinese firms producing electricity with renewable energy. Interestingly, this approach is akin to a "best-in-class" strategy.

[11] An alternative approach that would preserve regional and sectoral exposures would be to exclude most polluting firms and reinvest in the least polluting firms for each and every region-sector. This strict region-sector exclusion and reinvestment strategy would be detrimental to reducing the carbon footprint of the portfolio because it would prevent investors to exclude some of the most polluting firms. The reduction in the carbon metrics would be approximately halved compared to the proportionate or symmetric reinvestment approaches.

We also note that financial performance indicators are not altered by this approach. The Sharpe ratio is not affected. In addition, the table reveals that the tracking error is substantially reduced, almost three times smaller than in the overall exclusion case. The reason is that the (regional and sectoral) structure of the portfolio is very close to the one of the BAU benchmark.

Three main conclusions arise from this analysis. First, because of the highly skewed distribution of firms' carbon intensity, it is possible to considerably reduce the carbon footprint of a portfolio by excluding firms with the highest intensity. Second, this exclusion results in large sectoral and regional biases, as the composition of the portfolio is tilted toward less carbon intensive sectors and more developed countries. Third, investors can preserve the same sectoral and regional exposures as the BAU benchmark by reinvesting the proceeds of the exclusions in the stocks in the same regions and sectors as excluded firms. This approach is the most effective from a carbon footprint reduction and financial performance perspectives. It excludes the most polluting firms while having no material impact on the risk-adjusted performance.

[Insert Table 4 and Figure 4 here]

4 Building Benchmark Portfolios Targeting Net Zero Emissions

4.1 Worldwide Investment

In this section, we build benchmark portfolios that converge to net zero emissions. The IPCC in its Sixth Assessment Report estimates that the remaining carbon budget to limit global warming to 1.5°C is equal to 300 $GtCO_2$ with a 83% probability and 400 $GtCO_2$ with a 67% probability from the beginning of 2020 (IPCC, 2021).[12] Estimates by the

[12] The carbon budget that keeps warming below 2°C with a 83% chance is 900 GtCO2 (1,150 $GtCO_2$ for a 67% chance) from the beginning of 2020 (IPCC, 2021). The economic effects of Covid-19 pandemic caused fossil fuel emissions to decrease by almost 6% in 2020, but this effect is likely to be short lasting.

International Energy Agency (IEA) indicates that global energy-related CO_2 emissions amount to 31.5 $GtCO_2$ in 2020.[13] Following Bolton *et al.* (2021), we assume a remaining carbon budget of 300 $GtCO_2$, initial annual carbon emissions of 31.5 $GtCO_2$, and a target of zero emission in 2050, so that CO_2 emissions should decrease between 9% and 10% per annum on average over the next 30 years.

We use past data to simulate a reduction in a portfolio carbon footprint consistently year after year for alternative reduction targets. We report the effects of reducing carbon emissions by either 5%, 10%, and 15% per annum for 10 years, from 2010 to 2019. If successful in delivering such targets, the investor would reduce the carbon footprint of the portfolio by 40%, 65%, and 80% respectively. Our simulations illustrate the reallocation efforts needed by the investor to deliver such reductions in carbon emissions.

Precisely, we consider a passive investor who wants to decarbonize a portfolio that is otherwise as close as possible to the BAU benchmark. We assume an annual carbon reduction target equal to λ (say, $\lambda = 10\%$). In year 1, the investor implements the regional/sectoral reinvestment strategy described in Section 3.5: The investor selects the level of exclusion of corporates with the highest carbon intensity such that the overall emissions of the portfolio are reduced by a fraction λ relative to the emissions of the initial BAU benchmark (as observed at end of year 0). In year $n > 1$, the investor rebalances the portfolio so that the weights are again as close as possible to the weights of the BAU benchmark at the end of year $n - 1$, while reducing the carbon emissions of the portfolio by a fraction λ relative to the emissions of the portfolio at the end of year $n - 1$. Therefore, in year n, the weights of the new portfolio are defined relative to the BAU benchmark in year $n - 1$ (to facilitate the benchmarking of passive investors) and the reduction in the carbon emissions of the portfolio is relative to the emissions of the portfolio in year $n - 1$ (to monitor the decarbonization objective). For a $\lambda = 10\%$ carbon reduction per annum, we exclude enough firms to reduce the carbon footprint by 10% after 1 year, by 19% after 2 years, ..., and 65% after 10 years.

We evaluate the impact of this dynamic approach on the last 10 years of our sample

[13] See https://www.iea.org/data-and-statistics/charts/global-energy-related-co2-emissions-1990-2020.

(2010–2019). We consider an investor who wants to reduce the carbon emissions of its portfolio by a fraction λ per year over the 10 years. At the end of 2019, we measure the reduction in the carbon emissions of the portfolio relative to the initial carbon emissions of the benchmark at the end of 2009.

Results are reported in Table 5 for annual emission reduction targets $\lambda = 5\%$, 10%, and 15%. After 10 years, the carbon emissions by the firms in the portfolio have declined by a 42%, 64%, and 76%, respectively. Figure 5 displays the temporal evolution of some characteristics of the decarbonized portfolio for an emission reduction target equal to $\lambda = 10\%$. We note that, in years when the global emissions of the BAU benchmark tend to decrease, reducing the portfolio emissions is relatively easy. In contrast, in years when firms' emissions increase substantially, reducing carbon emissions, even by a modest margin, requires excluding a higher proportion of firms to achieve the targeted reduction of carbon emissions and reaching the targeted objective may even be impossible. As Panel A of the figure clearly demonstrates, in 2011 and 2018, carbon emissions by the BAU benchmark increase (by 18% and 23%, respectively), which requires an additional effort to reach the 10% reduction in portfolio emissions: The threshold is reduced and the proportion of market value (and the number of firms) excluded from the portfolio is increased.

Overall, over the 10 years, emissions of the BAU benchmark have decreased by almost 39% (or 5% per annum). Therefore, the actual additional reduction contribution of the three portfolios (with 5%, 10%, and 15% targets) is approximately equal to 3.2%, 25.6%, and 37.7%, respectively. Clearly, reaching the 5% annual reduction objective requires hardly any exclusion of firms from the portfolio.[14]

Even in year 10, when the carbon emission reduction is the most demanding, we achieve the emission reduction target by excluding a relatively small number of firms.

[14] The reduction in the carbon emissions of the BAU benchmark by 40% between 2010 and 2019 is in sharp contrast with the path of global carbon emissions, which have increased by approximately 10%, from 30.4 $GtCO_2e$ in 2010 to 33.4 $GtCO_2e$ in 2019, according to IEA. This divergence reflects that a large fraction of global emissions are not due to the activity of listed corporates, e.g., the heating and cooling of private homes, private transports, or agriculture. In addition, the BAU benchmark is based on market weights and therefore tends to overweight corporates in advanced economies, where carbon emissions tend to be lower than in Emerging Countries.

In 2019, reducing the carbon footprint by 65% compared to the end of 2009, i.e., a cumulative reduction by 10% per annum over 10 years, requires the exclusion of 11% of the firms available in the BAU benchmark, accounting for 5.4% of the portfolio market value. Excluded firms typically belong to a sub-set of sectors such as utilities and materials, especially in North America and Emerging Countries. However, in each and every sector from each and every region, some firms have a carbon intensity below the global exclusion threshold, so that reinvestment can maintain the region and sector weights of the benchmark, even in year 10.

The proportion of the BAU benchmark market value and the number of firms that need to be excluded tend to increase over time for three reasons: first, the number of firms in the BAU benchmark increases over time; second, the carbon emissions of the most polluting firms tend to increase over time; third, the cumulative required effort increases over time. Overall, with the $\lambda = 10\%$ reduction target, the proportion of the BAU benchmark market value excluded increases from 0.5% in 2010 to 5.4% in 2019. The number of excluded firms increases from 1% in 2010 to 11% in 2019.[15]

As Table 5 also demonstrates, all these strategies result in massive reduction in the carbon footprint of the PC portfolios with no material consequences on their financial performance. In all cases, the resulting PC portfolios have a Sharpe ratio that is at least as high as the BAU benchmark Sharpe ratio. In addition, the annual tracking error is equal to 0.04% with the 5% reduction target and 0.2% with the 10% target. Increasing the target to 15% per annum increases the tracking error to 0.45%. This result is consistent with the tracking error reported in Table 4 for the 90% exclusion threshold, as the dynamic strategy with a reduction target of 15% per annum excludes 10.6% of the market value on average.

[Insert Table 5 and Figure 5 here]

We see this simulation on the past 10 years as a proof of concept. Building PC

[15]Year 2018 is particularly demanding because of an increase by 23% in the carbon emissions firms in the BAU benchmark. Consequently, in that year, the proportion of the BAU benchmark market value excluded increased to 1.4%, 14.6%, and 21.7% and the number of firms excluded increased to 3%, 20%, and 27.7% for the 5%, 10%, and 15% reduction targets, respectively.

benchmark portfolios such that their carbon emissions shrink cumulatively at 10% or 15% per annum with respect to the initial carbon emissions in year 0 is feasible for as long as 10 years. What is more, it can be achieved while avoiding any divestment from Emerging Countries. The impact on returns is nil. So, the only "cost" of this approach is an increase in the tracking error, although this increase remains moderate.

4.2 Regional Portfolios

In Table 6, we report results when the strategy is implemented at the regional level, for North America, Europe, Pacific, and Emerging Countries over the 2010–2019 period. The PC portfolio is constructed to maintain the sectoral exposures of the BAU benchmark. The table reveals that the evolution of the carbon emissions of the BAU benchmark is very different from one region to the other. Carbon emissions have been reduced by 58% in North America, by 35% in Europe, by 24% in the Pacific, and have increased by 1% in Emerging Countries. In all four regions, the PC strategy manages to reduce overall carbon emissions by approximately 60% relative to initial BAU benchmark emissions.

In Europe, the reduction is slightly below the 60%, partly because the BAU benchmark emissions increased by 22% in 2018, rendering virtually impossible to reach the annual 10% reduction objective in 2019. In Emerging Countries, the decrease in carbon emissions by 58% in 10 years is remarkable, given that the emissions of the BAU benchmark did not decrease at all over the same period.

Contemplating the financial performance of the exclusion portfolios, we find that again the impact on the risk-adjusted return is minimal. The only exception is the Pacific allocation, which results in an increase of the Sharpe ratio. Finally, we note that the tracking error is substantial in Europe and Pacific (2.2% and 3.2% per annum, respectively). This result can be explained by the large reallocation of the exclusion portfolio necessary to attain the annual 10% reduction target. For these regions, the rebalancing is close to 15% of the market value of the portfolio at the end of the period.

[Insert Table 6 here]

5 Discussion

Our dynamic experiment, which is based on data from 2010 to 2019, allows us to assess the feasibility of the approach and evaluate the financial performance of the strategy. The future need not be like the past, however. We discuss in turn five important issues.

First, in the 2010–2019 period, the carbon emissions of the BAU benchmark declined by a cumulative 40% in 10 years. It is unclear whether the next 10 years will see more or less reduction in the carbon emissions of firms covered by the BAU benchmark. We may see a faster decarbonization of corporates between 2021 and 2030. In such a case an annual 10% reduction per annum would be easy to fulfill. It is likely that several technologies will be developed during this period that will help reduce carbon intensity even further, including renewable energies but also technologies to be discovered.[16] However, it may also be the case that low hanging fruits to reduce carbon emissions will be exhausted after a few years, raising the bar to keep the pace of decarbonization.

Second, as mentioned above, in 2018, e carbon emissions by firms in the BAU benchmark have increased by 23%, partly because of the increase in carbon intensity and partly because of the increase in the number of constituents in the BAU benchmark. This illustration suggests that some years in the future may also be particularly challenging. In such instances, there may be a trade off between the decarbonizing objective and preserving a sectoral composition of the index identical to that of the BAU benchmark.

Third, looking forward, the financial performance of decarbonized portfolios remains uncertain. Recent empirical evidence from portfolios based on the reduction in carbon emissions is mixed. In *et al.* (2019) find that a portfolio that is long stocks of firms with low carbon emissions and short stocks of firms with high emissions generates positive abnormal returns. In contrast, Bolton and Kacperczyk (2020) find that investors are already demanding compensation for their exposure to carbon emission risk in the United States. This contradicting results may be explained by the opposition between *expected* and *realized* returns. On the one hand, in equilibrium green assets should have low

[16]Implementing this exercise using emission targets provided by corporates may be misleading, suggesting a limited effort.

expected returns if investors have green preferences. Pastor *et al.* (2021a) consider a model in which investors are ready to pay a premium to hold green stocks because of investors' tastes for green assets. This implication is consistent with the empirical evidence of Hong and Kacperczyk (2009), who find that sin stocks have more depressed prices and higher expected returns than otherwise comparable stocks. Pedersen *et al.* (2021) adopt a different approach and describe a model in which the expected returns of green stocks can be lower or higher than the expected returns of brown stocks depending on the type of investors that drives the market. Yet, in a market driven by investors with green preferences, these authors also obtain low expected returns for green stocks in equilibrium. These theoretical results suggest that portfolio decarbonization should reduce the relative performance of the PC portfolio, at least in the long run.

On the other hand, in the recent period, there has been a large demand for green stocks and investors have been willing to pay a higher price to buy such shares, resulting in higher *realized* returns. This demand pressure has given rise for instance to the so-called "greenium", i.e., the recent outperformance of green bonds relative to their brown counterparts. Using an index of climate change concern based on news about climate change published by major U.S. newspapers, Ardia *et al.* (2021) and Pastor *et al.* (2021b) find that the recent outperformance of green stocks is is mainly driven by climate-concern shocks. Rohleder *et al.* (2022) also find that high carbon intensity firms suffered from decarbonization selling pressure from equity mutual funds. Similarly, using the demand system approach of Koijen and Yogo (2019), van der Beck (2021) obtains that the recent performance of ESG investments has been strongly driven by price-pressure arising from flows towards sustainable funds.

In our view, this valuation effect is likely to continue because of the strong commitment of a large number of countries to reducing emissions to net zero by mid-century. If a coalition of large institutional investors, such as the 450 financial firms of the Glasgow Allianz for Net Zero, which together manage assets worth \$130 trillion, engages in a massive decarbonization of their portfolio, adopting for instance the approach described in this paper, the demand pressure may have a positive impact on the financial performance of decarbonized portfolios. Also if some assets such as fossil fuel reserves become stranded, there may be a run against brown firms, which would have a more severe impact on the performance of the BAU benchmark than on the performance of decarbonized portfolios. Therefore, the outcome on the portfolio financial performance is likely to be positive in the short run and neutral or negative in the long run. Importantly, the method we propose also has the advantage to provide an intuitive path of a gradual decarbonization that can be used by regulators to guide the reallocation of capital and limit the risks of sudden Minsky moments where investors could dump their brown assets abruptly. Fourth, we have considered that the investor is a price taker. However, if similar decarbonizing strategies were implemented on a massive scale, it would have a substantial impact on the price of stocks of both the excluded firms and the best-in-class ones that receive the proceeds of this exclusion. This may also emulate faster adoption of cleaner technologies, notably in the worst polluting sectors, for instance by reallocating financing from firms producing electricity with coal to firms producing electricity with renewable energy. Measuring these effects, however, goes beyond the scope of this paper.

Fifth, one may argue that exclusion strategies are less effective at reducing the global carbon emissions at the world level than at greening the portfolio of a specific investor. The reason is that the sold shares are bought by another investor on the secondary market with limited impact on the excluded firm. At best, the strategy would result in an increase in the cost of financing if a coalition of investors decides to exclude the firm from their portfolio as discussed above. An alternative strategy would be for investors to "voice" their preferences to the management of corporates. Instead of selling their shares in polluting firms, investors would express their low-carbon preferences, for instance at annual general meetings, and put pressure on these firms to directly reduce their carbon emissions. Clearly, if successful, such a strategy would be more effective as it would directly change the business model of polluting firms. However, this strategy is also more expensive and requires either to be a critical investor or to form an alliance across investors so that a majority of shareholders impose decarbonization as a priority to the management.

6 Conclusion

There is a growing willingness from asset managers to improve the carbon footprint of their portfolio, and ideally to comply with a limit of global warming to 1.5°C or 2°C above pre-industrial levels. In this paper, we demonstrate that using an exclusion approach based on firms' carbon intensity would have been very effective to reduce massively the carbon footprint of an otherwise passive portfolio between 2010 and 2019.

Our approach is simple and easily implementable. We first identify the threshold of carbon intensity above which firms should be excluded. Then the proceeds of the excluded firms are reinvested in the same sector and region so as to preserve the regional and sectoral mix of the portfolio. We show that an emission reduction target of 10% per annum implemented over 10 years between 2010 and 2019 would have reduced the carbon emissions by 64% with respect to the 2009 BAU benchmark. This target would be reached without divestment from Emerging Countries and without any material impact on the risk-adjusted performance of the decarbonized PC portfolio.

We leave the assessment of the success of decarbonizing portfolio on the cost of finance for brown firms and the potential acceleration of effective decarbonizing by corporations to future, complementary research.

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Table 1. Information about the Sample of Firms

	Trucost	**ACWI**			**Developed markets**			**Emerging markets**		
Year	Nb firms	Nb firms in index	Proport. of firms	Proport. mkt cap	Nb firms in index	Proport. of firms	Proport. mkt cap	Nb firms in index	Proport. of firms	Proport. mkt cap
2005	3756	2630	76.9	87.0	1457	80.8	87.2	565	68.3	84.7
2006	4039	2754	81.2	88.4	1586	83.3	88.9	649	76.4	83.5
2007	4175	2884	85.7	91.6	1712	87.4	92.1	760	82.2	87.4
2008	4155	2439	91.6	94.4	1567	92.6	94.8	668	89.5	90.6
2009	4442	2423	93.9	95.6	1548	93.5	95.4	726	94.7	96.3
2010	4613	2462	94.8	95.8	1564	94.3	95.4	767	95.6	96.8
2011	4713	2435	95.3	95.9	1526	94.6	95.6	792	96.6	96.9
2012	4750	2431	95.1	95.9	1521	94.5	95.5	790	96.2	97.2
2013	5628	2434	96.0	96.5	1539	95.6	96.2	796	96.6	98.1
2014	6024	2470	96.4	96.6	1570	96.0	96.3	810	97.1	98.3
2015	6114	2491	96.6	96.3	1591	96.3	95.9	814	97.1	98.3
2016	13502	2486	97.4	98.2	1610	97.3	98.1	812	97.6	98.7
2017	14400	2499	97.8	98.2	1611	97.5	98.1	832	98.3	99.2
2018	15088	2758	98.2	98.0	1600	98.0	97.9	1108	98.5	99.0
2019	15663	3051	98.0	98.1	1610	97.8	98.0	1380	98.3	99.0

Note: This table reports the number of firms in Trucost dataset; the number of firms in the MSCI ACWI index and its two main components (Developed markets and Emerging markets); the proportion of firms in the index with carbon measures in Trucost; the proportion of the market capitalization of the index with carbon measures in Trucost dataset. The sample covers the period from 2005 to 2019.

Table 2. Reduction in Carbon Metrics – Proportionate and Symmetric Reinvestments

	Exclusion threshold 75%	Exclusion threshold 90%	Exclusion threshold 99%	BAU bench.	MSCI Index
Panel A: Proportionate reinvestment					
Carbon metrics					
Weighted average carbon intensity (tCO_2e/m$)	137.1	218.2	352.5	425.9	–
Annual growth (%)	-67.8	-48.8	-17.2	–	–
Carbon intensity(tCO_2e/m$)	156.2	257.2	412.0	517.2	–
Annual growth (%)	-69.8	-50.3	-20.4	–	–
Carbon footprint (tCO_2e/m$)	129.2	223.2	362.0	430.2	–
Annual growth (%)	-70.0	-48.1	-15.8	–	–
Financial performance					
Annual return (%)	8.5	8.2	7.9	7.9	7.8
Annual volatility (%)	16.7	16.5	16.6	16.6	16.3
Sharpe ratio	0.51	0.50	0.48	0.48	0.48
Annual tracking error (%)	1.77	0.71	0.10	–	–
Panel B: Symmetric reinvestment					
Carbon metrics					
Weighted average carbon intensity (tCO_2e/m$)	112.7	199.6	349.3	425.9	–
Annual growth (%)	-73.5	-53.1	-18.0	–	–
Carbon intensity (tCO_2e/m$)	129.2	232.2	408.7	517.2	–
Annual growth (%)	-75.0	-55.1	-21.0	–	–
Carbon footprint (tCO_2e/m$)	103.7	204.0	358.7	430.2	–
Annual growth (%)	-75.9	-52.6	-16.6	–	–
Financial performance					
Annual return (%)	7.8	7.7	7.9	7.9	7.8
Annual volatility (%)	17.5	16.9	16.7	16.6	16.3
Sharpe ratio	0.44	0.45	0.47	0.48	0.48
Annual tracking error (%)	2.57	1.05	0.20	–	–

Note: This table reports the average values of the carbon metrics of the exclusion portfolios, their reduction relative to the MSCI ACWI benchmark, and financial performance measures. Panel A corresponds to the proportionate reinvestment case. Panel B corresponds to the symmetric reinvestment case. Selection is based on Scope 1–3 carbon intensity. Emissions correspond to a portfolio of $100 million. The sample covers the period from 2005 to 2019.

Table 3. Characteristics of Excluded Firms

	Whole sample				2019			
	BAU	Exclusion threshold			BAU	Exclusion threshold		
	bench.	75%	90%	99%	bench.	75%	90%	99%
Panel A: Sectors								
Financials	16.6	1.3	1.3	–	16.8	1.1	1.3	–
Industrials	15.9	15.4	14.1	2.5	15.5	18.1	11.5	3.8
Consumer discretionary	14.5	13.2	10.2	–	13.2	14.3	13.1	–
Materials	10.1	31.8	37.5	37.0	9.8	27.3	37.7	38.0
Information technology	9.9	2.4	0.7	–	11.8	4.1	1.5	–
Consumer staples	8.0	6.2	1.6	–	8.2	9.8	1.9	–
Health care	6.0	0.5	0.4	–	7.6	1.3	0.6	–
Utilities	5.3	14.6	23.2	57.0	4.8	11.8	19.0	53.2
Energy	5.3	13.8	10.6	3.5	4.0	10.6	12.7	5.1
Real estate	5.0	0.5	0.3	–	5.5	1.3	0.8	–
Panel B: Countries								
United States	23.8	18.9	16.7	20.3	21.1	16.7	14.6	15.2
Japan	13.7	13.0	9.7	3.5	10.8	11.1	7.5	1.3
China	6.0	7.0	8.5	14.3	21.2	22.4	22.7	30.4
United Kingdom	4.4	3.1	2.3	2.1	3.0	2.0	1.5	–
Taiwan	4.1	4.4	4.0	3.1	2.9	3.8	2.9	1.3
Korea	4.0	3.6	3.2	1.0	3.7	3.4	3.3	1.3
Canada	3.8	5.2	4.9	2.5	3.0	3.5	4.4	–
Australia	2.9	3.4	3.7	1.2	2.3	2.7	3.5	2.5
France	2.8	2.1	2.2	0.8	2.4	1.6	1.0	–
Hong Kong	2.8	2.5	3.2	8.0	2.9	2.9	2.9	7.6
India	2.8	3.8	4.5	13.6	2.8	3.8	3.5	8.9
Brazil	2.4	3.0	3.7	–	1.7	2.1	2.3	–
Germany	2.1	1.8	1.9	0.8	1.9	1.4	1.7	2.5
South Africa	1.9	2.2	2.9	2.5	1.4	1.3	1.7	1.3
Malaysia	1.7	2.5	4.0	3.7	1.3	1.9	3.5	1.3
Switzerland	1.5	1.3	0.8	1.5	1.3	1.5	0.6	1.3
Sweden	1.3	0.7	0.3	–	1.0	1.1	–	–
Singapore	1.2	1.0	1.1	0.1	0.9	0.6	0.6	1.3
Thailand	1.2	1.7	2.5	4.5	1.3	1.6	2.7	5.1
Saudi Arabia	1.1	0.1	0.2	0.3	1.1	1.5	3.1	3.8
Indonesia	1.1	1.6	2.0	4.2	0.9	1.3	1.9	2.5
Italy	1.0	0.9	0.8	0.7	0.7	0.7	0.4	–
Spain	1.0	1.1	1.3	–	0.8	0.7	0.6	–
Mexico	0.9	1.3	0.9	0.1	0.8	1.1	1.3	1.3
Turkey	0.9	1.3	1.2	–	0.5	0.6	0.8	–
Netherlands	0.9	0.5	0.2	–	0.7	0.4	–	–
Russia	0.8	1.7	1.9	2.3	0.7	1.7	2.7	7.6
Poland	0.8	0.9	1.2	1.7	0.6	0.5	1.0	1.3

Note: This table reports the proportion of excluded firms in a given sector (Panel A) or country (Panel B) in the BAU benchmark and as selected by the 75%, 90%, and 99% thresholds. Sectors and countries are sorted according to the benchmark frequency. Selection is based on Scope 1–3 carbon intensity. The sample covers the period from 2005 to 2019.

Table 4. Reduction in Carbon Metrics – Regional/Sectoral Reinvestment

	Exclusion threshold 75%	90%	99%	BAU bench.	MSCI Index
Carbon metrics					
Weighted average carbon intensity (tCO_2e/m$)	164.2	237.7	353.8	425.9	–
Annual growth (%)	-61.4	-44.2	-16.9	–	–
Carbon intensity (tCO_2e/m$)	181	275.7	412.3	517.2	–
Annual growth (%)	-65.0	-46.7	-20.3	–	–
Carbon footprint (tCO_2e/m$)	169.3	247.0	363.2	430.2	–
Annual growth (%)	-60.6	-42.6	-15.6	–	–
Financial performance					
Annual return (%)	8.2	7.9	7.9	7.9	7.8
Annual volatility (%)	16.6	16.4	16.6	16.6	16.3
Sharpe ratio	0.49	0.48	0.48	0.48	0.48
Annual tracking error (%)	0.97	0.45	0.06	–	–

Note: This table reports the average values of the carbon metrics of the exclusion portfolios, their reduction relative to the MSCI ACWI benchmark, and financial performance measures, when the exclusion is performed at the overall level with regional/sectoral reinvestment. Selection is based on Scope 1–3 carbon intensity. Emissions correspond to a portfolio of $100 million. The sample covers the period from 2005 to 2019.

Table 5. Reduction in Carbon Metrics – Dynamic Selection

	Reduction target			BAU	MSCI
	5%	10%	15%	bench.	Index
Panel A: 2010–2019					
Starting emissions ($GtCO_2e$)	46.4	46.4	46.4	46.4	–
Final emissions ($GtCO_2e$)	26.8	16.5	10.9	28.4	–
Cumulative growth (%)	-42.2	-64.4	-76.5	-38.8	–
Annual growth (%)	-5.3	-9.8	-13.5	-4.8	–
Annual return (%)	9.8	9.8	9.8	9.8	9.7
Annual volatility (%)	14.4	14.4	14.5	14.4	14.1
Sharpe ratio	0.68	0.68	0.68	0.68	0.69
Annual tracking error (%)	0.04	0.20	0.45	–	–
Number of firms excluded	27.0	176.3	393.9	–	–
Prop. of firms excluded (%)	1.1	6.9	15.6	–	–
Prop. of market value excluded (%)	0.5	4.0	10.8	–	–
Panel B: 2015–2019					
Starting emissions ($GtCO_2e$)	35.3	35.3	35.3	35.3	–
Final emissions ($GtCO_2e$)	26.8	20.8	15.7	28.4	–
Cumulative growth (%)	-24.0	-41.0	-55.6	-19.6	–
Annual growth (%)	-5.3	-10.0	-15.0	-4.3	–
Annual return (%)	13.2	13.1	13.2	13.2	12.9
Annual volatility (%)	15.6	15.6	15.5	15.6	15.1
Sharpe ratio	0.84	0.84	0.85	0.84	0.85
Annual tracking error (%)	0.02	0.06	0.31	–	–
Number of firms excluded	20.6	76.8	261.0	–	–
Prop. of firms excluded (%)	0.8	2.8	9.5	–	–
Prop. of market value excluded (%)	0.3	1.2	6.2	–	–

Note: This table reports the percent reduction in the carbon emissions relative to the initial portfolio emissions and financial performance measures, when the exclusion is performed at the overall level with regional/sectoral reinvestment. We consider reduction targets of 5%, 10%, and 15%, respectively. Selection is based on Scope 1–3 carbon intensity. Starting and final emissions correspond to a portfolio of $100 billion. The sample covers the periods from 2010 to 2019 and from 2015 to 2019 (Panels A and B, respectively).

Table 6. Reduction in Carbon Metrics – Dynamic Selection by Region

	Portfolio	BAU bench.	Portfolio	BAU bench.
	North America		**Europe**	
Starting emissions ($GtCO_2e$)	32.8	32.8	50.0	50.0
Final emissions ($GtCO_2e$)	11.7	13.9	20.8	32.4
Cumulative growth (%)	-64.2	-57.7	-58.5	-35.2
Annual growth (%)	-9.8	-8.2	-8.4	-4.2
Annual return (%)	13.4	13.4	6.0	6.0
Annual volatility (%)	14.0	14.0	17.5	17.6
Sharpe ratio	0.95	0.96	0.34	0.34
Annual tracking error (%)	0.39	–	2.21	–
Number of firms excluded	18.2	–	36.0	–
Prop. of firms excluded (%)	2.7	–	8.5	–
Prop. of market value excluded (%)	1.6	–	8.9	–
	Pacific		**Emerging Countries**	
Starting emissions ($GtCO_2e$)	47.4	47.4	84.6	84.6
Final emissions ($GtCO_2e$)	18.4	35.9	35.4	85.6
Cumulative growth (%)	-61.1	-24.3	-58.2	1.1
Annual growth (%)	-9.9	-2.7	-8.4	0.1
Annual return (%)	7.2	6.6	4.6	4.7
Annual volatility (%)	14.0	14.3	18.0	18.0
Sharpe ratio	0.51	0.46	0.26	0.26
Annual tracking error (%)	3.21	–	1.92	–
Number of firms excluded	52.8	–	93.5	–
Prop. of firms excluded (%)	11.5	–	9.9	–
Prop. of market value excluded (%)	8.2	–	6.7	–

Note: This table reports the percent reduction in the carbon emissions relative to the initial portfolio emissions and financial performance measures for four regions. We consider that the exclusion is performed at the overall level with regional/sectoral reinvestment and a reduction target of 10%. Starting and final emissions correspond to a portfolio of $100 billion. Selection is based on Scope 1–3 carbon intensity. The sample covers the period from 2010 to 2019.

Figure 1. Histogram of the Scope 1–3 Carbon Intensity (2019)

This figure represents the histogram of the Scope 1–3 carbon intensity of firms in the MSCI ACWI index in 2019. Carbon intensity is measured in tCO_2e/m\$. The histogram is in log scale. The figure also displays the 75%, 90%, and 99% thresholds.

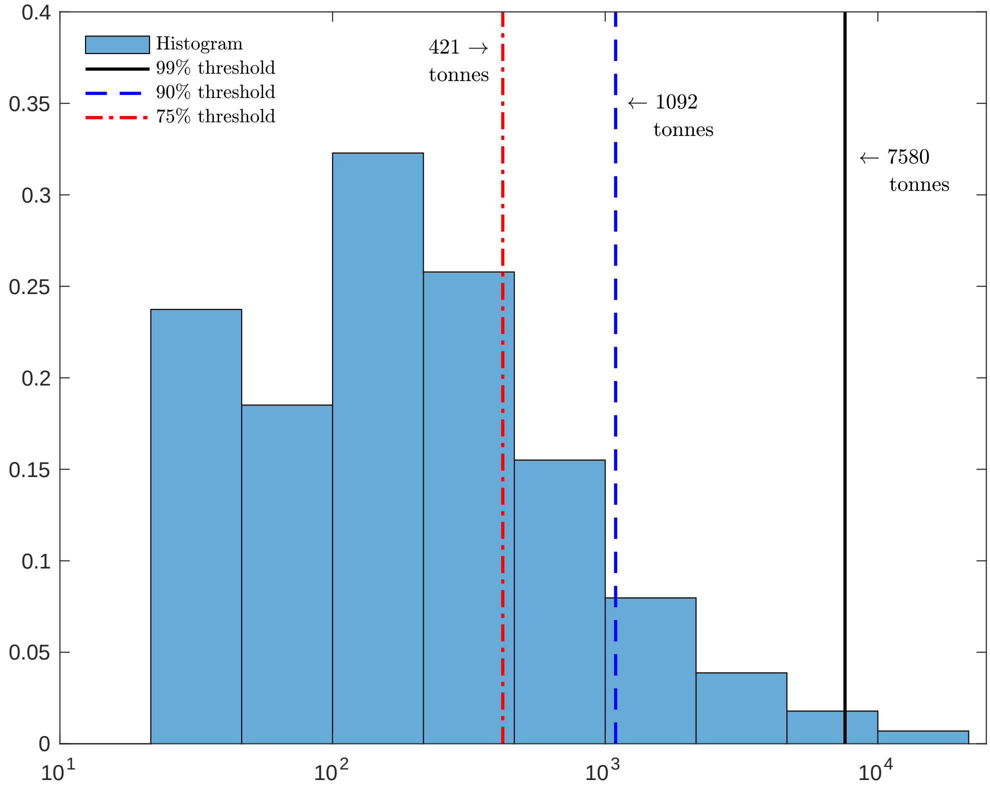

Figure 2. Characteristics of Carbon Emissions Depending on the Threshold

This figure reports some characteristics of Scope 1–3 carbon emissions for several high probabilities, for the MSCI ACWI index. Panel A corresponds to the quantiles of probability $\theta = 75\%$, 90%, 95%, and 99% (thousand tCO_2e/m$ revenue). Panel B corresponds to the average carbon intensity of firms above the $\theta = 75\%$, 90%, 95%, and 99% quantiles (thousand tCO_2e/m$ revenue). Panel C corresponds to the average carbon emissions of firms above the same quantiles (million tCO_2e). The sample covers the period from 2005 to 2019.

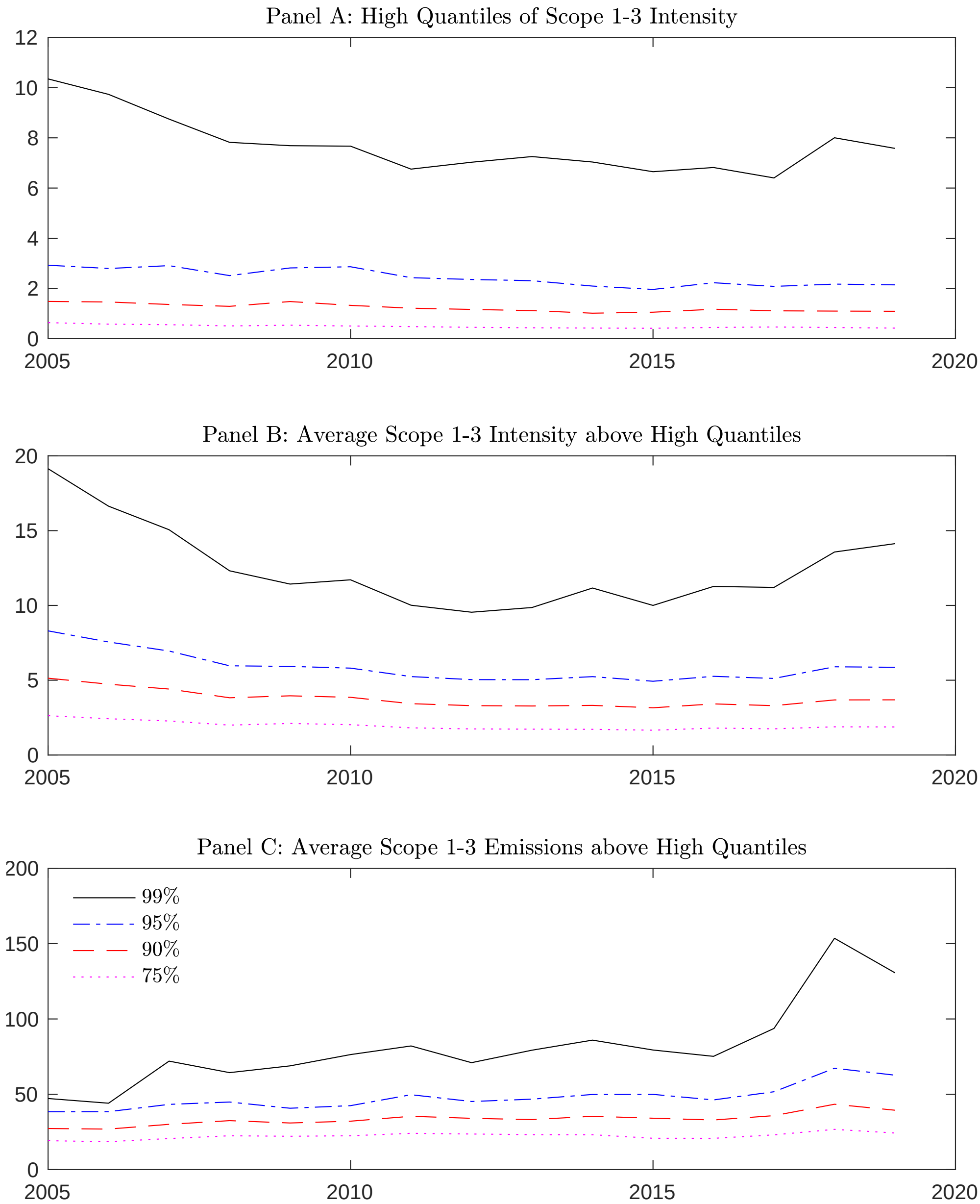

Figure 3. Carbon Metrics of Selected Portfolio – Proportionate Reinvestment

This figure displays the carbon metrics for the benchmark portfolio and for the portfolio based on the overall exclusion of the firms with carbon intensity above the 75%, 90%, 99% thresholds and proportionate reinvestment, when Scope 1–3 carbon intensity is used for the MSCI ACWI index. The sample covers the period from 2005 to 2019. Carbon numbers are in thousand tCO_2e/m$.

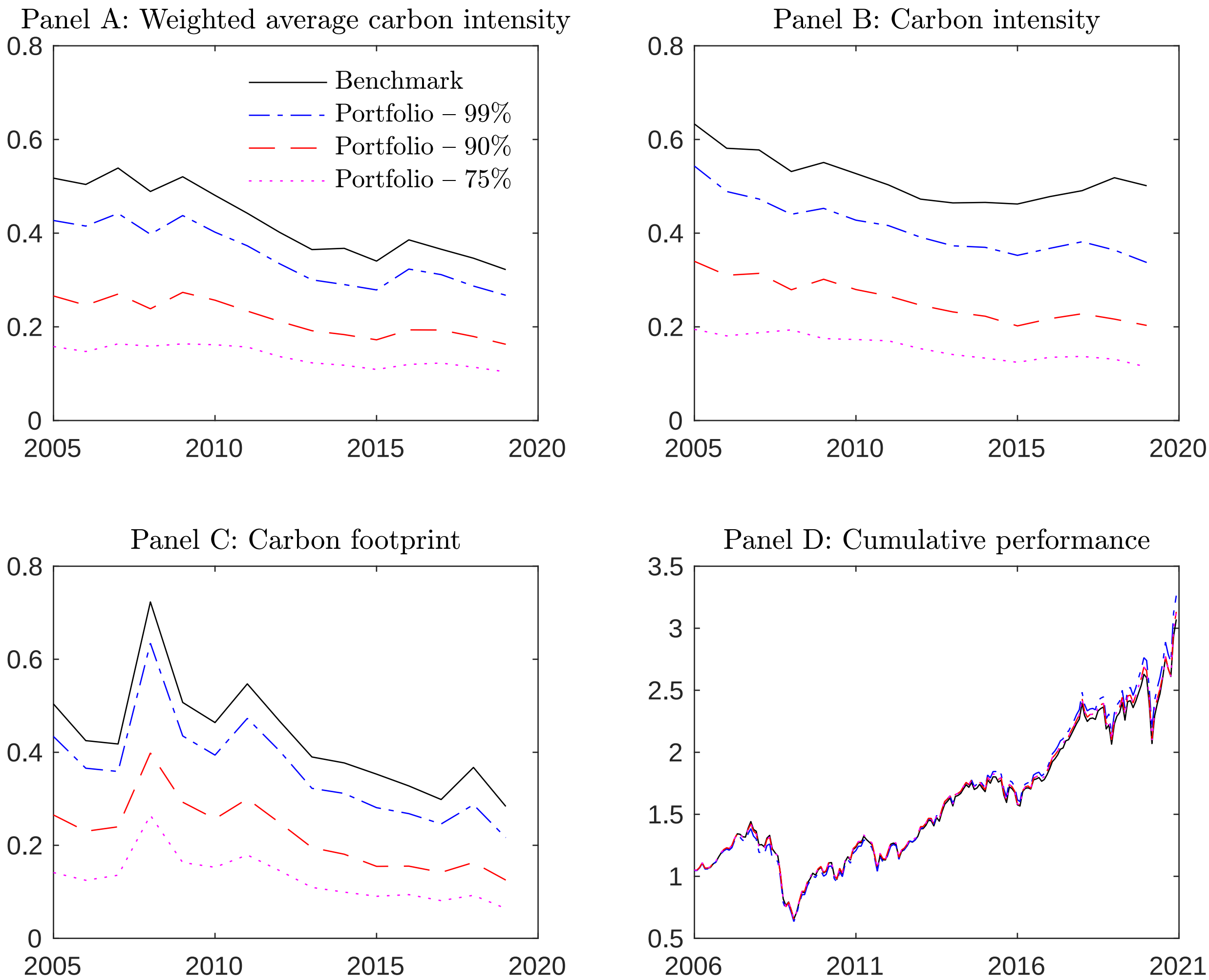

Figure 4. Carbon Metrics of Selected Portfolio – Regional/Sectoral Reinvestment

This figure displays the carbon metrics for the benchmark portfolio and for the portfolio based on the overall exclusion of the firms with carbon intensity above the 75%, 90%, 99% thresholds and the reinvestment of the proceeds in the same region and sector, when Scope 1–3 carbon intensity is used for the MSCI ACWI index. The sample covers the period from 2005 to 2019. Carbon numbers are in thousand tCO_2e/m$.

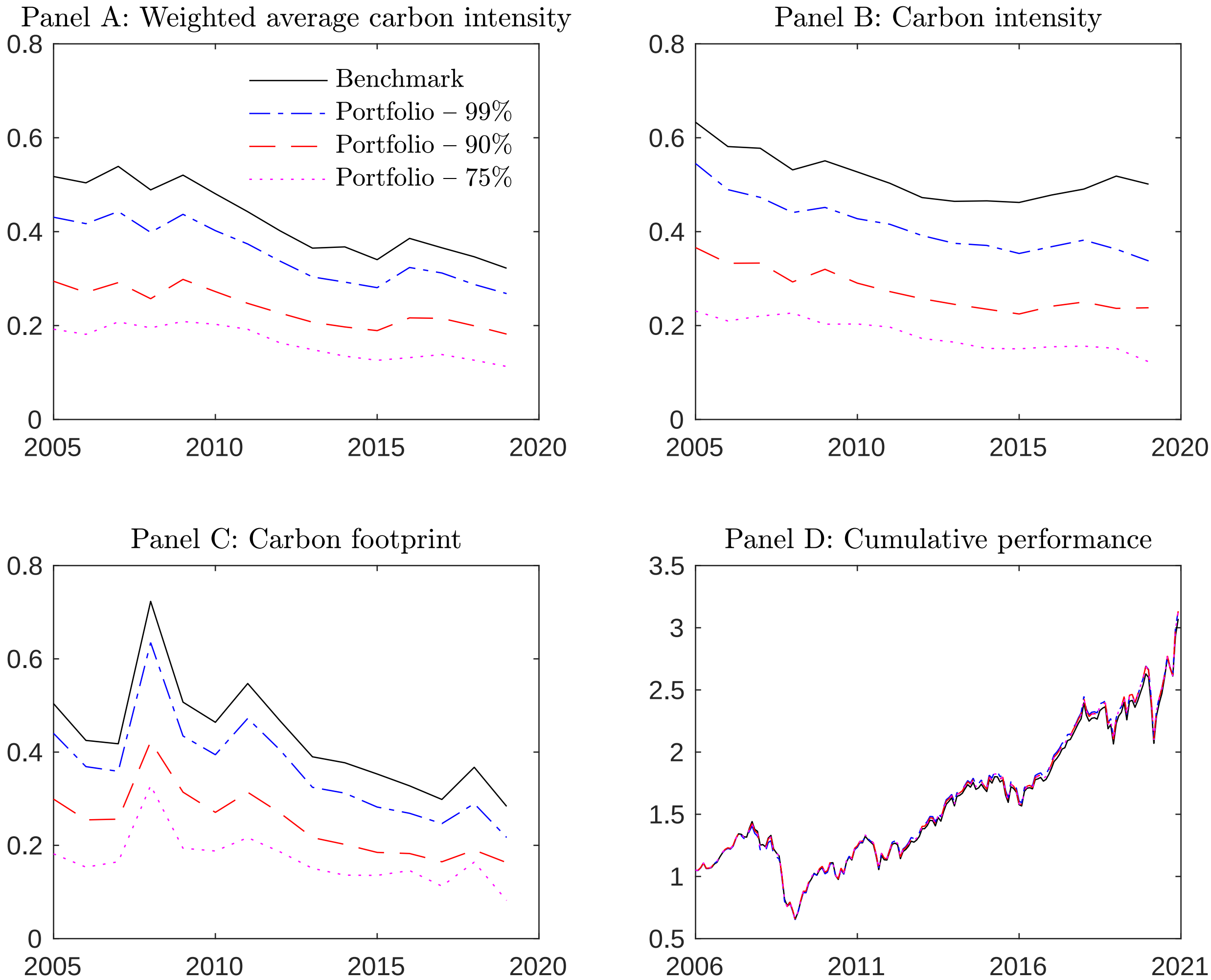

Figure 5. Characteristics of the dynamically decarbonized portfolio (annual target of $\lambda = 10\%$)

This figure displays some characteristics of the decarbonized portfolio obtained by reducing its carbon emissions by $\lambda = 10\%$ per year between 2010 and 2019. Panel A reports the evolution of the carbon emissions of the BAU benchmark and the PC portfolio (million tCO_2e). Panel B reports the annual carbon intensity threshold above which firms are excluded (thousand tCO_2e/m$ revenue). Panel C reports the proportion of the market value of the BAU benchmark that is excluded from the PC portfolio, because it is above the threshold. We use the overall exclusion and regional/sectoral reinvestment strategy