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Improving the EU SFDR Paris-Aligned Benchmark for Net-Zero portfolio construction

Master thesis of

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ABSTRACT

In this paper, we show that without the analysis of firm-specific emission reduction behaviour, asset managers run the risk of long-term underperformance due to exposure to climate-related risk. We do this by applying and improving forward-looking firm-specific forecasting methods. We construct a Net-Zero portfolio (NZP) for the European market and find a 95% reduction in carbon exposure without significantly sacrificing risk-adjusted return, and with minimal tracking error to a benchmark portfolio. We show that the expected 2030 EPS of our NZP is not affected (–0.15%) by EU-ETS Carbon pricing, while a conventional or EU Paris aligned portfolio might risk significant underperformance (–15.4%) in the medium term. With this, we illustrate how the NZP is better protected against the financially material carbon risks and conclude that this method should be preferred over traditional ESG-factor investing.

Keywords: climate risk, carbon risk, portfolio finance, investing, asset management, climate change, Net-Zero, Paris Climate Agreement, ESG

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1. INTRODUCTION

In 2015 the Paris Climate Agreement (PCA) was signed by all 193 countries. This agreement set the goal of keeping global warming below 1.5°C. To reach this target, the International Panel on Climate Change (IPCC), has estimated that the global society must be Net-Zero emitters by the year 2050. In climate policy like the EU Green Deal (EUGD), private investment is key to financing this green transition (Ohnesorge & Rogge, 2021). While the consideration of carbon emission for asset management has become widespread since the 2015 PCA (Redington, 2022; Amel-Zadeh & Serafeim, 2018), there is no commonly accepted method for aligning investment portfolios with the PCA (Barahhou et al. 2022). In addition, Environment, Social and Governance (ESG)-scores, the most popular sustainable investment consideration (NinetyOne, 2022; PwC, 2022; Amel-Zadeh & Serafeim, 2018), might not sufficiently identify which assets are (poorly) aligned with a green shift. In this paper, we show that without the analysis of firm-specific emission reduction behaviour, asset managers run the risk of long-term underperformance due to exposure to climate-related risk.

This paper adds to the literature in four ways. Firstly, we conduct a review of the current literature, where we use a set of four criteria to assess Net-Zero alignment (NZA) method appropriateness (section 2.2, appendix III & IV). An overview and assessment of all available methods did not exist previously but is necessary to select the method that has the best chance of efficiently reducing climate-risk exposure. Secondly, we apply the highest quality method, a trend-based method as described by Le Guenedal and Roncalli (2022), to investigate empirical performance of a portfolio constructed with this method (section 3 & section 5). This method had thus far only been theorized by the authors. Thirdly, we take Le Guenedal et al. (2022) conceptualization of emission velocity, discuss how the method is biased against firm history, and present an alteration that reduces this issue (section 3.4). With the altered velocity, we develop nonlinear forecasting capability and incorporate this in the original trend-method, to test empirical performance. Something that has not been done previously (section 5). Here we show that the NZP has 95% less carbon-risk exposure with minimal sacrifice in risk-adjusted return. Finally, we expose cash-flow risk embedded in traditional portfolio allocation methods, to highlight the benefit of the NZP. We identify two channels of risk; The risk of stranded assets, quantified using self-reported climate-risk estimates (section 6.1), and the risk of carbon-pricing exposure (section 6.2), to discuss the volatility of portfolio EPS to carbon-pricing. Carbon-risk exposure is quantified using current and future carbon-pricing estimates,. Here, we find the NZP is not significantly exposed to this risk, while benchmark portfolios have significant (~15%) exposure. While the relevance of stranded assets and carbon pricing is widely discussed, the monetization of these climate-risks as presented in this paper is a novel development. From the collection and analysis of a novel dataset, we conclude that the NZP firms have better reporting of stranded asset risk, which could indicate better climate-risk management altogether.

The structure of this paper:

In section 2, we provide a short overview of the literature landscape to show that the selection and construction of the NZA method consists of two components. We conclude that the 43% 2030 1.5 ℃ target by the IPCC (2021) appears the most suited Net-Zero target (Component 1), following our detailed analysis of the various targets (appendix II). To select Component 2, we briefly discuss how each method can be most accurately applied at the asset-level. This is important because the climate-risk implied by a Net-Zero transition cannot be diversified away, making it important that each asset in the portfolio is Net-Zero aligned on its own. From our detailed analysis of all Net-Zero methods (appendix IV), we conclude that *Trend methods* (Le Guenedal & Roncalli, 2022) appear the most suited alignment method (Component 2).

In section 3, we enhance this method by accounting for Covid-distortion, allowing Net-Zero alignment through cumulative compliance and improving nonlinear methods presented by Le Guenedal et al. (2022). This latter improvement addresses current biases against accounting track-records (section 3.4).

In section 4, we apply the NZA method to the EuroStoxx600 European index. Here, future emissions are forecasted based on 10 years of historic data, using both linear and nonlinear methods to measure alignment against the target: a 43% emission reduction requirement in 2030, compared to 2019 firm-specific total emissions (Scope 1+2+3). The resulting Net-Zero aligned universe is subjected to a Markowitz portfolio-optimization driven by Würtz and Chalabi's (2009) NLMINB2 algorithm, with mechanically restricted sector balance. This sector restriction is done to ensure that the NZP is sufficiently diversified and selects climate winners in each sector, as dictated by the current literature (Edmans et al., 2022; Fankhauser et al., 2022).

In section 5, we compare the resulting NZP's financial performance, key financial descriptives, sector exposure and ESG performance to a non-aligned portfolio, an ESG-focused portfolio, and an *EU Paris Aligned Benchmark (PAB)* (Hodges et al., 2022) proxy portfolio constructed from the EuroStoxx600 index. We show that, compared to other portfolios, the NZP has comparable financial performance and comparable exposure to traditional risk factors, while significantly outperforming on emission footprint and ESG performance. We compare the NZP to a traditional ESG-focused portfolio to show that the ESG-focused portfolio increases ESG performance at a large financial cost without significantly reducing exposure to carbon- and transition-risk.

All the while, we argue increasing regulation and the scaling of carbon pricing instruments (European Council, 2023) make carbon risk more financially material than ever before. In section 6, we highlight how the non-aligned, ESG-focused, and *PAB* portfolio have significant exposure to carbon-pricing instruments and other risk of stranded assets, with the help of a new forward-looking stranded-asset risk dataset and an EUA risk model.

Finally, we conclude that this paper illustrates how current inaccurate measures, such as the *EU PAB*, do not present the asset manager with the tools necessary to construct a Net-Zero aligned portfolio that manages carbon risk. We argue that we address this gap in the literature by illustrating how this papers' NZP outperforms alternative portfolios in climate risk management, without sacrificing financial performance. We find that this contribution is particularly valuable for asset managers in European markets as the NZP method is well-adjusted to the development and consistency of climate policy and carbon pricing in the European Economic Area (EEA). This paper also has valuable insights for regulators and policymakers.

2. THEORETICAL BACKGROUND

In recent years, both methods for responsible investment (Dreyer et al., 2023; Brooks & Oikonomou, 2018) and potential financially material benefits of ESG considerations have been well documented (Cerqueti et al., 2022; De Angelis et al., 2022; Hodges et al., 2022; Kaul et al., 2022; Maxfield & Wang, 2021). While methods for Net-Zero alignment are still in their infancy, various methodologies have been suggested (Barahhou et al., 2022; Kolle et al., 2022; Le Guenedal et al., 2022; Le Guenedal & Roncalli, 2022; Bolton et al., 2021; Hohne-Sparborth et al., 2021; Urban et al., 2021; Wang et al., 2021; Bender et al., 2019; EU TEG, 2019; Andersson et al., 2016). The NZA method presented in this paper is based on the methods proposed and critique provided by this area of the literature.

A Net-Zero alignment method has two components: 1) The Net-Zero target, this is an amount of annual emissions that must be reached before a certain time. (e.g., zero tons of CO_2 by 2050). 2) An alignment method that measures "alignment" with the target by measuring or estimating the asset's amount of annual emissions at a certain point in time. The alignment method is partially dictated by the choice of target (Hohne-Sparborth et al., 2021; TCFD, 2021).

2.1 Component 1: The target

Although the PCA goal is simple; try to limit global warming to 1.5℃ (UN, 2015), the climate science behind reaching this goal is rather complex. There are various models that present annual reduction targets for society. As there is no way to tell which target is the correct one, we select our target based on the ease and accuracy with which the target can be applied to a single asset.

Because negative emission technologies are likely not available at large scale in the near future (IPCC, 2018), it is unlikely that there are assets with negative emission, to compensate for assets with positive emission. As such, we can state that a portfolio's carbon risk cannot be diversified away and reaching Net-Zero at the portfolio level requires reaching Net-Zero for each individual asset in the portfolio. Therefore, we must be able to analyse the emission reduction behaviour of each individual asset. To do that we need targets at the asset-level.

In the literature, most targets are based on IPCC, IEA, or EU CTI climate models (IPCC, 2021; IEA, 2021; ECF, 2018; IPCC, 2018; IPCC, 2014). Sometimes, targets are defined as a share of the global *carbon budget* (Bolton et al., 2022; EU TEG, 2019). But deciding how much of the allowed global emissions should be for the assets you own is nearly impossible, as it requires an estimation of the entire economy and your assets' share of it.

Others apply Net-Zero targets based on past firm performance, often combined with sector-, country-, or industry-specific reduction characteristics (Kolle et al., 2022; Hohne-Sparborth et al., 2021). These more granular targets can increase accuracy of the alignment method. However, due to the complexity this approach creates for multi-sector firms, we decide to apply the IPCC AR6 2030 target, which requires 43% reduction compared to 2019 emissions, by 2030 (IPCC, 2021, p. 329). We choose this target because the percentagewise (43%) reduction target is easily applied at the individual asset-level with minimal distortion from firm characteristics. We choose a 2030 target over a 2050 target to increase forecasting accuracy (Bolton et al., 2022) and to allow for interim adjustments, something deemed important by the literature and practitioners (Swiss RE, 2023; Bolton et al., 2022, p.21; Meissner et al., 2021, p.9). Furthermore, the difference between different targets is the biggest after 2030. Choosing a 2030 target makes our choice of target therefore less important. We choose to estimate annual targets between 2019 and 2030 linearly, in graphing and in the methods where needed (Addition 1 & Addition 2, section 3).

Detailed discussion of the targets and the climate science behind targets can be found in appendix I and appendix II.

2.2 Component 2: The alignment method

Generally, the literature neither agrees on what should be the target (Component 1) nor how alignment should be measured (Component 2). Empirical testing of methods is limited and mostly focuses on the popular *PAB*. As such the advice of expert groups (TCFD, 2021; EU TEG, 2019) and authors' critique and discussion of current methods (Bohn et al., 2022, Barahhou et al., 2022; Steffen, 2022; Hohne-Sparborth et al., 2021) is mostly a theoretical discussion.

In the appendix (III) we derive evaluation criteria from the current debate and review each available method along these criteria. We find that early methods do not allow one to measure emission reduction (Bender et al., 2019; Andersson et al., 2016), making these methods useless for comparison against a reduction target. Other methods rely on the derivation of a *portfolio-level carbon-budget* (Bolton et al., 2022; Le Guenedal et al., 2022; Urban et al., 2021). But estimating a personal carbon budget from the global budget requires the estimation of one's fair share of the earth's allowed emissions, which is practically impossible. *Temperature scores* (Kolle et al., 2022; Le Guenedal & Roncalli, 2022) are ambiguous and too difficult to understand (Barahhou et al., 2022, p.3), and *firm commitments* (Barahhou et al, 2022; Bolton et al., 2022; Le Guenedal et al., 2022; Hohne-Sparborth et al., 2021; Bender et al., 2019) are too exposed to greenwashing concerns (Foerster & Spencer, 2023, p.28). *Green investment metrics*, such as the share of R&D that goes to carbon-neutral products (Barahhou et al., 2022), are forward-looking but materialization of R&D is uncertain and too far into the future.

Change in *green revenue*, the carbon-neutral share of revenue (Le Guenedal & Roncalli, 2022, Barahhou et al., 2022, Wang et al., 2021) is a much more direct forward-looking measure of emission reduction. However, this data is not readily available. Bender et al. (2019) are only able to retrieve *green revenue* data for 577 firms for the developed markets (2017), using FTSE Russell. Barahhou et al. (2022, p. 3) also conclude that the metric is relatively young as they are unable to retrieve enough historical data to perform a dynamic analysis.

Because of these limitations, most methods are based on *emission intensity* (Barahhou et al., 2022; Hodges et al., 2022; Kolle et al., 2022; Hohne-Sparborth et al., 2021; Bender et al., 2019), defined as the asset's absolute emissions divided by a financial metric (e.g., revenue). Both absolute emissions data and financial data is readily available for most assets.

Proponents of *emission intensity* argue that the method is required to allow for better comparison between firms (Barahhou et al., 2022, p. 18; EU TEG, 2019), more precise and fair targets (Hohne-Sparborth et al., 2021), better identification of firms that have decoupled emissions from value creation (EU TEG, 2019), or to better account for inorganic firm growth (Hohne-Sparborth et al., 2021; EU TEG, 2019).

However, most of these issues are the result of method design choices and virtually all are resolved by using a percentage-wise target, and by focusing on absolute emission reduction rather than absolute emission levels. We argue, for example, that by performing portfolio optimization on a universe of assets that are all individually aligned with the PCA, we look for the assets that decrease their emissions but still have attractive financial returns. Meaning that this two-step approach effectively selects the assets that have decoupled value creation from emissions. Without looking at emission intensity.

After we show how *emission intensity* has no real benefits as a measure, we criticize *emission intensity* for its poor construct validity. As we discuss how a change in the financial metric, as a result of inflation, price volatility or M&A activity, will decrease *emission intensity* without actual decrease in emissions (Hohne-Sparborth et al., 2021; Meissner et al., 2021). We discuss how accounting for price volatility and inflation is both complex, labour-intensive, and often impossible without a significant data-lag.

The popular *EU PAB* and less stringent *Climate Transition Benchmark (CTB)* are based on *emission intensity* and suffer from many of the same issues. On top of that, the method has large (50% & 30% respectively) initial reduction requirements that seem theoretically unfounded (Barahhou et al., 2022; Steffen, 2022). The alignment-requirement at the portfolio-level rather than the asset level (EU TEG, 2019, p.47) results in a *PAB* that is virtually unable to manage climate risk (as shown in section 5).

As such we argue in concurrence with Hohne-Sparborth et al. (2021, p. 7) and recognise that the alignment method must be one based on absolute emissions, rather than a derivative, to ensure a direct measurement of emission reduction. Here the *Trend method* (Le Guenedal & Roncalli, 2022) and *Ambition method* (Hohne-Sparborth et al., 2021) are the most robust absolute-emission-based methods available. Based on historic absolute emissions data, these methods estimate the orientation of the emission reduction slope with respect to a target emission reduction slope. The two methods differ in that *trend methods* estimate this emission reduction slope by taking the beta from a simple regression on historic data, where they rely on the large empiric autocorrelation of emissions

(Bolton et al., 2022), while the *ambition method* estimates its slope as the ambition of a firm, compared to a target trajectory. If an asset has been having 120% of the target's annual emissions over time, the *ambition method* estimates that this asset will continue to have 120% of the target annual emissions into the future, following the reduction target's trajectory in relative parallel.

In the end we argue that the *trend method* is the preferred approach because: 1) the method relies more on firm-specific data and 2) Le Guenedal and Roncalli suggest how to account for nonlinearity within *trend methods*, an adjustment that is not available for *ambition methods*. Nonlinear modelling capability is important as most climate science agrees a non-linear downwards-sloping s-curve is the most likely societal reduction trajectory (Hohne-Sparborth et al., 2021) (appendix II.e, figure 17).

Following the literature, we consider both direct and indirect emissions (Scope 1, Scope 2 & Scope 3) (Barahhou et al., 2022; Bolton et al., 2022; Le Guenedal & Roncalli, 2022; EU TEG, 2019), but we don't adjust for the double counting issue (appendix IV.h, ¶. 3), following the judgment of the EU TEG (2019). To guarantee sector balance and the financing of a green transition in all sectors, we are mechanically restricting sector exposure in our portfolio construction, as proposed by the literature (Bolton et al., 2022; EU TEG, 2019). The method should also be applied to achieve alignment at the asset-level, rather than on the aggregate portfolio, as discussed in section 2.2. We recognise the issue of inorganic growth (Hohne-Sparborth et al., 2021) but find no robust solution for this issue in the literature, and therefore consider adjustments for this issue beyond the scope of this research.

Detailed discussion of every single method, as well as detailed arguments for and against methods, can be found in appendix IV.

Empirical performance

In the literature, there is only limited attention for the empirical performance of Net-Zero aligned portfolios. The most tested method, the *PAB*, is usually found to have very little impact on portfolio composition and tracking error, compared to a non-restricted optimized portfolio. Hodges et al. (2022) find an identical Sharpe ratio for a *PAB-portfolio* compared to the benchmark. Other authors also find a negligible tracking error for the *PAB* (Barahhou et al., 2022; Bolton et al., 2022; Le Guenedal & Roncalli, 2022). Bassen et al. (2023) presents a sustainable development (ESG/SDG/GC/SDI) optimised portfolio that more closely resembles the risk-management ambition of an NZA method as envisioned in this paper. These authors construct a portfolio from only 20% of the benchmark investible universe. Their portfolio achieves a 9% increase in the portfolio ESG-score and considerable improvement in other non-financial performance metrics. The authors achieve this at the non-significant cost of –7% in risk-adjusted return (return / portfolio standard deviation).

HYPOTHESIS

We expect to apply and improve trend-methods (Le Guenedal & Roncalli, 2022) to construct a portfolio that significantly outperforms on carbon risk exposure, with only minimal impact on risk-adjusted return. In line with recent empirical findings in the field of sustainable investing (Bassen et al, 2023; Hodges et al., 2022).

3. METHODS

The *trend method* is a dynamic absolute emission method with a direct link to emission reduction. An advantage of an absolute emissions metric is that they are easily aggregated into a portfolio metric using weighted averages.

Le Guenedal and Roncalli (2022) first discuss the estimated firm emissions reduction as a linear trend derived through a linear regression for each emission Scope ($j = 1,2,3$) for a given firm (i) at a given time (t) so that:

$$Scope\ j\ Emissions: \boldsymbol{E_{i,j}}\,(t) = \beta_0 + \beta_1 \times t + u_t \qquad for\ t \leq t_0$$

(1)

With the beta found through this regression, we are then able to argue that the emission trend for a given Scope, for the forecasting period *N*, equals:

$Expected\ Scope\ Emissions\ for\ scope\ j$:

$$\boldsymbol{\hat{E}_{i,j}}(t_0 + h) = E_{i,j}\,(t_0) + \hat{\beta}_1 \times h \qquad for\ h = 1,2,\ldots,N$$

(2)

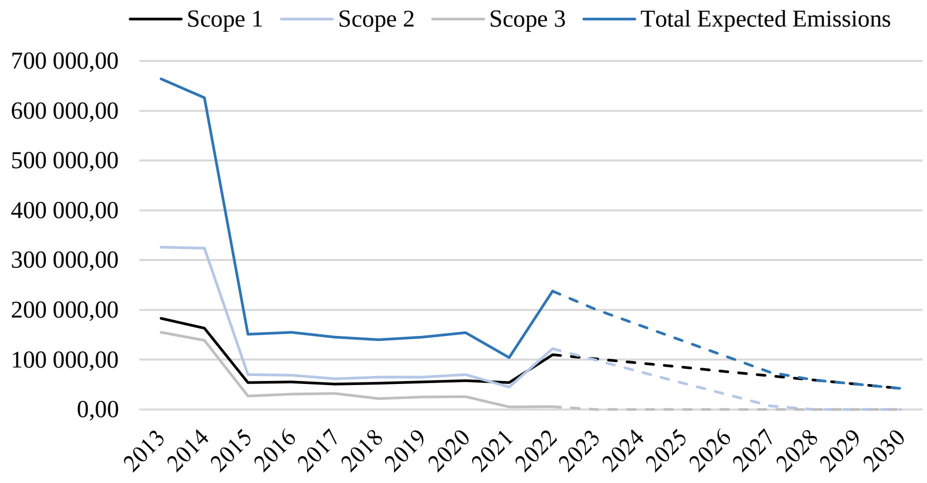
And as absolute emissions are simply additive, expected total emissions are therefore:

$$Total\ Expected\ Emissions: \boldsymbol{\hat{E}_i^{total}}(t_0 + h) = \sum_{j=1}^{n=3} \hat{E}_{i,j}(t_0 + h)$$

(3)

Figure 1 shows how the total expected emissions are simply the sum of the linearly estimated emissions for each emissions Scope. Here Scope 1 emissions are direct emissions from the firm's operations, Scope 2 emissions are emissions from purchased electricity and Scope 3 are all other value chain emissions.

Figure 1:Trend-based emission forecast for an individual company



The figure shows the annual emissions in tCO_2-eq. (vertical) for each year (horizontal) for an unspecified firm. The solid lines show historical emissions, and the dotted lines show the linear forecast based on a regression as discussed in section 3.1. Scope 1 emissions shows the firm's direct emissions from operations, Scope 2 emissions show the firm's emissions from purchased energy and Scope 3 emissions show all other firm-related value-chain emissions. The total emissions are a sum of the Scope emissions, both for historic and forecasted emissions. Data is retrieved for "Alstom SA" (Ticker: ALSO.PA), to serve as an example. Data is retrieved from Refinitiv.

By estimating the slope on each individual emission Scope, the accounting effect of starting to report on a new emission Scope is not considered as an increase. Much rather the slope of the emission Scope will be estimated based only on the available data for that Scope. If trend estimation on total emissions (Scope 1+2+3) would have been used, the inclusion of Scope 3 emissions will show as an increase in emissions opposed to a change in accounting. As such, regressing on individual Scopes is the most accurate method.

Bolton et al. (2022) note that *trend methods* might have strong empirical foundation based on the high autocorrelation of firm-emissions, providing a potential argument in favour of linear methods.

In a subsequent paper, Le Guenedal et al. (2022) suggest several additions to the *trend approach*. One empirical suggestion is the introduction of *velocity*, which captures the year-to-year change in the emission reduction slope. The authors suggest this change as they recognize a poor historic track record can make it very difficult for firms to tilt their trend. *Velocity* can be calculated with a linear regression at two points in time (*t, t – h*) and is defined as the relative change in the normalized slope:

$$\boldsymbol{v}_h = \frac{\hat{\beta}_1(t) - \hat{\beta}_1(t - h)}{h}$$

(4)

Here we can confirm if firms with bad track-records are taking the necessary action, being $\boldsymbol{v}^h(t) < 0$ for low values of *h.* The authors suggest *h* to be 1,2 or 3 years.

Barahhou et al. (2022) expand on this by suggesting the construction of *long-term momentum (LTM)* and *short-term momentum (STM)* metrics (appendix IV.i), where they divide the long-term beta (LTM) and the velocity (STM) by emissions level at time *t.* We argue that the relevance of LTM and STM for portfolio alignment against a Net-Zero target is minimal, as comparison to the firm's current level of emissions is already done by the percentage-wise IPCC target, based on past firm emissions level. And as such, doing that comparison inside the method is unnecessary. The condition:

$$\hat{\boldsymbol{E}}_{\boldsymbol{i}}^{\boldsymbol{total}}(t^*) \leq \boldsymbol{E}_{\boldsymbol{i}}^{\boldsymbol{Target}}(t^*) \qquad where\ t^* = target\ year\ (e.g.\ 2030)$$

Based on equation 5, already tests if the slope is such that total emissions will reduce to zero at a satisfactory rate.

While velocity does not have to be compared to firm level of emissions, a measure that compares the annual change in slope (velocity) against the current slope $(\hat{\beta}_1)$ and the required slope (β_1^*) could provide insight into the number of years misaligned firms might need to become aligned. We construct such a measure in section 3.4.

3.1 The Trend method: Technical summary

We combine Le Guenedal and Roncalli's with the 2030 43% reduction target and the choice to include Scope 1, 2 & 3, as discussed in section 2.2.

For each Scope, the trend of historical emissions is estimated using linear regression:

$$Scope\ j\ Emissions: \boldsymbol{E_{i,j}}\,(t) = \beta_0 + \beta_1 \times t + u_t \qquad for\ t \le t_0$$

(1)

So that the expected future emission, as a function of emission trend is:

$Expected\ Scope\ Emissions\ for\ scope\ j$:

$$\boldsymbol{\hat{E}_{i,j}}(t_0 + h) = E_{i,j}\,(t_0) + \hat{\beta}_1 \times h \qquad for\ h = 1,2,\dots,N$$

(2)

And as absolute emissions are simply additive, expected total emissions are:

$Total\ Expected\ Emissions$:

$$\boldsymbol{\hat{E}_i^{total}}(t_0 + h) = \sum_{j=1}^{n=3} \hat{E}_{i,j}(t_0 + h)$$

(3)

With the applied 2030 43% reduction, compared to 2019 emissions, as the Net-Zero target (IPCC, 2021, p.329), the alignment condition then becomes:

Expected 2030 Emissions and alignment:

if: $\boldsymbol{\hat{E}_i^{total}}(2030) = \sum_{j=1}^{n=3}\left[E_{i,j}\,(2022) + \hat{\beta}_{1,j} \times (2030 - 2022)\right]$

$$\le (1 - 43\%) \times E_i\,(2019)$$

*then: asset **i** is **Net-Zero aligned.***

(5)

To this method, we add; a *Covid rebound condition* to consider discrepancies in the data, a *cumulative compliance* alternative compliance condition, and a *nonlinear compliance* alternative compliance condition to account for various other firm behaviours.

3.2 Addition 0: Covid rebound condition

With a linear *trend method*, we are able to judge the emission reduction effort of a firm over a timeframe of several years. As most GHG emission reporting requirements have been instated not too long ago. Most reporting and the most complete firm-data is of the recent years (section 5.1, figure 5). This means that a disproportionate majority of observations might have been affected by the Covid-19 pandemic. Specifically, reduced economic activity during the pandemic might have caused lower output and lower absolute emissions during the pandemic. As a result, reduced emissions during the pandemic's economic downturn might have contributed substantially to tilting firm's emission trend downwards. Therefore, we deem it relevant to apply an adjustment to account for the fact that firm emission reduction ambition might be overstated.

The European Union statistics organ Eurostat suggests that the emission profile of the European economy has largely recovered from the Covid depression since Q1 2021, as emissions by economic activity appear to have restored back to pre-Covid levels (2019) for the most part (Eurostat, 2022). There are many thinkable ways to confirm if firm emissions also sprung back to pre-Covid levels or if emission reduction since 2019 was structural.

We propose a very simple and intuitive condition:

if: $\boldsymbol{E_{i,2019}^{total}} \leq \boldsymbol{E_{i,2022}^{total}}$

then: *asset* ***i*** *might be considered for* ***Net-Zero alignment.***

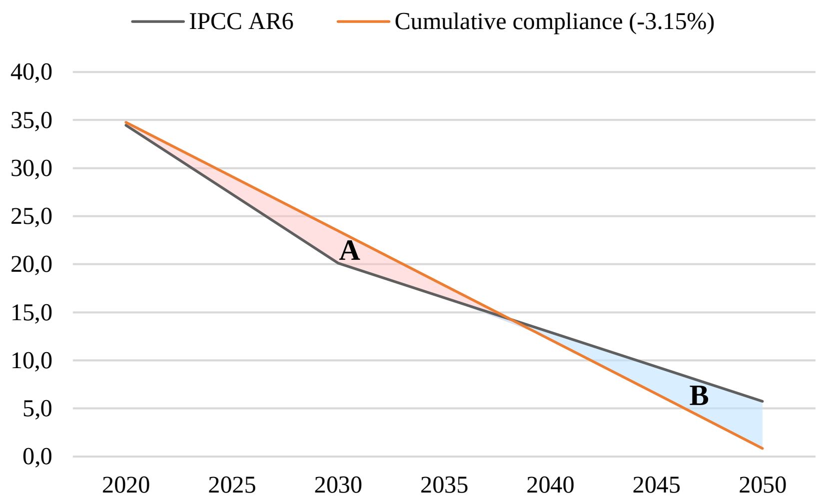
(6)

For companies where 2022 data is missing, the condition will be considered as not violated.

3.3 Addition 1: Cumulative compliance condition

While some firms might miss the 43% reduction target (43% of 2019 by 2030) with the total of their linearly forecasted Scope emissions, they might make the 2050 reduction target (84% of 2019 reduction by 2050). We follow Le Guenedal et al. (2022) methods and propose to allow for this type of alignment, using the original *trend methods*. Due to the cumulative nature of emissions, one can approach alignment by calculating the sum of all past and projected annual emissions and compare this sum to the sum of the maximum emissions, the *carbon budget*, on which the IPCC goals are based (Le Guenedal et al., 2022). Applied to the IPCC AR6 targets, this means a firm that overshoots the 2030 43% target will have to "undershoot" the 2050 84% target to be compliant with the *carbon budget* behind the IPCC AR6 goals. In mathematical terms, this means the surface area of overshoot (A) must be equal or smaller than the surface area of the undershoot (B) so that the total cumulative emissions of the firm (2019-2050) are smaller or equal to the total cumulative emissions as permitted by the Net-Zero trajectory (figure 2). The maximum slope with which cumulative compliance is reached, equals – 3.15% per year.

Figure 2: Addition 1: Cumulative compliance example



The figure shows the hypothetical case in which the linear forecast of a firm's future emissions (solid orange line) creates the same cumulative emissions (defined as the surface area below the orange line) as the Intergovernmental Panel on Climate Change AR6 (IPCC AR6) emission reduction pathway for scenario C1(>50%) (IPCC, 2021, p.329). This scenario is estimated to reduce global mean temperature increase by 1.5°C, with at least 50% certainty. The coloured areas "A" and "B" have the same surface area. The slope of the orange line (equal to – 3.15%) results in the hypothetical firm not exceeding the total amount of cumulative emissions for the time period 2020-2050 as set by the IPCC AR6 target, making the firm compliant with the target. As such, this line is referred to as the "Cumulative compliance" slope (see legend). The annual emissions are presented in tCO_2-eq. (vertical) per year (horizontal). This example is hypothetical, and data is as such artificial.

This can be written as the following mathematical condition:

$$if\colon \sum_{h=2019}^{H=31} \sum_{j=1}^{n=3} \hat{E}_{i,j}(h) \leq \sum_{h=2019}^{H=31} E^{*}(h)$$

then: *asset* ***i*** *is* ***Net-Zero aligned.***

(7)

Where the "h" sum-operator sums the absolute emissions for each year. E^{*} is the linearly approximated IPCC AR6 trajectory and $\hat{E}$ represents the expected Scope emissions for asset *i*. Where expected emissions equal historic emissions for the years in which this data is available.

3.4 Addition 2: Nonlinear compliance condition

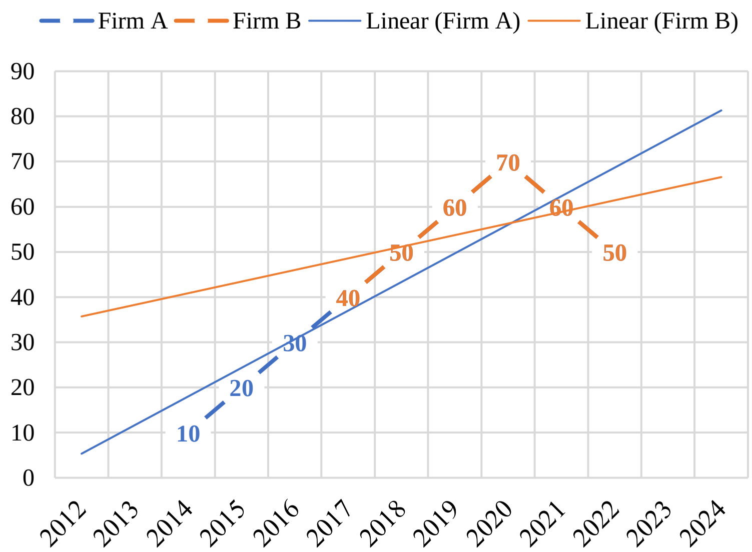
We concur with Hohne-Sparborth et al. (2021) and current climate science (appendix II.e, figure 17), and recognise a nonlinear reduction trajectory might be the most realistic reduction trajectory for society. To capture nonlinear changes in emission reduction we construct a measure based on emission velocity by Le Guenedal et al. (2022) (equation 4):

$$\boldsymbol{v}_h = \frac{\hat{\beta}_1(t) - \hat{\beta}_1(t - h)}{h}$$

(4)

Equation 4 is developed by the authors to measure a change in emission reduction behaviour in the recent past. The authors recognize that firms with a history of high and increasing emissions will struggle to change the sign of their trend beta. As such, the authors present a velocity-measure that better captures if firms' current reduction behaviour is satisfactory. The current velocity measure estimates the recent emission reduction behaviour by measuring the relative difference in beta that results from the last years (h). However, for firms with many years of reported historic emissions, the addition of new data points will have a smaller effect than for firms with fewer reported years. Hence, the same change in ambition (compared to past track record) will be credited much less for firms with a long reporting history than for firms with a short reporting history. As the amount of historic data is not equal for all firms, this method will give biased estimates, punishing firms with a long reporting history. Figure 3 shows two hypothetical identical firms that only differ in the year that they started reporting their emissions. Firm A started reporting in 2014, while firm B started reporting in 2017 (overlapping firm A data in figure 3). These two identical firms have both started equal significant emission reduction efforts in 2020. However, these efforts affect their linear trend ($\hat{\beta}_1(t)$) differently. Here, firm A experiences a smaller change in the emission trend due to the new emission reduction effort and is as such being punished for their decision to report emissions since 2014.

Figure 3: Velocity bias against track-record



The figure shows simulated annual emissions for two firms, firm A (blue) and firm B (orange). Both firms have the same emissions between 2017 and 2022, meaning the data for firm A is covered by the data for firm B. Contrary to Firm A, Firm B did not report data before 2017. For both firms the average linear slope, estimated through linear regression and formulated as $\hat{\beta}_1(t)$ in equation 4, is represented as a skinny solid line in corresponding colours. This linear slope is estimated on all available data for each firm. This example is a hypothetical example and data is as such artificial.

To avoid this bias in our NZP construction, we consider the short-term performance individually. We suggest estimating the short-term beta on only the recent (h) emission reduction behaviour, to find the linear trend if recent reduction behaviour is a good proxy for future reduction. In figure 3, this recent behaviour would be for example the emission data between 2020 and 2022. This estimate will be unaffected by past track-record or reporting history. The trend for firm A and B for this period would be equal. We then follow the literature and subtract the long-term beta from the short-term beta to find the change in slope. We divide this number by the number of "short-term" years (h) and compute the average yearly change in slope that the firm achieved, compared to expected emissions that followed from the long-term trend (equation 8). We also suggest estimating betas for each emission Scope j separately:

$$\boldsymbol{v}_h = \frac{\sum_{j=1}^{n=3} \hat{\beta}_{1,j}(t-h:\ t) - \hat{\beta}_{1,j}(t)}{h}$$

(8)

We construct this velocity for $h = 2$ and $h = 1$. We choose a rather low h to attempt to omit potential effect from the Covid-19 pandemic. With the pandemic in mind, a 1-year (2021-2022) velocity might be particularly relevant as this is the longest possible post-covid period. The period in which the European economy no longer suffers from Covid restrictions (European Commission, 2022).

We take this velocity, the absolute average annual change in emission reduction behaviour in period h (compared to the expected behaviour for that year) and apply it to an emission forecast. This means that each year, the amount with which the annual emission is reduced, increases by the average annual change in the slope, the velocity. Figure 4 shows how, as a result, the slope of the emission reduction increases (more negative) over the next three years. The opposite logic can be applied to firms with a positive velocity and increasing emissions. The expected nonlinear emissions, as a function of the velocity can be applied to estimate emissions:

Total Expected Nonlinear Emissions:

$$\widehat{\boldsymbol{ENL}}_{\boldsymbol{i,h}}^{\boldsymbol{total}}(t) = E_{i,t-1} + \left[(t-t_0) \times \boldsymbol{v}_h + \sum_{j=1}^{n=3} \hat{\beta}_{1,j}(t_0 - h:\ t_0)\right]$$

(9)

Where t_0 is the latest reported year, in our case 2022.

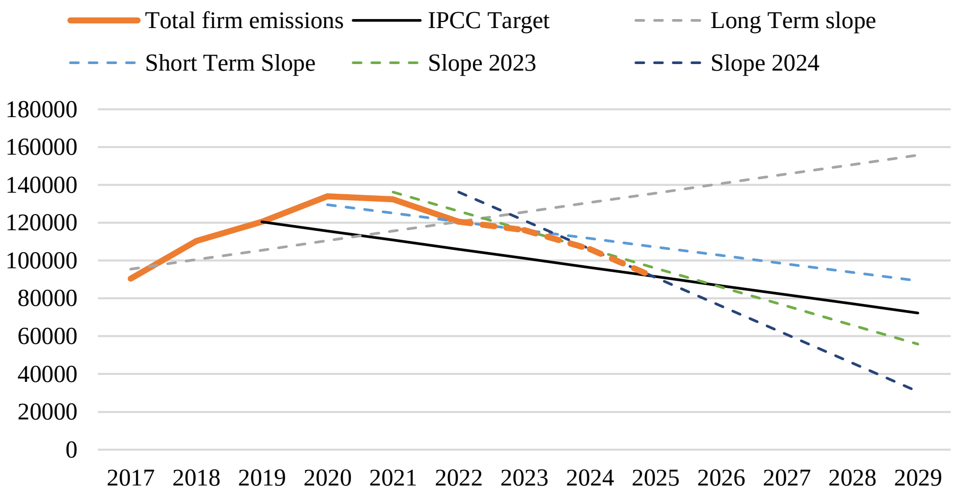
Then we require firms that have a non-compliant slope to reach compliance within 3 years. This means that:

$if: \widehat{\boldsymbol{ENL}}_{\boldsymbol{i,h}}^{\boldsymbol{total}}(2025) \leq \boldsymbol{E}_{\boldsymbol{i}}^{*}(2025), \qquad for\ h = 2 \vee 1$

then: *asset* ***i*** *is* ***Net-Zero aligned.***

(10)

Figure 4: Addition 2.1: Nonlinear compliance



The figure presents the non-linear forecast (orange dotted line) that results from the velocity approach discussed in section 3.4 and equation 9. The long-term linear estimate of emissions (grey dotted line) is based on the historic firm performance (orange solid line) of a hypothetical firm. The short-term slope (light blue dotted line) is estimated based on the past two years of historic firm performance only. The subsequent yearly change in the slope for the forecasting period is equal to the initial difference between the long-term slope and the short-term slope, divided by the number of years considered for the short-term slope estimation. As a result, the forecast for each subsequent year has a steeper slope than the preceding forecasted slope, resulting in a non-linear forecast. The forecasted slope is compared to the Intergovernmental Panel for Climate Change emission reduction target (IPCC, 2021, p.329) (solid black line). The emissions are presented in tCO_2*-eq. (vertical) per year (horizontal). This example is a hypothetical example of nonlinear alignment, and data is as such artificial.*

While data-based nonlinearity is better than nonlinearity based on technology assumptions. Asset managers should be aware of the unpredictable nature of nonlinearity. While arguably realistic, assumptions on nonlinearity like these might clash with the precautionary principle (Rio Declaration, 1992). In addition, do we recognise that firms will not be able to continuously increase their emission reduction slope over time. When creating nonlinear forecasts for periods exceeding 2025, we take the nonlinear slope until 2025 and the apply a linear forecast based on that 2025 slope. This means, a nonlinear forecast is always only nonlinear for the next 3 years and is linear after that. Our choice of three years is an assumption based on the suggestions for the length of *h* (=3) given by Le Guenedal et al. (2022), which might be discussed or changed based on investor preference.

3.5 Alignment conditions summary

In summary, an asset might be included in the Net-Zero aligned universe in four ways:

1) If the asset satisfies our Covid rebound condition (equation 6) and if the asset satisfies the alignment condition (equation 5), Resulting from the linear trend estimation (equation 1:3) as presented by the Le Guenedal & Roncalli (2022) and combined with our choice of the AR6 2030 target as provided by the IPCC (2021), then the asset is considered Net-Zero aligned. Mathematically formulated:

$$\textit{if: } \boldsymbol{E_{i,2019}^{total}} \leq \boldsymbol{E_{i,2022}^{total}} \tag{6}$$

and

$$\textit{if: } \boldsymbol{\hat{E}_{i}^{total}}(2030) = \sum_{j=1}^{n=3}\left[E_{i,j}\,(2022) + \hat{\beta}_{1,j} \times (2030 - 2022)\right] \tag{5}$$

$$\leq (1 - 43\%) * E_i\,(2019)$$

then: *asset **i** is **Net-Zero aligned.***

Where *j* indicates emission Scope 1, Scope 2, and Scope 3 for asset *i* at time *t*.

2) if the asset satisfies our Covid rebound condition (equation 6) and the additional cumulative compliance condition (equation 7), then the asset is considered Net-Zero aligned. This cumulative compliance method, developed by Le Guenedal et al. (2022), can be mathematically formulated as:

if: $\boldsymbol{E}_{\boldsymbol{i},\mathbf{2019}}^{\boldsymbol{total}} \leq \boldsymbol{E}_{\boldsymbol{i},\mathbf{2022}}^{\boldsymbol{total}}$ *(6)*

and

$$if: \sum_{h=2019}^{H=31} \sum_{j=1}^{n=3} \hat{E}_{i,j}(h) \ \leq \ \sum_{h=2019}^{H=31} E^{*}(h) \tag{7}$$

then: asset ***i*** *is* ***Net-Zero aligned.***

Where *j* indicates emission Scope 1, Scope 2, and Scope 3 for asset *i* at time *t*.

3) if the asset satisfies the nonlinear compliance condition (equation 10), based on our improvement (equation 8:9) of the velocity metric (equation 4) developed by Le Guenedal et al. (2022), then the asset is considered Net-Zero aligned. If we combine equation 9 and equation 10, the condition is mathematically formulated as:

$$if: \widehat{\boldsymbol{ENL}}_{\boldsymbol{i,h}}^{\boldsymbol{total}}(t) = \ E_{i,t-1} + \ \left[(t - t_0) \times \boldsymbol{v}_h + \sum_{j=1}^{n=3} \hat{\beta}_{1,j}(t_0 - h : \ t_0)\right] \leq \ \boldsymbol{E}_{\boldsymbol{i}}^{*}(2025), \qquad for\ h = \ 2 \ \vee 1$$

then: asset ***i*** *is* ***Net-Zero aligned.***

(11)

Where *j* indicates emission Scope 1, Scope 2, and Scope 3 for asset *i* at time *t*. E_i^* indicates the target amount of annual emissions for the year 2025, as dictated by the linear IPCC AR6 target that is defined as a linear line between 2019 historic emissions and (1 – 43%) × 2019 emissions set as the target for 2030 (figure 4).

As seen in equation 11, This condition is applied with two different time-windows for the short-term trend estimation. Firstly, the condition is applied with a short-term trend estimation based on the last three data points (*h = 2*). This gives the time-window 2020-2022. Applied to equation 11, this condition for *h=2* is mathematically formulated as:

if: $\widehat{\boldsymbol{ENL}}^{\boldsymbol{total}}_{\boldsymbol{i,h=2}}(2025) = E_{i,2024} + \left[(3) \times \boldsymbol{v}_{h=2} + \sum_{j=1}^{n=3} \hat{\beta}_{1,j}(2020 : 2022)\right]$

$\leq \boldsymbol{E}^{*}_{\boldsymbol{i}}(2025)$

then: *asset* ***i*** *is* ***Net-Zero aligned.***

(12)

Where *j* indicates emission Scope 1, Scope 2, and Scope 3 for asset *i* at time *t*. E_i^* indicates the target amount of annual emissions for the year 2025.

4) Secondly, the condition is applied with a short-term trend estimation based on the last two data-points (*h = 1*). This gives the time-window 2021-2022. Applied to equation 11, this condition is mathematically formulated as:

if: $\widehat{\boldsymbol{ENL}}^{\boldsymbol{total}}_{\boldsymbol{i,h=1}}(2025) = E_{i,2024} + \left[(3) \times \boldsymbol{v}_{h=1} + \sum_{j=1}^{n=3} \hat{\beta}_{1,j}(2021 : 2022)\right]$

$\leq \boldsymbol{E}^{*}_{\boldsymbol{i}}(2025)$

then: *asset* ***i*** *is* ***Net-Zero aligned.***

(13)

Where *j* indicates emission Scope 1, Scope 2, and Scope 3 for asset *i* at time *t*. E_i^* indicates the target amount of annual emissions for the year 2025.

4. DATA & EMPIRICAL TESTING

4.1 Data selection

We apply the method on the **EUROPE STOXX600** index. This data is more suited than other common indices such as the SP500 for several reasons. Firstly, the turbulent climate policy of the past US presidencies might have disincentivised emission reporting and reduction. Opposed to the EU, where steadily increasing regulation and climate ambition has likely improved the quality of reporting and the magnitude of reduction.

Secondly, for the EU, more detailed transition pathways exist. Pathway tools such as the EU CTI 2050 Roadmap tool give more detailed insight in the likely behaviour of emissions in the future. Here, the use of a world index might be undesirable as different countries, especially Northern developed countries, and Equatorial developing countries, will likely have vastly different transition pathways (Barahhou et al., 2022). Where the latter is likely allowed a flatter delayed reduction pathway.

Finally, the positive financial impact of a Net-Zero aligned portfolio, presented in chapter 6, is more apparent in the EU regulatory environment, where carbon-pricing regulation such as the EU-Emissions trading system (EU ETS) leads to tangible impacts on firm profitability over time.

4.2 Empirical testing: Portfolio optimization

For empirical testing, besides the application of the Net-Zero alignment method, this paper applies portfolio optimization and statistical significance testing.

4.2.1 Portfolio optimization: NLMINB2

To optimize portfolios, we apply a Markowitz (1959) model that optimizes risk-adjusted return using a quasi-Newtonian optimization algorithm called NLMINB2, based on Fortran code written by David Gay (1990) and further developed by Würtz and Chalabi (2009), accessed through their package “fportfolio” and applied in R.

As the literature dictates (section 2.2 & appendix IV.h), we require a portfolio sector balance comparable to the benchmark universe. To do this, we apply inequality constraints to the optimization function, where sector exposure (in percent) might not differ more than 2% from the universe sector exposure (in percent), following Bolton et al. (2022).

4.2.2 Statistical testing of portfolio performance

"Energy" and "*Jacque-Bera"* testing for normality show clear violation of normality for all variables. However, even though normality is usually violated in financial data, a recent literature review by Kim & Ji (2015) shows that the t-test is the most common significance test in top finance journals. We therefore apply a Welch's t-test for two means with unequal variances (Welch, 1947).

To apply this test to portfolio performance data, which are weighted averages, we have to adjust the sample-variances of the means. We do this using Snedecor and Cochran (1967). For the comparison of risk-adjusted return, we apply an approximation of Sharpe-ratio variance that Andrew Lo (2002) presents as a part of his statistical methods for Sharpe-ratios. The methods presented by Lo are based on central limit theorem and follow a t-distribution, closely resembling a t-test. While Lo also presents an alternative method for non-normal distributions, Mertens (2002) shows that Sharpe ratios will follow a normal distribution even if return data does not. As such we apply Lo's variance approximation with IDD assumption.

In short, this paper applies Welch's (1947) t-test for unequal variances with variances adjusted for weighted means (Snedecor & Cochran, 1967, p.515) and Sharpe-ratios characteristics (Lo, 2002). Difference in variances is tested using the f-test. Following the literature (Kim & Ji, 2015), this paper will apply a common significance level of 95% ($\alpha = 0.05$).

Mathematical formulation of statistical testing is provided in appendix V.

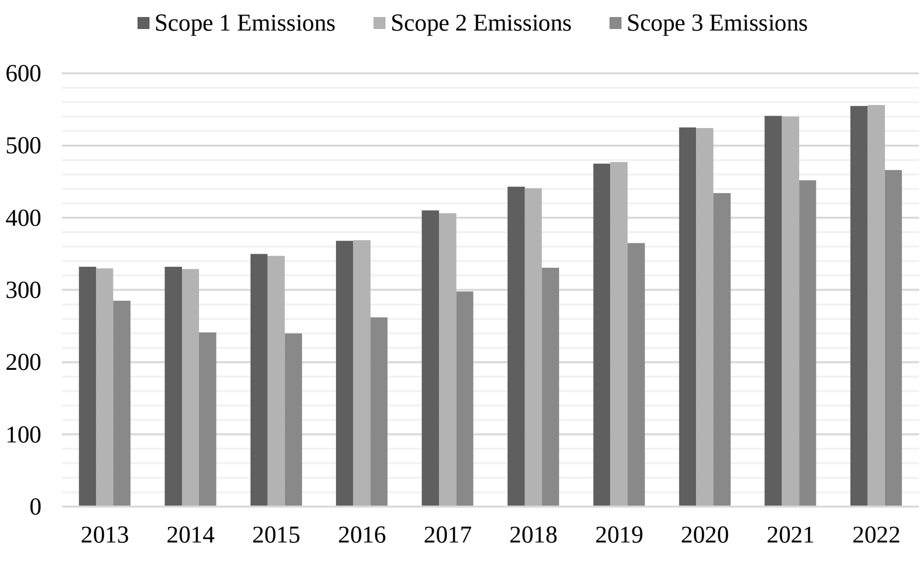
5. EMPIRICAL TESTING RESULTS

5.1 Data characteristics

Data is collected through **Refinitiv** and processed in Microsoft Excel and R analytical software. Data quality is satisfactory (>80% desired observations) for all variables except for "Revenue Growth". Notably, data quality for emissions data decreases from Scope 1 to 3 as expected. Over the last 10 years, most companies have reported Scope 1 and 2 emissions while considerably fewer companies have reported Scope 3 emissions. time-series data is collected for return and Scope emissions for analysis. time-series data for ESG pillars is mostly for graphical analysis purposes. For time-series data, the *Energy* test for multivariate normality is applied through R, to test normality. For other data, *Jacque-Bera* test is used. Unsurprisingly, none of the variables are normally distributed (appendix VI: Data Characteristics).

For the selection of the Net-Zero aligned portfolio, sufficient emission data is necessary. From a sample of 600 companies, 561 (–6%) make the minimum data requirement ($n \geq 2$). We note that data quality after 2019 is considerably higher as much more of the sample is reporting Scope 1, 2 & 3 emission data (figure 5).

Figure 5: Number of companies reporting



The figure presents the number of firms in the EuroSTOXX600 index that reported Scope 1, Scope 2, and Scope 3 emissions (vertical) per year (horizontal). Scope 1 emissions are the direct emissions from operations, Scope 2 emissions are the emissions *from purchased energy and Scope 3 emissions are all other firm-related value-chain emissions. Annual emission data for the EuroSTOXX600 is retrieved from Refinitiv.*

The risk-free rate

To compare the Sharpe ratios of the optimized portfolios, we retrieve the risk-free rate as the average rate over the time-series for the last ten years for the European market. This data is a part of the *Fama/French European 3 Factors* dataset, where the risk-free rate is defined as the US 1-Month Tbill (French, 2023). The average European risk-free rate for the past ten years equals 0.10% ($rf = 0.10\ \%$).

5.2 The Net-Zero Aligned universe

From a dataset of 599 assets. 561 assets have enough data to apply the NZA method. For assets where 2019 data was missing, the earliest available observations between 2019 and 2022 were used to construct the target. For assets where 2022 data was missing, emission forecasting was started from the latest available observations between 2019 and 2022. From 561 assets, the NZA method initially identifies 152 assets. After the Covid rebound condition, 120 assets are left. From a graphical analysis, we conclude that the Covid-adjusted NZA method has been rather harsh on 7% of the sample. Where 4% of trend-based exclusions and 3% of Covid-Relapse exclusions might be the result of change in accounting methods or M&A activity. The suspected number of wrong judgements is limited and acceptable.

The application of the cumulative compliance condition (Addition 1) adds 5 assets to the universe (+5%). The nonlinear compliance condition (Addition 2) adds 128 assets (+102%) for $h = 2$, and 29 additional assets (+11%) for $h = 1$. We find that replacing $h = 1$ with $h = 3$ does not significantly change the selected universe. The NZA universe, with all additional conditions applied, contains 282 assets. This is the universe considered for the remainder of the paper.

Interestingly, the number of assets that satisfy both Addition 1, and Addition 2.1 ($h=2$) equals 121. This universe, that satisfies both conditions, contains the exact same assets as the original 120 assets identified by the Covid-adjusted NZA trend-method, with the exception of one additional asset. This fact might illustrate well that the Additional Conditions capture different parts of the same emission reduction behaviour as judged by the initial NZA method.

5.3 Index Performance comparison

The NZA universe index has financial performance that is comparable to the STOXX index benchmark. The NZA index Sharpe ratio of *0.22* is not significantly different from the STOXX index *0.24* Sharpe ratio at a 95% confidence interval (table 1). Theoretically, it could have been possible that the NZA universe had a financial performance that was significantly worse than the STOXX index benchmark. Here the argument is that decreasing emissions might not only be a sign of a decoupling of value creation from emission, but that a decrease in emissions could also be a proxy for a decrease in economic activity. Hence, it could be expected that the NZA method identifies firms that have decreasing financial performance. This argument has motivated the use of carbon intensity measures in the *PAB* (EU TEG, 2019, p. 40). Our results show that, although this argument is not disproven, the effect is not obvious. Without correction, sector balance of the two indices is comparable. Note that the sector balance for the STOXX index will be used as a sector exposure constraint in the portfolio optimization process (section 5.4). We apply a 3-factor asset pricing model to better understand exposure to common risk factors. the Excess market return, SMB, and HML factors are retrieved from the *Fama/French European 3 Factors* dataset (French, 2023). We see that the factors do not load cleanly as the SMB appears to also take all market risk exposure (table 1). We can confirm this weakness when we run a 3-factor regression, where the factors are constructed from the EuroSTOXX600 index. Here the market-factor will take most of the loading. Nevertheless, a relatively comparable portfolio standard deviation results in no significant differences in factor loadings. As comparison is our main concern, we choose to not attempt to improve the current factor loadings.

Table 1: NZA Index performance

Index Performance	STOXX index	NZA index	p-value	sign.
number of assets	599	282	-	-
sum of weights	1.00	1.00	-	-
Expected return: E[rp]	1.0998%	1.0588%	0.956	'
Standard deviation: σ(p)	4.1094%	4.3457%	0.063	*
Sharpe ratio*	0.24	0.22	0.756	'
μ/σ	0.27	0.24	0.744	'
ESG	65.05	67.10	0.002	***
Market beta	0.07	0.07	0.977	'
Fama French SMB beta	0.69	0.74	0.307	'
Fama French HML beta	0.16	0.17	0.869	'

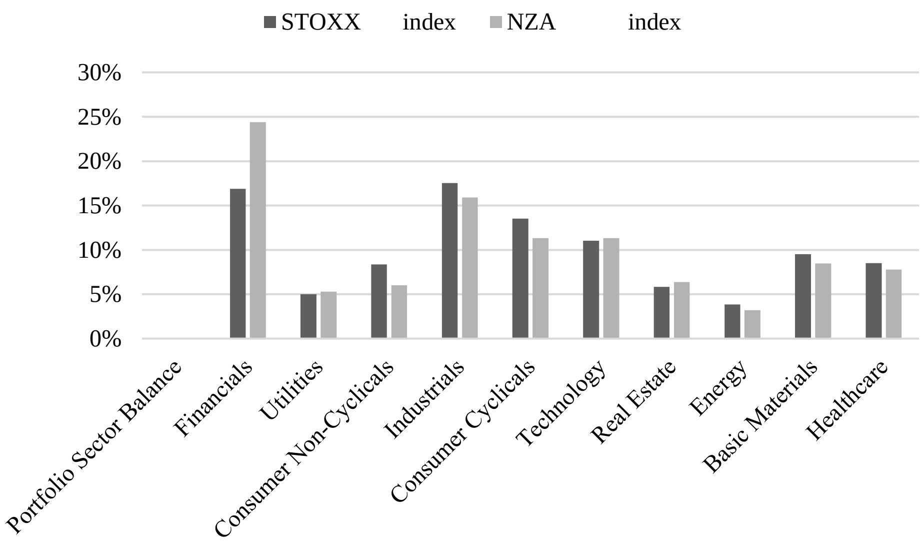
**10-yr average US 1-Month Tbill as Risk-free rate: 0.10%*

Portfolio Sector Balance	STOXX index	NZA index	p-value	sign.
Financials	17%	24%		*
Utilities	5%	5%		'
Consumer Non-Cyclicals	8%	6%		'
Industrials	18%	16%		'
Consumer Cyclicals	14%	11%		'
Technology	11%	11%		'
Real Estate	6%	6%		'
Energy	4%	3%		'
Basic Materials	10%	8%		'
Healthcare	9%	8%		'

The figure, presents the performance descriptives of the EuroSTOXX600 index (STOXX) and a Net-Zero aligned index based on the EuroSTOXX600, constructed with the method as discussed in section 3. The risk-free rate applied to construct the Sharpe-ratio is defined as the 10-year average risk-free rate, retrieved from the Kenneth French database for Fama-French 3-factor model for Europe. Factor exposure is calculated using the methods specified in the Kenneth French database for 3-factor model for Europe. We apply the factors from this dataset. Sector balance is calculated as a percentage of the portfolio that belongs to a certain TRBC Economic Sector.

*Percentages might not sum to 100% due to rounding. The two columns on the right-hand side (grey) mention the p-value and significance (***= significant at 99%, ** = significant at 95%, * = significant at 10%, ‘ = other) for the significance tests for portfolio data as discussed in section 4.2.2. For sector exposure data, a star indicates more than 4% (2*2%) difference between the two portfolios. Percentages might not sum to 100% due to rounding. All calculations are done with financial & descriptive data retrieved from Refinitiv.*

Figure 6: NZA Index sector balance



The figure shows the sector balance for the EuroSTOXX600 index (STOXX) and a Net-Zero aligned index that is constructed from the EuroSTOXX600 index using the method discussed in section 3. Sector balance is calculated as a percentage of the portfolio (vertical) that belongs to a certain TRBC Economic Sector (horizontal). Percentages might not sum to 100% due to rounding. All calculations are done with descriptive data retrieved from Refinitiv.

While industry sector balance is comparable and differences are non-significant, we note that the NZA universe has slightly higher exposure to the *Utilities* sectors. This is an indication that emission reduction is not the same as low carbon.

5.3.1 Index ESG Performance

While both indices have comparable financial performance, clear differences exist for ESG performance. For the NZA universe, the Environmental pillar score is significantly higher at a score of 74.7 compared to 68.3 for the STOXX index (table 2). 2022 emissions are all significantly higher for the NZA universe.

This shows the important notion that assets that are significantly reducing emission, are not necessarily low-carbon assets. While the NZA index has higher ESG-ratings, it does not have better emission performance, for the same year (2022). The notion, that ESG ratings do not necessarily align with carbon risk exposure, is further covered in section 5.4.4.

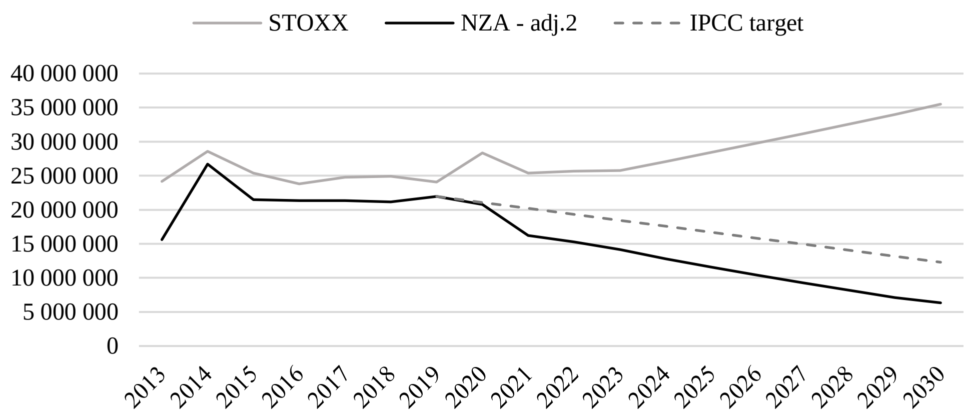
Table 2: NZA Index ESG performance

Portfolio ESG Performance	STOXX index	NZA index	p-value	sign.
Environmental Score	68.32	74.68	0.000	***
Social Score	73.25	77.00	0.000	***
Governance Score	72.04	74.52	0.001	***
Combined ESG Score	65.18	67.10	0.007	***
Scope 1 Emissions* (2022)	2,180,627.89	2,800,348.0	0.000	***
Scope 2 Emissions* (2022)	345,104.99	383,647.5	0.000	***
Scope 3 Emissions* (2022)	17,837,073.51	29,512,046.0	0.000	***
Total Emissions* (1+2+3)	20,362,806.40	32,696,041.5	0.000	***

*The figure shows the ESG performance of the EuroSTOXX600 index (STOXX) and a Net-Zero aligned index that is constructed from the EuroSTOXX600 index using the methods discussed in section 3. Emissions are presented in Metric tons of CO2 equivalence and ESG scores are the weighted average scores based on ESG Scores from Refinitiv. The two columns on the right-hand side (grey) mention the p-value and significance (***= significant at 99%, ** = significant at 95%, * = significant at 10%, ‘ = other) for the significance tests for portfolio data as discussed in section 4.2.2. All calculations are done with ESG data retrieved from Refinitiv.*

The following figures illustrate the behaviour of emissions in the NZA universe and explain why current (2022) emissions might be higher for the NZA index. Figure 7 displays the Total emissions (Scope 1 + 2 + 3) for the STOXX index and the NZA index without Additional Condition 2. Firms included under Additional Condition 2 are excluded in figure 7 to show the universe from a pure linear trend based NZA method. The graph shows a linear forecast based on the portfolio trend and nonlinear firm behaviour is therefore not considered. Without Additional Condition 2, the Emission reduction behaviour of the NZA universe is considerably more aligned with the PCA and easily makes the IPCC 2030 reduction target. Without the inclusion of firms that satisfy the nonlinearity (velocity) condition, the NZA index total emissions are always lower than the STOXX benchmark index emissions.

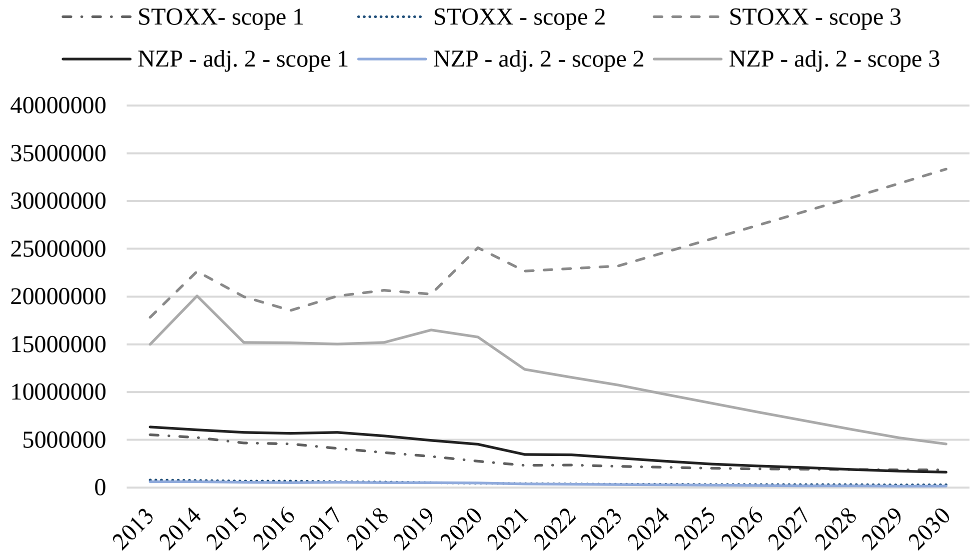
Figure 7: Total index emissions (linear forecast)



The figure shows the weighted-average yearly emission and a 2022-2030 forecast (solid lines) for the EuroSTOXX600 index (STOXX) and a linear Net-Zero aligned (NZA – adj.2) index that is constructed from the EuroSTOXX600 index using the methods discussed in section 3.1-3.3. The forecasted slope of the Net-Zero aligned portfolio is compared to the Intergovernmental Panel for Climate Change (IPCC) emission reduction target, defined as a 43% of 2019 reduction by 2030 (IPCC, 2021, p.329) (dotted black line). The emissions are presented in tCO_2-eq. (vertical) per year (horizontal). All calculations are done with ESG data retrieved from Refinitiv.

Figure 8 below, shows a breakdown of emission Scope performance for the two indices. While there is a small difference in Scope 1 emissions, the biggest difference between the two portfolios stems from a divergence in Scope 3 emissions.

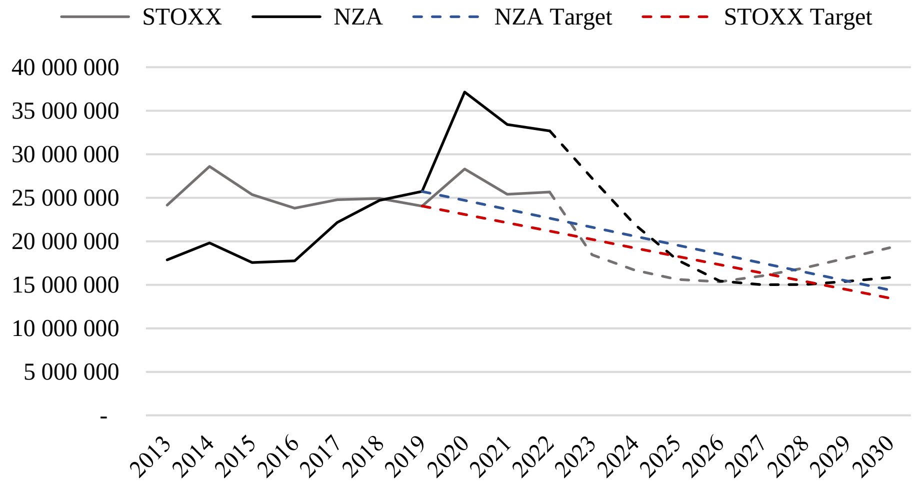
Figure 8: Index Scope emissions (linear forecast)



The figure shows the weighted-average yearly emission and a 2022-2030 forecast for each emission Scope for the EuroSTOXX600 index (STOXX) and a linear Net-Zero aligned (NZA – adj.2) index that is constructed from the EuroSTOXX600 index using the methods discussed in section 3.1-3.3. Scope 1 emissions are the direct emissions from operations, Scope 2 emissions are the emissions from purchased energy and Scope 3 emissions are all other firm-related value-chain emissions. The emissions are presented in tCO_2-eq. (vertical) per year (horizontal). All calculations are done with ESG data retrieved from Refinitiv.

With the application of a nonlinear forecast, the final-form NZA emissions are illustrated in figure 9 below. The Nonlinear forecasts are based on Additional Condition 2.1 *(h=2)* for the total NZA universe. As the Additional Conditions are only an inclusion condition and not an exclusion condition, applying nonlinear estimation on assets selected by the initial linear trend-based NZA, results in a convex curve that becomes upwards-sloping closer to 2030. This is a modelling limitation, and it is unlikely that this will happen in reality. Nonlinear forecasts show that 2022 total emissions might be higher for the NZA index compared to the STOXX index. However, a larger downward sloping velocity causes the NZA index to exceed the STOXX index in emission reduction performance, in the next four years.

Figure 9: NZA nonlinear emissions forecast (nonlinear)



The figure shows the weighted-average yearly emission (solid line) and a 2022-2030 forecast (dotted lines) for the EuroSTOXX600 (STOXX) index and a nonlinear Net-Zero aligned index that is constructed from the EuroSTOXX600 index using the methods discussed in section 3. The nonlinear forecast is based on Additional Condition 2, with an "h" = 2. As discussed in section 3.4. The forecasted slope of the portfolios are compared to the Intergovernmental Panel for Climate Change (IPCC) emission reduction target (coloured dotted lines), defined as a 43% of 2019 reduction by 2030 (IPCC, 2021, p.329). The emissions are presented in tCO_2-eq. (vertical) per year (horizontal). All calculations are done with ESG data retrieved from Refinitiv.

5.4 Optimal Portfolio comparison

From the data we find no sign of decreasing emissions serving as a proxy for poor firm performance. This means that emissions seem to be decoupled from financial value creation. To illustrate the true potential of the NZA method for asset managers, we apply a portfolio optimization to the NZA universe.

The optimized portfolio performance for the two indices is comparable with an insignificant 0.07 difference in Sharpe ratio (table 3). We apply a 3-factor asset pricing model (Fama & French, 1992) to better understand exposure to common risk factors. the Excess market return, SMB, and HML factors are retrieved from the *Fama/French European 3 Factors* dataset (French, 2023). Just as in the index comparison, the portfolio excess returns load disproportionally on the SMB factor, which takes most of the market-risk as well. Here a significant difference in SMB factor-exposure is likely a significant different in market-risk exposure, driven by the difference in portfolio standard deviations (table 3). We argue that the difference is not driven by actual SMB factor-exposure as the significantly higher market-cap of the NZP (table 3) argues that the NZP is not more exposed to small firms, rather the opposite. The conflicting market-cap and SMB-factor loading and the conflicting low Price-earnings ratio, but high EV/EBIT ratio make us argue that there is no structural difference between the portfolios. As such, we conclude that the portfolios have a comparable financial outlook. The sector exposure constraint is able to keep the sector exposures close together in all sectors but *Energy*. As the NZA contains a balanced number of *Energy* firms (table 1), with comparable (1.01% vs. 1.0%) expected return as the non-aligned index. We suspect this finding might be a modelling limitation.

Table 3: NZP Portfolio performance

Portfolio Performance	STOXX optim	NZP optim	p-value	sign.
number of assets	356	282		
sum of weights	1.00	1.00		
Expected return: E[rp]	1.4309%	1.5685%	0.942	'
Standard deviation: σ(p)	2.1768%	2.6885%	0.063	*
Sharpe ratio*	0.61	0.55	0.447	'
difference	0.07			
μ/σ	0.66	0.58	0.395	'

**10-yr average US 1-Month Tbill as Risk-free rate: 0.10%*

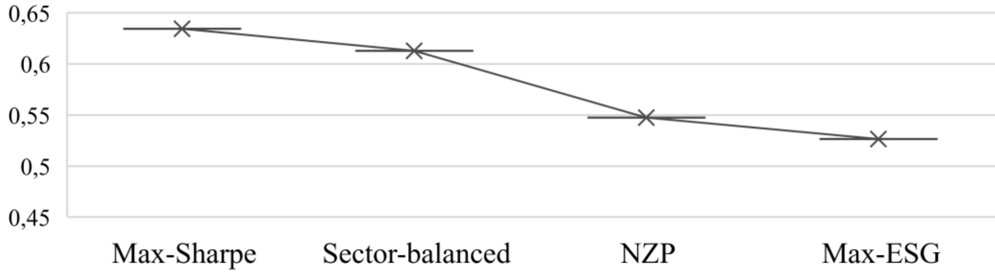
Portfolio Descriptives	STOXX optim	NZP optim	p-value	sign.
Market beta	0.03	0.02	0.517	'
Fama French SMB beta	0.29	0.37	0.004	***
Fama French HML beta	0.05	0.08	0.267	'
ROE	19%	21%	0.839	'
ROA	7%	8%	0.920	'
EV/EBIT	24.48	28.87	0.000	***
Gross Profit Margin	38%	45%	0.462	'
Revenue Growth (3yr) historic	7%	8%	0.960	'
Market Cap. (bln.)	€ 20.03	€ 22.04	0.000	***
Price/Earnings ratio	23.88	18.66	0.000	***
Debt/Equity ratio	1.14	1.15	0.960	'
EPS	€ 3.67	€ 3.81	0.625	'

Portfolio Sector Balance	STOXX optim	NZP optim	p-value	sign.
Financials	19%	20%		'
Utilities	7%	7%		'
Consumer Non-Cyclicals	10%	11%		'
Industrials	17%	16%		'
Consumer Cyclicals	12%	13%		'
Technology	9%	10%		'
Real Estate	4%	4%		'
Energy	4%	0%		*
Basic Materials	8%	8%		'
Healthcare	11%	11%		'

*The figure presents the performance descriptives of an optimized portfolio based on the EuroSTOXX600 index (STOXX optim) and a Net-Zero aligned optimized portfolio (NZP optim) based on the Net-Zero aligned universe derived from the EuroSTOXX600, with the method as discussed in section 3 and section 4. The risk-free rate applied to construct the Sharpe-ratio is defined as the 10-year average risk-free rate, retrieved from the Kenneth French database for Fama-French 3-factor model for Europe. Factor exposure is calculated using the methods specified in the Kenneth French database for 3-factor model for Europe. We apply the factors from this dataset. Performance metrics are calculated as the weighted average of the asset data as retrieved from Refinitiv. Sector balance is calculated as a percentage of the portfolio that belongs to a certain TRBC Economic Sector. During the portfolio optimization, sector exposure is mechanically constraint to a maximum 2% deviation from the index sector balance, as specified in section 4.2.1. Percentages might not sum to 100% due to rounding. The two columns on the right-hand side (grey) mention the p-value and significance (***= significant at 99%, ** = significant at 95%, * = significant at 10%, ‘ = other) for the significance tests for portfolio data as discussed in section 4.2.2. For sector exposure data, a star indicates more than 4% (2*2%) difference between the two portfolios. All calculations are done with financial data retrieved from Refinitiv.*

Naturally, an unconstrained optimized portfolio will always have the highest possible Sharpe ratio. Interestingly, the NZP outperforms an ESG-focused portfolio constructed from a universe comprising of the 294 assets (50%) with the highest combined ESG score (figure 10).

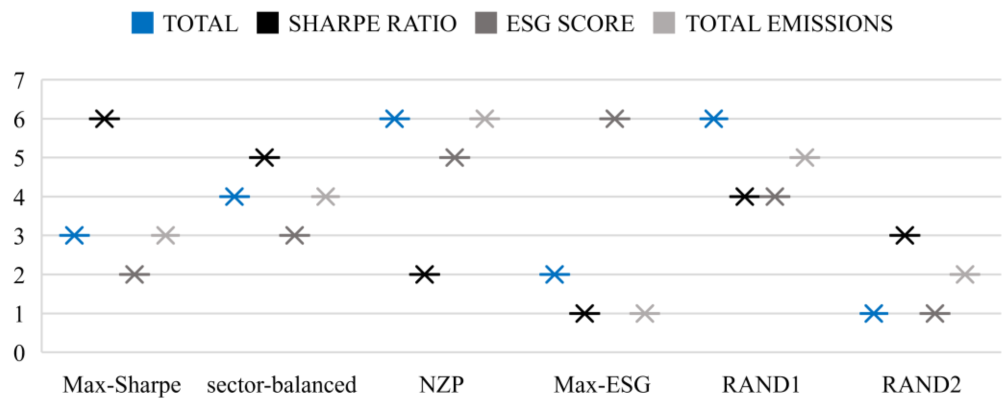
Figure 10: Portfolio Sharpe ratios



The figure presents the Sharpe-ratios (vertical) for various optimized portfolios (horizontal). The "Max-Sharpe" portfolio is a Markowitz-optimized portfolio on the EuroSTOXX600 index without constraints, using the methods discussed in section 4.2.1. The "Sector-balanced" portfolio is an optimized portfolio based on the EuroSTOXX600 index (STOXX optim), that is constrained so that sector exposure might not deviate more than 2% from the index sector balance, as discussed in section 4.2.1. The NZP is a sector-constrained optimized portfolio constructed from the Net-Zero aligned universe, derived from the EuroSTOXX600 index as specified in section 3. The "Max-ESG" portfolio is a sector-constraint optimized portfolio that is constructed from the top 50% of the EuroSTOXX600 index, selected based on ESG-score, as discussed in section 5.4. All calculations are done with financial and ESG data retrieved from Refinitiv.

In addition, If the various portfolios are ranked based on their Sharpe Ratio, weighted-average Combined ESG Score, and weighted-average Total CO_2-eq. Emissions, then the NZP ranks highest on total performance, only matched by a highly concentrated portfolio (RAND1). This portfolio has 30 assets of which 45% in the Healthcare sector, the biggest asset weight is 13.7% (figure 11). In addition, this low-carbon portfolio does not exhibit the desired decline in emissions over time, meaning it might be more exposed to regulatory risk. Note how the ESG-focused portfolio combines a high ESG-score with a high emission footprint.

Figure 11: Holistic portfolio performance rank



The figure presents the rank (vertical)(6=best) of various portfolios (horizontal) on 3 performance metrics: The portfolio Sharpe-ratio, the weighted-average ESG rating score from Refinitiv, the weighted-average total (Scope 1+2+3) emissions of the portfolio, and an overall rank combining the three performance-metric ranks. The "Max-Sharpe" portfolio is a Markowitz-optimized portfolio on the EuroSTOXX600 index without constraints, using the methods discussed in section 4.2.1. The "Sector-balanced" portfolio is an optimized portfolio based on the EuroSTOXX600 index (STOXX optim), that is constrained so that sector exposure might not deviate more than 2% from the index sector balance, as discussed in section 4.2.1. The NZP is a sector-constraint optimized portfolio constructed from the Net-Zero aligned universe, derived from the EuroSTOXX600 index as specified in section 3. The "Max-ESG" portfolio is a sector-constraint optimized portfolio that is constructed from the top 50% of the EuroSTOXX600 index, selected based on ESG-score, as discussed in section 5.4. The random portfolios (RAND1 & RAND2) are portfolios constructed from a universe that was defined as a random selection of 300 assets from the EuroSTOXX600. For these portfolios no sector balance constraint was applied. All calculations are done with financial data and ESG data retrieved from Refinitiv.

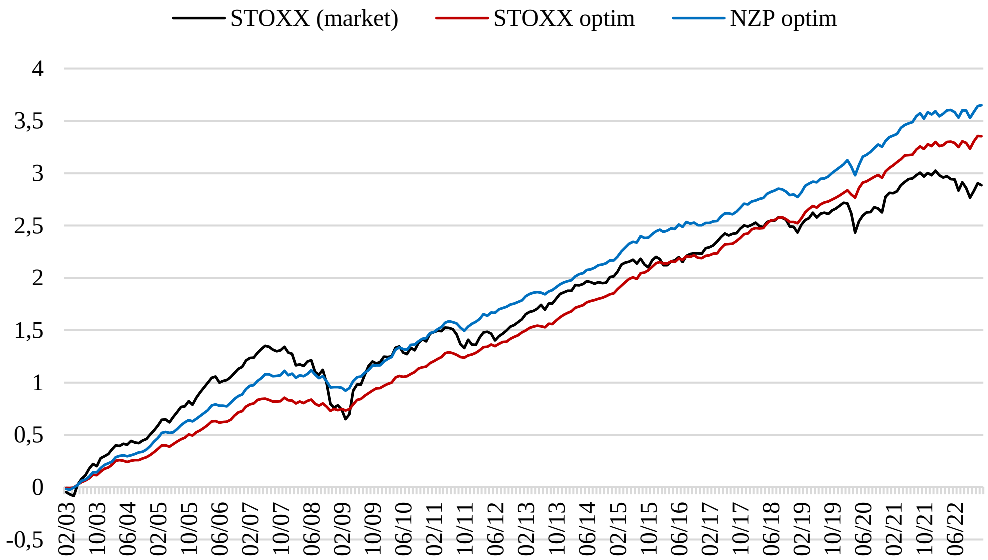
5.4.1 Tracking Error

The tracking error of the NZP to the STOXX optimized portfolio is defined as the standard deviation of the difference between the two returns:

$$TE = \sqrt{\frac{\sum_{i=1}^{n} (R_{NZP} - R_{Stoxx})^2}{N-1}} \tag{14}$$

The NZP has a relatively small tracking error of 1.14% to the STOXX optimized portfolio. This is comparable to the 1% tracking error of Hodges et al. (2022) their equity portfolio on the MSCI world universes. Their Paris-aligned portfolio is based on the *EU PAB* method, with "alpha-seeking" adjustments. Figure 12 below illustrates the relative co-movement of the NZP and STOXX optimized portfolio.

Figure 12: €1 invested in the NZP



The figure shows the logged cumulative increase in value of 1 euro invested in three portfolios on the 1st of January 2003. The graph shows the performance of the EuroSTOXX600 index (STOXX (market)), an optimized portfolio based on the EuroSTOXX600 index (STOXX optim) and a Net-Zero aligned optimized portfolio (NZP optim) based on the Net-Zero aligned universe derived from the EuroSTOXX600, constructed with the method as discussed in section 3 and section 4. The portfolio composition is based on current data (2013-2022) and is as such constructed with ex-ante information. The figure's purpose is as such mainly to show co-movement and tracking-error. The figure presents performance in euro (vertical) over time (horizontal). All calculations are done with financial data retrieved from Refinitiv.

5.4.2 Optimal portfolio ESG Performance

While Financial performance is comparable for the STOXX optimized portfolio and the NZP, the NZP significantly outperforms on ESG dimensions. The NZP has significantly lower emissions for all scopes where the NZPs total emissions are only one-twentieth that of the STOXX portfolio. In this case, all ESG-related scores are also significantly higher for the NZP, compared to the STOXX portfolio (table 4).

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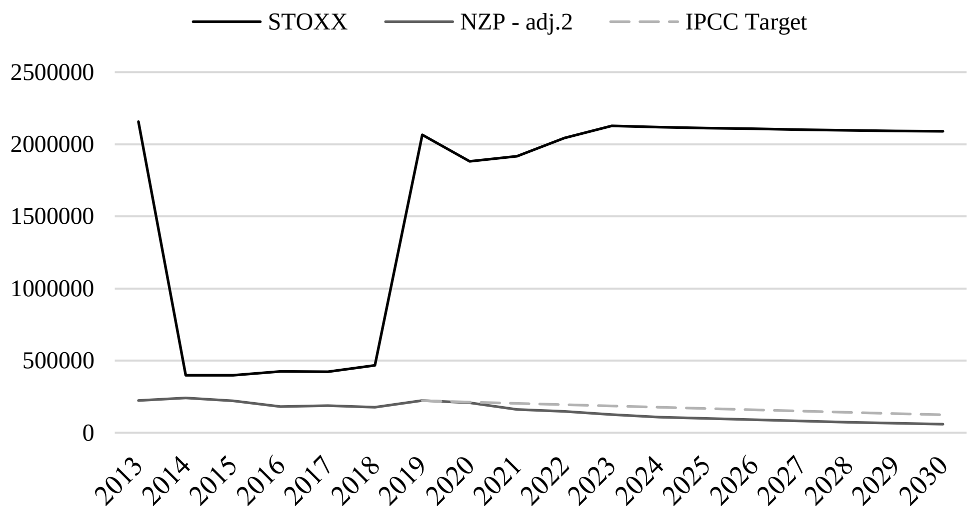
Table 4: NZP ESG performance

Portfolio ESG Performance	STOXX optim	NZP optim	p-value	sign.
Environmental Score	57.24	66.20	0.000	***
Social Score	65.71	71.62	0.000	***
Governance Score	67.39	72.96	0.000	***
Combined ESG Score	59.89	63.21	0.006	***
Scope 1 Emissions* (2022)	293,292.35	17,963.58	0.000	***
Scope 2 Emissions* (2022)	107,129.96	55,601.64	0.000	***
Scope 3 Emissions* (2022)	1,642,705.01	142,137.17	0.000	***
Total Emissions* (1+2+3)	2,043,127.32	215,702.40	0.000	***

*The figure shows the Environmental, Social, and Governance (ESG) performance of an optimized portfolio based on the EuroSTOXX600 index (STOXX optim) and a Net-Zero aligned optimized portfolio (NZP optim) based on the Net-Zero aligned universe derived from the EuroSTOXX600, with the method as discussed in section 3 and section 4. Emissions are presented in Metric tons of CO2 equivalence and ESG scores are the weighted average scores based on ESG Scores from Refinitiv. The two columns on the right-hand side (grey) mention the p-value and significance (***= significant at 99%, ** = significant at 95%, * = significant at 10%, ‘ = other) for the significance tests for portfolio data as discussed in section 4.2.2. All calculations are done with ESG data retrieved from Refinitiv.*

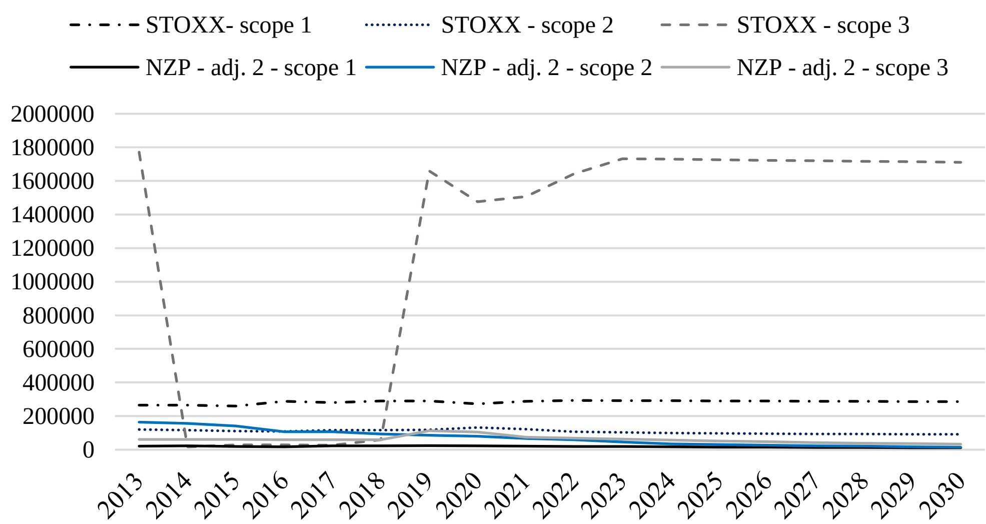
A linear forecast of both portfolios’ emission behaviour further illustrates the large differences in emission footprint (figure 13). Differences become more visible when we graph the Scope emissions breakdown. Figure 14 shows that Scope 3 emissions are still the largest contributor to the differences between the two portfolios.

Figure 13: NZP Total emissions (linear forecast)



The figure shows the weighted-average yearly emission and a 2022-2030 forecast (solid lines) of an optimized portfolio based on the EuroSTOXX600 index (STOXX) and a Net-Zero aligned optimized portfolio (NZP – adj.2) based on the Net-Zero aligned universe derived from the EuroSTOXX600, with the methods discussed in section 3.1-3.3. The forecasted slope of the Net-Zero aligned portfolio is compared to the Intergovernmental Panel for Climate Change (IPCC) emission reduction target, defined as a 43% of 2019 reduction by 2030 (IPCC, 2021, p.329) (dotted grey line). The emissions are presented in tCO_2-eq. (vertical) per year (horizontal). All calculations are done with ESG data retrieved from Refinitiv.

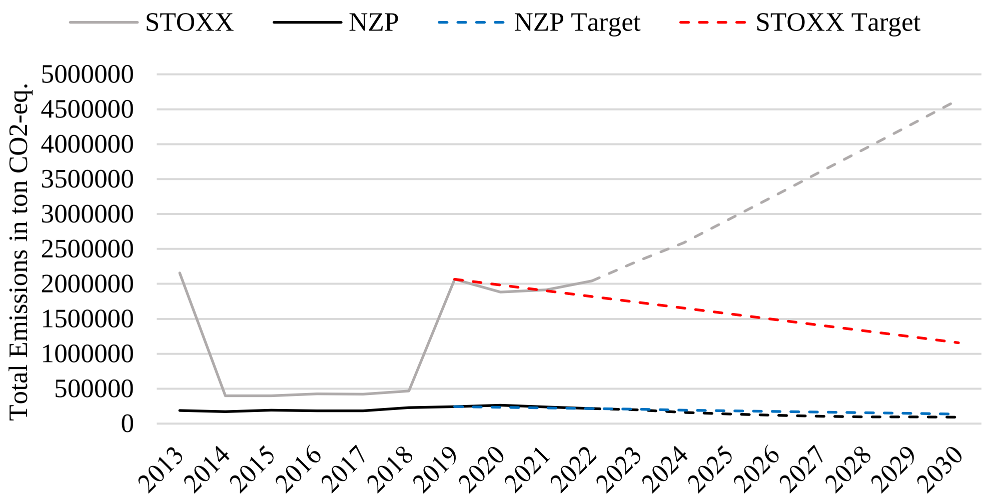
Figure 14: NZP Scope emissions breakdown (linear)



The figure shows the weighted-average yearly emission and a 2022-2030 forecast of an optimized portfolio based on the EuroSTOXX600 index (STOXX) and a Net-Zero *aligned optimized portfolio (NZP – adj.2) based on the Net-Zero aligned universe derived from the EuroSTOXX600, with the methods discussed in section 3.1-3.3. Scope 1 emissions are the direct emissions from operations, Scope 2 emissions are the emissions from purchased energy and Scope 3 emissions are all other firm-related value-chain emissions. The emissions are presented in* tCO_2*-eq. (vertical) per year (horizontal). All calculations are done with ESG data retrieved from Refinitiv.*

The nonlinear (Addition 2.1) forecast further increases the expected divergence of the non-aligned STOXX portfolio and the NZP. Figure 15 clearly shows the STOXX portfolio is expected to be increasingly more exposed to transition risk, with an expected emission increase that is more aggressive than the linear forecast. Figure 16 shows the Additional Condition 2.1 (Adj.2.1) nonlinear forecast of the NZP in detail. Here we see that the NZP makes the IPCC target with a slightly lower cumulative emission profile than shown by the linear forecast. Note that differences between the linear and nonlinear forecasts are much smaller for the NZP.

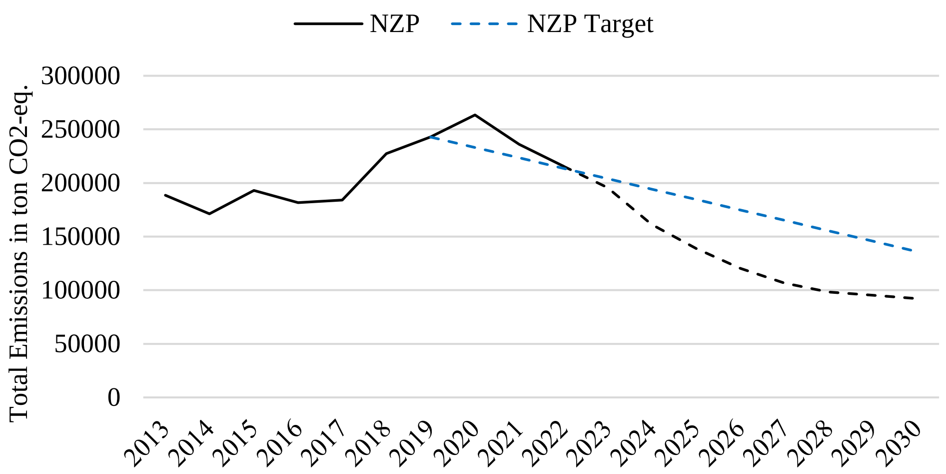
Figure 15: NZP nonlinear emissions forecast



The figure shows the weighted-average yearly emission (solid line) and a 2022-2030 forecast (dotted lines) for an optimized portfolio based on the EuroSTOXX600 index (STOXX) and a Net-Zero aligned optimized portfolio (NZP) based on the Net-Zero aligned universe derived from the EuroSTOXX600, with the method as discussed in section 3 and section 4. The nonlinear forecast is based on Additional Condition 2, with an "h" = 2. As discussed in section 3.4. The forecasted slope of the portfolios are compared to the Intergovernmental Panel for Climate Change (IPCC) emission reduction target (coloured dotted lines), defined as a 43% of 2019 reduction by 2030

(IPCC, 2021, p.329). The emissions are presented in tCO_2-eq. (vertical) per year (horizontal). All calculations are done with ESG data retrieved from Refinitiv.

Figure 16: NZP nonlinear emission forecast close-up



The figure shows the weighted-average yearly emission (solid line) and a 2022-2030 forecast (dotted lines) for a Net-Zero aligned optimized portfolio (NZP) based on the Net-Zero aligned universe derived from the EuroSTOXX600, with the method as discussed in section 3 and section 4. The nonlinear forecast is based on Additional Condition 2, with an "h" = 2. As discussed in section 3.4. The forecasted slope of the portfolio is compared to the Intergovernmental Panel for Climate Change (IPCC) emission reduction target (coloured dotted line), defined as a 43% of 2019 reduction by 2030 (IPCC, 2021, p.329). The emissions are presented in tCO_2-eq. (vertical) per year (horizontal). All calculations are done with ESG data retrieved from Refinitiv.

5.4.3 NZP vs. PAB method

In the literature, the most tested portfolio, the *PAB*, is usually found to have very little deviation from the benchmark in terms of composition and financial performance (Barahhou et al., 2022; Bolton et al., 2022; Hodges et al., 2022; Le Guenedal & Roncalli, 2022). To compare, we applied the *PAB* decarbonization requirement (appendix IV.h) and the sector-balance constraint to the EuroStoxx600 universe to create a proxy-portfolio for the *PAB* without the *PAB* ethical exclusions applied. The STOXX optimized benchmark appears to satisfy the *PAB* portfolio constraints and the *PAB* proxy portfolio is as such equal to the STOXX optimized benchmark. As such, we show that the NZP has comparable financial performance as a *PAB* portfolio (section 5.4 & section 5.4.1) but considerably outperforms the *PAB* on ESG performance and emission behaviour (section 5.4.2 & section 5.4.4).

5.4.4 NZP vs. ESG-focused investing

Throughout our discussion of the results, we have noted the inconsistent relation between ESG scores and emissions (section 5.3.1 & section 5.4). These findings are apparent in the index data, where we find that across the whole sample the correlation between Environmental scores and Scope 1 emissions is very low ($\leq |0.2|$) and not consistently negative. This is somewhat surprising because Scope 1 emissions are the emissions closest to the firm's operations, and Environmental scores is the ESG metric most closely related to firm emission behaviour.

The inconsistency between emissions and ESG score clearly comes forward when the NZP is compared to an ESG-focused optimized portfolio derived from a universe consisting of the 294 assets (50%) with the highest ESG score (positive screening).

Table 5: NZP & Max-ESG portfolio performance

Portfolio ESG Performance	STOXX optim	NZP optim	Max-ESG Portfolio	p-value	sign.
Environmental Score	57.24	66.20	71.84	0.005	***
Social Score	65.71	71.62	75.82	0.038	**
Governance Score	67.39	72.96	72.70	0.896	'
Combined ESG Score	59.89	63.21	78.47	0.000	***
Scope 1 Emissions* (2022)	293,292	17,964	2,229,369	0.000	***
Scope 2 Emissions* (2022)	107,130	55,602	302,820	0.000	***
Scope 3 Emissions* (2022)	1,642,705	142,137	10,918,130	0.000	***
Total Emissions* (1+2+3)	2,043,127	215,702	13,450,319	0.000	***

The figure shows the ESG performance of an optimized portfolio based on the EuroSTOXX600 index (STOXX optim) and a Net-Zero aligned optimized portfolio (NZP optim) based on the Net-Zero aligned universe derived from the EuroSTOXX600, with the method as discussed in section 3 and section 4. And a "Max-ESG" portfolio, a sector-constrained optimized portfolio that is constructed from the top 50% of the EuroSTOXX600 index, selected based on ESG-score, as discussed in section 5.4 of this paper.3. Emissions are presented in Metric tons of CO2 equivalence and ESG scores *are the weighted average scores based on ESG Scores from Refinitiv. The two columns on the right-hand side (grey) mention the p-value and significance (***= significant at 99%, ** = significant at 95%, * = significant at 10%, ‘ = other) for the significance tests for portfolio data as discussed in section 4.2.2. All calculations are done with ESG data retrieved from Refinitiv.*

Particularly, when we compare the NZP and the ESG-focused portfolio, we see the ESG-focused portfolio does considerably worse on all Scope emissions (significant at $\alpha = 0.01$) (table 5). The ESG portfolio even underperforms the STOXX optimized portfolio for Scope 1 and Scope 2, Scopes for which only small differences exist for most portfolios. One might argue that the broad focus of ESG scores and the distance of Scope 3 emissions from the ESG-analysis Scope for an asset might justify a discrepancy between emissions and ESG score. However, especially for the more emission-focused *Environmental Pillar Score*, the difference between the NZP and ESG portfolio is significant and the largest ($\Delta = 5.65$) compared to S, and G dimensions.

When we divide the Scope emissions of the ESG portfolio by the Scope emissions of the NZP portfolio, we find other issues with the ESG investing strategy. The Scope 1 emissions of the ESG portfolio are x124 (124/1) that of the NZP portfolio. This discrepancy is by far the biggest for Scope 1, where the second difference, from Scope 3, is only an x77 difference with the NZP (table 5).

It is especially alarming that Scope 1 is so substantial, because these Scope emissions are the emissions that are most directly linked to the firm. Naturally, Environmental scores capture more than just emission exposure. But Scope 1 emissions are the most financially material environmental externality (OECD, 2019) as it is priced in many countries, such as under the EU-ETS.

From these findings, we conclude that ESG-scores, and even Environmental scores, do not accurately reflect exposure to financially material GHG emissions. This means that ESG-based or ESG factor investing alone might not protect the investor against carbon risk, regulatory risk, and other material transition risks. It appears that an ESG-focused investor cannot rely solely on ESG-scores to manage their carbon-risk.

6. IMPLICATIONS

While being a disputed phenomenon, recent literature shows that firms with higher carbon exposure have a higher cost of capital (De Angelis et al., 2022). Other research finds that portfolios with higher ESG performance also appear to have lower left-tail risk (Maxfield & Wang, 2021) and appear less exposed to contagion risk from fire-sale spill over among equity mutual funds (Cerqueti et al., 2022). The literature also proposes the existence of "sustainable alpha" as carbon exposure signals are found to have predictability in equity and fixed income returns (Hodges et al., 2022; Kaul et al., 2022). In addition are roughly half of institutional investors (PwC, 2022, p. 9) and half of asset managers (Redington, 2022, p. 26) indicating that they divest or reject investments due to poor ESG performance. Which might further affect performance of these low-ESG assets.

While these findings are reputable, most are based on historic time-series analysis. To discuss implications for the current and future financial performance of our portfolio we decide to look at forward-looking data for two climate-related financial risks: 1) Risk of stranded assets, and 2) Carbon pricing risk. The monetary quantification of portfolio risks in this way is a novel development.

6.1 Stranded Assets risk exposure

A stranded asset is an asset that fails to generate expected profits due to environmental changes. Risk of stranded assets pose a significant threat to investors and poor management of these risks could lead to substantial financial losses (Atanasova et al., 2020; Bosa & Gupta, 2019; IRENA, 2017; Caldecott et al., 2014). While investors are already recognising this risk and tilting their portfolios away from stranded asset risk (EY, 2020; Sen & von Schickfus, 2020), methods for managing portfolio-risk of stranded assets are virtually non-existent in the literature. Currently the only quantitative method, developed by Atanasova et al. (2020), is specific to the oil sector and cannot be applied at the portfolio level. While data availability is holding back the development of measures, scenario analysis, a potential source of stranded asset risk reporting, is gaining popularity and might present a solution (Morgan Stanley, 2020, p.25).

To quantify stranded assets, we retrieve self-reported climate-related financial risks from the Carbon Disclosure Project (CDP) for each company in the EuroSTOXX600 index. This data is largely unstructured as it allows firms to report an unlimited number of risks. For each risk, firms are asked to report; 1) Timing, 2) Likelihood and 3) monetary estimate. Both timing and likelihood are verbally reported: short-term / medium-term / long-term for timing, and an 8-step scale reaching from “exceptionally unlikely” to “virtually certain” for likelihood. To quantify this data, timing is defined as 5, 10 or 20 years respectively, motivated by comments from the reports. Likelihood is given equally spaced probabilities reaching from 0.125 to 1.00. Data is available for 315 firms.

To our semi-structured data, we apply a probability-weighted Present Value (PV) calculation for Stranded Assets (SA):

$$Total\ PV\ of\ SA_i = \sum_{j=1}^{j} \frac{prob_{j,i} \times CF_{j,i}}{(1 + wacc)^{t_j}} \tag{15}$$

Where *i* represents the firm, *j* represents the risk for that firm, and *CF* may be a single estimate or the average of a minimum and a maximum. It's important to note that *j* is not defined as each firm may report a different number of risks. We obtain the weighted average cost of capital (WACC) data for the EuroSTOXX600 from Refinitiv.

The total PV of SA risk from equation 15 is presented in local currency. To aggregate the risk of stranded assets to a portfolio, we convert all PV estimates to Euro using the rates from the European Central Bank average currency rates for January 2, 2023. Using the Euro-PVs of SA, we can create aggregated portfolio estimates by calculating the weighted average of the assets' Euro-PV of SA.

Table 6: Present Value of Stranded Asset Risk

Portfolio Stranded Assets Risk	STOXX optim	NZP optim	p-value	sign.
# assets in portfolio	356	282	-	-
share of portfolio reporting	55%	57%	0.860	'
share of portfolio with range est.	40%	44%	0.678	'
minimum PV of SA (mil.)	€ 13.60	€ 7.83	0.991	'
maximum PV of SA (mil.)	€ 30.30	€ 34.60	0.996	'
Average PV of SA (mil.)	€ 781.02	€ 1,348.96	0.912	'
Total # of risks	519	476	-	-
# of risks / # assets	1.46	1.69	-	-
W.Avg. # of risks per asset	1.54	2.36	0.000	***
W.Avg. # of ST risks	0.27	0.71	0.000	***
W.Avg. # of MT risks	1.13	1.40	0.131	'
W.Avg. # of LT risks	0.14	0.26	0.091	*

*The table shows the weighted average present value of the climate-related financial risks for an optimized portfolio based on the EuroSTOXX600 index (STOXX optim) and a Net-Zero aligned optimized portfolio (NZP optim) based on the Net-Zero aligned universe derived from the EuroSTOXX600, with the method as discussed in section 3 and section 4. All descriptive data on reporting is calculated as the weighted average of the asset data as retrieved from the CDP portal and processed as described in section 6.1. PVs are calculated using risk-data from the CDP, WACC-data from Refinitiv and currency exchange rates retrieved for 02-01-2023 from the European Central Bank. The data is processed as described in section 6.1 and the assets' PV of stranded assets are calculated as the sum of the probability-weighted PV of the asset's risks, as stated in equation 15. The two columns on the right-hand side (grey) mention the p-value and significance (***= significant at 99%, ** = significant at 95%, * = significant at 10%, ' = other) for the significance tests for portfolio data as discussed in section 4.2.2.*

Subsequently, we conducted a comparative analysis between our NZP portfolio and the Stoxx600 portfolio. From table 6 we might draw one of two conclusions:

1) The NZP has a (although not significant) higher risk of stranded assets, due to climate-related risks exposure, as the probability-weighted PV of stranded assets is almost double that of the STOXX portfolio (yellow cells).

2) The NZP firms are much more transparent about their risks as they report significantly more risks. On average, the NZP firms report twice as many short-

term risks, long-term risks and risks in general (green cells), mechanically giving the NZP a higher PV of stranded assets.

Besides insignificance, conclusion 1 seems unlikely given the really low emission exposure of the NZP compared to the STOXX portfolio (table 4 & figure 13-16). Conclusion 2 seems more plausible and has significance. This implies that firms that effectively manage emissions are more likely to report stranded asset risks. Which arguably suggests that the firms that are reducing their emissions at the 1.5℃ required rate are more likely to measure, quantify, and understand their climate-related financial risk as well. This better management and awareness will decrease the actual risk of stranded assets and likely result in a more resilient firm. While the evidence is not conclusive, there are indications that the NZP portfolio has better stranded asset risk management and is as such more financially resilient than a non-aligned portfolio. This notion supports the finding that portfolios with better ESG performance have lower left-tail risk (Maxfield & Wang, 2021)

6.2 EUA Risk exposure

To better understand the financial materiality of carbon-risk, we show the financial impact of *European Union Allowance* (EUA) prices on the portfolios. These allowances are permits-to-emit that roughly half of the European economy are bound to. Table 7 below shows the change in the expected portfolio weighted-average EPS for 2030, as a result of an adjustment for the cost-of-carbon per share. Where the EPS is constructed with forward-looking 10-year *Cumulative average growth-rates* (CAGR), and cost of carbon reflects carbon pricing instruments such as the EU-ETS. Mathematically formulated, the *Carbon-Adjusted Estimated EPS* (CAE EPS) is:

$$CAE\ 2030\ EPS = EPS(2022) \times \left(1 + CAGR_{10yr}\right)^8 - \frac{\hat{E}_i^{total}(2030) \times p_{EUA}}{\#\ shares} \tag{16}$$

Where the 10-year CAGR is the EPS expected growth, total emissions for 2030 are derived using equation 1 to 3 (section 3.1), the 2030 EUA price is varied, and the number of shares is the total number of shares outstanding.

Once we account for forecasted emissions, and apply the current EUA price of €100, the Net-Zero aligned portfolio has a significantly better expected EPS of € 6.51 compared to the STOXX comparable portfolio's €4.56 (table 7). The effect of EUA pricing on the EPS holds at a 95% confidence interval, significance also holds for most scenarios (3/5) when we adjust for the initial difference in 2030 EPS. EUA risk illustrates well how misalignment might have significant financial impact. Here we assume that all assets are covered under the EU-ETS or comparable carbon pricing legislation. Currently less than half of the participating countries' economy is covered by the EU-ETS. However, with continuous reform, such as the recently adopted inclusion of maritime transport, buildings, road transport and fuels (European Council, 2023) the assumption of total EU-ETS coverage by 2030 is reasonable. We note that there is a significant difference in shares outstanding between the two portfolios as a result of arbitrarily high weights on a few firms with an unusually substantial number of shares outstanding. This should however not affect the accuracy of the EUA risk measure as both cost of carbon per share and EPS will have been equally affected by this.

Table 7: Portfolio EUA risk

Portfolio EUA Risk	STOXX optim	NZP optim	p-value	sign.
EPS (2022)	€ 3.67	€ 3.81	0.625	'
EPS 10yr forward CAGR	7%	6%	0.765	'
Estimated EPS 2030	**€ 5.13**	**€ 6.52**	0.000	***
Shares outstanding (bln.)	7.88E+08	4.40E+09	0.000	***
Est. Scope 1 Emissions 2030	285,921	13,599	0.000	***
EUA price 12-03-2023	€ 100	€ 100	1.000	'
Total Cost of Carbon* / Share	€ 0.09	€ 0.01	0.012	**
Cost of Carbon / EPS (pct.)	5%	1%	0.113	'
Carbon adjusted Est. EPS	**€ 4.56**	**€ 6.51**	0.000	***

The table shows the Portfolio European Emission Allowance (EUA) risk exposure of an optimized portfolio based on the EuroSTOXX600 index (STOXX optim) and a Net-Zero aligned optimized portfolio (NZP optim) based on the Net-Zero aligned universe derived from the EuroSTOXX600, with the method as discussed in section 3 and section 4. All descriptive data is calculated as the weighted average of the asset data as retrieved from Refinitiv. Following equation 16, the 10-year forward-looking EPS CAGR is a proprietary estimate of the cumulative average growth-rate (CAGR) for a given firm for *the next ten years., as estimated by Refinitiv. *Total Cost of Carbon is calculated as Scope 1 Emissions in metric ton of CO_2-equivalence multiplied by the EUA price per ton in Euro. The Carbon adjusted estimated EPS assumes all sectors are incorporated in the EU-ETS by 2030. All calculations are weighted averages of calculations, calculations with the weighted average in the table might result in deviation due to missing values. The two columns on the right-hand side (grey) mention the p-value and significance (***= significant at 99%, ** = significant at 95%, * = significant at 10%, ' = other) for the significance tests for portfolio data as discussed in section 4.2.2. All calculations are done with financial and emission data retrieved from Refinitiv and EUA price data retrieved on the 12th of March 2023, from Ember-climate.org.*

6.2.1 sensitivity and outperformance compared to other methods.

When we apply different price estimates for the 2030 EUA, nonlinear emission forecasts and forecast the EUA price based on the 5-year linear trend. We see not only that the difference holds, but that the sensitivity of the STOXX portfolio to these prices, is much larger and significant in an f-test (table 8).

Table 8: EUA risk sensitivity

Portfolio EUA Risk Sensitivity	STOXX optim	NZP optim	p-value	sign.
CAE EPS Nonlinear (€ 100)	**€ 4.47**	**€ 6.51**	0.000	***
difference	*-13%*	*0%*		
CAE EPS real trend (€ 222)	**€ 4.45**	**€ 6.50**	0.000	***
difference	*-13%*	*0%*		
CAE EPS (€ 80)	**€ 4.58**	**€ 6.51**	0.000	***
difference	*-11%*	*0%*		
CAE EPS (€ 100)	**€ 4.56**	**€ 6.51**	0.000	***
difference	*-11%*	*0%*		
CAE EPS (€ 120)	**€ 4.54**	**€ 6.51**	0.000	***
difference	*-11%*	*0%*		
sensitivity (standard deviation)	*5.32%*	*0.31%*	0.0013	***

The figure shows the Carbon-adjusted estimated 2030 Earnings per Share (CAE EPS) of an optimized portfolio based on the EuroSTOXX600 index (STOXX optim) and a Net-Zero aligned optimized portfolio (NZP optim) for different prices of one metric ton of CO_2-equivalence. The NZP optim is based on the Net-Zero aligned universe derived from the EuroSTOXX600, with the method as discussed in section 3 and section 4. The first CAE EPS also calculates EUA risk for the portfolios if nonlinear emission forecasting is applied. EUA risk is calculated using equation 16, as discussed in section 6.2. The real trend EUA price of €222 is derived by applying the average 5-year price-

*increase as an estimate for future price increase. The difference is defined as the percentual decrease of the 2030 forecasted EPS as presented in table 7 (before adjustment for carbon price). The sensitivity is the volatility of the price, taken as the standard deviation of the Carbon-adjusted estimated EPS values presented in this table and table 7. The two columns on the right-hand side (grey) mention the p-value and significance (***= significant at 99%, ** = significant at 95%, * = significant at 10%, ' = other) for the significance tests for portfolio data as discussed in section 4.2.2. All calculations are done with financial and emission data retrieved from Refinitiv and EUA price data retrieved on the 12th of March 2023, from Ember-climate.org.*

We also test the ESG-focused portfolio and find that the Expected 2030 EPS is also significantly impacted by EUA price risk (–4.0% : –37.5%). However, unlike the STOXX optimised benchmark, the significance for most price scenarios disappears when accounting for the difference in 2030 expected EPS. This is the result of the large variance of this group of assets. This variance is reflected in a much larger EUA price sensitivity, when comparing to the STOXX benchmark. This finding is partially due to the larger emission exposure of the Max-ESG portfolio.

7. CONCLUSION & DISCUSSION

This paper shows that it is possible to construct a Net-Zero aligned portfolio that has less exposure to transition-risk, without significantly sacrificing financial performance.

While the integration of ESG data into investment decision-making has become widespread, there is no commonly accepted method for aligning investment portfolios with the PCA. This paper reviewed current methodologies to show that most methods are based on inferior targets, are overly complex and suffer from low construct validity. By combining concepts from the *EU TEG PAB* with methods based on Le Guenedal & Roncalli (2022), we improve the current literature and present a forward-looking dynamic Net-Zero alignment method with possibility for nonlinear forecasting. By focusing on emission reduction, rather than current absolute emissions, the method is able to select climate-winners in each sector of the economy. To guarantee that the method selects climate winners in all sectors, we mechanically balance the sector exposure of the portfolio. Tilting the portfolio towards climate winners in each sector is important to identify investment opportunities and finance the green shift (Edmans et al., 2022).

With the application of this method, we show that an NZP for the European market outperforms on ESG risk metrics and carbon performance (–95%) without sacrificing risk-adjusted return and with minimal (1.14%) tracking error. We find that assets selected by the NZP have more and better reporting on stranded assets, which suggests better ESG awareness and climate-risk management. The NZP also shows significantly less exposure and sensitivity to carbon-pricing instruments such as the EU-ETS. We show this by adjusting expected 2030 EPS for the *cost of carbon per share*. We find that the non-aligned comparable portfolio has significant exposure to EUA risk, with an expected decrease in 2030 EPS of € 0.85 to € 0.99. These forward-looking indicators of climate-risk management are novel developments that help us illustrate how we improve upon popular methods such as the *EU PAB.*

We find that the PAB does not significantly reduce investors exposure to PCA-related transition risks and other carbon risks. The PAB portfolio performs comparable to a non-aligned optimized portfolio and has similar financial and ESG-performance, meaning it performs as bad as non-aligned portfolios.

Finally, this paper investigates an ESG-focused investment strategy and finds that the poor link between direct firm emissions and Environmental scores cause a traditional ESG-factor investor to be greatly exposed to climate-related risk. We find that an ESG-focused portfolio does not sufficiently protect against the impact of carbon pricing regulation and related carbon risks and conclude that ESG scores do not present investors with the tools required to manage their assets through a green transition.

Recommendations for regulators

- Alignment requirements might not be based on carbon intensity to ensure construct validity. Absolute emissions provide the best direct link to emission reduction.
- A focus on emission reduction, alongside current emission footprint (through emission pricing), reduces discrimination against size and sector while still providing economic incentives to reduce emissions.

Recommendations for asset managers

- It is possible to construct a Net-Zero aligned portfolio without significantly sacrificing financial performance.
- The NZP portfolio has significantly better emission reduction and is as such less exposed to current and future financially material transition risk, such as the EU-ETS EUA-price development. Non-aligned portfolios and portfolios following the *PAB* do not have the same risk management abilities.
- ESG-scores do not provide investors with an accurate measure for climate-risk exposure and excessive trust in Environmental scores will likely leave an investor unnecessarily exposed to significant carbon-related risk.
- A Net-Zero aligned portfolio might select firms that better measure, report, and manage stranded asset risk, meaning the portfolio is more financially resilient and likely has lower left-tail risk than a non-aligned portfolio.

7.2 Direction of future research & research limitations

The findings in this paper are a result of the method and data. Firstly, future research might attempt to replicate the results with changes in emission forecasting method, different time-values (*h*) for velocity, and changes in portfolio optimization methods used. Where particularly, the latter change might increase the accuracy of our findings. Secondly, future research might attempt to replicate the results for different data: different time periods, across different markets or at different scales. Micale et al. (2020) argue for the importance of recognising differences in emission reduction trajectories for various countries. In this context, the application of current Net-Zero targets and emission forecasting to emerging markets is a topic that deserves more attention. The impact of the choice of emission reduction target (IPCC C1, IEA, EU CTI) on the NZA can give interesting insight into the impact of different reduction trajectories on the NZP financial performance.

Research limitations

This research has been reliant on data from Refinitiv. Hence, our research might be exposed to common issues in ESG data, financial data and emission data. These issues include biased self-reporting, lack of data and data entry errors. The data is sorted by fiscal year. Differences in fiscal year can cause small deviations in data. Seasonality of emissions and deviation in fiscal periods cause deviations in NZA universe selection and ultimately portfolio optimization.

The data showed to have non-normal distributions for all variables. As a result, t-distribution requirements are violated, and t-testing might not be statistically valid. While non-normality is common, t-tests are still the most used statistical tests in top finance journals (Kim & Ji, 2015). In addition, large samples, such as the ones used in this paper, suffer less from non-normality issues as follows from *Central Limit Theorem*.

For Additional Condition 2.1, the short-term beta was considered for $h = 2$ and $h = 1$. These intervals (2020-2022) cover the Covid-19 pandemic. As a result, emission reduction for certain assets might have been the result of longer term reduced economic activity experienced due to the societal consequences of the pandemic. As such, the number of firms initially selected for the NZA universe might be upwards biased and results might not be replicable for other time periods. However, as the portfolio optimization method selects assets that combine reduced emission with attractive economic performance, the likelihood that these Covid-victim firms were not selected for the portfolio, is large.

For the portfolio optimization process, the NLMINB2 algorithm was used. While this algorithm proved to be the most efficient and accurate among the methods available, it is not perfect. Results from an NZP portfolio optimization might contain 287 assets while the NZA universe only contains 282 assets. Here we find 5 assets have very small (E-19) positive weightings. For the results, we clean the optimizer output for these imperfections. As these imperfections seem to occur more for more restricted models, this issue might have under-estimated the true maximum Sharpe ratio of the NZP more than other portfolios. This means the difference between the NZP and the STOXX comparable portfolio might actually be smaller than presented in this paper.

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9. LIST OF ABBREVATION

AR – Assessment reports

AR5 – Assessment report 5

AR6 – Assessment report 6

CAE – Carbon-adjusted estimated

CAGR – Compound annual growth rate

CDP – Carbon Disclosure Project

CDR – Carbon Dioxide Removal

CF – Cash Flow

CO_2 – Carbon dioxide

COVID-19 – Coronavirus Disease 2019

CTI – Carbon Transparency Initiative

ECF – European Climate Foundation

EEA – European Economic Area

EPS – Earnings per share

ESG – Environment, Social, Governance

EU – European Union

EU CTB – the EU Climate Transition Benchmark

EU TEG – European Union Technical Expert Group

EUA – European University Association

EU-ETS – EU emissions trading systems

EUGD – the EU Green Deal

FTSE – Financial Times Stock Exchange

GC – Global compact

GEA – German Environmental Agency

GHG – Greenhouse gasses

IEA – International Energy Agency

IPCC – the Intergovernmental Panel on Climate Change

IPO – Initial Public Offering

LTM – Long term momentum

MSCI – Morgan Stanley Capital International

NZA – Net Zero alignment

NZP – Net Zero portfolio

PAB – Paris Aligned Benchmark

PAC - participation, ambition and credibility

PAT – Portfolio Alignment Team

PCA – Paris Climate Agreement

PV – Present Value

R&D – Research and Development

SA – Stranded assets

SDG – Sustainable development goals

SDI – Sustainable Development Investing

SFDR – Sustainable Finance Disclosure Regulation

SR – Special Reports

SR 1.5 – Special Report 1.5

STM – Short term momentum

TCFD – Task Force on Climate-Related Financial Disclosers

TE – Tracking Error

UNEP – United Nations Environment Program

US – the United States of America

WACC – Weighted Average Cost of Capital

10. APPENDIX

APPENDIX I: The Climate science behind Net-Zero targets

Climate change is driven by the emission of GHGs by mankind. The concentration of these gasses in the atmosphere cause global warming. As climate change mitigation focuses on the management and reduction of the cumulative emissions into the biosphere. Limiting climate change to 1.5℃, means limiting the cumulative emissions to a certain maximum. The maximum amount of cumulative GHG emissions minus the current concentration of emissions is often called the *carbon budget*. This budget is the amount of GHGs society can still emit if it is to reach the PCA. In principle, the timing of the emissions is irrelevant, as long as the total amount of GHG emissions does not exceed the *carbon budget*.

Besides the allocation of the *carbon budget* throughout time, the literature also considers the possibility of actively removing carbon from the air using Carbon Dioxide Removal devices (CDR). However, the feasibility of these technologies is uncertain and as such, exceeding the *carbon budget* with the hope of actively reducing the concentration of emissions in the atmosphere in the future is risky. The IPCC presents different temperature scenarios with different assumptions. The most precautionary target (C1) is the *1.5℃ with no or limited overshoot*. A scenario that doesn't allow the exceeding of the *carbon budget* (overshoot) with the intention to apply CDR in the future (IPCC, 2018). As climate science is complex and has uncertainty, various models and simulations for the same budget will result in a different expected global mean temperature. The emission reduction trajectory that is most aligned with the PCA is scenario C1; *1.5℃ with no or limited overshoot* with at least 50% (>50%) certainty. Which means >50% of the simulations for the chosen reduction trajectory (budget) limit the global mean temperature increase to 1.5 ℃.

The AR5 and later SR 1.5 reports by the IPCC, calculated percentual reduction targets based on the estimation of a *carbon budget* that satisfies C1 (>50%). These percentual emission targets are based on a benchmark level of annual emissions. In the case of AR5 and SR 1.5, 2010 emission levels has been the benchmark. Here the IPCC presented a 2030 target of 45% reduction and a 2050 goal of Net-Zero (100% reduction) (IPCC, 2014, p. 33).

The IPCC AR6 report (2021), has updates based on global developments in climate science and achieved emission reduction. An increase in measured annual emissions since 2010 and the development of various new pathways with steep emission decline between 2020 and 2030 are some of the developments considered (IPCC, 2021). While the first requires more rapid reduction to meet the temperature target, the latter suggest the ability of society to do so. AR6 uses 2019 as the new benchmark level of emissions. With respect to this level, C1(>50%) requires a reduction of 43% by 2030, and 84% by 2050 (IPCC, 2021, p. 329). Here the authors note that the slight delay of the Net-Zero date, away from 2050, is dependent on the rapid reductions between 2030 and 2040 (IPCC, 2021 p. 327). The stricter 43% target (compared to SR 1.5) incorporates this increase in reduction-rate in the short-term.

APPENDIX II: Review of Net-Zero targets (Component 1)

While some literature only describes the methodology (Le Guenedal et al., 2022; Andersson et al., 2016) and recognises that firms tend to have their self-defined targets, most firms apply one of four science-based targets.

II.a IPCC

The IPCC combines climate research from around the globe to shape the recommendations for mitigating climate change. The IPCC has played an expert role in the PCA and currently reports on progress and the measures necessary to reach the PCA.

The Net-Zero target developed in the fifth assessment report (AR5) (IPCC, 2014) and the special report (SR1.5) (IPCC, 2018) is used for most of the methods (Barahhou et al., 2022; Hodges et al., 2022; Le Guenedal & Roncalli, 2022; EU TEG, 2019). Here all consider scenario "*C1(>50%)*" as the PCA target, where the latter three authors apply a more ambitious derivative based on this target. The C1 target does not allow firms to stray away from the trajectory with the promise of future negative emission technology. Appendix I further explains the details of climate scenarios.

In 2021, updated science and emission reduction pathways were published as a part of the sixth assessment report (AR6) (IPCC, 2021). The most recent literature now bases their method on the C1 target from this report (Barahhou et al, 2022; Bolton et al., 2022).

II.b IEA

Much like the IPCC target, the IEA scenario (Barahhou et al., 2022; IEA, 2021) is a constructively designed PCA pathway based on the analysis of factors such as energy consumption patterns, technology developments, and policy initiatives. While the IEA and IPCC trajectories are comparable, the IEA scenario has a slightly larger nonlinearity (s-curve) that assumes sharp reductions around 2030 (appendix II.e, figure 17).

II.c EU CTI

The European Union Carbon Transparency Initiative (EU CTI) 2050 roadmap tool (ECF, 2018) is an emission reduction tool that is based on the CTI model and has been adjusted for the EU. Both the IEA and EU CTI roadmap contain industry-specific targets. Industry specific targets are considered by some to increase target accuracy (Barahhou et al., 2022; Hohne-Sparborth et al., 2022; Kolle et al., 2022).

II.d EU TEG benchmark

The EU PAB and CTB (Barahhou et al., 2022; Hodges et al., 2022; Le Guenedal & Roncalli, 2022; EU TEG, 2019) require a portfolio to have an initial emission reduction compared to the universe in 2020 (30% and 50% respectively), and a subsequent 7% self-decarbonization yearly. This target is slightly stricter than the AR6 2030 goal (55% vs. 43% reduction) and aligns closely with the EU "fit for 55" ambition (Consilium, 2023). This excess reduction in 2030 is necessary for the geometric design to be aligned with the AR6 2050 reduction target of 84% reduction and the 7% is motivated with UN research (UNEP, 2019). The EU benchmarks have been scrutinized for being overly aggressive and lacking a theoretical foundation for the initial reduction (Barahhou et al., 2022; Steffen, 2022). Without theoretical foundation for any adjustments, we concur with the critique and do not see reason to deviate from the IPCC AR6 target.

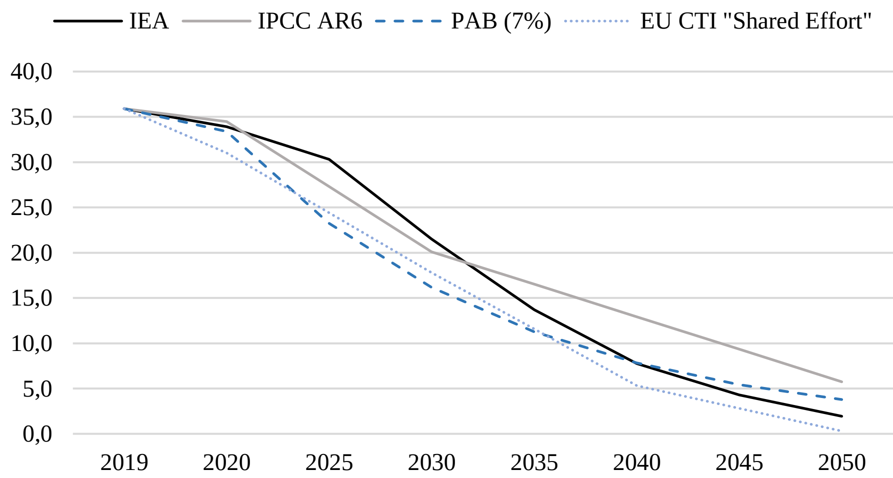
II.e Our Choice: The best NZA target

Both the IEA, EU CTI and the IPCC Scenario C1, present emission reduction targets and trajectories that are aligned with the PCA. In the literature there is no clear preference for the target. We argue that, while the granularity of industry-specific targets in the IEA and EU CTI scenario might be more precise, the existence of multi-sector firms makes the application of sector-specific targets complex and labour-intensive. The C1 scenario; *1.5℃ with no or limited overshoot* with at least 50% certainty, is much simpler as it requires all assets to reduce annual emissions by 43% by 2030, and by 84% by 2050, based on 2019 emissions (IPCC, 2021, p. 329). The relative availability of firm-level emission data for 2019, makes the application of this target at the firm-level cost-efficient and uncomplicated. As such, we argue this target is the best target for Net-Zero alignment.

Most articles base their target on the 2050 Net-Zero target (Barahhou et al., 2022; Hohne-Sparborth, 2022; Le Guenedal et al., 2022; Le Guenedal & Roncalli 2022; EU TEG, 2019). However, both academics (Bolton et al; 2022, p. 31) and practitioners (Swiss RE, 2023, Meissner et al., 2021, p.9) argue that targets for 2050 only, do not allow for interim review of the target before the Net-Zero date. These authors argue that developments in climate science and policy would likely require adjustments at a certain moment in time.

Furthermore, the use of a 2030 target would reduce the effect of our choice of reduction trajectory. The difference in trajectory cumulative emissions, the area under the trajectory that the various trajectories allow, is smaller before 2030 and becomes more pronounced after 2050. This means that the various institutes agree more on how much emissions should be allowed in this period. As all available reduction trajectories approach linearity in a shorter timeframe (figure 17), we will consider a 43% by 2030 AR6 linear reduction trajectory starting in 2019, to calculate interim targets where necessary (Addition 1 & Addition 2) and to visualize the reduction trajectory towards the target, in graphs.

Figure 17: Linear and Nonlinear trajectories



This figure displays the reduction in annual emissions in $GtCO_2$ (vertical) over time (horizontal) that is required to reach the 1.5°C maximal mean global temperature increase target, as developed by various organizations: The International Energy Agency (IEA) (IEA, 2021), The Intergovernmental Panel on Climate Change, AR6 (IPCC AR6) (IPCC, 2021, p. 329) , The European Union Paris Aligned Benchmark (PAB) that applies a 7% geometrically decreasing slope (EU TEG, 2019), The "Shared Effort" scenario, from the EU CTI 2050 Roadmap model developed by the European Climate Foundation (ECF) and the CTI (ECF, 2018). Emission reduction trajectories are retrieved as referenced and scaled so that all trajectories emerge from the same

2022 emissions of 35.9 $GtCO_2$ matching the IEA estimate, to better show trajectory shapes.

The decision to linearly approximate the IPCC trajectory for Addition 1 and Addition 2 is supported by the argument that firm-level emissions are highly autocorrelated (Bolton et al., 2022) and corporate and governmental reduction efforts have been largely linear in the recent past (GEA, 2023; Ørsted, 2021; Klimarådet, 2020, p.27).

APPENDIX III: Review of alignment methods (Component 2)

Generally, the literature neither agrees on what should be the target (Component 1) nor how alignment should be measured (Component 2). Empirical testing of methods is limited and mostly focuses on the popular *PAB*. As such the advice of expert groups (TCFD, 2021; EU TEG, 2019) and authors' critique and discussion of current methods (Bohn et al., 2022, Barahhou et al., 2022; Steffen, 2022; Hohne-Sparborth et al., 2021) is mostly a theoretical discussion. From the current debate we derive four evaluation criteria.

These four criteria, with the articles that cover them, are: **1) Simplicity & transparency**, the method should be easy to understand and communicate. The method should be as simple as possible, but no simpler. Meaning assumptions and simplifications should be clear, accurate and theoretically sound (Bohn et al., 2022; Barahhou et al., 2022; TCFD, 2021). **2) Objective stringency**, the method's alignment requirements should follow the science-based emission reduction targets' trajectory with reasonable accuracy. Any deviation should have theoretical foundation, unfounded excessive stringency should be limited (Barahhou et al., 2022; Steffen, 2022). Likewise, absence of adequate stringency, resulting in increased probability of overshoot should also be limited (Rio Declaration, 1992). **3) Construct validity**, the method should accurately measure emission reduction. The method should adhere to the precautionary principle (Rio Declaration, 1992) and should not implement design changes at the cost of emission reduction measurement accuracy (Kolle et al., 2022; Hohne-Sparborth et al., 2021; TCFD, 2021). **4) Data availability**, the method should be practically applicable for most asset managers. Methods that require sophisticated measures often rely on firm-level data that is not readily available. At this moment in time, these methods are impossible to apply and as such undesirable (Barahhou et al., 2022).

Table 9 shows the criteria violations for each method. The table shows that *trend methods* (Le Guenedal & Roncalli, 2022) have the least structural problems. In appendix IV, we further discuss specific mechanisms and shortcomings of methods in our effort to select the NZA method that allows us to best manage portfolio climate-risk.

Table 9: Overview of methods' criteria violations

Criteria Violation Method type	Simplicity & transparency	Objective stringency	Construct validity	Data availability
IV.a: Low carbon portfolios		X	X	
IV.b: Carbon budgets		X	X	
IV.c: Temperature scores	X			
IV.d: Firm commitments	X		X	
IV.e: Green investment metrics		X	X	X
IV.f: Green revenue			X	X
IV.g: Emission intensity			X	X
IV.h: EU CTB and PAB		X	X	X
IV.i: Trend methods				
IV.j: Rate-of-reduction methods		X	X	
IV.k: Ambition methods			X	

This table displays the various methods in the literature (vertical) and indicates where the methods violate the criteria for good Net-Zero alignment methods (horizontal), as discussed in appendix IV.

APPENDIX IV. REVIEW OF THE METHODOLOGY

IV.a Low carbon portfolios

The earliest approaches to managing carbon emission exposure for asset managers came in the form of *low-carbon* portfolios (Andersson et al., 2016). With this method, one looks at an emission metric and applies a constraint or otherwise indicates a preference for low-emissions stocks. The resulting portfolio with a low exposure to carbon risk is often referred to as a "green" portfolio. These portfolios do not align with emission reduction targets for two reasons. 1) The decarbonization of society requires emission reduction in each sector of products/services that society consumes. Low-carbon portfolios are virtually always underweighted in traditionally high-carbon sectors such as utilities and manufacturing (Bolton et al., 2021; Bender et al., 2019; Andersson et al., 2016). By doing this, low-carbon portfolios are not selecting the financially interesting climate winners in traditionally emission-intensive sectors. 2) by looking at the emissions of an asset at one point in time, low-carbon portfolios fail to identify which firms are reducing carbon at the required rate and which are not. As a result, high-emission firms that are reducing emissions at impressive speeds are excluded, while low-emission firms that are not working towards their 43% reduction are celebrated. As a result, these methods are left without a way to measure alignment with the PCA. As such these are not Net-Zero alignment methods, violating the *Construct validity (3)* and *Objective stringency (2)* criterion.

In addition, it might be recognised that these portfolios could harm a green transition by reducing the ability of heavy emitters to access financing for *green investment* with high societal impact (Hohne-Sparborth et al., 2021).

IV.b Carbon budgets

From *low carbon portfolios*, emerged the consideration of *Carbon Budget*s for individual assets (Le Guenedal et al., 2022; Urban et al., 2021). Where firms are judged against their ability to stay within their maximum amount of cumulative emissions (their budget). These portfolios do not align well with the PCA for two reasons: 1) The application of *Carbon Budgets* to an investment portfolio is inaccurate because it requires an analyst to decide which share of the global emission budget, might rightfully belong to one asset. Doing this requires vast assumptions on the size of the global public and private economy and a single asset's share of that economy. A nearly impossible task that requires many simplifications to work (Bolton et al., 2022).

2) Due to the cumulative nature of emissions in the atmosphere, the use of *carbon budgets* allows for a waterbed effect. This effect describes that if a firm can emit 1000 tons of emission between now and 2030, the choice to emit less in 2023, allows the firm to emit more in the future (2024-2030). However, one can easily argue for the opposite: Firms can continue to emit disproportionate amounts of greenhouse gasses (GHG) in the present, by promising to reduce emissions quickly, completely or achieve negative emissions in the future. With this rationale, firms can comply with a *carbon budget* with empty promises, while using insufficient effort and resources on achieving tangible emission reduction in the present.

Overall, this method violates the *Objective stringency* (2) criteria as overshoot cannot be sufficiently prevented, and the *construct validity* (3) criteria as *carbon budgets'* application to individual assets has poor theoretical foundation. In addition, the method does not present any way to estimate the asset's emission reduction, other than the required trajectory implied by the *carbon budget*. As such the method is <u>not</u> an alignment method.

IV.c Temperature scores

Temperature scores, indicate the global temperature that will be achieved with the current GHG emissions behaviour of a firm (Le Guenedal & Roncalli, 2022). Kolle et al. (2022) use *temperature scores* provided by Vivid Economics to construct a Net-Zero aligned portfolio, without much explanation. Le Guenedal and Roncalli (2022) describe a second method that compares individual emission reduction to temperature pathways. Both methods can also include adjustments to for declared reduction ambitions or green R&D. Both Kolle et al., as well as Le Guenedal and Roncalli, appear to base the *temperature score* on the yearly emission reduction trend at the firm-level (although, this is not entirely clear for the former).

A method such as *temperature scores*, that considers forward-looking emission reduction, is an important step in the right direction. However, *temperature scores* are not a good alignment method for the following two reasons: 1) They are considerably difficult to understand. As Barahhou et al. argue; *"a rating system of carbon temperature is often perceived as a black box"*, and as such they argue that; *"we may consider a simplified approach that is more transparent"* (Barahhou et al., 2022, p.3).

2) The methods are also often based on a multitude of measures that are either ambiguous (e.g., reduction ambitions), or require non-financial reporting at a level that has not yet been achieved by most firms (e.g., reporting on *green revenue*).

Because *temperature scores* are difficult to construct, compare and interpret, this method violates the *Simplicity & Transparency* (1) criterion. Simplicity and Transparency are important for methods to be implemented, understood, and trusted. This method might violate more criteria, but the method's complexity makes it difficult to assess this.

IV.d Firm commitments

Firm commitments, which refer to the published emission reduction ambitions and goals of firms, are often suggested as an adjustment applied to other quantitative measures of GHG reduction (Barahhou et al, 2022; Bolton et al., 2022; Le Guenedal et al., 2022; Hohne-Sparborth et al., 2021; Bender et al., 2019).

While *firm commitments* can give an important indication of paradigm shifts and change in ambitions at the firm level. The metric does not measure alignment for two reasons: 1) There is no agreement on how the impact of various commitments might be measured or combined. 2) Corporate greenwashing through empty promises has unfortunately become common practice (Foerster & Spencer, 2023, p.28), especially among the heaviest emitters, and verifying these statements is very difficult. Overall, this method violates the *Simplicity & Transparency* (1) and *Construct validity* (3) criteria.

IV.e Green investment metrics

Green investment metrics present an alternative way to measure and account for future reductions in GHGs. *Green investment metrics* are defined as the share of a financial accounting measure that is spent on emission-neutral products. Specifically *Green CapEx* and *Green R&D* are proposed as *green investment* measures that can give insights into future GHG reductions of a firm (Barahhou et al., 2022).

These metrics do not measure alignment well for three reasons: 1) Just like *firm commitments*, *green investment* measures indicate the willingness of firms to abate and need not necessarily correlate with actual reduction. More specifically, R&D expenses into carbon-neutral products might not result in a feasible product and might never be capitalized. The potential impact of *green investment* might be substantial, but such judgements cannot be deduced from the amount of *green investment* expenses alone. 2) Barahhou et al. (2022, p. 4) find that the data on these metrics is currently underdeveloped and won't be readily available before 2024. 3) The materialization of R&D can take years to decades. The deadline for the next reduction target is only eight years away (AR6 2030).

Because the method does not accurately measure actual reduction, because data is not readily available, and because R&D does not materialize in the near future, the method violates the *Construct validity (3), Data availability (4)* and *Objective stringency (2)* criteria and is not a good alignment method.

IV.f Green revenue

Green Revenue might be an alternative green metric, that more directly measures emission reduction in the present and near future. *Green revenue*, defined as the share of revenues that result from emission-neutral products, is often proposed as a potential interesting addition to methods (Le Guenedal & Roncalli, 2022, Barahhou et al., 2022, Wang et al., 2021). For example, Wang et al. (2021) first apply the *EU PAB* method to construct a portfolio. In which they then upweight assets based on *green revenue* and *firm commitments*. Bender et al. (2019) uses the metric as one of five metrics in their strategy for creating low-carbon portfolios.

However, much like *green investment metrics*, *green revenue* share is currently underreported. Bender et al. (2019) are only able to retrieve *green revenue* data for 577 firms for the developed markets (2017), using FTSE Russell. Barahhou et al. (2022, p. 3) also conclude that the metric is relatively young as they are unable to retrieve enough historical data to perform a dynamic analysis. Because of this, the literature does not present a method for estimating future emission reduction. Overall, the *green revenue* metric violates the *Construct validity* (3) and *Data availability* (4) criteria.

IV.g Emission intensity

A measure that is closely comparable to *green revenues* is *Emission intensity*. This measure, that divides firm GHG emission by a financial performance measure, is easy to construct and data is readily available. This has made the measure one of the most popular metrics for Net-Zero alignment in the literature.

By being one of the most widely adopted metrics for Net-Zero alignment methods, shortcomings of this metric have the biggest impact on the misalignment and inefficiency of the current methods in the literature. As such we will discuss this metric more intensively.

Popular arguments for emission intensity

A large section of the literature (Barahhou et al., 2022; Hodges et al., 2022; Kolle et al., 2022; Hohne-Sparborth et al., 2021; Bender et al., 2019) applies methods based on *emission intensity*. Widely recognized benchmarks such as the *EU CTB* and *PAB* (EU TEG, 2019) use *emission intensity* as well. Kolle et al. (2022) use the argument that *emission intensity* is the preferred method as it achieves portfolios with a better sector balance compared to low-carbon methods that underweight high emitters. This is not inherently the case, as industries with a higher amount of emissions per € of product would still be disadvantaged.

Barahhou et al. (2022, p. 18) as well as the *TEG*, authors of the *PAB* (EU TEG, 2019), argue that asset managers should measure emission reduction in *emission intensity* as it allows for comparison of carbon performance between companies of vastly different sizes as well as firms' ability to decouple value creation from GHG emission. While it is true that intensity prevents bias against large firms, considering relative absolute emission reduction, rather than emission levels would solve this same problem and remove bias against firm size. In an asset management context, the portfolio optimization of a universe of emission-reducing firms would also already select the emission-reducing assets with the best risk-adjusted return. Effectively selecting assets that decoupled financial performance (value creation) from GHG emission. Choosing *emission intensity* specifically for this purpose is as such unnecessary.

Arguments against emission intensity

In addition, the ability to compare assets with each other, TEG's argument for *emission intensity*, is entirely irrelevant to an NZA method. Firm-firm comparison might be beneficial for asset managers in fundamental analysis and can be used for tilting portfolio weights after Net-Zero alignment (Hodges et al., 2022; Weng et al., 2022). But it is entirely irrelevant when assessing the firm's ability to reach the Net-Zero target.

Furthermore, any intensity-based measure inevitably suffers from construct validity issues (Hohne-Sparborh et al., 2021; Meissner et al., 2021). Hohne-Sparborth et al. (2021, p. 7) note in their paper that: "*the fundamental climate objective should not be for a company to reduce its emissions intensity, but* *rather for it to reduce its absolute emissions, for it is absolute emissions that define cumulative emissions and impact on global warming*." Concluding that intensity-based measures are only a proxy for real emission reduction. The authors concur with the TCFD report (2021) that argues that the financial component of intensity measures allow for *emission intensity* to improve without emissions actually decreasing. Revenue can increase due to a number of economic factors such as 1) inflation, 2) product market prices, 3) product premia, 4) industry growth and 5) company inorganic growth. Which means revenue-based carbon intensity can improve without real emission reduction. Adjusting for these discrepancies is time-intensive and complex. Adjustments for inflation, industry growth and subsequently company growth can be standardized, but adjustments like this can often only be performed with a multi-year lag (Hohne-Sparborth et al., 2021). Furthermore, ambiguity increases for firms with operations in several different industries and adjustment for volatile price-dynamics is not practically feasible at all. To fix this, the literature suggests the use of production-output intensity instead of revenue-based intensity for markets with highly volatile prices, mostly commodities. However, Hohne-Sparborth et al. (2021) highlight that lack of data, product heterogeneity and issue of multi-sector firms make this solution impractical as well. Finally, to prove with credibility that a firm that increased market share, simultaneously decreased emissions in society, the asset manager would have to establish that the firm outcompeted competitors and did not grow through increased product-demand. While this is possible to compute by subtracting industry growth from company growth, many of the same concerns (data lags) would apply.

While recognising *emission intensity's* lack of construct validity, the TCFD (2021) and Hohne-Sparborth et al. (2021) still argue that *emission intensity* is the preferred method as it does not punish firms that have already substantially decarbonized, by requiring these firms to follow the same industry-average emission reduction rate, referred to as *rate-of-reduction* methods. In appendix IV.j, we discuss how this argument is irrelevant as the faulty construction of that method unnecessarily creates the need for intensity-based measures.

Finally, Both the TCFD report (2021) and Hohne-Sparborth et al. (2021) argue intensity should be used because aligning on absolute emissions disincentivises inorganic growth. Which they argue, might actually be very important to the green transition. While intensity is often proposed as the solution to this problem, M&A activity is likely to affect firm growth rates which affects the consistency of intensity measures (Hohne-Sparborth et al., 2021, p. 9). We recognise that a method based on absolute emissions has no inherent solution for inorganic growth. However, intensity-based methods do not present a clear solution to this problem either.

Without a clear benefit of using intensity-based measures to outweigh the shortcomings, *emission intensity* does not appear to be a preferred metric for emission reduction. Methods that argue that *emission intensity* is the best method, often do not discuss how alternative methods and assumptions result in different outcomes while ignoring the obvious construct validity issues. Proponents of *emission intensity* rightfully recognise how absolute emission methods punish inorganic growth (Hohne-Sparborth et al., 2021; EU TEG, 2019) but do not present a credible intensity-based solution either. Overall, the intensity-method violates the *Construct validity* (3) and *Data availability* (4) criteria as the many adjustments that an intensity measure requires might require data that is not or only available with a lag. Overall, we argue measures based on absolute emissions are preferred to intensity-based measures.

IV.h European Union CTB and PAB

One of the most recent standardized methods for Net-Zero alignment is the *CTB* and *PAB*, developed as a part of the EU green deal regulation arena (Hodges et al., 2022; Weng et al., 2022; EU TEG, 2019). This method deserves our particular attention as the method is popular in the literature and a large number of assets and asset managers are under EU legislation. The *CTB* and *PAB* both consist of two requirements that need to be satisfied: 1) An initial portfolio reduction compared to a benchmark index, 2) A subsequential year-on-year emission reduction of 7% for the portfolio and 3) firm-specific exclusions. Where the *PAB* requires a 50% initial reduction in *emission intensity* compared to the benchmark, the *CTB* only requires 30% initial reduction. Making the decarbonization condition for the *PAB*:

$$E_{PAB\ portfolio} \leq E_{universe} \times 0.5 \times (1 - 0.07)^{t-2020}$$

(17)

Where *E* resembles portfolio *Emission intensity* and *t* is the current year. The *CTB* and *PAB* were designed as such to accommodate both ambitious investors *(PAB)* as well as more restricted institutional investors *(CTB)* (EU TEG, 2019). The method measures emission reduction in *emission intensity* where the financial performance metric is *total capital, w*here the book value of equity and debt are considered as denominator and where emissions are defined as total absolute emissions, meaning Scope 1+2+3. (EU TEG, 2019). This method is less sensitive to prices but would still require many of the same adjustments for inflation, industry growth and long-term prices.

The addition and gradual phase-in of Scope 3 emissions is in line with the state of the art (Barahhou et al., 2022; Kolle et al., 2022; Le Guenedal et al., 2022; Le Guenedal & Roncalli, 2022; Hohne-Sparborth et al., 2021) and other expert recommendations (TCFD, 2021). With the incorporation of Scope 3 emissions comes the issue of *double counting* emissions. The TEG argues double (or even triple) counting of emissions need not be managed as it is a distortion that actually serves global emission reduction and investors' risk reduction objectives. While this is true, we argue it is also possible that emission reduction is counted double. In this case the same ton of emission reduction in a value chain might be reported as Scope 1 reduction by the consumer, and a Scope 3 reduction by the manufacturer. This could cause effective emission reduction to be only half that of the reported reduction. As both effects stem from the same source, we can assume the net effect to be zero. However, it is important to recognise this is only an assumption and firms might have incentives to adjust for double reporting while ignoring (or maximising) double reduction.

The *PAB* requires minimal exposure to high-emission sectors to incentivize the funding of the transition in those industries and to make sure the transition portfolio reflects the emission reduction of society as a whole. This practice is consistent with the current literature and best-practices (Swiss RE, 2023; Fankhauser et al., 2022), where tilting towards poor performers that show corrective action is preferred above divestment of entire industries (Edmans et al., 2022).

The *PAB* 7% self-decarbonization requirement is measured at the aggregate (portfolio) level (EU TEG, 2019, p.47). While this is not necessarily a construct validity issue. This method cannot prevent that portfolio re-balancing is used as an alignment strategy. Adherence to the decreasing *PAB carbon budget*, at the portfolio level, also only works with intensity-based carbon measures. If absolute emissions were considered; the method would be biased against firm size (carbon footprint). The possibility that emission reduction is “driven” by portfolio rebalancing, and the method inflexibility resulting from the risk of biases is a shortcoming of the method.

The *CTB* and *PAB* have also been criticized by the literature (Barahhou et al., 2022) and industry (Steffen, 2022) for being overly aggressive. The initial reduction and 7% year-on-year reduction combined, far overshoot the IPCC target. While the TEG motivates the reduction with the precautionary principle, we argue there should be some theoretical or empirical motivation for the significant deviation from the IPCC scenario pathways. Without sufficient grounds, there is no clear benefit and as such, we argue against the use of a large initial reduction in the NZA method.

Overall, the *PAB* method has clear shortcomings. The intensity-based measure, although based on less sensitive *Total Capital*, still suffers from construct validity issues. In addition, the method is disconnected from real emission reduction by allowing portfolio-level alignment. Which makes the poorly supported overly aggressive initial reduction rather easy to achieve. As such this method violates the *Objective stringency* (2) and *Construct validity* (3) criteria. Just as with other intensity measure, the lagged availability of data necessary for adjustments indicates the *Data availability* (4) criterion might also be violated. The inclusion of Scope 3 emissions and the minimum requirements for sector exposure supplement the method, to ensure true alignment with the Net-Zero target, are meaningful and should be applied to other methods.

IV.i Trend methods

Based on our previous analysis, it is evident that dynamic measures based on absolute emissions most accurately capture assets' emission reduction performance. As Hohne-Sparborth et al. (2021, p.8) highlight, these dynamic absolute emission methods have a more direct link to the Net-Zero target and alignment is more easily and immediately assessable compared to other methods, as no corrections are necessary. In addition, these methods have no exposure to price volatility and do not discriminate between different ways of achieving emission reduction. Finally, individual firm performance can be aggregated into a portfolio metric with weighted averages. Which is the simplest and most scientifically robust way.

Le Guenedal and Roncalli (2022) first discuss the estimated firm emissions reduction as a linear trend derived through a linear regression for each emission Scope (*j = 1,2,3*) for a given firm (*i*) at a given time (*t*) so that:

$$Scope\ Emissions: \boldsymbol{E_{i,j}}\,(t) = \beta_0 + \beta_1 \times t + u_t \qquad for\ t \leq t_0$$

(1)

So that the emission trend for a given Scope, for the forecasting period *N*, equals:

$$Expected\ Scope\ Emissions:$$
$$\boldsymbol{\widehat{E}_{i,j}}(t_0 + h) = E_{i,j}\,(t_0) + \hat{\beta}_1 \times h \qquad for\ h = 1,2,\ldots,N$$

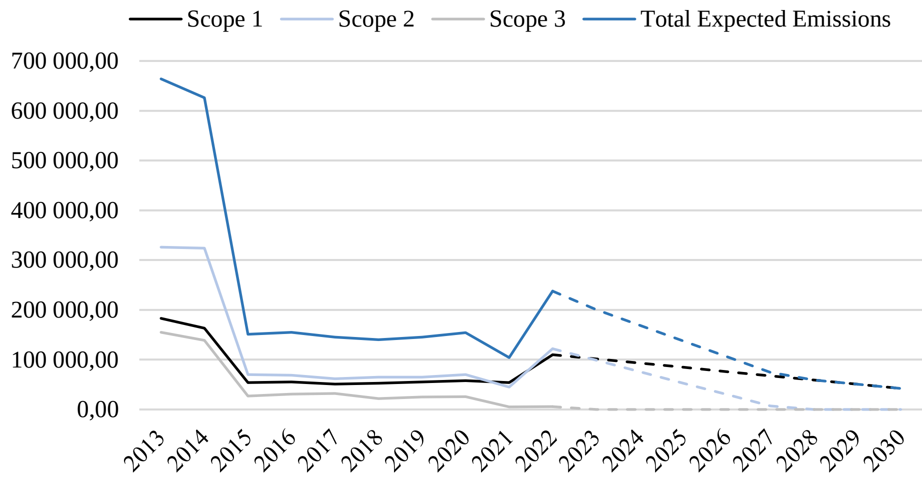
(2)

And as absolute emissions are simply additive, expected total emissions are:

$$Total\ Expected\ Emissions: \boldsymbol{\widehat{E}_i^{total}}(t_0 + h) = \sum_{j=1}^{n=3} \widehat{E}_{i,j}(t_0 + h)$$

(3)

Figure 18: Trend-based emission forecast for an individual company



The figure shows the annual emissions in tCO_2-eq. (vertical) for each year (horizontal) for an unspecified firm. The solid lines show historical emissions, and the dotted lines show the linear forecast based on a regression as discussed in appendix IV.i. Scope 1 emissions shows the firm's direct emissions from operations, Scope 2 emissions show the firm's emissions from purchased energy and Scope 3 emissions show all other firm-related value-chain emissions. The total emissions are a sum of the Scope emissions, both for historic and forecasted emissions. Data is retrieved for "Alstom SA" (Ticker: ALSO.PA), to serve as an example. Data is retrieved from Refinitiv.

By estimating the slope on each individual emission Scope, the accounting effect of starting to report on a new emission Scope is not considered as an increase. Much rather the slope of the emission Scope will be estimated based only on the available data for that Scope. If trend estimation on total emissions (Scope 1+2+3) would have been used, the inclusion of Scope 3 emissions will show as an increase in emissions opposed to a change in accounting. Hence, regressing on individual Scopes is the most accurate method.

Bolton et al. (2022) note that *trend methods* might have strong empirical foundation based on the high autocorrelation of firm-emissions, providing a potential argument in favour of linear methods.

In a subsequent paper, Le Guenedal et al. (2022) suggest several additions to the *trend* approach. One empirical suggestion is the introduction of *velocity*, which captures the year-to-year change in the emission reduction slope. The authors suggest this change as they recognize a poor historic track record can make it very difficult for firms to tilt their trend. *Velocity* can be calculated with a linear regression at two points in time (*t, t – h*) and is defined as the relative change in the normalized slope:

$$\boldsymbol{v}^{h} = \frac{\hat{\beta}_1(t) - \hat{\beta}_1(t - h)}{h}$$

(4)

Here we can confirm if firms with bad track-records are taking the necessary action, being $\boldsymbol{v}^{h}(t) < 0$ for low values of *h*. The authors suggest *h* to be 1, 2 or 3 years.

Barahhou et al. (2022) expand on this by suggesting the construction of *long-term momentum (LTM)* and *short-term momentum (STM)* metrics:

$$Long - term\ Momentum\colon\ \boldsymbol{M}^{\boldsymbol{long}}(t) = \frac{\hat{\beta}_1(t)}{E(t)}$$

(18)

$$Short - term\ Momentum\colon\ \boldsymbol{M}^{\boldsymbol{short}}(t) = \frac{\boldsymbol{v}^{h}(t)}{E(t)}$$

(19)

LTM is a metric that helps evaluate the slope against the *emission intensity* of a firm. LTM indicates the percentage of emissions that are reduced on a yearly basis. A higher LTM indicates the firm is expected to be Net-Zero in a shorter timeframe. STM is a less intuitive metric. STM indicates the yearly change in the emission reduction slope relative to the emissions level of a firm. We argue that the relevance of LTM and STM for portfolio alignment against a Net-Zero target is minimal, as comparison to the firm’s current level of emissions is already done by the percentage-wise IPCC target and is as such unnecessary. The condition:

$$\widehat{\boldsymbol{E}}_{\boldsymbol{i}}^{\boldsymbol{total}}(t^{*}) \leq \boldsymbol{E}_{\boldsymbol{i}}^{\boldsymbol{Target}}(t^{*}) \qquad where\ t^{*} = target\ year\ (e.g.\ 2030)$$

Already tests if the slope is such that total emissions will reduce to zero at a satisfactory rate.

While velocity does not have to be compared to firm level of emissions, a measure that compares the annual change in slope (velocity) against the current slope $(\hat{\beta}_1)$ and the required slope (β_1^*) could provide insight into the number of years misaligned firms might need to become aligned. This is discussed in section 3.4.

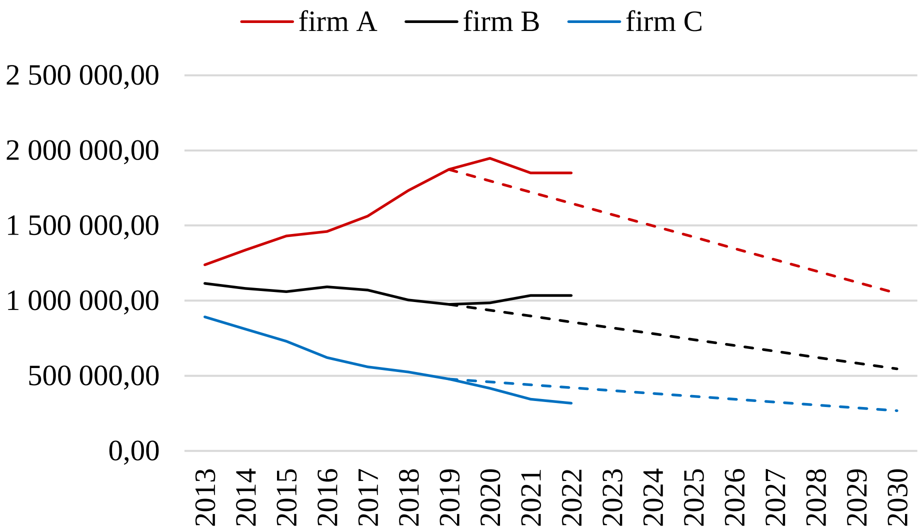
IV.j Rate-of-reduction methods

Hohne-Sparborth et al.' (2021) *rate-of-reduction* method recognises different industries have different emission reduction pathways. The authors suggest an industry-specific rate-of-reduction target (a linear pathway) to the Net-Zero target. However, the authors note that applying the same (average) rate of reduction requirement to all firms favours high emitters and punishes low emitters in the same industry. This will result in too strict reduction requirements for the low emitter, and not strict enough reduction requirements for the heavy emitter, resulting in overshoot. The authors suggest solving this issue by combining the rate-of-reduction approach with a *convergence* method that requires an intensity-based measure.

In short, the method inherently allows overshoot and solutions to that issue are based on *emission intensity*, a faulty metric. Hence, this method violates the *Construct validity* (3), and the *Objective stringency (2)* criterion.

By considering firm-specific rate of reduction rather than industry-average rate, firms are only required to reduce exactly the amount of emission, that is needed to reach the Net-Zero target. Adopting a percentagewise Net-Zero target will solve many of the authors' problems and guarantee "fair" reduction targets for both under- and out-performers, as show in figure 18. Here one can see that climate champions are automatically rewarded with flatter reduction targets, compared to climate laggards.

Figure 19: Percentage-wise targets do not punish outperformers



The figure shows the 43% percentage-wise IPCC AR6 2030 emission reduction target (dotted) for three hypothetical firms with different annual emission footprints (solid line). Annual emissions are displayed as tCO_2-eq. (vertical) for each year (horizontal). This example is a hypothetical example and data is artificial.

IV.k Ambition methods

Hohne-Sparborth et al. (2021) also apply dynamic analysis on absolute emissions but argue against the use of a linear method and base nonlinear emission forecasts on the EU CTI industry pathways (ECF, 2018).

From the EU CTI tool, the authors retrieve two reduction trajectories: *Business-as-usual*, the least ambitious, and *Shared effort*, which is the most ambitious trajectory. Based on past performance, the authors estimate the firm's ambition ranging from *Business-as-usual* to *Shared effort*. If the firm has had emission reduction that is exactly between the two scenarios. Their ambition will be characterized as 50% *business-as-usual* and 50% *shared effort*. The authors then estimate that the firm's ambition will stay at this constant level and emission reduction will follow the same relative path to the two Roadmap tool trajectories.

In essence, Hohne-Sparborth et al. (2021) *ambition methods* are rather close to *trend methods* in that they estimate a certain orientation (slope) of the emission reduction trajectory based on past performance. To then compare that slope to the Net-Zero target (required slope). Firms for which the historic emission reduction slope was aligned, are expected to remain aligned.

This means that the biggest difference between ambition- and trend-methods originate from the choice of target. A firm emission forecast based on a nonlinear climate model requires both assumptions on the correct climate model, the acceptance of all the climate model's assumption, as well as the assumption that firms follow the industry reduction trajectories throughout time. We argue that the vast number of assumptions that this method requires, outweighs the data-based component of this method so that the *Construct validity (3)* might be compromised. Contrary to trend-methods, the *ambition method* also does not provide instruction on how to consider changes in ambition over time.

Adjusting for inorganic growth

As identified in appendix IV.g methods based on absolute emissions do not have an inherent solution to the issue of inorganic growth. Methods that punish an increase in absolute emission will punish firms that increase emission due to M&A activity. All the while, total societal emissions did not increase, and the new acquirer might have sufficiently reduced emissions over the existing assets and potentially even over the newly acquired assets during the accounting period. Hohne-Sparborth et al. (2021) suggest adjusting absolute emissions for inorganic growth by dividing the data by normalized market share. Here a market share value above one indicates growth and a market share below zero indicates the firm lost market share in the industry. The authors derive market share by comparing industry revenue to firm revenue for each point in time. While the present method will adjust for inorganic growth, it can be challenging to derive market-share growth for multi-sector firms and does not consider sudden changes in absolute emissions due to change in accounting standards.

IV.l Our choice: The best NZA method

From the review of methods follows that dynamic absolute emission methods clearly satisfy more alignment method criteria than other metrics. With the exclusion of the poorly designed rate-of-reduction method, this leaves us with two dynamic absolute emission methods: the *trend method* and the *ambition method*. The choice between the linear *trend method* or the nonlinear *ambition method* is less straight forward due to their similarity.

Compared to the *ambition method*, we argue that the *trend method* has three advantages; 1) the *trend method* discusses velocity, allowing us to consider changes in behaviour over time. 2) *Trend methods* are better grounded in firm-specific data, supported by evidence for linearity (Bolton et al., 2022). And 3) *trend methods* require fewer assumptions on macro-economic developments as *trend methods*, contrary to the *ambition method*, do not base firm forecasts on the trajectories from macro-economic climate-models. For these reasons, we argue that *trend methods* (Le Guenedal & Roncalli, 2022) are the best available method (table 9).

From the literature (appendix IV.h), we find that this method might best be applied to Scope 1, Scope 2 and Scope 3 emissions separately to include all firm-emissions (Barahhou et al., 2022; Bolton et al., 2022; Le Guenedal & Roncalli, 2022; EU TEG, 2019). While this introduces the issue of double counting, we follow the literature and do not consider any adjustments (EU TEG, 2019). To guarantee sector balance and the financing of a green transition in all sectors, we consider mechanical sector exposure constraints as proposed by the literature (Bolton et al., 2022; EU TEG, 2019). The method should be applied to achieve alignment at the asset-level, rather than on the aggregate portfolio.

From appendix IV.k, we conclude that even though accounting for inorganic growth and gain in market share is important (Hohne-Sparborth et al., 2021), issues such as the existence of multi-sector firms make it difficult to construct accurate metrics to account for inorganic growth. The improvement of carbon accounting methods, another accounting distortion, is difficult to adjust for and closely linked to inorganic growth. We choose to not adjust for these accounting distortions and consider it a potential area for future research.

APPENDIX V: STATISTICAL TESTING TECHNICAL SUMMARY

Welch's t-test (Welch, 1947):

$$t = \frac{(\bar{X}_1 - \bar{X}_2)}{\sqrt{\left(\frac{s_1^2}{n_1} + \frac{s_1^2}{n_2}\right)}} \qquad , df = \frac{\left(\frac{s_1^2}{n_1} + \frac{s_1^2}{n_2}\right)^2}{\frac{s_1^4}{n_1^3} + \frac{s_1^4}{n_2^3}}$$

(20)

Weighted averages variance (Snedecor & Cochran, 1967, p. 515):

$$Weighted\ variance\ (s_w^2) = \frac{1}{n-1}\sum\left[\left(\frac{m_i}{\bar{m}}\right)^2 \times\ (m_i x_i - \bar{X}_w)^2\right]$$

(21)

Where x_i is the observation for a single asset, and m_i is the portfolio-weight for that asset. $\bar{m}$ is the average weight over the whole portfolio $(1/n)$, *n* is the number of assets in the portfolio and $\bar{X}_w$ is the weighted average of a given variable for the portfolio.

Sharpe-ratio variance (Lo, 2002):

$$Sharpe\ Variance\ IDD\ (\sigma_{SR}^2) = 1 + \frac{1}{2} \times \widehat{SR}$$

(22)

Where $\widehat{SR}$ is the estimated Sharpe-ratio for the portfolio.

APPENDIX VI: DATA CHARACTERISTICS

Portfolio Performance	Return	TRBC Economic Sector Name	Scope 1 Emissions	Scope 2 Emissions	Scope 3 Emissions	Refinitiv ESG Combined Score	Refinitiv Environmental Pillar Score	Refinitiv Social Pillar Score	Refinitiv Governance Pillar Score
Mean	0,01	-	3,65E+06	5,58E+05	2,14E+07	63,01	65,01	71,13	66,71
Median	0,01	-	4,80E+04	6,84E+04	1,14E+05	64,26	70,40	75,03	70,54
Maximum	4,63	-	1,82E+08	2,10E+07	1,90E+09	94,22	99,16	98,33	98,57
Minimum	-0,98	-	0,00E+00	0,00E+00	0,00E+00	4,14	0,00	2,96	1,34
Std. Dev.	0,09	-	1,58E+07	1,66E+06	1,06E+08	16,10	23,36	18,52	19,38
Skewness	1,74	-	7,12	6,13	9,93	-0,51	-0,77	-0,96	-0,71
Excess Kurtosis	57,13	-	55,67	43,62	122,23	-3,03	-3,17	-2,42	-3,09
Energy-test	7,23	-	1495,44	1125,92	1187,94	12,72	46,76	48,13	33,89
Prob.	0,00 ***	-	0,00 ***	0,00 ***	0,00 ***	0,00 ***	0,00 ***	0,00 ***	0,00 ***
Frequency	Monthly	-	FY	FY	FY	FY	FY	FY	FY
Time frame	2002-2022	2022	2013-2022	2013-2022	2013-2022	2019-2022	2019-2022	2019-2022	2019-2022
Observations *(/599)	207	599	7.23*	7.21*	5.63*	3.89*	3.90*	3.90*	3.90*
Unit of measure	%	chr.	tCO2-eq.	tCO2-eq.	tCO2-eq.	%	%	%	%

Portfolio Descriptives	ROE	ROA	EV / EBIT	Gross Profit Margin	Revenue Growth (3yr) historic	Market Cap. (bln.)	Price / Earnings ratio	Debt / Equity ratio	EPS	EPS forward - looking 10-year CAGR	Total Shares Outstanding	WACC
Mean	0,15	0,06	22,18	0,48	11,30	2,01E+10	29,39	1,08	10,30	0,07	1,16E+09	8,22 %
Median	0,13	0,05	15,45	0,45	4,66	8,80E+09	18,20	0,66	1,23	0,07	9,98E+08	7,80 %
Maximum	2,82	1,87	758,09	1,00	265,21	3,42E+11	1473,72	16,78	2412,93	0,47	7,20E+10	23,46 %
Minimum	-0,54	-0,38	-20,71	0,00	-46,62	1,60E+09	1,21	0,00	-26,52	-0,34	2,18E+05	2,51 %
Std. Dev.	0,20	0,11	48,39	0,26	25,50	3,45E+10	77,67	1,50	115,99	0,05	3,59E+09	0,03
Skewness	4,40	9,14	11,71	0,42	4,93	4,73	14,09	4,98	18,40	-0,11	11,61	1,30
Excess Kurtosis	52,14	154,43	156,14	-3,73	33,11	26,13	234,83	32,14	349,73	14,67	189,31	0,13
Jarque-Bera	7,16E+04	5,75E+05	5,88E+05	2,53E+01	2,70E+04	2,30E+04	1,28E+06	3,01E+04	3,09E+06	6,80E+03	3,32E+04	414
Prob.	0,00 ***	0,00 ***	0,00 ***	0,00 ***	0,00 ***	0,00 ***	0,00 ***	0,00 ***	0,00 ***	0,00 ***	0,00 ***	0,00 ***
Frequency	Quarterly	Quarterly	Quarterly	Quarterly	Quarterly	Quarterly	Daily	Quarterly	Quarterly	Quarterly	Yearly	Daily
Time frame	2022	2022	2022	2022	2022	2022	2022	2022	2022	2022	2002-2022	2023
Observations	561	559	555	491	473	598	546	551	599	533	0	597,00
Unit of measure	%	%	ratio	%	%	€	ratio	%	€	%	number	%