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JOURNAL OF INVESTMENT MANAGEMENT, Vol. 20, No. 4, (2022), pp. 35–51

FACTOR INVESTING IN PARIS: MANAGING CLIMATE CHANGE RISK IN PORTFOLIO CONSTRUCTION

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The 2015 Paris Agreement is a landmark in limiting emissions and targeting global warming well below 2°C, preferably 1.5°C compared to pre-industrial levels. In this light, we investigate how to efficiently construct equity portfolios that help mitigating climate change risk but at the same time enable harvesting well-established return drivers such as value, momentum or quality. A pure reduction in greenhouse gas intensity or a divestment from fossil fuel sectors is not necessarily leading to a better temperature alignment of a portfolio. Given the limited set of temperature-aligned assets, keeping the average temperature increase below 2 degrees comes with considerable active risks. To this end, we propose a net zero portfolio construction framework that brings temperature alignment together with a reduction in carbon intensity while harvesting equity factor premia.

Climate change is among the most prevalent environmental challenges of our times. Anthropogenic greenhouse gas emissions, especially carbon emissions, are a major contributing factor to global warming. Across the globe, people are facing the reality of climate change, often manifesting in an increase of extreme weather events. According to the latest report by the Intergovernmental Panel on Climate Change (IPCC), current global warming has already reached 1.1°C compared to the times of the industrialization (cf. IPCC, 2021b), seeing climate change scenarios with a 1.5°C temperature increase by as early as 2030. Climate models come with a degree of uncertainty. Yet, it is widely accepted that global warming is to be limited to 2°C, preferably 1.5°C, compared to pre-industrial levels to avoid tipping points and cascade effects that could lead to an irreversible release of currently stored greenhouse

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gases (e.g., by melting of the Permafrost or deforestation of the Amazon region).

In light of these challenges, the Paris Agreement[1] is an important step forward in addressing the mitigation of, adaptation to, and financing of climate change. Specifically, the agreement requires signatories to commit to reducing their greenhouse gas (GHG) emissions. Furthermore, to enforce such reductions in GHGs, litigations against Sovereigns and companies have been initiated based on the Paris agreement. Different jurisdictions around the world have set up pricing mechanisms for GHG emissions, with the EU emission trading scheme representing the most developed market. Also, different financial regulations require investors to manage climate risks (both transitional and physical) and to increase transparency on the climate effects of their investments. Therefore, such solutions need to be provided to help investors accelerate temperature alignment.

As a result, academic and practitioner research in climate change or general environmental, social and governance (ESG) matters is growing rapidly. Diverse sustainability preferences across investors result in different portfolio construction methodologies to satisfy their overall investment objectives. Krueger *et al.* (2020) show that most investors similarly care about their portfolio's ESG profile as well as an attractive risk–return profile; this leads to different efficient frontiers, as shown in Pedersen *et al.* (2021). While most studies seek to incorporate ESG into portfolio construction without altering the existing portfolio profile, we specifically incorporate the two objectives into the portfolio construction process. Instead of enforcing constraints, we propose a two-step optimization approach which targets temperature alignment in the first optimization step and refines the ensuing outcome through an active management of factor exposures in the second optimization. Thus translating temperature alignment from a constraint into an investment objective allows to better assess the associated risk with alignment as well as further impacts on overall portfolio characteristics. Related work of Alessandrini and Jondeau (2020) evaluates the effect of ESG exclusions in terms of portfolio risk and return. The authors show that ESG exclusions can induce country and sector tilts and therefore an increase in tracking error, suggesting to control unrewarded risk factors during portfolio construction. In this vein, Kaiser (2020) and Alessandrini and Jondeau (2021) add control variables when analyzing factor strategies, respectively, concluding that such ESG integration does not materially harm the risk–return profile of the resulting portfolio.

Climate change implications are harder to analyze as they are dependent on the choice of climate model. Most studies focus on the risk stemming from climate change, both transitional and physical. For instance, Hong *et al.* (2019) see a negative effect of prolonged droughts on food companies, and suggest that there is an underreaction of investors to climate change risks. Engle *et al.* (2020) construct a hedge portfolio that dynamically leverages a natural language processing framework to underweight firms with low environmental scores when there are negative climate change news while overweighting companies with high environmental scores when there are positive climate change news. Their approach thus blends risk mitigation with return objectives.

The aim of the present paper is to investigate and manage the interplay of climate change objectives with a given original investment strategy. To this end, we analyze common equity factor investments that represent a relevant reference point to evaluate our efforts. On the one hand, factor strategies have a strong footing in asset pricing theory; on the other hand, they reasonably approximate for common investment styles, prevalent not only among quantitative but also traditional investors, just think of value or momentum investing. Importantly, factor investing aims at limiting the impact of unsystematic risk, rendering portfolios more diversified. In turn, a factor investing approach is well suited to cater ESG objectives: assets with unfavorable sustainability characteristics can often be readily replaced by ones that are compliant with ESG guidelines but have similar factor exposures. In this vein, improving the carbon intensity of a multi-factor equity portfolio need not jeopardize its factor exposures; moreover, a carbon-aware factor strategy shows similar performance compared to a conventional factor strategy. Andersson *et al.* (2016) highlight the minor additional risk needed to substantially reduce the carbon footprint of a given portfolio. In a similar vein, Bender *et al.* (2020) find that significantly reducing carbon intensity preserves key investment objectives. Only for extreme reductions in carbon intensity do they detect adverse impacts on sector allocations. Given that carbon intensity data is highly skewed toward few high emitters, this outcome is expected. Simply reducing weight for highly emitting companies significantly reduce the portfolio carbon exposure while not changing portfolio characteristics of a well-diversified portfolio. Yet, the temperature alignment distribution is skewed in the opposite direction—there are only a few companies that are on target with respect to the temperature goal of 1.5°C. It is important to note that temperature alignment encompasses companies' temperature trajectory and therefore extends beyond its current carbon emissions. Therefore, incorporating temperature alignment via constraints is likely more difficult and could alter portfolio characteristics, calling for directly targeting temperature alignment as an investment objective in a risk-controlled manner.

We contribute to the literature by investigating different routes to constructing a temperature-aligned portfolio and ultimately by providing an efficient net zero framework.[2] Note that this framework does not necessarily coincide with the Net Zero framework as defined by the IIGCC (Institutional Investors Group on Climate Change). A net zero-aligned strategy according to the IIGCC is difficult to simulate because of the uncertainty of future net zero pathways as defined by the IIGCC framework in terms of decarbonizations and an increase in aligned assets (IIGCC, 2021). Therefore, this paper's focus is on aggregating current alignment metrics of single securities into an overall portfolio measure. The ease of implementing a net zero strategy will ultimately depend on future pathways to decarbonization.

Our paper adds to the body of research on climate change and ESG in finance. The debate on the effect of a carbon-reduced strategy on return predictability is still ongoing. Bolton and Kacperczyk (2021) find that higher carbon emissions lead to an increase in expected returns for a U.S. equity universe. Conversely, Kazdin *et al.* (2021) document that lower carbon intensity companies experience higher productivity and vis-à-vis provide a positive excess return. Contrasting to Dunn *et al.* (2018), we do not analyze risk and return implications of ESG investments but propose a framework to construct portfolios incorporating dual investment objectives: addressing temperature alignment while actively managing factor exposures. Dunn *et al.* (2018) observe an increase in total risk for stocks with the worst ESG exposure, hence corroborating the relevance of controlling such risk, including climate change risks in portfolio construction. Along these lines, we investigate the effect of merely excluding high exposure names versus that of optimizing a temperature-aligned anchor portfolio.

Depending on the adaption of temperature alignment in the economy, we can utilize active risk budgets to improve temperature alignment as well as exclude sectors of significant harm. If the economy decarbonizes faster than estimated by climate change models, we can readily reduce the active risk budget, whereas we can increase tracking error if the economy decarbonizes slower. Every estimated climate scenario comes with uncertainty, either relating to the trajectory of economic activity, the climate evolution and the underlying climate model itself. Giglio *et al.* (2021) summarize different impacts of these uncertainties on asset prices and their equilibrium. The two main drivers in the authors' analysis are the climate model and the development of the economy. Both ingredients have different impacts on the outcome of temperature alignment, and the associated uncertainty will be reflected in the temperature alignment scores. As a result, such uncertainty will be reflected in the final portfolio allocation because one depends on data derived from climate change models. Therefore, risk management and continuous validation of the underlying climate scenario methodology must be carried out.

Specifically, we propose a two-step portfolio construction methodology to marry the two investment objectives: (1) Aim for temperature alignment and (2) Maintain an attractive risk–return profile, resonating well with common investor preferences as outlined in Coqueret (2022). The first step in the two-step optimization brings a temperature-aligned anchor portfolio, respecting the targeted temperature path. This portfolio construction enables analyzing the portfolio according to the realization of different scenarios in which the economy decarbonizes in line with, or faster or slower than the anchor.

The second step of the proposed two-step optimization aims to actively position the portfolio toward the salient drivers of risk and return and we focus on classic quality, momentum and value factors. A risk-controlled factor overlay allows adhering to both investor objectives, temperature alignment and attractive risk and return characteristics. Given that climate change and the resulting temperature alignment is a slow-moving process, controlling factor exposures is crucial to also achieve an attractive risk–return profile in the short-term to accommodate the adoption of climate change objectives.[3]

Section 1 speaks to the available data to measure climate change risks in terms of temperature alignment. We analyze existing Paris-aligned benchmarks and their contribution toward the Paris Agreement target of 1.5°C. Section 2 lays out the proposed portfolio construction methodology to account for the dual investment objective of incorporating climate change considerations whilst actively managing the portfolio's factor exposures. Section 3 concludes.

1 Measuring Climate Change Risk

1.1 Climate data

There exist various data providers in the field of climate change and temperature alignment,[4] and we first scrutinize the quality of climate change data. According to Hain *et al.* (2022), Berg *et al.* (2022), and others, ESG and climate change data ratings can vary across providers despite similar methodologies, mostly driven by differences in the underlying materiality mappings. To present a consistent picture, we use data from a single source, Vivid Economics. Given their focus on carbon intensity while calculating portfolios' temperature alignment helps foster the incorporation of a more holistic temperature alignment framework.

The nature of temperature alignment is highly model dependent, as assumptions have to be made on the current emissions and the sector's decarbonization trajectory. Furthermore, future scientific progress and economic development will have a major impact on GHG emissions. In general, a given company contributes to global warming via multiple channels, either directly via Scope 1 and 2 emissions or indirectly via Scope 3 emissions. Scope 1 emissions are emitted directly by company plants (or similar) and Scope 2 emissions include the purchased energy; Scope 3 emissions are summarized over the whole value chain, starting with raw materials, considering employee commuting, and all emissions of products over their life cycle. Vivid Economics utilizes a sector-specific model to weight the contributions of Scope 1 and 2 emissions relative to those of Scope 3 emissions. For Scope 1 and 2, the temperature alignment derives from the current emission intensity, is calculated using different decarbonization pathways based on the sector and region profile of a certain business unit. Decarbonization trajectories simply describe the necessary GHG reduction as defined in the IPCC scenarios. The resulting carbon emissions are then mapped on different warming scenarios, which serve as a translation of GHG emissions and

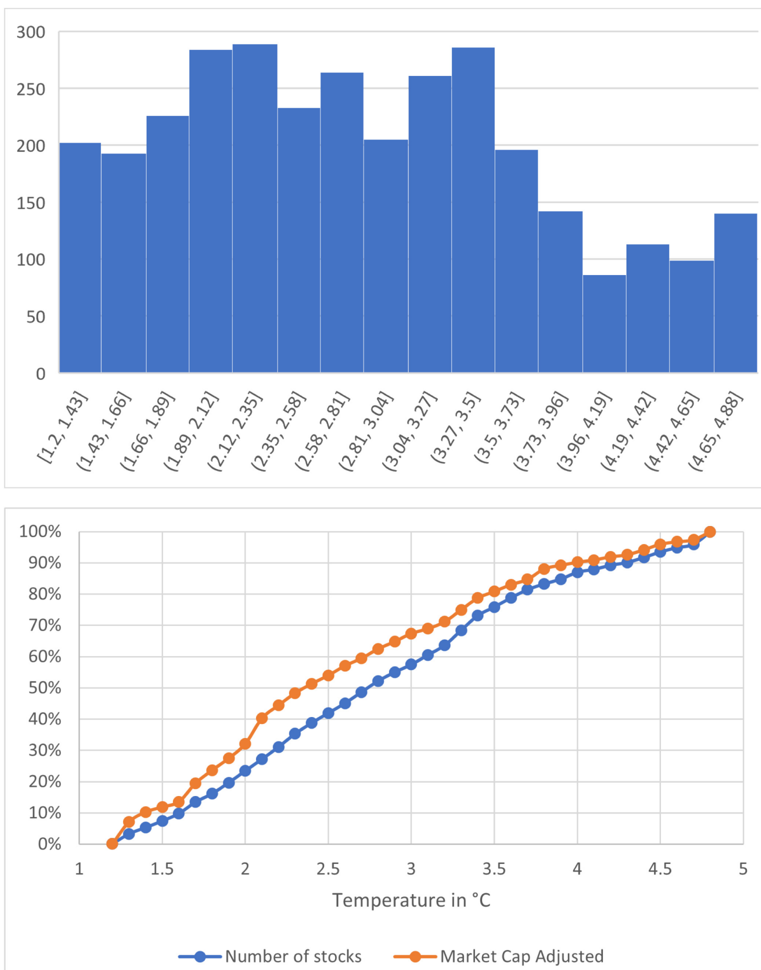

Figure 1 Distribution of Temperature Alignments.

The figure gives the temperature alignment of 3,219 large and mid-cap companies, from a global stock universe both in a histogram (upper chart) and a cumulative distribution (lower chart). Numbers are calculated as of 31 August 2021.

global warming using climate models. For Scope 3 contributions, Vivid Economics aligns the valuation impact of a company to the downstream impact of emissions or avoided emissions and thus computes an alignment measure. Provided that most companies today have a temperature alignment, these can be aggregated to a portfolio temperature alignment. Vivid Economics weights an asset's temperature both by dollar invested and the emission intensity of the respective asset. Therefore, a temperature reduction in low emitting sectors is not reducing the portfolio temperature significantly. This process ensures to account for the higher climate materiality of emission reduction in high impact sectors.

The raw company temperature score is therefore a mixture between Greenhouse gas emissions via Scope 1, 2, and 3 as well as the company temperature alignment which is calculated using the company's decarbonization pathway and the downstream Scope 3 emissions. Vivid Economics uses an industry-specific weighting to account for the different emission intensities that exist across industries. When calculating the temperature alignment for a given portfolio, we follow Vivid Economics in utilizing emission-weights of temperature scores. As a result, we put more emphasis on temperature scores with higher current carbon emissions, thus combining current data (carbon emission intensity) and forward-looking data (temperature scores).

Given this toolkit, it is natural to examine the current temperature trajectory of various investment portfolios. Notably, the temperature alignment of the most common global equity benchmark, the MSCI World, currently stands at 3.93°, more than twice the 1.5° target. Moving ahead on this trajectory would massively increase the probability of extreme weather events and is likely to severely challenge global economies, see Dell *et al.* (2012). We consider an investable universe of 3,219 developed market stocks. These stocks derive from a process that considers membership in large- and mid-cap stock indices for developed markets from MSCI, S&P, FTSE, and STOXX, have minimum liquidity requirements, as well as temperature alignment estimates. The temperature estimates in the universe range from 1.20°C to 4.80°C and the average universe temperature is 2.82°C; when weighting by market cap instead of emissions, the average temperature is slightly lower (2.58°C). In Figure 1, we plot the temperature alignment distribution across the universe. Given the cutoff of 1.5°C, only a small fraction of companies (7.5%) is aligned with the Paris agreement. These assets make up for 11.9% of the investment universe in terms of market capitalization.

For validating a company's temperature alignment, one can check whether the company has joined the science-based target initiative. These companies follow (or have committed to follow) a decarbonization path which is in line with global warming at either 1.5°C or well below 2°C. We compute an average temperature alignment of 2.84°C for companies with no commitment, and 2.71°C for those with concrete targets set, and 2.63°C for those committed to science-based targets. Given that temperature alignment takes current emissions and simulates based on a sector and regional decarbonization pathways, it is no surprise to find companies with temperatures >2°C in the leading groups of science-based target companies. Though, one would expect a strong reduction in carbon emissions and a better temperature alignment for this cohort over time.

Clearly, temperature alignment should relate to current carbon emissions, being its main driver. Moreover, there is a clear sector bias in carbon emissions; for instance, the average carbon intensity of the Energy sector is more than 100 times the number of the Telecommunications sector.

Table 1 Correlation Between Emission Intensity and Temperature Alignment.

	Scope 1	Scope 1–2	Scope 1–3
Industrials	0.29	0.32	0.33
Materials	0.36	0.40	0.40
Consumer staples	0.49	0.54	0.54
Financials	0.33	0.38	0.38
Utilities	0.33	0.31	0.33
Consumer discretionary	0.09	0.33	0.33
Energy	0.67	0.69	0.68
Health care	0.43	0.52	0.53
IT	0.21	0.28	0.30
Telecommunications	0.52	0.66	0.65

Correlations are calculated using data available as of 31 August 2021.

We eliminate such biases by neutralizing carbon emissions within each sector and calculate correlations over the entire cross-section as per 31 August 2021, see Table 1. All sectors exhibit a positive correlation between temperature alignment and Carbon intensity for Scope 1, Scope 1 and 2 as well as Scope 1–3 emissions. The highest correlation obtains for the energy sector (0.7). Interestingly, the utilities sector only has a correlation of 0.3 despite carrying a high emission intensity.[5]

We next compare Vivid Economics temperature alignments to ESG ratings from Vigeo Eiris. The temperature alignment then shows a negative correlation of −0.09 to the overall ESG rating, a negative correlation of −0.07 to the E pillar score and −0.11 to the Energy Transition Score,[6] which aims to measure a company's performance regarding the risk and opportunities of transitioning to a low-carbon economy. A negative correlation is expected because higher Vigeo Eiris ratings imply a stronger sustainability profile, which should coincide with an improved temperature alignment.

Table 2 Temperature Alignment Cluster.

	Number of companies	Temperature
Panel A: Vigeo Eiris		
Weak performance	1215	2.89
Limited performance	883	2.77
Robust performance	270	2.65
Advanced performance	220	2.50
Panel B: MSCI		
Asset stranding	11	3.97
Product transition	192	3.27
Operational transition	329	3.41
Neutral	2,397	2.71
Solutions	137	2.34

Temperature alignment of different categories according to the Vigeo Eiris Energy Transition Score (based on value of the score and the proprietary VE categorization) and the MSCI Low Carbon Transition Score. Numbers are calculated as of 31 August 2021.

Vigeo Eiris defines four categories based on the Energy Transition score as illustrated in Table 2. The correlation pattern is preserved when bucketing the companies using the Energy Transition Score: a higher Energy transition score leads to a lower temperature alignment.

As for MSCI ESG ratings, the correlations of temperature alignment and overall ESG score (−0.10), as well as the E score (−0.16) are of similiar magnitude to those from Vigeo Eiris; however, the low carbon transition score (LCTS) shows a stronger correlation with the temperature alignment score (−0.40). Similar to the Vigeo Eiris classification, MSCI defines clusters in terms of the LCTS. Table 2 lists the average temperatures by LCTS clusters: Generally, the companies in the advanced buckets show better temperature alignment. The odd one out is the Product and Operational Transition cluster, where the less advanced group has a lower temperature alignment.

Vivid Economics also stresses the importance of carbon intensity when calculating an aggregate portfolio temperature score, TS_P.

$$TS_P = \frac{\sum_{i \in P} TS_i \cdot GHG_i \cdot w_i}{\sum_{i \in P} GHG_i \cdot w_i} \qquad (1)$$

where w_i denotes the portfolio weight of company i, TS_i its temperature score, and GHG_i its greenhouse gas intensity (measured as carbon emissions relative to the companies' revenues). As a result, TS_P is more affected by temperature scores coming from high carbon intensity companies. Thus, one is not only focusing on the individual temperature scores but also actively managing overall carbon intensity. To illustrate the procedure, let us consider two companies with the same market capitalization, one having a temperature score of 2°C and the other a temperature score of 3°C. Naturally, market-cap weighting would see an average temperature of 2.5°C. Yet, if the first company's carbon intensity is just a minor fraction of the second company's carbon intensity, emission weighting will lead to an average temperature score close to 3°C. This very effect is also visible when comparing the simple market-cap weighted average of the considered universe (2.82°C) with a carbon-weighted portfolio temperature score—calculated as shown in equation 1—with the MSCI World sitting at 3.93°C. The difference emerges from the carbon-weighting of the individual temperature scores, stressing to not only actively manage the temperate score but also the individual and overall carbon exposure. This procedure takes into account two considerations: the current carbon intensities as well as the forward-looking nature of the temperature scores.

1.2 Paris-aligned benchmarks

Given the importance of climate change risk for investors, index providers have engineered Paris-aligned benchmark indices. In this section, we compare the available Paris-aligned benchmarks, investigating the underlying construction methodology and holdings along with their performance and risk characteristics.

The European Union defines minimum criteria for two sets of climate benchmarks: EU climate transition benchmarks (CTB) and EU Paris-aligned benchmarks (PAB), see the Commission Delegated Regulation (EU) 2020/1818. Both benchmark types shall be constructed using the 1.5 degrees scenario from the Intergovernmental Panel on Climate Change (IPCC). That is, they require a minimum reduction of a portfolio's carbon footprint by 7% p.a. (self-decarbonization) and a greenhouse gas intensity reduction of at least 30% for a CTB or at least 50% for a PAB. Also die Regeln sagen, dass wir gewisse harmful activities ausschlies en müssen. Aber auch, dass wir eine Mindestallokation in braunen Sektoren haben muessen? Oder ein Maxallokation?

We examine the MSCI World Climate PAB Index and the S&P Developed Ex-Korea LargeMidCap Net Zero 2050 PAB ESG Index. These indices come with a relatively short history and partly represent backtested performance. The sample period ranges from May 2018 to July 2021 using monthly data. Given the short history, the construction of Paris-aligned benchmarks is a fairly new phenomenon still lacking generally accepted construction principles.

Both indices seek to minimize tracking error to their respective parent index under several constraints, i.e., the MSCI World and the S&P Developed Ex-Korea LargeMidCap[7], respectively. Naturally, the constraints shrink the eligible number of names. MSCI and S&P use different data for assessing temperature alignment: While MSCI builds on the MSCI Climate Value-at-Risk score, S&P uses their Global Trucost's Transition Pathway model.[8] In addition, both indices have a built-in self-decarbonization trajectory of around 10%

to meet the requirements laid out in both, the draft EU Delegated Act as well as the recommendations from the Task Force for Climate-related Financial Disclosures (TCFD) and Intergovernmental Panel on Climate Change (IPCC).

Building on these key characteristics and objectives, both providers add constraints to limit exposure to physical risks from climate change (utilizing the MSCI Low Carbon transition score or the S&P Global Trucost's Physical Risk dataset)

Figure 2 Paris-Aligned Benchmark Cumulative Performance, May 2018–July 2021.

The upper chart plots the cumulative performance of selected Paris-aligned indices. The lower chart plots the active performance of the PABs relative to MSCI World.

Table 3 Temperature Alignment and Portfolio Characteristics.

	TE	Temperature	Carbon	1/HHI or	MOM		QAL		VAL		ESG
	ex-ante	in °C	intensity	Eff #stocks	absolute	active	absolute	active	absolute	active	Score
Panel A: Benchmark											
MSCI World	—	3.93	139.84	166	0.10		0.30		−0.11		6.22
Panel B: Paris-aligned benchmarks											
MSCI	1.19	2.42			0.05	−0.05	0.28	−0.02	−0.14	−0.03	
S&P	1.61	2.20			0.16	0.06	0.41	0.11	−0.16	−0.05	
Panel C: Introducing constraints											
Fossil Fuel Exclusions (FFE)	0.25	3.92	128.20	166	0.10	0.00	0.30	0.00	−0.11	0.00	6.24
FFE + Carbon Reduction	0.25	3.56	69.92	166	0.10	0.00	0.30	0.00	−0.09	0.02	6.25
Panel D: Integrating TA and return objectives											
1-step optimization	2.38	1.49	69.92	83	0.73	0.63	0.72	0.42	0.34	0.45	6.44
2-step optimization											
1. step: Anchor Portfolio	0.93	1.49	69.92	135	0.12	0.02	0.34	0.04	−0.09	0.02	6.33
2. step: Factor Overlay	2.44	1.49	69.92	90	0.73	0.63	0.82	0.52	0.63	0.74	6.46

Portfolios in Panel C are constructed using a minimum tracking error approach relative to the MSCI World while incorporating ESG and carbon constraints. Portfolios in Panel D are constructed with a mean–variance approach, keeping the constraints from Panel C and adding temperature alignment. Tracking error is estimated by using a factor risk model and is denoted as expected active risk versus MSCI World. Temperature denotes the weighted temperature alignment of the portfolio using the Vivid Economics climate change model. HHI denotes the Herfindahl index, and its inverse gives the effective number of stocks in a portfolio. Active factor exposures are calculated relative to the MSCI World. All numbers are as of 31 August 2021.

and to control investments into the fossil fuel sector. Additionally, both benchmarks exclude companies that are involved in controversies or have violated the United Nations Global Compact (UNGC). Lastly, high carbon emitters are constrained as well.

Given the tracking error minimization, the indices might substantially differ in their portfolio holdings, likely affecting the performance experience. We will thus look into performance, holdings and factor exposures of the two indices. The upper chart of Figure 2 shows the cumulated performance of the two PAB portfolios using the MSCI world as a reference index. Although, both PABs are generally following similar objectives in their construction, their return is quite different, especially when considered relative to the MSCI World (Figure 2, lower chart). While the MSCI World PAB Index outperforms the MSCI World by 1.3% p.a., the S&P PAB Index generates an active return of 2.6% p.a.

The PABs from MSCI and S&P both have a TE of around 1.5% relative to the reference index but also relative to each other. As both PAB benchmarks consider similar constraints, a low tracking error is expected. However, one might wonder, if the risk budget is used efficiently to mitigate climate change risk and construct an efficient temperature-aware portfolio.

Both PABs strongly reduce the portfolios' overall carbon intensity but need to reduce it even further in the future to comply with regulation. Although reducing carbon intensity is a key objective in the Paris Agreement, it is not yet sufficient to construct a portfolio closer to the target of 1.5°C. Analyzing the holdings of both indices, the weighted temperature score for MSCI is 2.42°C and 2.20°C for S&P, respectively (Panel B in Table 3). This is indeed a noteworthy reduction relative to the cap-weighted MSCI World, but still some way to the 1.5°C target fixed in the Paris Agreement.

It is good to see important improvements at the level of temperature alignment; yet, we are eager to learn whether this is complicating the pursuit of certain investment styles. This is a relevant concern given that both indices do not control for common equity factor exposures. Table 3 unveils both PAB indices to carry similarly negative value exposure (as measured by the aggregation of the underlying value factor scores).[9] Furthermore, both indices load positively toward quality and momentum, with S&P having higher exposures than MSCI, which could partly explain the return differences between both indices. Yet, all factor exposures can be considered modest at best and active management of these exposures is expected to help enhance the risk–return profile.

2 Managing Climate Change Risk in Portfolio Construction

In this section, we propose a framework for constructing a temperature-aligned portfolio that targets harvesting common equity factor premia. We construct four different portfolios to bring a temperature score closer to the Paris agreement target of 1.5°C; (1) exclusion of significant harm, (2) carbon reduction, and (3) constrained-based temperature alignment (one-step optimization) as well as (4) objective-based temperature alignment (two-step optimization). Given the short data history for temperature scores, we focus on a point-in-time optimization to analyze the resulting portfolio characteristics, rather than investigating a backtest.

2.1 Efficient portfolio construction

To address the duality of the investment objective, we propose a two-step optimization. Specifically, we consider a factor investing framework which linearly combines K factors with scores F into a multi-factor model. Hence, the aggregate multi-factor score S_i of stock i at time t is simply:

$$S_i^t = w_1 \cdot F_{1,i}^t + \cdots + w_K \cdot F_{K,i}^t \qquad (2)$$

To determine mean–variance optimal portfolio holdings h, we run the following optimization:

$$\max_h h'\alpha - \frac{\lambda}{2} h'\Sigma h \qquad (3)$$

where α is the expected return from Equation (2), λ is a risk-aversion parameter, and Σ is the covariance matrix of stock returns. Specifically, Σ is governed by a linear factor structure:

$$\Sigma = \mathbf{F}'\Omega\mathbf{F} + \epsilon \qquad (4)$$

where Ω is the estimated factor covariance matrix, F denotes the factor score matrix displaying all factor scores for each asset, and ϵ denotes the specific risk portion.

A seemingly natural way to account for climate change is to augment optimization (3) by a maximum temperature constraint. We will investigate a corresponding one-step optimization approach below. It is important to note that such additional constraints can reduce the solution space in the one-step optimization, likely leading to unfavorable corner solutions. As an alternative, we propose a two-step optimization as put forward in Dichtl *et al.* (2022). The key idea is to separate the temperature alignment goal from maximizing the portfolios' factor exposure. Specifically, the first optimization builds on the negative carbon-weighted temperature scores to minimize the overall portfolio temperature, given an active risk budget of 1% relative to the benchmark index that best represents the investment universe. The second optimization augments this temperature-aware anchor portfolio by a factor overlay that derives from information ratio maximization relative to the anchor. Importantly, the two-step optimization procedure allows for a clean performance attribution as one can disentangle the costs and benefits associated with both investment objectives.

2.2 *Carbon intensity and temperature alignment*

We have seen earlier that carbon intensity and temperature alignment are close cousins. In the following section, we test the effect of excluding fossil fuel companies and similar carbon reductions in terms of active risk as well as projected temperature alignment. We keep the fossil fuel exclusions in place when constructing the carbon reduction portfolio to analyze the additional benefit of limiting greenhouse gas emissions. Recalling that the MSCI World embodies a weighted carbon-dependent temperature alignment of 3.9°C suggests that economic policies currently fall short of the targeted 1.5°C warming of the Paris agreement. Ritchie and Roser (2020) argue that the Energy sector is responsible for more than 70% of the global GHG emissions, hence excluding this sector seems a natural choice to decarbonize a portfolio. While excluding those companies helps to instantly decarbonize the overall portfolio, Blitz and Swinkels (2020) show that exclusions might not be the most effective way to contribute to a more sustainable world. Rather than divesting from a company the authors make a case for using active shareholder tools, like voting and engagement, to influence a company's ESG pathway.

2.2.1 *Introducing constraints*

The Energy sector currently has a weight of 2.7% in the MSCI World Index. When excluding portions of the index, two reweighting schemes come to mind: a simple market cap-based reweighting or an optimization which seeks to minimize tracking error against the market cap benchmark. Alessandrini and Jondeau (2020) show that simple exclusions can lead to significant changes and potentially introduce country and sector biases. To enable control of active positions in the remaining sectors, we opt for the latter option and minimize active risk relative to the parent index using tight industry and country constraints. The minimum tracking error required to implement the fossil fuel sector exclusion is 0.25%.[10] Yet, in terms of temperature path reduction excluding fossil fuel companies does not really help as the temperature path stays at benchmark level (3.9°C). This observation is intuitive as the minimum tracking error optimization will likely prompt us to replace fossil fuel companies by companies from other sectors that score similarly high in terms of temperature alignment and GHG. Therefore, we impose an additional GHG constraint: Reducing greenhouse gas emission intensity by applying a relative optimization constraint of −50% relative to the MSCI World on top of excluding the fossil fuel sector brings the temperature down to 3.56°C, while consuming an active risk of only 0.25%.

A modest degree in temperature decrease is expected, since the objective of both portfolios is to minimize active risk relative to the MSCI World. Similar to the Paris-aligned benchmarks analyzed in Section 1.2, neither a fossil fuel exclusion nor an additional carbon reduction is sufficient to generate a Paris-aligned portfolio. Note that excluding fossil fuels and/or reducing carbon intensity only comes with marginal effects on active factor exposures. The MSCI World is a cap-weighted index that does not control factor exposures. At the current end, we observe slightly positive exposure to Momentum and Quality (0.1 and 0.3), whilst the MSCI World's exposure to Value is negative with −0.11. It turns out that excluding fossil fuels and/or reducing carbon intensity is not genuinely altering factor exposures relative to the MSCI World.

2.2.2 Integrating temperature alignment and return objectives in a one-step optimization

To enhance the risk–return profile of the portfolio it seems natural to consider a mean–variance optimization to maximize factor exposures while adhering to a temperature alignment constraint. Specifically, we build on the same constraints investigated before: fossil fuel exclusions and a carbon reduction of 50% relative to the MSCI World. Also, we enforce the same temperature alignment of 1.5°C. We choose a quite wide active risk budget of 3% against the MSCI World and tightly control active positions in sectors, industries, and countries while allowing a deviation of ±2% relative to the cap-weighted benchmark. Utilizing this one-step optimization, factor exposures improve meaningfully compared to simple exclusions. All factor exposures are positive in absolute terms and add to the factor exposure provided by the benchmark with Momentum having the highest exposure of 0.73 (0.63 relative to the MSCI World) and Value having the lowest with 0.34 (0.45 in relative terms). Thus, while the one-step optimization improves factor exposures as intended, the ensuing factor profile is yet not balanced.

Although mean–variance approaches are workhorse models in portfolio management they are subject to various criticism, such as their high input sensitivity and the estimation error maximization property, see Michaud (1989). Along these lines, Kritzman *et al.* (2010) show that corner solutions can occur as the mean–variance portfolios tend to be concentrated and therefore could be non-optimal from an ex-post perspective (cf. DeMiguel *et al.* (2009)). While most of these studies focus on unbounded problem settings, introducing additional (potentially binding) constraints amplifies the tendency of mean–variance optimization to find local optima rather than the global optimum, see Soleimani *et al.* (2009). To avoid ending up with such corner solutions, we next propose a two-step optimization that separates the temperature alignment objective from the return objective.

2.3 The two-step temperature alignment framework in practice

To efficiently address the dual investment objective in practice, we propose a two-step optimization approach. In the first step, we construct the anchor portfolio that aims for temperature alignment. In the second step, we implement a factor overlay on top of the temperature-aligned anchor portfolio while enforcing a constraint to keep the temperature score close to that of the anchor portfolio. This approach is beneficial in a few aspects and helps foster a net zero framework. First, one can exert control on risk and portfolio characteristics. Second, a potentially overly binding constraint is less likely to prompt a corner solution that is typically sub-optimal in a real-world implementation. As the climate objective is reflected in the optimized anchor portfolio from Step 1, the factor overlay basically reshuffles the portfolio weights to render the final portfolio more attractive from a factor perspective.

To provide a net zero framework and actually reach a temperature path reduction close to the Paris agreement target of 1.5°C, we construct the anchor portfolio by running a mean–variance optimization. The respective expected return input is simply the negative of the carbon-weighted temperature score. To avoid common drawbacks of mean–variance optimization (see DeMiguel *et al.*, 2009; Michaud, 1989; Best and Grauer, 1991; Chopra and Ziemba, 2013), we tightly constrain the risk budget to 1% tracking error, thus mitigating the risk of error maximization and ensuring a diversified portfolio. A 1% tracking error budget is also close to the active risk observed for the two Paris-aligned benchmarks. Yet, the resulting temperature path for this optimized anchor portfolio is spot on regarding the 1.5°C target (Table 3). However, note that we do not explicitly target the 1.5°C temperature score but rather want to best position the portfolio in terms of temperature alignment with the given risk budget of 1%. Of course, there might be times when one is not able to hit this target. Similar to excluding fossil fuels or reducing carbon intensity, bringing down the portfolio temperature to 1.5°C does not come with considerable changes in factor exposure relative to the MSCI World, see Table 3.

For the subsequent factor overlay, we choose a quite wide active risk budget of 3% against the temperature-aligned anchor portfolio. Additionally, we fix the temperature path and do not allow the final portfolio to deviate from the 1.5°C trajectory. All portfolios inherit the constraints from the previous optimization, meaning that all portfolios exclude fossil fuel companies and obey a constraint to reduce greenhouse gas emissions by 50% (which is applied in all portfolios but the fossil fuel exclusion portfolio). Moreover, we tightly control active positions in sectors, industries and countries by applying constraints relative to the cap-weighted benchmark of ±2%.

Notably, the temperature alignment does not come at the cost of diversification losses. To illustrate, we compute the inverse of the Herfindahl–Hirschman index (HHI) that yields the effective number of stocks in a given portfolio. The HHI is calculated as follows:

$$HHI = \sum_{i=1}^{n} w_i^2 \tag{5}$$

The more equally-distributed the weights are, the lower the HHI will be and, vice versa, the higher the effective number of stocks. For instance, for the MSCI World with 1,557 constituents, the effective number of stocks is 166.

This is somewhat preserved when constructing the temperature-aware anchor portfolio, with 135 effective stocks. Yet, actively managing factor exposures in the second optimization step leads to a reduction in effective stocks to 90; this is expected given a wide active risk budget of 3% for the factor overlay. For the one-step optimization, the resulting effective number of stocks is merely 83. Notably, the two-step optimized portfolio comes with an increase in value and quality exposures relative to the one-step optimized portfolio, whilst the momentum exposure is on par. All in all, we observe a more balanced factor profile for the two-step optimization as a result. Importantly, the two-step optimization obtains a higher value of the utility function (1.21) compared to the one-step optimization (0.92), putting a spotlight on a corner solution emerging from the one-step optimization.

While creating the temperature-aligned anchor portfolio does not show significant changes in factor exposures compared to the cap-weighted benchmark, the second factor overlay step is expected to bring these improvements by design. Indeed, all factor exposures are positive, and the increase is 0.62 for Momentum, 0.48 for Quality, and 0.72 for Value, resulting in a balanced overall factor exposure in absolute terms for the final portfolio. With the PAB-anchor portfolio and the cap-weighted index being very similar in factor exposures, the active positioning of the final portfolio is similar as well.

3 Conclusion

Managing climate change risks in a well-diversified portfolio will be a top priority in the coming years. Yet, building temperature-aligned portfolios is not straightforward. We show that harvesting salient equity factor premia and mitigating climate change risk can be efficiently tackled in a two-step optimization. Notably, achieving a 1.5°C temperature path can come at a fairly low active risk. Instead of relying on a tracking error minimization subject to regulatory-driven constraints, we directly construct a temperature-aware portfolio with an active risk budget of 1%, resulting in a temperature alignment of 1.5°C. Additionally, we augment this anchor portfolio by active factor exposures without sacrificing the achieved temperature alignment. Notably, the two-step optimization approach enables more pronounced and balanced exposure to the targeted equity factors when compared to a one-step optimization, highlighting the benefits of sequentially addressing the two investment objectives. Naturally, companies and economies will evolve in the pursuit of addressing climate change portfolios, calling for active monitoring of relevant data distributions and the resulting portfolio characteristics.

Endnotes

1 The Paris Agreement is named after the place of the United Nations Framework Convention on Climate Change, 21st Conference of the Parties, in short COP 21.

2 As the remaining GHG budget is finite, GHG emissions must be zero at some point. This can be achieved using the reduction of GHG emissions. As some economic activities are difficult to impossible to decarbonize, the term net zero emerged. Under a net zero framework, inevitable GHG emissions must be offset.

3 In a related vein, Blitz and Swinkels (2021) highlight the expected loss that can result from inefficient ESG implementation and the corresponding lower factor exposures.

4 The idea of temperature alignment is to derive emission budgets for every industry. Taking the Carbon emissions of a company and assuming every company in the respective sector would have the same emission intensity, one can calculate how much of the emission budget is used (in most cases more than 100%). The overshoot of emissions can be mapped to a temperature increase using climate models.

5 Note that Utilities play a crucial role in decarbonizing the economy: most scenarios imply a change of energy sources from fossil fuels to renewable energy. While the

Utilities sector currently produces the majority of electricity using coal or other fossil sources, it also provides solutions via renewable energy.

[6] Methodology available https://vigeo-eiris.com/wp-content/uploads/2020/06/MAX_2020_Q1_Energy_Transition_One_Pager_FINAL.pdf

[7] Specific index methodology can be found at https://www.msci.com/documents/10199/505f8123-d418-ed1f-f83
d-f58df1181dcd for MSCI and https://www.spglobal.com/spdji/en/idsenhancedfactsheet/file.pdf?calcFrequency=M&force_download=true&hostIdentifier=48190c8c-42c4-46af-8d1a-0cd5db894797&indexId=92393210 for S&P.

[8] The models' methodology can be found at https://www.msci.com/documents/1296102/16985724/MSCI-ClimateVaR-Introduction-Feb2020.pdf (MSCI) and https://www.marketplace.spglobal.com/en/datasets/trucost-paris-alignment-(186) (S&P).

[9] The factor exposures are calculated using common indicators established in the academic literature to represent a given factor. Factor scores are industry-neutralized and adjusted to follow a standard-normal distribution; therefore, the final scores range from ~ -3 to $\sim +3$, see Grinold and Kahn (2000).

[10] To estimate risk numbers, we utilize a global risk model from Axioma. This risk model includes industry, country, and currency factors, as well as other factors deemed relevant for explaining the cross-section of expected equity returns.

Acknowledgments

We are grateful to Jennifer Bender, Kenneth Blay, David Blitz, Laurens Swinkels, and seminar participants at the 2021 Fall Conference of JOIM on "Climate Change: Investment Management Implications". This paper expresses the authors' views, which do not necessarily coincide with those of Invesco or Robeco.

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Keywords: Factor investing; portfolio optimization; sustainable investments; net zero framework; Paris alignment.

JEL Classification: G11; C61; D81