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Research article

Using net-zero alignment measures for sustainable portfolio choice

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Abstract: We offer a new climate risk metric, *net-zero alignment strength* (NZAS), which can be used by socially responsible investors for portfolio choice. NZAS is based on the current corporate GHG emission intensity (EI) and its reduction rate (ERR). Hence, in contrast to considering EI alone, NZAS can be used for choosing among the companies with high EI and high ERR versus the companies with low EI and low ERR. We incorporated NZAS and a widely used climate risk measure, *implied temperature rise* (ITR), separately into the mean-variance portfolio (MVP) framework. This led to simultaneous optimization upon the stock price returns, volatility, and climate risk. The NZAS/ITR contribution to the MVP minimization function is controlled by the *net-zero commitment parameter* (NZCP), which is investor's choice. An example for a portfolio with major constituents of the Energy sector in 2022–2024 illustrated the climate risk effects on the weights of portfolio holdings. We suggest to use this framework for finding the best-in-class companies within the chosen equity sectors.

Keywords: climate finance; GHG emissions; portfolio choice; mean-variance portfolio

JEL Codes: G11, M14, Q54, Q56

1. Introduction

Net-zero alignment implies corporate activity that mitigates global warming by attaining net-zero greenhouse gas (GHG) emissions by the target year of 2050. This goal can be achieved by decreasing

and/or removal of GHG emissions. Investment portfolios in which all holdings are aligned are called net-zero portfolios (NZP, e.g.; Bolton et al., 2022).

Implied temperature rise (ITR) has become the leading indicator for evaluating net-zero alignment (GFANZ, 2022; Hohne-Sparborth et al., 2021; Haalebos and Fouret, 2022; Le Guenedal et al., 2022; Nagy et al., 2023). ITR is defined in such a way that its high values have a negative sentiment. It is based on the current estimates of the corporate GHG emission intensity (EI), GHG emission reduction rate (ERR), and the forecasts of the future GHG emissions based on various climate pathway scenarios (NGFS, 2024). Another forward-looking measure, so-called distance-to-exit (DTE), was offered by Cendese et al. (2023). DTE is an estimate of the time period (in years) at which a company stops satisfying the NZP requirements and needs to be removed from it.

Unfortunately, the accuracy of ITR and DTE may suffer from geopolitical, macroeconomic, regulatory, and technological uncertainties typical for long-term forecasts. As a result, there are significant differences among the corporate ITRs offered by different providers (Chmel et al., 2024). This may complicate portfolio choice for socially responsible investors who may be interested in the *current* best-in-class companies.

Here, we introduce a new metric consistent with the net-zero alignment framework that can be used for portfolio selection. It combines two main net-zero alignment metrics, the current EI and ERR, into a single indicator. Specifically for company i at time t, we suggest using the net-zero alignment strength

$$\mathrm{NZAS}_i(t)=\mathrm{F}*(1+\mathrm{ERR}_i(t))/\mathrm{EI}_i(t) \quad (1)$$

The numeric factor F of the order of magnitude of a typical EI is added to have the values of NZAS in a preferable range close to unity, which may be attained by setting F to the minimum EI of the portfolio holdings. NZAS has a heuristic nature similarly to the other net-zero alignment indicators. Its scaling with the factor F implies that this measure is best suited for comparing companies within the same industry for finding the best-in-class companies rather than for multi-sector portfolios. The unit in the numerator of (1) is added to avoid a zero value of NZAS_i in case of zero ERR_i. This does not change the ranking of portfolio holdings by their NZAS.

We measure EI_i as the amount of GHG emissions per company revenue. Since the corporate business may change over time due to selling its part or acquiring (part of) another company, we define ERR_i with the difference between the past and present GHG emission intensities rather than with the difference between the past and present absolute GHG emissions, as it is generally suggested (e.g., PAT (2020) and the later references to ITR)

$$\mathrm{ERR}_i=[\mathrm{EI}_i(t\text{-}1)-\mathrm{EI}_i(t)]/\mathrm{EI}_i(t\text{-}1) \quad (2)$$

NZAS (1) is defined in such a way that it decreases with growing EI and increases with growing ERR. Thus, NZAS has a positive sentiment and can be helpful in choosing between a company that has a higher EI and a higher ERR versus a company that has a lower EI and a lower ERR. The NZAS advantage over the ITR and DTE is that it addresses the *current* corporate GHG emissions and their reduction rates, and does not rely on the long-term forecasts of the company behavior.

Another problem for forming a sustainable portfolio is that the correlations between the corporate EI and stock returns are very low or negative (Aswani et al., 2023; Schmidt, 2024a). As a result, portfolios with a better net-zero alignment may have lower Sharpe ratios (SR) than the net-zero neutral portfolios. This may lead to a confusion for socially responsible investors willing to increase their wealth. To address this issue, we offered using the climate risk-tilted SR (Schmidt, 2024a). The idea

behind it is that socially responsible investors need to account for climate risks in the same way as many rational investors account for price volatility risk and use portfolio SR rather than returns.

In this work, we incorporate both concepts, NZAS and NZAS-tilted SR (SR-NZAS), into the mean-variance portfolio (MVP) framework (denoted further as NZAS-tilted MVP) that has been used to account for non-pecuniary risks (Gasser et al., 2017; Pedersen et al., 2021; Schmidt, 2020; Schmidt, 2024a; Schmidt, 2024b; Blitz et al., 2024). In this methodology (sometimes called 3D investing), portfolio weights are optimized in terms of stock price returns, volatility, and non-pecuniary risks. We also introduced similarly defined ITR-tilted MVP. As an example of climate risk-tilted MVPs, we applied our framework to a portfolio of 24 major constituents of the Energy sector in 2022–2024 for which both NZAS and ITR were available to us. The limited number of holdings in our portfolio was determined by significant survival bias as some energy companies were merged or acquired, and others did not (or stopped to) provide the GHG emission data.

It should be noted that we do not suggest using the climate risk-tilted MVPs as a universal tool for deriving well-diversified portfolios since the highly concentrated nature of MVPs can exclude all carbon-intense industries. We recommend our approach to identify the best-in-class companies in the chosen sector, particularly for those socially responsible investors who do not want to abandon the carbon-intense industries altogether. Indeed, as Edmans et al. (2022) suggested, the optimal divestment strategy from "brown" industries is holding the best-in-class companies rather than their total exclusion.

Furthermore, the NZAS/ITR-tilted MVP framework, the data used in this work, our results, and conclusions are described in the next four sections, respectively.

2. The mean-variance model for optimal net-zero portfolios

The classical MVP theory is based on minimizing the following objective function (see, e.g., Elton et al., 2009):

$$U_{MVP}=0.5\lambda\sigma_p^2-r_p \tag{3}$$

In (3), λ is market volatility risk aversion parameter. Portfolio variance σ_p^2 equals

$$\sigma_p^2=\sum_{i,j=1}^{N} w_i w_j \sigma_{ij}, \tag{4}$$

w_i are portfolio weights, i=1, 2, …, N; N is the number of portfolio holdings; $\sum_{i=1}^{N} w_i=1$, σ_{ij} are covariances between the asset returns, r_p is mean portfolio return

$$r_\mathrm{p}=\sum_{i=1}^{N} w_i r_i \tag{5}$$

and r_i are mean portfolio asset returns. In classical finance, SR is defined as

$$\mathrm{SR}=(r_\mathrm{p}-r_\mathrm{f})/\sigma_\mathrm{p} \tag{6}$$

where r_f is risk-free rate of return (neglected in this work).

For the NZAS-tilted MVP, U_{MVP} is expanded with the portfolio NZAS (PNZAS)

$$U_{NZAS}=U_{MVP}-\delta*\mathrm{PNZAS} \tag{7}$$

In (7), δ is the net-zero commitment parameter (NZCP), which is investors' choice. PNZAS is assumed to be a weighted sum of the portfolio holdings' $NZAS_i$

$$\text{PNZAS}=\sum_{i=1}^{N} w_i NZAS_i \tag{8}$$

PNZAS is included with the negative sign in the minimizing function (7) since it has a positive sentiment.

Similarly, we can introduce the ITR-tilted MVP. Specifically,

$$U_{ITR}=U_{MVP}+\delta*\text{PITR} \tag{9}$$

$$\text{PITR}=\sum_{i=1}^{N} w_i ITR_i \tag{10}$$

PITR is included in (9) with the positive sign in the minimizing function (9) since it has a negative sentiment.

Unconstrained MVPs may have large short positions undesirable for most investors (see, e.g., Jacobs et al., 2013). Therefore, the long-only constraint ($w_i \geq 0$) was used in this work.

We are interested in the derivation of the maximum Sharpe portfolio. Then, the risk aversion parameter λ can be dropped from consideration, and the maximum Sharpe portfolio can be found by searching various values of the mean portfolio return r_p. Thus, we have the following quadratic programming problem for NZAS-tilted MVP and ITR-tilted MVP, respectively:

$$\min\left[0.5\sum_{i,j=1}^{N} w_i w_j \sigma_{ij} - \delta \sum_{i=1}^{N} w_i\, NZAS_i\right] \tag{11a}$$

$$\min\left[0.5\sum_{i,j=1}^{N} w_i w_j \sigma_{ij} + \delta \sum_{i=1}^{N} w_i\, ITR_i\right] \tag{11b}$$

$$\text{s.t.}\quad \sum_{i=1}^{N} w_i r_i = r_\text{p} \tag{12}$$

$$\sum_{i=1}^{N} w_i = 1 \tag{13}$$

$$w_i \geq 0;\ i=1, 2, \ldots, N \tag{14}$$

Note that factor F in the definition of NZAS (1) is multiplied by NZCP δ in (11a). Both these factors have a heuristic nature; however, importantly, the NZAS effects on the MVP solution are that both RHS terms in (11) should have similar value magnitudes. This implies that that the individual values of F and δ are not important in our framework.

A general problem with MVPs is that they are usually highly concentrated. One might expect that minimization of portfolio variance would produce well diversified portfolios; yet, the optimization algorithm usually chooses only a handful of the past top winners while the rest of the long-only portfolio holdings have negligible weights. A popular method to reduce portfolio concentration is adding the maximum allocation constraint on portfolio weights; $w_i \leq$ Wmax (Jagannathan and Ma, 2003). While we tested the effects of this constraint in this work, we also increased the MVP diversity by replacing Pearson's correlations in (11) with partial correlations conditioned on the total equity market returns (Nadler and Schmidt, 2014). The motivation for introducing the partial correlations-based MVP (PartMVP) as an alternative to the Pearson's correlations-based MVP (PearMVP) is that most individual stock returns generally follow the total market trend according to the capital asset pricing model, which increases their Pearson's correlations. On the other hand, partial correlations conditioned on the total market return (usually estimated using the return of the S&P 500 index ETF, ticker SPY) describe co-movements of the

excess asset returns unaffected by the market momentum. As a result, partial correlations are lower than the corresponding Pearson's correlations, and the PartMVPs are often much more diversified than the PearMVPs. Additionally, the PartMVPs may outperform the PearMVPs and equal-weight portfolios out of sample (Nadler and Schmidt, 2014; Cai and Schmidt, 2020). It should be noted that there is some similarity in terms of the increased portfolio diversification effect between partial correlations and the famous covariance shrinkage estimator (Ledoit and Wolf, 2004): While the latter increases the diagonal covariance terms explicitly, the former do this implicitly by weakening the off-diagonal terms.

Unfortunately, partial correlations of the energy stocks conditioned on the SPY return are not notably different from the Pearson's correlations (Schmidt, 2024a). This is because price dynamics of the "brown" stocks (Energy, Materials, and Utility sectors) can significantly differ from that of the S&P 500 index since the latter is heavily overweighted by technology stocks. As a result, the industry beta may be more relevant to these stocks than the market beta (Schmidt, 2024c). Therefore, we conditioned the energy stock partial correlations using the Energy ETF (ticker XLE), which implies filtering out the impact of the macroeconomic and the energy industry-specific news. This, as it is shown below, significantly increases diversity of the energy stock portfolio.

As we indicated in Introduction, we define optimal NZAS-tilted MVP as a portfolio with the maximum value of the NZAS-tilted SR. Since the higher NZAS (ITR) values have a positive (negative) sentiment, we used the following definition of SR-NZAS and SR-ITR:

$$\text{SR-NZAS}=\text{SR}(1+\text{PNZAS}) \tag{15}$$

$$\text{SR-ITR}=\text{SR}(1-\text{PITR}) \tag{16}$$

This metrics enables socially responsible investors to account for climate risks explicitly, similarly to how price volatility risk-averse investors use the classical SR as a portfolio performance measure rather than portfolio return. Similar ideas for ESG-tilted portfolio performance measures were proposed by Chen and Mussalli (2020), Schmidt (2020), and Alessandrini and Jondeau (2021).

We used the optimization problem (11)–(14) to derive the optimal NZAS-tilted MVPs and ITR-tilted MVPs by searching the maximum SR-NZAS and SR-ITR, respectively, in the r_p–δ parameter space. When the maximum allocation constraint on portfolio weights was not applied, we continued to search over higher δ until our portfolio had a single holding with the highest (lowest) NZAS (ITR). The case with the maximum allocation constraint on portfolio weights was considered separately.

3. The data

To avoid survival bias, the portfolio considered in this work was formed with 24 major constituents of the Energy equity sector that were traded in 2022–2024 for which NZAS and ITR values were available to us. The size of our portfolio was constrained with the significant survival bias: In 2022–2024, several energy companies merged or were acquired, or they did not (or stopped to) provide GHG emissions data.

The climate risk metrics for portfolio holdings is provided in the Appendix Tables A1–A3 for each year in 2022–2024, respectively. The NZAS values of the portfolio holdings were calculated using their EIs obtained from Trucost. The ITRs of the portfolio holdings were calculated using the LOAM methodology (Hohne-Sparborth et al., 2021) and scaled by their maximum value in our

portfolio to avoid negative values of SR-ITR. The optimal MVPs for each year were calibrated using one-year adjusted daily closing stock prices available on *finance.yahoo.com*.

The data listed in Table 1 show a negative correlation between ITR and NZAS, which is expected since ITR and NZAS have the opposite sentiments. Importantly, positive correlations between ITR and SR in 2022 and 2023, and negative correlations between NZAS and SR in 2023 and 2024 are the reasons for possible investor confusion that we mentioned in the Introduction. This implies that the climate risk in terms of NZAS and ITR cannot be the sole criterion for investing as long as rational investors strive for increasing their wealth. Hence, there is a need of a trade-off that can be accomplished with the 3D portfolio optimization over stock returns, volatility, and climate risks, and with introducing the climate risk-tilted SRs.

Table 1. Correlations in the Energy portfolio.

Year	ITR/NZAS	ITR/SR	NZAS/SR
2022	−0.32	0.39	0.10
2023	−0.25	0.32	−0.21
2024	−0.24	−0.05	−0.09

4. The results

The net-zero neutral PearMVPs (i.e., when NZCP δ is zero) in 2022–2024 were (unsurprisingly) highly concentrated: They had no more than 4 holdings (out of 24) with the significant weights (0.01 or higher). However, the XLE-conditioned net-zero neutral PartMVPs had 17, 18, and 8 significant weights in 2022, 2023, and 2024, respectively (see Table 2). We also listed the Energy portfolio weights with the maximum allocation constraint Wmax=0.1. Predictably, the latter significantly increased diversity of PearMVP. As for PartMVP, Wmax of 0.1 somewhat increased its diversity in 2022 and 2024 but not in 2023.

In 2022, the net-zero neutral PearMVP had only 3 holdings (OXY, MPC, and XOM) due to their relatively high returns (see Table 3). With growing NZCP, these holdings were first replaced with PSX. The latter had a lower return but the 2nd highest NZAS. Finally, at very high NZCP values, Baker Hughes (BKR), with the highest NZAS in our portfolio, has become the only NZAS-tilted MVP holding. Note that SR monotonically decreased with growing NZCP while SR-NZAS was non-monotonic, similarly to some ESG-tilted portfolios (Schmidt, 2020; Schmidt, 2024b; Schmidt and Zhang, 2024). The highest SR-NZAS may be interpreted as the optimal NZAS-tilted MVP.

Table 2. The weights of the Energy portfolio with zero NZCP.

Year	Corr	BKR	BP	CNQ	COP	CVX	DVN	E	EOG	EQNR	FANG	HAL	MPC	OKE	OXY	PSX	REPYY	SHEL	SLB	TRGP	TRP	TTE	VLO	WMB	XOM	Wmax	W ≥ 0.01
2022	Pearson	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.45	0.00	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.44	NA	3
		0.00	0.00	0.00	0.10	0.10	0.00	0.00	0.00	0.08	0.00	0.00	0.10	0.00	0.10	0.00	0.08	0.00	0.10	0.00	0.00	0.07	0.10	0.06	0.10	0.10	11
	Partial	0.01	0.00	0.00	0.06	0.20	0.05	0.00	0.07	0.01	0.04	0.03	0.03	0.03	0.04	0.04	0.00	0.00	0.05	0.01	0.00	0.00	0.04	0.06	0.24	NA	17
		0.03	0.01	0.01	0.10	0.10	0.04	0.02	0.09	0.02	0.03	0.03	0.03	0.04	0.06	0.07	0.00	0.01	0.07	0.01	0.00	0.00	0.06	0.09	0.10	0.10	21
2023	Pearson	0.00	0.00	0.02	0.00	0.00	0.00	0.38	0.00	0.00	0.00	0.00	0.18	0.00	0.00	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	NA	4
		0.10	0.00	0.10	0.00	0.00	0.00	0.10	0.00	0.00	0.10	0.00	0.10	0.10	0.00	0.10	0.00	0.10	0.00	0.10	0.00	0.00	0.00	0.10	0.00	0.10	10
	Partial	0.03	0.00	0.00	0.04	0.19	0.03	0.00	0.07	0.00	0.05	0.02	0.04	0.02	0.05	0.04	0.00	0.01	0.04	0.02	0.00	0.01	0.03	0.07	0.23	NA	18
		0.07	0.00	0.05	0.07	0.10	0.00	0.05	0.01	0.00	0.10	0.00	0.10	0.04	0.04	0.10	0.00	0.05	0.00	0.02	0.00	0.00	0.00	0.10	0.10	0.10	15
2024	Pearson	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.92	0.08	0.00	0.00	0.00	0.00	NA	2
		0.10	0.00	0.00	0.00	0.10	0.00	0.00	0.10	0.00	0.10	0.00	0.00	0.10	0.00	0.00	0.00	0.10	0.00	0.10	0.10	0.00	0.00	0.10	0.10	0.10	10
	Partial	0.06	0.00	0.00	0.00	0.19	0.00	0.00	0.03	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.09	0.09	0.28	NA	8
		0.10	0.00	0.01	0.00	0.10	0.00	0.00	0.10	0.00	0.06	0.00	0.00	0.10	0.00	0.02	0.00	0.06	0.00	0.10	0.04	0.00	0.10	0.10	0.10	0.10	12

Table 3. Performance and weights of the NZAS-tilted PearMVP in 2022[1), 2)].

NZCP	PNZAS	SR	SR-NZAS	Porfolio weights						
				OXY	MPC	XOM	SLB	COP	PSX	BKR
0.00E+00	0.368	1.99	2.73	0.11	0.45	0.44	0.00	0.00	0.00	0.00
2.00E−04	0.393	1.98	2.75	0.13	0.46	0.35	0.06	0.00	0.00	0.00
5.00E−04	0.489	1.79	2.67	0.43	0.28	0.00	0.29	0.00	0.00	0.00
1.00E−03	0.504	1.65	2.49	0.64	0.00	0.00	0.36	0.00	0.00	0.00
1.60E−03	0.633	1.62	2.64	0.38	0.00	0.00	0.55	0.07	0.00	0.00
1.80E−03	0.730	1.56	2.70	0.19	0.00	0.00	0.55	0.26	0.00	0.00
2.00E−03	0.830	1.48	2.71	0.00	0.00	0.00	0.39	0.61	0.00	0.00
4.00E−03	0.835	1.48	2.71	0.00	0.00	0.00	0.43	0.53	0.04	0.00
5.00E−03	0.924	1.31	2.53	0.00	0.00	0.00	0.21	0.15	0.64	0.00
6.00E−03	0.980	1.12	2.21	0.00	0.00	0.00	0.00	0.00	1.00	0.00
2.00E−02	0.990	1.19	2.37	0.00	0.00	0.00	0.00	0.00	0.81	0.19
3.00E−02	1.000	0.82	1.65	0.00	0.00	0.00	0.00	0.00	0.28	0.72
4.00E−02	1.010	0.65	1.30	0.00	0.00	0.00	0.00	0.00	0.00	1.00

[1)] Maximum SR-NZAS is in bold font.

[2)] Maximum SR and SR-NZAS are in bold font.

The maximum allocation constraint changes the asymptotic behavior of the NZAS-tilted PearMVP weights with increasing NZCP. An example for Wmax=0.1 is given in Table 4. Specifically, this constraint always kept 10 holdings in the NZAS-tilted PearMVP with non-zero NZCP and shifted the portfolio concentration toward the holdings with higher NZAS. At very high NZCP values, 10 holdings with the highest NZAS values had equal weights of 10%. This represents a major difference with the case without the maximum allocation constraint that yields a single holding with the maximum NZAS value. These results imply that MVP with the highest possible PNZAS for a chosen Wmax is an equal-weight portfolio with K=1/Wmax holdings that have the highest NZAS values.

Now, let us consider the NZAS-tilted PartMVP. While the net-zero-neutral PartMVP had 17 holdings in 2022, only 9 varied with the NZCP value (see Table 5). For this PartMVP, SR and SR-NZAS had maximums at moderate NZCPs. Similar to PearMVP in the absence of the maximum allocation constraint, BKR with the highest NZAS value was the only holding in the portfolio at very high values of NZCP.

Table 4. Performance and weights of the NZAS-tilted PearMVP with Wmax=0.1 in 2022[1), 2)].

NZCP	PNZAS	SR	SR-NZAS	Porfolio weights															
				BKR	BP	COP	CVX	EOG	EQNR	FANG	HAL	MPC	OXY	PSX	REPYY	SHEL	SLB	TTE	VLO	WMB	XOM
0.00E+00	0.492	1.69	2.52	0.00	0.00	0.10	0.10	0.00	0.08	0.00	0.00	0.10	0.10	0.00	0.08	0.00	0.10	0.07	0.10	0.06	0.10
2.00E−04	0.568	1.67	2.61	0.00	0.00	0.10	0.10	0.00	0.10	0.00	0.00	0.10	0.10	0.10	0.08	0.00	0.10	0.03	0.10	0.00	0.10
5.00E−04	0.590	1.65	2.60	0.00	0.00	0.10	0.07	0.10	0.09	0.00	0.03	0.10	0.10	0.10	0.00	0.00	0.10	0.00	0.10	0.00	0.10
1.00E−03	0.583	1.63	2.60	0.00	0.00	0.10	0.10	0.10	0.00	0.00	0.10	0.10	0.10	0.10	0.00	0.00	0.10	0.00	0.10	0.00	0.10
2.00E−03	0.642	1.55	2.54	0.10	0.00	0.10	0.00	0.10	0.00	0.00	0.10	0.10	0.10	0.10	0.00	0.00	0.10	0.00	0.10	0.00	0.10
4.00E−03	0.672	1.49	2.49	0.10	0.00	0.10	0.00	0.10	0.02	0.00	0.10	0.10	0.10	0.10	0.00	0.08	0.10	0.00	0.10	0.00	0.00
6.00E−03	0.692	1.46	2.47	0.10	0.00	0.10	0.00	0.10	0.10	0.00	0.10	0.10	0.10	0.10	0.00	0.10	0.10	0.00	0.00	0.00	0.00
2.00E−02	0.737	1.25	2.16	0.10	0.10	0.10	0.00	0.10	0.10	0.10	0.10	0.00	0.00	0.10	0.00	0.10	0.10	0.00	0.00	0.00	0.00
4.00E−02	0.737	1.25	2.16	0.10	0.10	0.10	0.00	0.10	0.10	0.10	0.10	0.00	0.00	0.10	0.00	0.10	0.10	0.00	0.00	0.00	0.00
1.00E−01	0.737	1.25	2.16	0.10	0.10	0.10	0.00	0.10	0.10	0.10	0.10	0.00	0.00	0.10	0.00	0.10	0.10	0.00	0.00	0.00	0.00

[1)] Maximum SR-NZAS is in bold font.

[2)] Maximum SR and SR-NZAS are in bold font.

Table 5. Performance and weights of the NZAS-tilted PartMVP in 2022[1), 2)].

NZCP	PNZAS	SR	SR-NZAS	Porfolio weights								
				BKR	COP	HAL	MPC	OXY	PSX	SLB	VLO	XOM
0.00E+00	0.481	1.57	2.32	0.01	0.06	0.03	0.03	0.04	0.04	0.05	0.04	0.24
5.00E−05	0.633	1.69	2.76	0.00	0.31	0.03	0.08	0.11	0.07	0.16	0.02	0.22
1.00E−04	0.667	1.67	2.78	0.00	0.40	0.00	0.09	0.16	0.01	0.24	0.01	0.09
2.00E−04	0.808	1.52	2.75	0.00	0.50	0.00	0.00	0.09	0.15	0.26	0.00	0.00
4.00E−04	0.746	1.57	2.75	0.00	0.48	0.00	0.00	0.17	0.00	0.35	0.00	0.00
8.00E−04	0.87	1.45	2.70	0.00	0.51	0.00	0.00	0.00	0.24	0.25	0.00	0.00
4.00E−03	0.87	1.44	2.69	0.00	0.39	0.00	0.00	0.00	0.26	0.35	0.00	0.00
6.00E−03	0.96	1.21	2.37	0.00	0.00	0.00	0.00	0.00	0.84	0.16	0.00	0.00
8.00E−03	0.99	1.06	2.11	0.24	0.00	0.00	0.00	0.00	0.76	0.00	0.00	0.00
4.00E−02	1.01	0.65	1.30	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

[1)] Only the holdings with weights dependent on NZCP are listed.

[2)] Maximum SR and SR-NZAS are in bold font.

The ITR-tilted MVPs in 2022 had a similar evolution with growing NZCP (see Tables 6, 7, and 8 for PearMVP without/with the maximum allocation constraint, and PartMVP, respectively). The important difference, however, was that it was ENI (ticker E) with the lowest ITR that was the only PartMVP holding at very high NZCP values when the maximum allocation constraint was not applied.

Table 6. Performance and weights of the Energy ITR-tilted PearMVP in 2022[1), 2)].

NZCP	PITR	SR	SR-ITR	Porfolio weights					
				OXY	MPC	XOM	TTE	SHEL	E
0.00E+00	0.658	1.99	0.68	0.11	0.45	0.44	0.00	0.00	0.00
2.00E−04	0.508	1.94	0.95	0.16	0.09	0.75	0.00	0.00	0.00
4.00E−04	0.463	1.90	1.02	0.23	0.00	0.77	0.00	0.00	0.00
6.00E−04	0.457	1.89	1.03	0.28	0.00	0.72	0.00	0.00	0.00
1.00E−03	0.444	1.86	1.03	0.39	0.00	0.60	0.01	0.00	0.00
3.00E−03	0.374	1.59	0.99	0.82	0.00	0.00	0.00	0.18	0.00
5.00E−02	0.375	1.58	0.99	1.00	0.00	0.00	0.00	0.00	0.00
8.00E−02	0.367	0.65	0.93	0.70	0.00	0.00	0.00	0.00	0.30
1.00E−01	0.349	0.60	0.39	0.08	0.00	0.00	0.00	0.00	0.92
1.10E−01	0.346	0.42	0.28	0.00	0.00	0.00	0.00	0.00	1.00

[1)] Maximum SR-ITR is in bold font.

[2)] Only the holdings with weights dependent on NZCP are listed.

Table 7. Performance and weights of the ITR-tilted PearMVP with Wmax=0.1 in 2022[1), 2)].

NZCP	PITR	SR	SR-ITR	Porfolio weights															
				BKR	BP	COP	CVX	DVN	E	EOG	EQNR	HAL	MPC	OXY	REPYY	SHEL	SLB	TTE	VLO	XOM
0.00E+00	0.658	1.99	0.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.45	0.12	0.00	0.00	0.00	0.00	0.00	0.44
2.00E−04	0.542	1.69	0.77	0.00	0.00	0.10	0.10	0.00	0.00	0.00	0.10	0.00	0.10	0.10	0.10	0.00	0.10	0.10	0.10	0.10
4.00E−04	0.525	1.67	0.79	0.00	0.00	0.10	0.10	0.00	0.00	0.07	0.10	0.00	0.10	0.10	0.00	0.03	0.10	0.10	0.10	0.10
6.00E−04	0.528	1.67	0.79	0.00	0.00	0.10	0.10	0.00	0.00	0.10	0.10	0.00	0.10	0.10	0.00	0.00	0.10	0.10	0.10	0.10
1.00E−03	0.554	1.64	0.73	0.00	0.00	0.10	0.10	0.03	0.00	0.10	0.09	0.08	0.10	0.10	0.00	0.00	0.10	0.00	0.10	0.10
3.00E−03	0.435	1.48	0.84	0.00	0.10	0.10	0.10	0.10	0.00	0.10	0.10	0.00	0.00	0.10	0.00	0.10	0.10	0.00	0.00	0.10
8.00E−02	0.417	1.45	0.85	0.00	0.10	0.10	0.00	0.10	0.00	0.10	0.10	0.00	0.00	0.10	0.00	0.10	0.10	0.10	0.00	0.10
1.00E−01	0.395	1.25	0.76	0.10	0.10	0.10	0.00	0.10	0.10	0.10	0.10	0.00	0.00	0.10	0.00	0.10	0.00	0.10	0.00	0.00
2.00E−01	0.395	1.25	0.76	0.10	0.10	0.10	0.00	0.10	0.10	0.10	0.10	0.00	0.00	0.10	0.00	0.10	0.00	0.10	0.00	0.00

[1)] Maximum SR-ITR is in bold font.

[2)] Only the holdings with weights dependent on NZCP are listed.

Table 8. Performance and weights of the Energy ITR-tilted PartMVP in 2022[1), 2)].

NZCP	PITR	SR	SR-ITR	Porfolio weights											
				BKR	BP	COP	CVX	DVN	E	EOG	EQNR	OXY	SHEL	SLB	XOM
0.00E+00	0.587	1.57	0.65	0.07	0.00	0.06	0.20	0.05	0.00	0.07	0.01	0.04	0.00	0.05	0.24
1.00E−04	0.444	1.63	0.9	0.03	0.05	0.18	0.00	0.07	0.01	0.06	0.03	0.09	0.00	0.09	0.38
4.00E−04	0.428	1.65	0.94	0.01	0.02	0.29	0.00	0.05	0.00	0.00	0.02	0.19	0.08	0.10	0.24
6.00E−04	0.421	1.66	0.96	0.00	0.00	0.34	0.00	0.02	0.00	0.00	0.00	0.27	0.09	0.11	0.16
1.00E−03	0.399	1.6	0.96	0.00	0.00	0.38	0.00	0.00	0.00	0.00	0.00	0.37	0.17	0.07	0.00
2.00E−03	0.380	1.58	0.98	0.00	0.00	0.17	0.00	0.00	0.00	0.00	0.00	0.49	0.34	0.00	0.00
4.00E−03	0.370	1.52	0.96	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.57	0.34	0.00	0.00
1.00E−02	0.365	1.43	0.90	0.00	0.00	0.00	0.00	0.00	0.36	0.00	0.00	0.64	0.00	0.00	0.00
1.00E−01	0.356	1.10	0.70	0.00	0.00	0.00	0.00	0.00	0.67	0.00	0.00	0.33	0.00	0.00	0.00
2.00E−01	0.346	0.42	0.39	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00

[1)] Only the holdings with weights dependent on NZCP are listed.

[2)] Maximum SR and SR-ITR are in bold font.

In 2023, the evolution of NZAS-tilted and ITR-tilted MVP weights with growing NZCP was similar to that of in 2022, and the stocks with the highest NZAS (BKR) and the lowest ITR (E) remained the same as in 2022 (see Tables A4–A5 for the NZAS-tilted PearMVP and PartMVP, respectively, and Tables A6–A7 for the ITR-tilted PearMVP and PartMVP, respectively, in the Appendix).

The major difference in 2024 was that Targa Resources (ticker TRGP) had a significantly higher return than the other Energy portfolio holdings. As a result, the net-zero neutral PearMVP had only 2 holdings with the TRGP weight of 92% (see Table 9).

Table 9. Performance and weights of the Energy NZAS-tilted PearMVP in 2024[1), 2)].

NZCP	PNZAS	SR	SR-NZAS	Portfolio weights		
				BKR	TRP	TRGP
0.00E+00	0.099	3.24	3.56	0.00	0.08	0.92
1.00E−04	0.105	3.23	3.57	0.00	0.00	1.00
2.25E−03	0.229	3.08	3.79	0.14	0.00	0.86
2.30E−03	0.382	2.78	3.84	0.31	0.00	0.69
2.40E−03	0.689	1.88	3.17	0.65	0.00	0.35
2.60E−03	1.00	0.82	1.84	1.00	0.00	0.00

[1)] Only the holdings with weights dependent on NZCP are listed.

[2)] Maximum SR-NZAS is in bold font.

Table 10. Performance and weights of the NZAS-tilted PearMVP with Wmax=0.1 in 2024[1)].

NZCP	PNZAS	SR	SR-NZAS	Portfolio weights														
				BKR	BP	CNQ	COP	CVX	E	EOG	FANG	HAL	OKE	SHEL	SLB	TRGP	TRP	WMB	XOM
0	0.271	1.48	1.89	0.10	0.00	0.00	0.00	0.10	0.00	0.10	0.10	0.00	0.10	0.10	0.00	0.10	0.10	0.10	0.10
2.0E−03	0.284	1.42	1.82	0.10	0.00	0.10	0.00	0.00	0.00	0.10	0.10	0.00	0.10	0.10	0.00	0.10	0.10	0.10	0.10
5.0E−03	0.338	1.18	1.53	0.10	0.00	0.10	0.00	0.00	0.00	0.10	0.10	0.00	0.10	0.10	0.10	0.10	0.10	0.10	0.00
1.0E−02	0.365	0.91	1.24	0.10	0.00	0.10	0.10	0.00	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.00	0.00	0.00	0.00
5.0E−02	0.409	0.02	0.03	0.10	0.00	0.10	0.10	0.00	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.00	0.00	0.00	0.00

[1)] Only the holdings with weights dependent on NZCP are listed.

Table 11. Performance and weights of the Energy NZAS-tilted PartMVP in 2024[1), 2)].

NZCP	PNZAS	SR	SR-NZAS	Portfolio weights								
				BKR	CVX	EOG	FANG	OKE	TRGP	VLO	WMB	XOM
0.00E+00	0.197	1.62	1.94	0.06	0.19	0.03	0.02	0.00	0.25	0.09	0.09	0.28
2.00E−05	0.302	1.49	1.94	0.17	0.15	0.07	0.02	0.02	0.22	0.08	0.03	0.24
5.00E−05	0.401	2.4	3.36	0.32	0.00	0.00	0.00	0.00	0.51	0.03	0.00	0.14
1.00E−04	0.262	3.03	3.82	0.17	0.00	0.00	0.00	0.00	0.83	0.03	0.00	0.00
2.40E−04	0.788	1.56	2.78	0.76	0.00	0.00	0.00	0.00	0.24	0.00	0.00	0.00
2.50E−04	1.00	0.92	1.84	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

[1)] Only the holdings with weights dependent on NZCP are listed.

[2)] Maximum SR and SR-NZAS are in bold font.

The maximum allocation constraint of 0.1 does not enable the highly profitable in 2024 TRGP to dominate PearMVP. The changes in its holdings with growing NZCP values were similar to those in 2022. Specifically, increasing NZCP shifts portfolio concentration toward the holdings with higher NZAS. At very high NZCP values, 10 holdings (that, somewhat ironically, did not include TRGP) with the highest NZAS values had equal weights of 10% (see Table 9). Note that SR-NZAS for the NZAS-tilted MVP in 2024 with the maximum allocation constraint monotonically decreased with growing NZCP. Thus, the maximum allocation constraint complicated the choice of the best-in-class Energy companies.

The net-zero neutral PartMVP had just 8 holdings in 2024 vs 17/18 holdings in 2022/2023 (cf. Table 2 and Table 11). Still, the TRGP weight was significantly diluted due to the weaker partial correlations. The difference in the results for 2022/2023 and 2024 illustrates the importance of regular portfolio rebalancing. BKR retained the highest NZAS value in 2024 and, thus, was the only NZAS-tilted PartMVP holding at very high NZCPs.

The ITR-tilted PearMVP holdings in 2024 were similar to that of NZAS-tilted holdings but it was Eni (ticker E) with the lowest ITR in our portfolio that was the only holding at very high NZCPs (see Table 12).

Table 12. Performance and weights of the Energy ITR-tilted PearMVP in 2024[1)].

NZCP	PITR	SR	SR−ITR	Portfolio weights			
				BKR	E	TRGP	TRP
0.00E+00	0.642	3.24	1.16	0.00	0.00	0.92	0.08
2.00E−04	0.618	3.23	1.23	0.00	0.00	1.00	0.00
9.60E−03	0.607	3.18	1.25	0.05	0.00	0.95	0.00
1.00E−02	0.541	2.64	1.21	0.37	0.00	0.63	0.00
1.60E−02	0.410	0.92	0.54	1.00	0.00	0.00	0.00
1.70E−02	0.392	0.71	0.43	0.79	0.21	0.00	0.00
1.80E−02	0.366	0.22	0.14	0.47	0.53	0.00	0.00
2.00E−02	0.327	−0.77	−0.52	0.00	1.00	0.00	0.00

[1)] Only the holdings with weights dependent on NZCP are listed.

[2)] Maximum SR-ITR is in bold font.

The maximum allocation constraint had a similar effect on the ITR-tilted PearMVP weights as on the NZAS-tilted PearMVP weights (see an example for Wmax=0.1 in Table 13). Specifically, this constraint always keeps 10 holdings in the ITR-tilted PearMVP for non-zero NZCP values and shifts the portfolio concentration toward the holdings with lower ITR. At the very high NZCP values, 10 holdings with the lowest ITR values had equal weights of 10%. This contrasts with the case without the maximum allocation constraint that yields a single holding with the lowest ITR value. The SR-ITR of the ITR-tilted PearMVP in 2024 with the maximum allocation constraint had a maximum at an intermediate NZCP value, which might have helped investors choose the best-in class Energy companies in 2024.

Similar to the NZAS-tilted PartMVP, the ITR-tilted PartMVP in 2024 was much more diversified than the ITR-tilted PearMVP at low NZCP values (see Table 14). Yet, the ITR-tilted PartMVP in 2024, too, had a single holding at very high NZCP values.

Table 13. Performance and weights of the ITR-tilted PearMVP with Wmax=0.1 in 2024[1), 2)].

NZCP	PITR	SR	SR-ITR	Portfolio weights															
				BKR	BP	CNQ	COP	CVX	E	EOG	EQNR	FANG	OKE	OXY	SHEL	TRGP	TRP	TTE	WMB	XOM
0	0.627	1.48	0.55	0.10	0.00	0.00	0.00	0.10	0.00	0.10	0.00	0.10	0.10	0.00	0.10	0.10	0.10	0.00	0.10	0.10
2.0E−03	0.5445	1.33	0.60	0.10	0.10	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.10	0.00	0.10	0.10	0.10	0.00	0.10	0.10
5.0E−03	0.432	0.59	0.33	0.10	0.10	0.00	0.00	0.00	0.00	0.10	0.10	0.00	0.10	0.10	0.10	0.10	0.00	0.00	0.00	0.10
1.0E−02	0.407	0.24	0.14	0.10	0.10	0.00	0.00	0.00	0.00	0.10	0.10	0.00	0.00	0.10	0.10	0.10	0.00	0.10	0.00	0.10
2.0E−02	0.387	−0.30	−0.18	0.10	0.10	0.00	0.10	0.00	0.10	0.10	0.10	0.00	0.00	0.10	0.10	0.00	0.00	0.10	0.00	0.10
5.0E−02	0.387	−0.30	−0.18	0.10	0.10	0.00	0.10	0.00	0.10	0.10	0.10	0.00	0.00	0.10	0.10	0.00	0.00	0.10	0.00	0.10

[1)] Only the holdings with weights dependent on NZCP are listed.

[2)] Maximum SR-ITR is in bold font.

Table 14. Performance and weights of the Energy ITR-tilted PartMVP in 2024[1), 2)].

NZCP	PITR	SR	SR-ITR	Portfolio weights								
				BKR	CVX	E	EOG	FANG	TRGP	VLO	WMB	XOM
0.00E+00	0.615	1.62	0.63	0.06	0.19	0.00	0.03	0.02	0.25	0.09	0.09	0.28
5.00E−05	0.513	2.12	1.03	0.13	0.00	0.00	0.04	0.00	0.41	0.00	0.00	0.41
4.00E−04	0.543	2.68	1.22	0.24	0.00	0.00	0.00	0.00	0.62	0.00	0.00	0.14
6.00E−04	0.587	3.07	1.27	0.15	0.00	0.00	0.00	0.00	0.85	0.00	0.00	0.00
1.00E−02	0.519	2.37	1.14	0.47	0.00	0.00	0.00	0.00	0.53	0.00	0.00	0.00
1.50E−02	0.410	0.92	0.54	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.80E−02	0.384	0.60	0.37	0.70	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.00
2.00E−02	0.33	−0.77	−0.52	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00

[1)] Only the holdings with weights dependent on NZCP are listed.

[2)] Maximum SR and SR-ITR are in bold font.

5. Conclusions

In this work, we offer a new metric, NZAS, which can be helpful to socially responsible investors for their portfolio selection. NZAS is determined by the GHG EI and its ERR and can be used to choose among the companies with high EI and high ERR versus the companies with low EI and low ERR.

We incorporated NZAS into the MVP framework, which yields simultaneous optimization upon portfolio stock returns and volatility, and NZAS. The NZAS contribution to the MVP minimization function is controlled by the NZCP, which is investor's choice. Similar to the NZAS-tilted MVP, we incorporated a widely used climate risk measure, ITR, into MVP and used NZAS-tilted and ITR-tilted MVPs to analyze performance of a portfolio with 24 major holdings of the Energy sector in 2022–2024. The specifics of non-pecuniary risks are that their measures with positive (negative) sentiment may be negatively (positively) correlated with stock returns, which may confuse investors (Schmidt, 2024b; Schmidt and Zhang, 2024). A similar effect was found in this report for NZAS and ITR. That is why we offered to use non-pecuniary risk-tilted Sharpe ratios.

We discerned (the standard) Pearson correlations-based (PearMVP) and partial correlation-based (PartMVP) MVPs. The latter were conditioned using the Energy ETF returns rather than the total market returns as it was done in the past (Cai and Schmidt, 2020). The reason for this was that the energy stock price dynamics in 2022–2024 was very different from the total market proxy dynamics that is heavily overweighed with technology stocks. As a result, the energy PartMVPs were significantly more diversified than the PearMVPs. The ESG-tilted Sharpe ratios often exhibit non-monotonic dependence on the ESG risk, and their maxima can be interpreted as optimal portfolios (Schmidt, 2020). In this work, we found such an effect in NZAS-tilted PartMVPs and ITR-tilted PartMVPs.

While NZAS and ITR have opposite sentiments, their correlations in 2022–2024 were not strongly negative (~ −0.25). As a result, the NZAS-tilted and the ITR-tilted MVPs had overlapping, though not identical, holdings at small and moderate NZCPs. Hence, our approach is rather robust to the choice of climate risk measure. Moreover, very high NZCP values always yielded a single MVP holding with the highest NZAS or the lowest ITR. In our portfolio in 2022–2024, these were BKR and E, respectively.

We also checked the specifics of the NZAS-tilted and ITR-tilted MVPs with the maximum allocation constraint (Wmax=0.1) and found that the portfolios at very high NZCP values had K=1/Wmax holdings with the highest (lowest) NZAS (ITR) values.

In this work, we provide only in-sample results for the Energy portfolio. It would be interesting to do out-of-sample analysis for various industries but, unfortunately, limited data availability has prevented us from doing this so far. At this point, we recommend repeating the process we described here every time investors do portfolio rebalancing, similarly to what we did for the Energy portfolio for the years 2022–2024.

Since MVPs are notoriously highly concentrated, we do not suggest to blindly implement them. As with other non-pecuniary risks that may significantly vary in different industries, we recommend using this approach to find the current best-in-class companies within the chosen equity sectors (Schmidt, 2024b). This may help socially responsible investors choose the companies in "brown" industries with a better net-zero alignment rather than to divest from these industries.

Author contributions

Budha Bhattacharya: Project management, manuscript writing, and review. Maxime Kirgo: Data compilation, computations, and manuscript review. Anatoly Schmidt: Conceptualization, software development, computations, manuscript writing, and review.

Use of AI tools declaration

AI tools were not used.

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Conflict of interest

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Data availability statement

No data besides those provided in the paper are available.

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