Using Net-Zero Alignment Measures for Sustainable Portfolio Choice

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Abstract

We offer a new 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) and, hence, 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 separately NZAS and a widely used climate risk measure, *implied temperature rise* (ITR), into the mean-variance portfolio (MVP) framework. This leads to simultaneous optimization upon the stock price returns and 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 illustrates 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.

Key words: 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 (PAT 2020, 2021; ILB 2020; 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) and 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 recently 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 both ITR and DTE may suffer from various 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 rather than in long-term forecasts.

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*

$$NZAS_i(t) = F*(1+ERR_i(t))/EI_i(t) \quad (1)$$

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. The unit in the numerator of (1) is added to avoid zero value of $NZAS_i$ in case of zero ERR_i. 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)

$$ERR_i = [EI_i(t\text{-}1) - EI_i(t)]/EI_i(t\text{-}1) \quad (2)$$

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.

Another problem for forming a sustainable portfolio is that the correlations between the corporate EI and stock returns are very low or even 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. In order 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 by the same token as many rational investors account for price volatility risk and use portfolio SR rather than returns. Similar ideas for ESG-tilted portfolio performance measures were proposed by Chen & Mussalli (2020), Schmidt (2020), and Alessandrini & Jondeau (2021).

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 for accounting for various non-pecuniary risks (Gasser et al. 2017; Pedersen et al. 2021; Schmidt 2020, 2024a, 2024b; Blitz et al. 2024). In this methodology (sometimes called *3D investing*), portfolio weights are optimized in terms of stock price returns and volatility, and non-pecuniary risks. We also introduced similarly defined ITR-tilted MVPs. 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 NZAS and ITR were available to us.

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 for identifying the best-in-class companies in a given sector for those socially responsible investors who do not want to abandon the carbon-intense industries altogether. Indeed, as Edmans et al. (2022) demonstrated, the optimal divestment strategy from "brown" industries is holding the best-in-class companies rather than total exclusion.

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)

$$U_{MVP} = 0.5\lambda\sigma_p^2 - r_p \qquad (3)$$

In (3), λ is market volatility risk aversion parameter that is chosen in this work for yielding the maximum SR. Portfolio variance σ_p^2 equals

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

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

$$r_p = \sum_{i=1}^{N} w_i r_i \quad (5)$$

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

$$SR = (r_p - r_f)/\sigma_p \quad (6)$$

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)

$$U_{NZAS} = U_{MVP} - \delta * \text{PNZAS} \quad (7)$$

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' $NZAS_i$

$$\text{PNZAS} = \sum_{i=1}^{N} w_i NZAS_i \quad (8)$$

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

$$U_{ITR} = U_{MVP} + \delta * \text{PITR} \quad (9)$$

$$\text{PITR} = \sum_{i=1}^{N} w_i ITR_i \quad (10)$$

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. Then, the derivation of optimal MVP represents the following quadratic programming problem for NZAS-tilted MVP and ITR-tilted MVP, respectively:

$$\min [0.5\lambda \sum_{i,j=1}^{N} w_i w_j \sigma_{ij} - \delta \sum_{i=1}^{N} w_i \, NZAS_i] \quad (11a)$$

$$\min [0.5\lambda \sum_{i,j=1}^{N} w_i w_j \sigma_{ij} + \delta \sum_{i=1}^{N} w_i \, ITR_i] \quad (11b)$$

s.t. $$\sum_{i=1}^{N} w_i r_i = r_p \quad (12)$$

$$\sum_{i=1}^{N} w_i = 1 \quad (13)$$

$$w_i \geq 0;\ i = 1, 2, \ldots, N \quad (14)$$

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. One option to increase MVP diversity is to replace Pearson's correlations in (11) with partial correlations conditioned on the total equity market returns (Nadler & 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 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. Also, the PartMVPs may outperform the PearMVPs and equal-weight portfolios out of sample (Nadler & Schmidt 2014; Cai & Schmidt 2020).

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, Material, and Utility sectors) can significantly differ from that of S&P 500 index that is heavily overweighed 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 energy industry-sensitive 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 allows 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.

We derived the optimal NZAS-tilted MVPs and ITR-tilted MVPs by searching the maximum SR-NZAS and SR-ITR, respectively, in the $\lambda - \delta$ parameter space.

3. The data

To avoid survival bias, portfolio considered in this work was formed with 24 major constituents of the Energy equity sector that were traded in 2022 – 2024 for which the NZAS and ITR values were available to us. The climate risk metrics for these companies 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). 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 (as we indicated above) ITR and NZAS have 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 exactly the reason 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 criteria for investing as long as rational investors strive for increasing their wealth. Hence, a compromise determined with the 3D investing and the climate risk-tilted SRs.

Table 1. Correlations for the Energy portfolio holdings

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 is zero) in 2022 - 2024 were (unsurprisingly) highly concentrated: they had not more than four holdings (out of 24) with the weights of 1% or higher. However, the XLE-conditioned net-zero neutral PartMVPs had 17 and 18 significant weights in 2022 and 2023, respectively (see Table 2; the results for 2024 are described separately).

Table 2. The weights of XLE-conditioned PartMVP with zero NZCP in 2022 and 2023

Year	BKR	COP	CVX	DVN	EOG	EQNR	FANG	HAL	MPC	OKE	OXY	PSX	SHEL	SLB	TRGP	TTE	VLO	WMB	XOM
2022	0.01	0.06	0.20	0.05	0.07	0.01	0.04	0.03	0.03	0.03	0.04	0.04	0.00	0.05	0.01	0.00	0.04	0.06	0.24
2023	0.03	0.04	0.19	0.03	0.07	0.00	0.05	0.02	0.04	0.02	0.05	0.04	0.01	0.04	0.02	0.01	0.03	0.07	0.23

In 2022, the net-zero neutral PearMVP had only three holdings (OXY, MPC, and XOM) due to their relatively high returns (see Table 3). With growing NZCP, these holdings were first replaced with PSX that had a lower return but the 2nd highest NZAS. Finally, at very high NZCP values, Baker Hughes (ticker 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, 2024b; Schmidt and Zhang 2024). The highest SR-NZAS may be interpreted as a pointer to the optimal NZAS-tilted MVP.

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

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 in bold font.

Though net-zero neutral PartMVP had 17 holdings in 2022, only nine of them varied with NZCP (see Table 4). In this PartMVP, both SR and SR-NZAS-tilted had maximums at moderate NZCP.

Table 4. Performance and weights of the Energy 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 5 and 6 for PearMVP and PartMVP, respectively). The important difference, however, was that it was ENI (ticker E) with the lowest ITR that was the only MVP holding at very high NZCPs.

Table 5. Performance and weights of the Energy ITR-tilted PearMVP in 2022[1)]

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-NZAS in bold font.

Table 6. 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	0.07	0.01	0.06	0.03	0.09	0	0.09	0.38
4.00E-04	0.428	1.65	0.94	0.01	0.02	0.29	0	0.05	0	0	0.02	0.19	0.08	0.1	0.24
6.00E-04	0.421	**1.66**	0.96	0	0	0.34	0	0.02	0	0	0	0.27	0.09	0.11	0.16
1.00E-03	0.399	1.6	0.96	0	0	0.38	0	0	0	0	0	0.37	0.17	0.07	0
2.00E-03	0.380	1.58	**0.98**	0	0	0.17	0	0	0	0	0	0.49	0.34	0	0
4.00E-03	0.370	1,52	0.96	0	0	0	0	0	0.09	0	0	0.57	0.34	0	0
1.00E-02	0.365	1.43	0.90	0	0	0	0	0	0.36	0	0	0.64	0	0	0
1.00E-01	0.356	1.10	0.70	0	0	0	0	0	0.67	0	0	0.33	0	0	0
2.00E-01	0.346	0.42	0.39	0	0	0	0	0	1	0	0	0	0	0	0

[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 Appendix).

The specifics of the Energy portfolio performance in 2024 was that the Targa Resources (ticker TRGP) had a very high return comparing to other portfolio holdings. As a result, the net-zero neutral PearMVP had only two holdings with the TRGP weight of 92% (see Table 7).

Table 7. Performance and weights of the Energy NZAS-tilted PearMVP in 2024[1)]

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)] Maximum SR-NZAS in bold font.

Even the net-zero neutral PartMVP in 2024 had just eight holdings vs 17 - 18 holdings in 2022 and 2023 (cf. Table 2 and Table 8). Still, the TRGP weight was significantly diluted due to weaker partial correlations. These qualitative differences in the results for 2022 – 2023 and 2024 remind one the necessity of regular portfolio rebalancing. BKR retained its NZAS leadership in 2024 and, hence, was the only NZAS-tilted PartMVP holding at very high NZCP.

Table 8. Performance and weights of the Energy NZAS-tilted PearMVP in 2024[1)]

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

The ITR-tilted PearMVP holdings in 2024 were similar to that of NZAS-tilted holdings with a difference that Eni (ticker E) with the lowest ITR in our portfolio remained the only holding at very high NZCPs (see Table 9).

Table 9. 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)] Maximum SR-NZAS in bold font.

Similarly to NZAS-tilted PartMVP, the ITR-tilted PartMVP in 2024 was much more diversified than the ITR-tilted PearMVP at low NZCPs (see Table 10).

Table 10. Performance and weights of the Energy ITR-tilted PartMVP in 2024[1)]

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

5. Conclusions

In this work, we offer a new metric, net-zero alignment strength (NZAS), which can be helpful to socially responsible investors for their portfolio selection. NZAS is determined by the GHG emission intensity (EI) and its reduction rate (ERR) and can be used for choosing among the companies with high EI and high ERR versus the companies with low EI and low ERR.

We have 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 net-zero commitment parameter (NZCP), which is investor's choice. Similarly to the NZAS-tilted MVP, we incorporated a widely used climate risk measure, implied temperature rise (ITR), into MVP and used both 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 some non-pecuniary risk-tilted portfolios is that the 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

that explicitly account for these risks along with price volatility used in classical finance. 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 & 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 portfolio PartMVPs were significantly more diversified than the PearMVPs. The ESG-tilted Sharpe ratios often exhibit non-monotonic dependence on NZCP, and their maxima can be interpreted as optimal portfolios (Schmidt 2020). In this work, we found such an effect in the 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 but not identical holdings at small and moderate NZCPs. Very high NZCP values always yield a single MVP holding with the highest NZAS or the lowest ITR. In our portfolio in 2022 – 2024, these were Baker Hughes (ticker BKR) and Eni (E), respectively.

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 to use this approach for finding the current best-in-class companies within the chosen equity sectors (Schmidt 2024b).

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Appendix

Table A1. Net-zero metrics for the Energy sector holdings in 2022

Company	Ticker	NZAS	ITR	SR	SR-NZAS	SR-ITR
BAKER HUGHES	BKR	**1.006**	0.398	0.649	1.303	0.391
BP P.L.C.	BP	0.574	0.394	0.990	1.558	0.600
CANADIAN NATURAL RESOURCES	CNQ	0.192	0.922	1.039	1.238	0.081
CONOCOPHILLIPS	COP	0.839	0.419	1.433	**2.635**	0.833
CHEVRON	CVX	0.415	0.596	1.521	2.152	0.614
DEVON ENERGY	DVN	0.436	0.410	0.974	1.398	0.574
ENI S.P.A.	E	0.421	**0.346**	0.423	0.601	0.276
EOG RESOURCES	EOG	0.726	0.431	1.175	2.029	0.668
EQUINOR ASA	EQNR	0.594	0.384	1.072	1.708	0.660
DIAMONDBACK ENERGY	FANG	0.592	0.670	0.804	1.280	0.265
HALLIBURTON	HAL	0.562	0.761	1.255	1.962	0.300
MARATHON PETROLEUM	MPC	0.386	0.897	1.843	2.555	0.190
ONEOK	OKE	0.437	0.780	0.617	0.886	0.136
OCCIDENTAL PETROLEUM	OXY	0.328	0.375	1.577	2.095	**0.986**
PHILLIPS 66	PSX	0.980	1.000	1.116	2.211	0.000
REPSOL S.A.	REPYY	0.551	0.568	1.087	1.686	0.469
SHELL	SHEL	0.679	0.367	0.968	1.626	0.613
SCHLUMBERGER	SLB	0.816	0.482	1.337	2.428	0.692
TARGA RESOURCES	TRGP	0.202	0.727	1.048	1.259	0.286
TC ENERGY	TRP	0.062	0.944	-0.261	-0.277	-0.015
TOTALENERGIES	TTE	0.508	0.423	0.951	1.434	0.549
VALERO ENERGY	VLO	0.418	0.785	1.418	2.010	0.305
THE WILLIAMS COMPANIES	WMB	0.079	0.919	1.074	1.159	0.087
EXXON MOBIL	XOM	0.360	0.489	**1.875**	2.549	0.958

The lowest ITR, and the highest NZAS, SR-NZAS, and SR-ITR are in bold font.

Table A2. Net-zero metrics for the Energy sector holdings in 2023

Company	Ticker	NZAS	ITR	SR	SR-NZAS	SR-ITR
BAKER HUGHES	BKR	**1.212**	0.397	0.869	**1.923**	0.524
BP P.L.C.	BP	0.348	0.411	0.431	0.581	0.254
CANADIAN NATURAL RESOURCES	CNQ	0.189	0.922	1.064	1.266	0.083
CONOCOPHILLIPS	COP	0.172	0.417	0.360	0.422	0.210
CHEVRON	CVX	0.222	0.600	-0.392	-0.479	-0.157
DEVON ENERGY	DVN	0.221	0.395	-0.394	-0.481	-0.238
ENI S.P.A.	E	0.224	**0.327**	1.138	1.392	**0.766**
EOG RESOURCES	EOG	0.239	0.432	0.212	0.263	0.121
EQUINOR ASA	EQNR	0.367	0.388	0.438	0.598	0.268
DIAMONDBACK ENERGY	FANG	0.172	0.639	0.910	1.067	0.328
HALLIBURTON	HAL	0.368	0.766	0.115	0.157	0.027
MARATHON PETROLEUM	MPC	0.230	0.896	1.207	1.484	0.126
ONEOK	OKE	0.142	0.695	0.757	0.864	0.231
OCCIDENTAL PETROLEUM	OXY	0.108	0.355	0.099	0.110	0.064
PHILLIPS 66	PSX	0.269	1.000	**1.263**	1.603	0.000
REPSOL S.A.	REPYY	0.269	0.579	0.147	0.187	0.062
SHELL	SHEL	0.270	0.366	1.039	1.319	0.659
SCHLUMBERGER	SLB	0.656	0.715	0.256	0.424	0.073
TARGA RESOURCES	TRGP	0.073	0.618	1.052	1.129	0.402
TC ENERGY	TRP	0.064	0.944	0.408	0.434	0.023
TOTALENERGIES	TTE	0.352	0.374	0.747	1.010	0.468
VALERO ENERGY	VLO	0.246	0.774	0.511	0.636	0.115
THE WILLIAMS COMPANIES	WMB	0.053	0.916	0.814	0.858	0.069
EXXON MOBIL	XOM	0.203	0.483	0.003	0.004	0.002

The lowest ITR, and the highest NZAS, SR-NZAS, and SR-ITR are in bold font.

Table A3. Net-zero metrics for the Energy sector holdings in 2024

Company	Ticker	NZAS	ITR	SR	SR-NZAS	SR-ITR
BAKER HUGHES	BKR	**1.004**	0.410	0.917	**1.838**	0.542
BP P.L.C.	BP	0.169	0.340	-0.572	-0.668	-0.378
CANADIAN NATURAL RESOURCES	CNQ	0.294	0.886	-0.010	-0.013	-0.001
CONOCOPHILLIPS	COP	0.311	0.419	-0.620	-0.812	-0.360
CHEVRON	CVX	0.169	0.668	0.087	0.102	0.029
DEVON ENERGY	DVN	0.143	0.426	-1.176	-1.344	-0.675
ENI S.P.A.	E	0.269	**0.327**	-0.773	-0.981	-0.521
EOG RESOURCES	EOG	0.304	0.443	0.203	0.264	0.113
EQUINOR ASA	EQNR	0.196	0.379	-0.547	-0.655	-0.340
DIAMONDBACK ENERGY	FANG	0.337	0.813	0.384	0.514	0.072
HALLIBURTON	HAL	0.347	0.762	-0.853	-1.149	-0.203
MARATHON PETROLEUM	MPC	0.139	0.922	-0.182	-0.207	-0.014
ONEOK	OKE	0.267	0.658	2.004	2.539	0.686
OCCIDENTAL PETROLEUM	OXY	0.121	0.337	-0.805	-0.902	-0.534
PHILLIPS 66	PSX	0.253	1.000	-0.460	-0.577	0.000
REPSOL S.A.	REPYY	0.240	0.458	-0.655	-0.812	-0.355
SHELL	SHEL	0.252	0.366	-0.058	-0.072	-0.037
SCHLUMBERGER	SLB	0.708	0.485	-0.971	-1.659	-0.500
TARGA RESOURCES	TRGP	0.105	0.618	**3.233**	3.571	**1.235**
TC ENERGY	TRP	0.040	0.925	1.215	1.264	0.091
TOTALENERGIES	TTE	0.212	0.403	-0.798	-0.967	-0.476
VALERO ENERGY	VLO	0.146	0.874	-0.062	-0.071	-0.008
THE WILLIAMS COMPANIES	WMB	0.070	0.927	2.495	2.669	0.182
EXXON MOBIL	XOM	0.163	0.443	0.444	0.516	0.247

The lowest ITR, and the highest NZAS, SR-NZAS, and SR-ITR are in bold font.

Table A4. Performance and weights of the Energy NZAS-tilted PearMVP in 2023[1)]

NZCP	PNZAS	SR	SR-NZAS	Portfolio weights					
				BKR	CNQ	E	WMB	MPC	PSX
0.00E+00	0.225	1.42	1.74	0.00	0.02	0.38	0.08	0.18	0.34
5.00E-05	0.252	1.41	1.77	0.02	0.1	0.26	0	0.19	0.43
2.00E-04	0.336	1.36	**1.82**	0.01	0.15	0.00	0.00	0.20	0.64
3.00E-04	0.25	1.33	1.66	0.02	0.09	0.00	0.00	0.17	0.73
4.00E-04	0.238	1.3	1,61	0.00	0.03	0.00	0.00	0.15	0.83
5.00E-04	0.370	1,29	1.76	0.15	0.00	0.00	0.00	0.02	0.83
6.00E-04	0.569	1.25	**1.97**	0.42	0.00	0.00	0.00	0.00	0.58
8.00E-04	0.958	0.92	1.80	0.94	0.00	0.00	0.00	0.00	0.06
1.00E-03	1.004	0.87	1.74	1.00	0.00	0.00	0.00	0.00	0.00

[1)] Maximums SR-NZAS are in bold font.

Table A5. Performance and weights of the Energy NZAS-tilted PartMVP in 2023[1), 2)]

NZCP	PNZAS	SR	SR-NZAS	Portfolio weights					
				BKR	CNQ	E	FANG	MPC	PSX
0.00E+00	0.230	0.34	0.41	0.01	0.00	0.00	0.04	0.03	0.04
5.00E-05	0.493	1.26	1,88	0.33	0.21	0.05	0.07	0.19	0.16
2.00E-04	0.425	**1.32**	1.88	0.25	0.21	0.00	0.00	0.20	0.34
4.00E-04	0.439	1.32	1.90	0.27	0.07	0.00	0.00	0.14	0.53
6.00E-04	0.61	1.23	**1.99**	0.48	0.00	0.00	0.00	0.00	0.52
8.00E-04	0.98	0.90	1.77	0.96	0.00	0.00	0.00	0.00	0.04
1.00E-02	1.00	0.87	1.74	1.00	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.

Table A6. Performance and weights of the Energy ITR-tilted PearMVP in 2023[1)]

NZCP	PITR	SR	SR-ITR	Portfolio weights					
				CNQ	E	MPC	PSX	SHEL	WMB
0.00E+00	0.723	1.42	0.39	0.02	0.38	0.18	0.34	0.00	0.08
5.00E-05	0.692	1.42	0.44	0.00	0.43	0.24	0.33	0.00	0.00
1.00E-04	0.688	1.42	0.44	0.00	0.43	0.27	0.30	0.00	0.00
2.00E-04	0.679	1.41	0.45	0.00	0.44	0.33	0.23	0.00	0.00
4.00E-04	0.681	1.39	0.44	0.00	0.42	0.47	0.11	0.00	0.00
8.00E-04	0.334	1.16	**0.77**	0.00	0.81	0.00	0.00	0.19	0.00
1.00E-03	0.331	1.15	0.77	0.00	0.90	0.00	0.00	0.10	0.00
1.20E-03	0.327	1.14	0.77	0.00	1.00	0.00	0.00	0.00	0.00

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

Table A7. Performance and weights of the Energy ITR-tilted PartMVP in 2023[1), 2)]

NZCP	PITR	SR	SR-ITR	Portfolio weights							
				BKR	CNQ	E	MPC	OXY	PSX	SHEL	TRGP
0.00E+00	0.609	0.34	0.13	0.03	0.00	0.00	0.04	0.05	0.04	0.01	0.02
5.00E-05	0.633	1.35	0.49	0.14	0.12	0.27	0.25	0.00	0.08	0.06	0.09
1.00E-04	0.661	1.37	0.47	0.08	0.14	0.37	0.32	0.00	0.08	0.00	0.00
2.00E-04	0.733	**1.38**	0.37	0.00	0.13	0.32	0.47	0.00	0.09	0.00	0.00
3.00E-04	0.725	1.36	0.37	0.00	0.04	0.34	0.57	0.00	0.05	0.00	0.00
4.00E-04	0.61	1.36	0.53	0.00	0.00	0.52	0.48	0.00	0.00	0.00	0.00
8.00E-04	0.41	1.24	0.73	0.00	0.00	0.86	0.14	0.00	0.00	0.00	0.00
1.00E-03	0.329	1.13	0.76	0.00	0.00	0.92	0.00	0.02	0.00	0.06	0.00
6.00E-03	0.328	1.06	0.71	0.00	0.00	0.90	0.00	0.10	0.00	0.00	0.00
1.00E-02	0.327	1.14	**0.77**	0.00	0.00	1.00	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.