Sustainability Aware Asset Management

Project: Asset Allocation with a Carbon Objective

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Part 1: Standard Asset Allocation

1.1 Rolling window optimization

Data preprocessing

In preparation for optimizing the weights over a rolling window of 6 years, our initial step involved meticulous data preprocessing. We began by scrutinizing the dataset of historical prices, aiming to identify stocks with zero prices at any point in the data. The rationale behind this step was twofold:

Firstly, to exclude companies that had permanently ceased operations, as investing in such entities wouldn't reflect real-time market conditions.

Secondly, to eliminate firms that had undergone bankruptcy but were subsequently acquired by other entities, leading to a resurgence in stock prices from zero. In such cases, treating these firms as ongoing entities would distort the optimization process.

Upon identifying such stocks, we proceeded to filter out these instances, thereby refining our dataset. Subsequently, when converting the dataset into monthly returns, we encountered NaN values due to this transformation for the first month of the dataset. To address this, we removed the NaN values of the first month.

Following this data filtering process, our portfolio size reduced marginally from 2052 assets to 2033, which, relative to the initial size, was a negligible reduction.

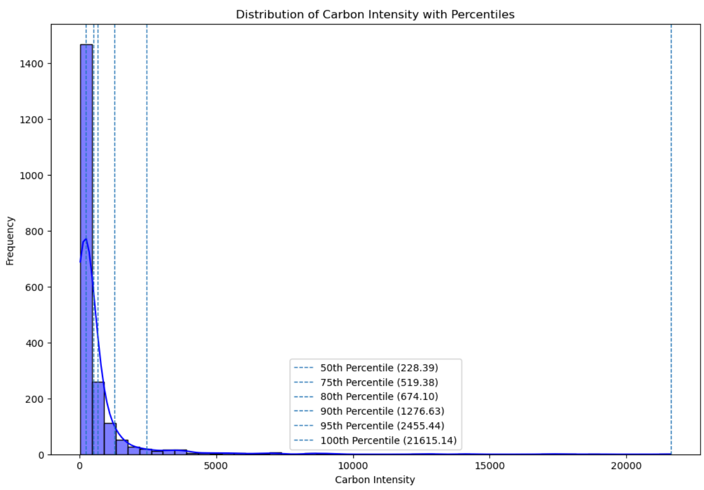

Figure 1

Figure 1 represents the distribution of carbon intensity for the full dataset, which includes all industry sectors. From this distribution, we observe the following quantiles:

- 50th Percentile: ~228
- 75th Percentile: ~519
- 80th Percentile: ~674
- 90th Percentile: ~1277

- 95th Percentile: ~2455
- 100th Percentile: ~21615

The histogram shows that the majority of firms have low carbon intensity, with a steep drop-off as intensity increases. The higher percentiles (90th, 95th, and 100th) show significant jumps, indicating the presence of firms with extremely high carbon intensities, which skew the distribution.

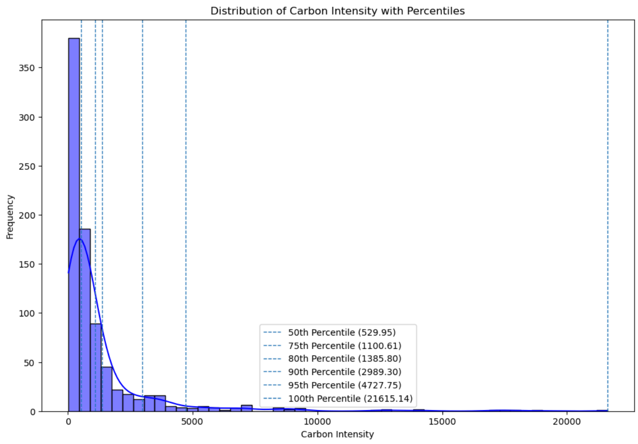

Figure 2

Figure 2 focuses on the distribution of carbon intensity after filtering to retain only highly polluting sectors: 'Energy', 'Materials', 'Utilities', and 'Industrials'. This reduced the size of our dataset from 2033 assets to 833 assets. The quantiles for this filtered dataset are:

- 50th Percentile: ~2301
- 75th Percentile: ~3626
- 80th Percentile: ~4853
- 90th Percentile: ~7984
- 95th Percentile: ~14768
- 100th Percentile: ~21615

This histogram also has a similar distribution of carbon intensity but with a less steep drop-off compared to the full dataset. The upper quantiles are significantly higher, reflecting the higher carbon intensity of firms in these sectors.

For the entire project, we will focus exclusively on high-polluting sectors: 'Energy', 'Materials', 'Utilities', and 'Industrials'. This approach ensures that our analysis targets the sectors with the most substantial environmental impact, aligning with our goal to understand and manage carbon-intensive investments better.

Optimization

An important consideration was the adjustment for tau = 71 for the initial window, necessitated by the absence of price data for December 1999, thereby precluding the computation of returns for January 2000. This adjustment ensured the consistency and accuracy of our optimization process to keep yearly optimized weights within the beginning

and the end of the year.
The optimization process was done 17 times in total, reflecting the progress of the rolling window with an end date from 2005 to 2022. In between each yearly optimization, the obtained optimized yearly weights were used to update the monthly weights of the following year. Then the ex post portfolio monthly returns of the optimized portfolio were computed by multiplying the updated monthly weight with the next month return.

This optimization process was done similarly for the other portfolios, only specified changes such as constraints or objectives to minimize were adapted for the other parts of the project.

Results

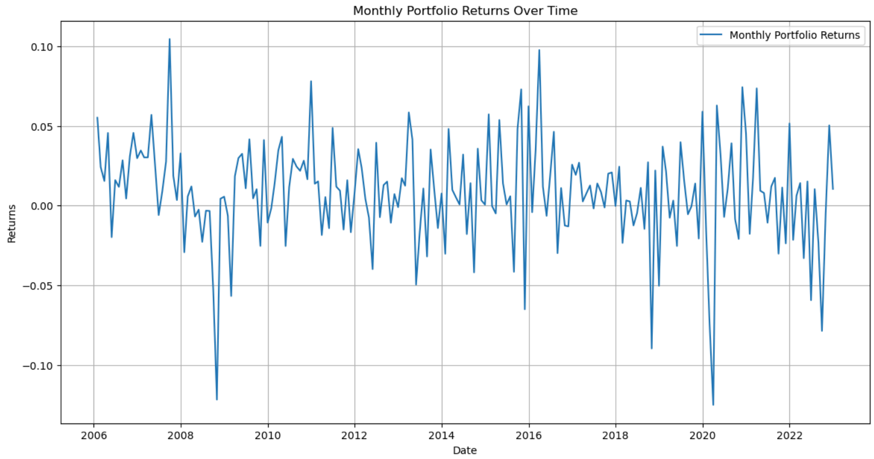

Figure 3

The portfolio exhibits significant volatility in its monthly returns, as seen from the large fluctuations above and below the zero return line. The returns show periods of high positive returns interspersed with notable negative returns, indicating a fluctuating performance.

The most significant downturn is observed around the 2008 financial crisis, where returns dropped below -10%. This period reflects the impact of the global economic downturn on the portfolio. Another notable period of volatility is during the early 2020s, coinciding with the COVID-19 pandemic, where both high positive and negative returns are observed.

Despite the fluctuations, there are multiple periods where the portfolio achieved monthly returns of around 5% or higher. These spikes in returns suggest that the portfolio was able to capitalize on certain market conditions effectively. After significant downturns, such as in 2008 and 2020, the portfolio shows a consistent recovery pattern. The rebounds in the returns post these crises indicate resilience in the portfolio structure.

The returns are relatively more stable in the later years, particularly from 2016 to 2022, where we observe fewer extreme positive or negative returns compared to the earlier period. This stability might be indicative of improved market conditions or adjustments in the portfolio strategy to mitigate volatility. Given that the portfolio is optimized for minimum variance, the presence of significant drawdowns during market crises suggests that while the portfolio may reduce overall risk, it is not immune to systemic market risks.

In conclusion the MVP portfolio demonstrates the complexities of balancing risk and return.

While it achieves periods of high returns, it also faces substantial volatility, particularly during global economic downturns. The overall trend suggests a resilient recovery capability and relatively stable returns in the later years, reflecting effective risk management and optimization strategies.

1.2 Benchmark comparison

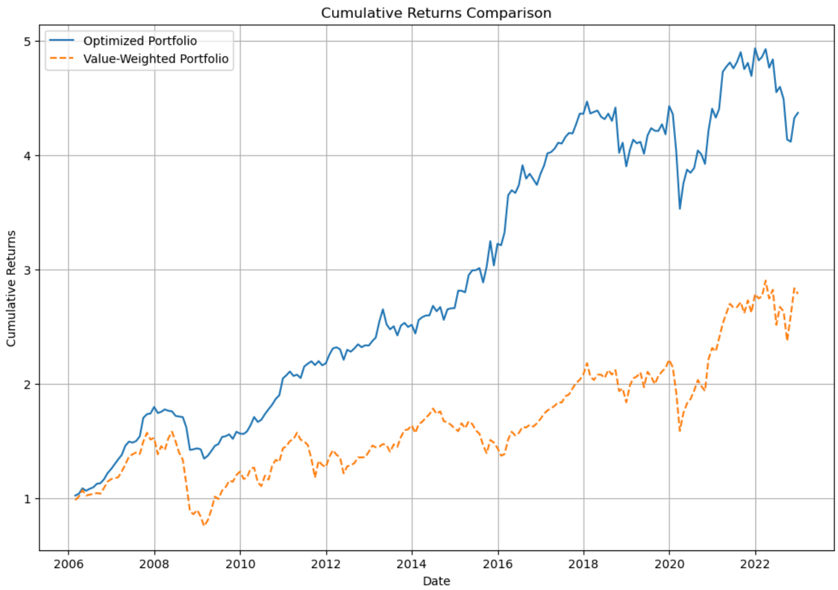

Figure 4

The cumulative returns of the optimized portfolio consistently outperform the value-weighted portfolio over the sample period from 2006 to 2022 despite being optimized for minimizing the risks. The optimized portfolio shows a steady growth, peaking significantly higher than the benchmark.

The value-weighted portfolio experiences more pronounced volatility, particularly during the financial crises around 2008 and the COVID-19 pandemic in 2020, as seen in the dips in cumulative returns.

The summary statistics are:

	Annualized Returns	Annualized Volatilities	Sharpe Ratio	Max Drawdown	Max returns	Min returns
MVP Portfolio	0.096632	0.113033	0.854904	-0.251175	0.104632	-0.125107
Value Weighted Portfolio	0.077248	0.180051	0.429034	-0.52156	0.14335	-0.211152

Figure 5

The optimized portfolio has an annualized return of 9.66%, compared to 7.72% for the value-weighted portfolio. This indicates that the optimized portfolio yields higher average yearly returns, likely due to better risk management and allocation efficiency. It also has a lower annualized volatility (11.30%) compared to the value-weighted portfolio (18.01%). Lower volatility suggests that the optimized portfolio is more stable and less exposed to market fluctuations.

The Sharpe Ratio of the optimized portfolio is significantly higher at 0.85, compared to 0.43 for the value-weighted portfolio. This implies that the optimized portfolio provides better risk-adjusted returns, making it a more attractive investment option for risk-averse investors.
The maximum drawdown for the optimized portfolio is -25.12%, much lower than the -52.16% for the value-weighted portfolio. This indicates that the optimized portfolio is more resilient during market downturns, recovering more quickly and reducing potential losses.
The maximum monthly return for the optimized portfolio is 10.46%, slightly lower than the 14.34% for the value-weighted portfolio. However, the minimum return for the optimized portfolio is -12.51%, less severe than the -21.12% for the value-weighted portfolio. This suggests that the optimized portfolio manages extreme positive and negative returns more effectively.

In conclusion the optimized portfolio clearly outperforms the value-weighted portfolio in terms of cumulative returns, risk-adjusted returns (Sharpe Ratio), and risk management (lower volatility and drawdown). These results demonstrate the effectiveness of the minimum variance optimization approach, which focuses on reducing portfolio risk while still being able to maintain competitive returns. The optimized portfolio provides a more stable and less volatile investment compared to the value-weighted benchmark, making it a superior choice for investors seeking a balanced risk-return profile.

Part 2: Asset Allocation with Carbon Emissions Reduction

In this part we aim to focus on the implementation of the climate dimension to a portfolio. To do that we need the carbon emissions of the firms and their scopes. First we have to understand the different scopes and what they mean:

- **Scope 1**: Direct emissions from owned or controlled sources (e.g., emissions from combustion in owned or controlled boilers, furnaces, vehicles).
- **Scope 2**: Indirect emissions from the generation of purchased electricity, steam, heating, and cooling consumed by the reporting company.
- **Scope 3**: All other indirect emissions that occur in a company’s value chain (e.g., emissions associated with the production of purchased goods and services, business travel, employee commuting, waste disposal, etc.).

We have to define what carbon intensity is. That will allow us to calculate our weighted-average carbon intensity (WACI) . The carbon intensity is defined as the total carbon emission of a company divided by its revenue. It is a volume of carbon emission(in tons of CO_2) per million of dollars of revenue (tCO_2e/mln \$). And the carbon intensity of a portfolio is just the sum multiplied by the fraction of the equity of the firm held in the portfolio.

2.1 WACI and CF calculations

The Weighted-Average Carbon Intensity (WACI) of a portfolio is a measure that provides an average of the carbon emissions intensities of all the firms within an investment portfolio, weighted by their respective share in the portfolio. It's calculated using the formula as follow:

$$WACI_Y^{(p)} = \sum_{i=1}^{N} \alpha_{i,Y} CI_{i,Y} \quad (1)$$

Where:
- $\alpha_{i,Y}$ is the proportion of the portfolio's value that is invested in firm *i* in year *Y*
- $CI_{i,Y}$ is the carbon intensity of firm *i* in year *Y*, in tons of CO2 per millions (usd) of revenue.

This measure essentially aggregates the carbon emissions per dollar of revenue of each firm, weighted by how much the portfolio is invested in each firm. It provides an insight into the average 'carbon cost' of generating revenue across the entire portfolio. The values of our calculation for the **WACI** are as follow:

Date	Value
2005.0	2610.928151
2006.0	2344.01262
2007.0	1880.591942
2008.0	1740.676628
2009.0	2234.804903
2010.0	2214.813844
2011.0	2207.590374
2012.0	1993.916785
2013.0	2612.834348
2014.0	4990.976861
2015.0	1755.719794
2016.0	1754.774189
2017.0	1766.372538
2018.0	1238.755858
2019.0	1904.240073
2020.0	1806.57973
2021.0	1531.512183

Figure 6

The Weighted Average Carbon Intensity (WACI) values are quite big but this seems logical with the sample that we chose, the highly polluting firms.

Year-to-year fluctuations in WACI highlight the dynamic nature of the portfolio’s composition, which may result from adjustments in investment strategies, such as divesting from high-emission sectors or increasing allocations to greener industries. The highest variation value occurs in 2014 at approximately 4990.98 tons of CO2 equivalent and the lowest value in 2021 at about 1531.51 tons. This significant peak in 2014 indicates a period of higher carbon intensity within the portfolio, possibly due to increased holdings in carbon-intensive industries. Conversely, the decline to the lowest value in 2021 reflects a substantial shift towards less carbon-intensive investments.

From 2016 to 2021, a generally declining trend in carbon intensity is observable. This trend aligns with the global movement towards sustainability and suggests an increased emphasis on incorporating environmentally friendly investments. The decline in WACI during these years indicates a strategic effort to reduce the portfolio’s carbon footprint, demonstrating responsiveness to the growing importance of environmental sustainability in investment decisions.

Overall, the WACI data underscores the portfolio's commitment to integrating sustainability principles, reflecting an adaptive approach to evolving environmental standards.

Next, we'll look at the carbon footprint of the portfolio (CF), as expressed in the formula:

$$CF_Y^{(p)} = \frac{1}{V_Y} \sum_{i=1}^{N} o_{i,Y} E_{i,Y} \tag{2}$$

Where:
- V_Y is the total dollar value of the portfolio in year *Y*
- $o_{i,Y}$ is the fraction of the firm *i* 's equity owned by the portfolio in year *Y*
- $E_{i,Y}$ is the total carbon emissions of firm *i* in year *Y,* in tons of CO2 equivalent.

This formula assigns a portion of each firm's total carbon emissions to the portfolio, proportional to the share of the firm's equity held by the portfolio. The values of our calculation for the **CF** are as follow:

Date	Value
2005.0	2294.113818
2006.0	1918.716846
2007.0	1149.012491
2008.0	1503.547602
2009.0	1505.398305
2010.0	1309.540402
2011.0	1492.514462
2012.0	1514.353475
2013.0	2223.421905
2014.0	4796.158677
2015.0	1426.02858
2016.0	3892.348107
2017.0	8027.000595
2018.0	1033.270355
2019.0	9007.804348
2020.0	4649.428996
2021.0	2671.357619

Figure 7

The Carbon Footprint (CF) values illustrate the change in portfolio intensity resulting from changes in the fraction of ownership in individual companies. Most years show substantial CF values, indicating that the portfolio's investments were predominantly in companies with high direct carbon emissions relative to the amount invested, and in industries that are carbon-intensive. These values reflect significant emissions due to the portfolio's focus on highly polluting firms.

Notable exceptions include 2014, 2016, 2017, 2019, and 2020, where CF values are particularly high (approximately 4796.16, 3892.35, 8027.00, 9007.80, and 4649.43 respectively). These spikes suggest either an increased equity ownership in more carbon-intensive companies during those years, changes in regulations, changes in reporting standards, or significant emission events or operational changes that increased their carbon output.

The generally high CF values in other years align with the portfolio's strategy of investing in highly polluting firms. These values reflect the nature of the investments, where even minor changes in the portfolio composition can lead to noticeable fluctuations in the carbon footprint. The trend observed emphasizes the portfolio's significant environmental impact due to its focus on high-emission sectors.

2.2 Long-only MVP portfolio with Carbon Footprint

In this part, we focus on incorporating environmental considerations into our portfolio optimization process calculated in point 1.1. Specifically, we aim to construct a Minimum Variance Portfolio (MVP) that not only minimizes volatility but also accounts for carbon emissions. This approach is intended to align the portfolio with sustainable investment principles by reducing its carbon footprint. We will construct an optimal long-only portfolio with a carbon footprint 50% below the carbon footprint of the initial optimal long-only portfolio. We will compare the performance of the traditional MVP with the carbon-constrained MVP to evaluate the impact of integrating carbon constraints on portfolio performance.

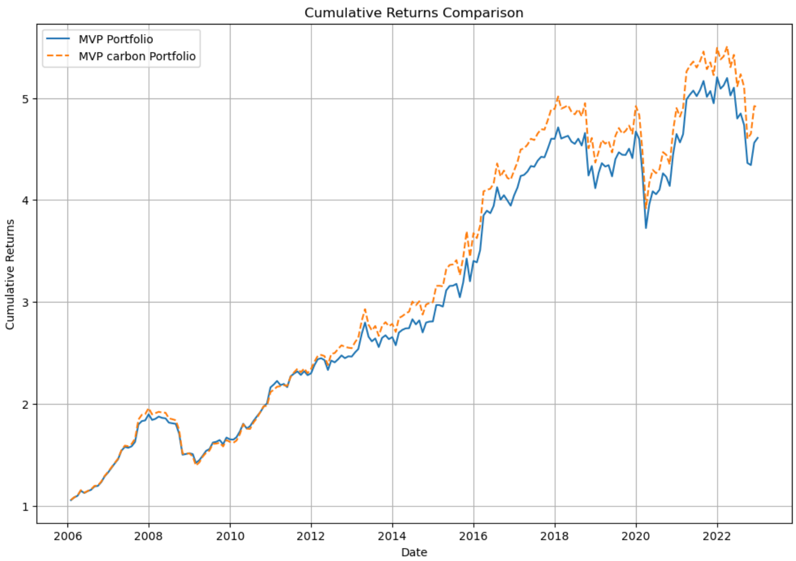

Figure 8

The graph presents a comparison of the cumulative returns between the traditional MVP Portfolio and the MVP Carbon Portfolio from January 2006 to December 2022. Both portfolios show a similar upward trend in cumulative returns, indicating overall growth in the investments over the period.

The MVP Carbon Portfolio generally outperforms the traditional MVP Portfolio, especially noticeable from around 2013 onwards. The divergence between the two portfolios becomes more pronounced during market recoveries, such as after the 2008 financial crisis and the 2020 COVID-19 pandemic.

The summary statistics are:

	Annualized Returns	Annualized Volatilities	Sharpe Ratio	Max Drawdown	Max returns	Min returns
MVP Portfolio	0.096632	0.113033	0.854904	-0.251175	0.104632	-0.125107
MVP carbon Portfolio	0.1008	0.116229	0.867249	-0.288016	0.11276	-0.133274

Figure 9

The traditional MVP Portfolio has an annualized volatility of 0.113033, while the MVP Carbon Portfolio has a slightly higher annualized volatility of 0.116229. This indicates that incorporating carbon constraints has introduced a marginal increase in portfolio volatility.The Sharpe Ratio for the MVP Portfolio is 0.854904, whereas for the MVP Carbon Portfolio, it is 0.867249. The higher Sharpe Ratio of the MVP Carbon Portfolio suggests that, despite the slightly higher volatility, it has achieved better risk-adjusted returns compared to the traditional MVP Portfolio.

The maximum drawdown for the MVP Portfolio is -0.251175, while for the MVP Carbon Portfolio, it is -0.288016. Although the MVP Carbon Portfolio has a slightly higher max drawdown, indicating greater peak-to-trough decline, it still recovers and outperforms the traditional MVP Portfolio over the long term. The MVP Portfolio has a maximum monthly return of 0.104632 and a minimum monthly return of -0.125107. The MVP Carbon Portfolio, on the other hand, has a higher maximum return of 0.112760 and a slightly lower minimum return of -0.133274. These extremes reflect the higher volatility in the MVP Carbon Portfolio, but also its potential for higher returns.

In conclusion the analysis reveals that the MVP Carbon Portfolio, while slightly more volatile, generally outperforms the traditional MVP Portfolio in terms of cumulative returns and risk-adjusted performance (Sharpe Ratio) which is not especially incoherent because the MVP Portfolio has been optimized for minimum volatility and not for maximizing returns.
The introduction of carbon constraints has led to a portfolio that aligns better with sustainable investment goals without significantly sacrificing performance (only slightly worse volatility). This demonstrates the viability of incorporating environmental considerations into portfolio optimization, achieving financial and sustainability objectives.

2.3 Tracking Error of the Value Weighted Portfolio

In this part we aim to optimize the portfolio by minimizing the tracking error relative to the Value Weighted Portfolio. Tracking error measures the deviation of the portfolio's returns from the benchmark returns. The goal is to create a portfolio that closely follows the benchmark but potentially achieves better risk-adjusted performance. We compare the performance of the TE VW Portfolio against the Value Weighted Portfolio to evaluate the effectiveness of this optimization strategy.

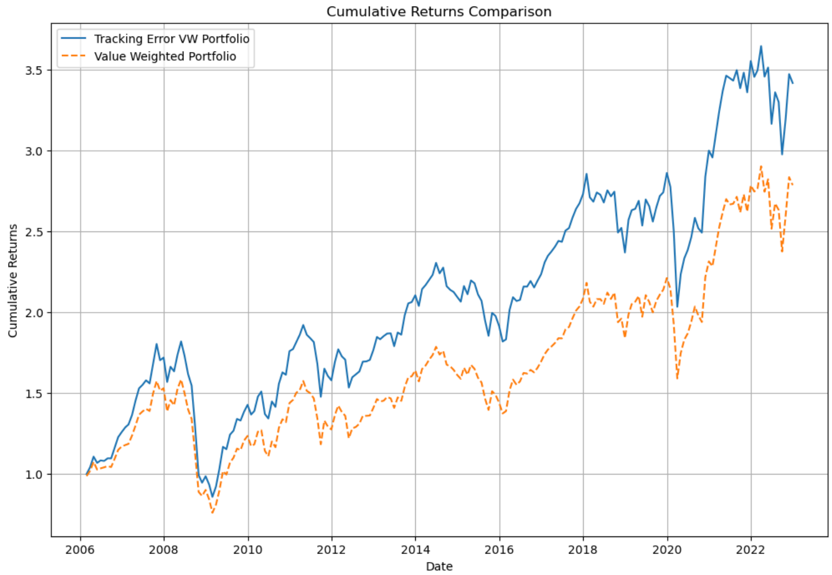

Figure 10

The graph presents a comparison of the cumulative returns between the TE VW Portfolio and the Value Weighted Portfolio from January 2006 to December 2022. The TE VW Portfolio shows a consistent upward trend, outperforming the Value Weighted Portfolio over the entire period. The divergence between the two portfolios becomes particularly noticeable post-2012, indicating the effectiveness of the tracking error optimization strategy.

The summary statistics are:

	Annualized Returns	Annualized Volatilities	Sharpe Ratio	Max Drawdown	Max returns	Min returns
Value Weighted Portfolio	0.077248	0.180051	0.429034	-0.52156	0.14335	-0.211152
Tracking Error VW Portfolio	0.089561	0.180393	0.496476	-0.529423	0.138809	-0.233124

Figure 11

Both portfolios exhibit similar levels of volatility, as reflected in their annualized volatilities (0.180051 for the Value Weighted Portfolio and 0.180393 for the TE VW Portfolio). This indicates that the tracking error optimization did not significantly alter the risk profile in terms of volatility.

The TE VW Portfolio has a higher Sharpe Ratio (0.496476) compared to the Value Weighted Portfolio (0.429034). This suggests that the TE VW Portfolio has better risk-adjusted returns, achieving higher returns for a given level of risk.

The maximum drawdown for the TE VW Portfolio is -0.529423, slightly higher than the Value Weighted Portfolios -0.521560. Despite this, the overall outperformance in cumulative returns suggests that the portfolio recovers more effectively from drawdowns.

The maximum monthly return for the Value Weighted Portfolio is 0.143350, while for the TE VW Portfolio, it is slightly lower at 0.138809.The minimum monthly return for the TE VW Portfolio is -0.233124, compared to -0.211152 for the Value Weighted Portfolio.The slightly higher maximum returns and lower minimum returns indicate that the TE VW Portfolio, while closely tracking the benchmark, can still experience greater variability in extreme market conditions.

In conclusion the analysis reveals that the TE VW Portfolio successfully tracks the Value Weighted Portfolio while achieving higher cumulative returns and better risk-adjusted performance (higher Sharpe Ratio). Despite the similar levels of volatility, the TE VW Portfolio's optimization for tracking error allows it to closely follow the benchmark while still enhancing returns. This demonstrates the effectiveness of the MVP portfolio by showing the difference between the return fluctuations of both portfolios. Here the high error indicates that the MVP portfolio substantially beat the benchmark. This approach provides a balanced strategy, maintaining a close resemblance to the benchmark while achieving superior performance metrics.

2.4 Trade-off between financial performance and CF reduction

In this part, we analyze the trade-off between financial performance and carbon footprint reduction by comparing the portfolios constructed in parts 2.2 and 2.3. Specifically, we look at the Minimum Variance Portfolio (MVP) with a 50% carbon reduction and the portfolio optimized to minimize tracking error relative to the Value Weighted (VW) Portfolio, also with a carbon footprint reduction target of 50%. The values of our calculation are as follow:

Date	MVP CF CF	MVP CF WACI	VW CF	VW WACI	TE CF	TE WACI
2005.0	1147.056099	2332.686279	1285.215598	1345.47596	687.414567	778.719819
2006.0	959.358423	1836.198841	1001.730227	1256.074054	569.665165	719.15149
2007.0	574.506245	1138.004929	881.179537	1192.400734	485.205783	758.535797
2008.0	751.773801	966.937824	1629.484468	1068.922004	853.480654	667.324933
2009.0	752.699153	1438.295057	1104.220599	1139.935201	601.235234	813.289646
2010.0	654.772021	1577.407017	1034.771897	1076.432233	532.266622	706.639103
2011.0	746.257231	1630.438218	1291.957731	1003.395359	675.014817	646.970292
2012.0	757.176737	1482.931723	1147.99324	979.809706	615.553338	633.355212
2013.0	1111.710952	1902.767526	1060.113327	962.622526	549.38948	629.611969
2014.0	2398.079339	5105.881611	1047.407501	993.446596	564.526542	742.969038
2015.0	713.01429	1128.552083	1369.001601	1009.962405	599.210526	700.394506
2016.0	1946.174053	1540.995096	1044.367894	1068.457577	529.31468	762.078371
2017.0	4013.520297	1425.537005	875.642041	1005.923917	467.989924	718.091064
2018.0	516.635177	758.118149	1032.384864	935.394068	567.333028	696.533817
2019.0	4503.902174	1606.847994	958.436897	894.846495	466.803247	651.083193
2020.0	2299.02679	1664.223979	884.1747	842.618647	403.679661	598.995033
2021.0	1335.678809	1199.522843	788.698599	842.618647	394.349299	579.19578

Figure 12

MVP Carbon Portfolio: Incorporating carbon constraints into the MVP resulted in slightly higher volatility but improved risk-adjusted returns. This demonstrates that sustainable investment practices can enhance portfolio performance while aligning with environmental objectives.

Tracking Error VW Portfolio: The tracking error optimization strategy effectively improved returns and risk-adjusted performance while closely following the benchmark. However, this approach introduced greater return variability and higher drawdowns.

Comparison of MVP and Tracking Error Portfolios : Comparing the MVP Portfolio and the Tracking Error VW Portfolio reveals that the MVP Portfolio generally outperforms the Tracking Error VW Portfolio over the entire period. This is consistent with the MVP's focus on minimizing volatility and achieving stable returns.

The MVP Carbon Portfolio exhibits significant fluctuations in both WACI and CF, reflecting a focused effort to reduce carbon intensity over time. This indicates a strategic shift towards more sustainable investments.

The VW Portfolio exhibits significant fluctuations in both WACI and CF, reflecting periods of high exposure to carbon-intensive industries. This indicates a less consistent focus on reducing carbon emissions.

The TE VW Portfolio shows a clear declining trend in both WACI and CF, indicating a strategic shift towards less carbon-intensive investments

Overall, the MVP Carbon Portfolio aligns better with sustainable investment goals without significantly sacrificing performance. The TE VW Portfolio offers a balanced strategy that enhances returns while maintaining close alignment with the benchmark, although it incurs higher volatility and drawdowns. The TE VW portfolio in this case is a good indicator of performance for an asset manager that wants to prove that his portfolio consistently beats the benchmark portfolio.

Part 3: Allocation with a Net Zero Objective

3.1 Net Zero Objective Portfolio

In this section, we focus on the Zero Net Portfolio and compare its performance to the Tracking Error VW Portfolio. The Zero Net Portfolio aims to achieve net-zero carbon emissions while optimizing for tracking error relative to the Value Weighted Portfolio.

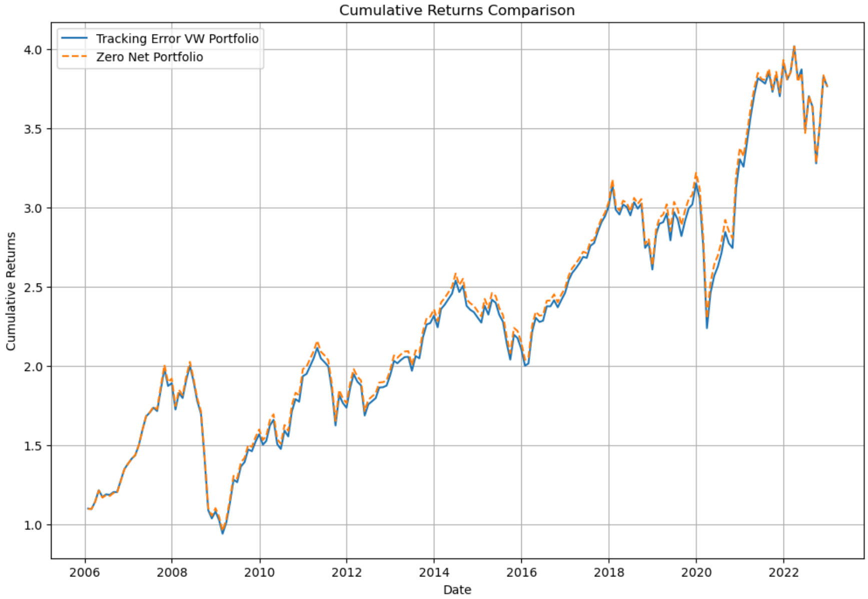

Figure 13

The figure 13 compares the cumulative returns of the Zero Net Portfolio and the Tracking Error VW Portfolio from January 2006 to December 2022. Both portfolios show a similar upward trend in cumulative returns, closely tracking each other throughout the period. The portfolios exhibit strong growth, particularly noticeable after the 2008 financial crisis and the 2020 COVID-19 pandemic.

The close alignment in cumulative returns between the two portfolios suggests that the Zero Net Portfolio successfully maintains performance parity with the Tracking Error VW Portfolio, despite the additional constraint of achieving net-zero carbon emissions.

The summary statistics are:

	Annualized Returns	Annualized Volatilities	Sharpe Ratio	Max Drawdown	Max returns	Min returns
Net Zero Portfolio	0.094931	0.180949	0.524626	-0.5261	0.14137	-0.230424
Tracking Error VW Portfolio	0.095068	0.181375	0.524152	-0.529423	0.138809	-0.233124

Figure 14

The Net Zero Portfolio has an annualized return of 0.094931, while the Tracking Error VW Portfolio has a slightly higher annualized return of 0.095068. The marginal difference indicates that the introduction of net-zero constraints does not significantly impact the portfolio's ability to generate returns.

The annualized volatility of the Net Zero Portfolio is 0.180949, compared to 0.181375 for the Tracking Error VW Portfolio. Both portfolios exhibit similar volatility levels, indicating that the net-zero constraint does not add significant risk in terms of return variability.

The Sharpe Ratio for the Net Zero Portfolio is 0.524626, marginally higher than the Tracking Error VW Portfolio's 0.524152. This suggests that the Net Zero Portfolio achieves slightly better risk-adjusted returns, demonstrating effective management of return and risk despite the net-zero constraint.

The Net Zero Portfolio experiences a maximum drawdown of -0.526100, slightly lower than the Tracking Error VW Portfolio's -0.529423. This indicates that the Net Zero Portfolio is slightly more resilient during market downturns. The Net Zero Portfolio has a maximum monthly return of 0.141370 and a minimum monthly return of -0.230424, compared to 0.138809 and -0.233124 for the Tracking Error VW Portfolio, respectively. These figures highlight that both portfolios exhibit similar return extremes, with the Net Zero Portfolio showing marginally higher maximum returns and slightly lower minimum returns.

We can further analyze by looking at the WACI and CF indicators :

Date	CF NZ	WACI NZ
2005.0	1237.346221	1238.41241
2006.0	1113.611599	1228.347348
2007.0	1002.250439	1277.604744
2008.0	902.025395	700.586194
2009.0	811.822856	996.476067
2010.0	730.64057	885.122417
2011.0	657.576513	634.204314
2012.0	591.818862	614.634926
2013.0	532.636976	614.061381
2014.0	479.373278	645.841283
2015.0	431.43595	522.57002
2016.0	388.292355	591.571427
2017.0	349.463128	574.770258
2018.0	314.516808	452.309191
2019.0	283.065127	455.548623
2020.0	254.758614	451.176639
2021.0	229.282753	416.244864

Figure 15

The NZ Portfolio shows a consistent and significant reduction in both WACI and CF, indicating a strong and sustained focus on minimizing carbon emissions and aligning with net-zero goals.
The analysis reveals that the Zero Net Portfolio closely tracks the performance of the Tracking Error VW Portfolio while achieving net-zero carbon emissions. Despite the additional environmental constraint, the Net Zero Portfolio maintains comparable returns and volatility levels, demonstrating effective integration of sustainability objectives without compromising financial performance. The slight edge in risk-adjusted returns (Sharpe Ratio) and resilience during drawdowns further underscores the viability of achieving both financial and sustainability goals.

This analysis put in evidence the potential for portfolios to align with environmental goals, such as net-zero carbon emissions, while still delivering competitive financial performance.

3.2 Comparison of the three VW Portfolios versions

In this part, we extend our analysis by comparing the performance of the Value Weighted Portfolio, Tracking Error VW Portfolio, and the Zero Net Portfolio. The objective is to evaluate the effectiveness of the tracking error optimization while incorporating a net-zero carbon emissions constraint.

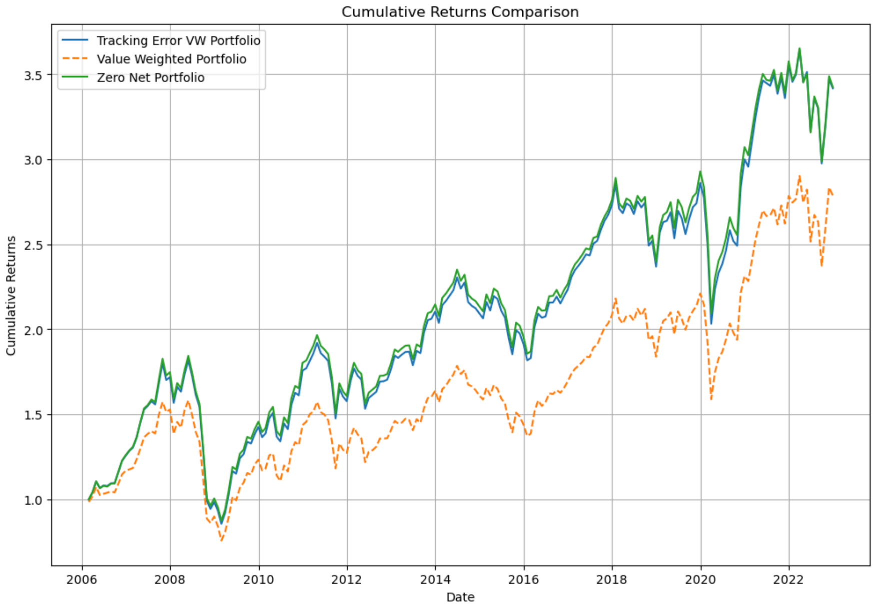

Figure 16

The graph presents the cumulative returns of the three portfolios from February 2006 to December 2022.

The Value Weighted Portfolio exhibits a steady upward trend but underperforms compared to the other two portfolios. Both the Tracking Error VW Portfolio and the Zero Net Portfolio closely follow each other, demonstrating strong performance and significant growth, particularly post-2012. The Zero Net Portfolio slightly outperforms the Tracking Error VW Portfolio in the later years, indicating that the net-zero carbon constraint did not hinder performance.

The summary statistics are:

	Annualized Returns	Annualized Volatilities	Sharpe Ratio	Max Drawdown	Max returns	Min returns
Value Weighted Portfolio	0.077248	0.180051	0.429034	-0.52156	0.14335	-0.211152
Tracking Error VW Portfolio	0.095068	0.181375	0.524152	-0.529423	0.138809	-0.233124
Net Zero Portfolio	0.094931	0.180949	0.524626	-0.5261	0.14137	-0.230424

Figure 17

Value Weighted Portfolio: While it has the lowest annualized returns and Sharpe Ratio, it also shows slightly lower volatility, making it a less aggressive but steady performer.

Tracking Error VW Portfolio: This portfolio achieves higher returns and better risk-adjusted performance compared to the Value Weighted Portfolio. However, it exhibits slightly higher volatility and maximum drawdown.

Zero Net Portfolio: Despite incorporating a net-zero carbon constraint, this portfolio closely matches the performance of the Tracking Error VW Portfolio, with marginally better risk-adjusted returns and slightly higher resilience during downturns.

In conclusion, both the Tracking Error VW Portfolio and the Zero Net Portfolio outperform the Value Weighted Portfolio, demonstrating the effectiveness of tracking error optimization and also demonstrating the MVP portfolio's superiority to the benchmark. The Zero Net Portfolio shows that sustainable investment strategies can achieve competitive performance while aligning with environmental goals, making it a compelling option for investors prioritizing sustainability without compromising on financial returns.