Green Data Science - Individual Assignment
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Executive Summary

- **Data Collection & Random Sampling**
  - Data was collected on each of the 2913 companies in the Russell 3000 index, 100 companies were randomly sampled to be used in portfolio construction.
- **Carbon Metric Rationale**
  - Weighted-Average Carbon Intensity (WACI) was chosen to assess the environmental impact of each of the constructed portfolios.
  - This metric was preferred as it accounts for company size, and as such should not unfairly penalize investments made in large companies.
- **Portfolio Optimization**
  - The market-capitalization weighted & tangency portfolios were created in order to provide a comparison to the constrained portfolios.
  - In total, 5 constrained portfolios were constructed, 3 of which aimed to replicate the returns offered by the market portfolio & 2 seeking to maximise Sharpe ratio, under various constraints on the WACI & sector proportions.
- **Comparison of Portfolio Statistics & Properties**
  - Market-tracking portfolios were not severely impacted by the CI constraints, with tracking error not exceeding 0.01% for any of the portfolios.
  - The risk-return profile of the constrained s was however impacted by the lower CI bounds.
  - The less severe constraint on the tangency portfolio saw performance only marginally below that of its benchmark, but including an sector balance constraint, lead to significantly diminished performance.
- **Portfolio ESG Performance Comparison**
  - The relationship between lower CI and ESG scores was not found to be universally strong.
  - Portfolios with the most stringent constraints achieved significantly better ESG scores, but this was not the case for more lenient restrictions.
  - Potential causes for this include lack of reporting standards, non-robustness of ESG metrics & the failure of carbon intensity as a measure of a portfolio's environmental impact.
- **Sector Composition Analysis**
  - Constrained market portfolios had sector compostions roughly in line with their benchmark.
  - Constrained tangency portfolios varied significantly from benchmark composition.
- **Sector Analysis for ESG Performance**
  - Sector contribution to ESG scores for the 20% reduced CI market portfolio were generally consistent between benchamrk & constrained portfolios.
  - No real pattern was found in sectors with highest deviation from benchmark proportions.

Data Collection & Random Selection

Based on the 2913 companies listed on the Russell 3000 index as of May 2023, and using the Refinitiv Eikon data API, the following fields (with a sample period for returns between January 2018 - December 2023) were gathered on each company:

- TRBC Economic Sector
- Scope 1 Emissions
- Scope 2 Emissions (Location-Based)
- Total Revenue
- Market Capitalisation
- Total Return
- ESG Score
- Environmental Pillar Score
- Social Pillar Score
- Governance Pillar Score

Of the 1040 companies with emissions data available, 100 companies were sampled. An outline of the sector distribution & market capitalisation of the sampled companies is provided as follows:

Sector	Count	Market Capitalisation (USD Billions)	Market Capitalisation Proportion
Industrials	19	380.10	14.61%
Technology	16	695.07	26.72%
Consumer Cyclicals	14	239.70	9.22%
Basic Materials	10	123.36	4.74%
Energy	10	88.29	3.39%
Real Estate	10	106.55	4.10%
Healthcare	9	406.89	15.64%
Financials	6	134.97	5.19%
Consumer Non-Cyclicals	4	393.71	15.14%
Utilities	2	32.46	1.25%

There were multiple companies that do not appear to have been listed at the beginning of the sample period, and thus do not returns data available at the beginning of the period. In order to address this, without impairing the analysis of constructed returns, missing data was resampled from the respective existing returns of that company.

Carbon Metric Rationale

As previously mentioned, many of the companies in the Russell 3000 index did not have emissions data available via the Eikon API, which constrained the pool from which we could draw our sample from. This may also have introduced an element of sampling bias, as some companies may not wish to disclose their emissions data if they believe it would reflect poorly on them.

Using both Scope 1 & Scope 2 emissions, a carbon intensity (CI) measure for each company was calculated, with these company level figures then aggregated on the basis of portfolio weights to obtain a Weighted-Average Carbon Intensity figure:

$$CarbonIntensity_i = \frac{Scope1Emissions_i + Scope2Emissions_i}{Revenue_i}$$

$$WACI_i = \sum_{i=1}^{n} w_i \cdot CarbonIntensity_i$$

Where Emissions are given in tCO_2e, & Revenue is given in Millions of USD.

This simple metric provides a robust measure of the carbon emissions of a portfolio. It should allow us give us an idea as to how efficiently a company operates in terms of carbon performance, whilst regularising for the effect of company size.

The increase in investor consciousness of the environmental impact of their portfolios, should lead to a shift in the market's outlook towards highly emitting industries, and thus disincentivize companies from engaging in such practices and adopt more sustainable policies. As data availability in the space tends to be quite poor, without further regulation on reporting practices, it remains difficult for investors to monitor the carbon profile of their investments.

This measure was preferred to total emissions, as it was felt that the use of this measure could result in a portfolio which would heavily favour investing in smaller companies, at a detriment to portfolio performance without necessarily yielding a significant reduction in carbon emissions.

Portfolio Optimization

Market Capitalisation-Weighted Portfolio

The first portfolio to be calculated was the market portfolio, which will serve as a benchmark which we seek to match the performance of for our decarbonised portfolios.

- **Objective:** Match industry returns
- **Constraints:**
  - Portfolio weights sum to 1
  - No short-selling of stocks

Tangency Portfolio

This portfolio seeks to obtain the highest possible risk-adjusted return, as measured by the Sharpe ratio.

- **Objective:** Maximise Sharpe ratio
- **Constraints:**
  - Portfolio weights sum to 1
  - No short-selling of stocks

Market Cap-Weighted Portfolios w/ Carbon Intensity Reductions

Three portfolios were created to match the returns profile of the market portfolio, as measured by the ex-post tracking error, whilst limiting the carbon intensity of the portfolio to 10%, 20% & 50% of that of the benchmark respectively.

- **Objective:** Minimise Tracking Error vs. Market Portfolio
- **Constraints:**
  - Portfolio weights sum to 1
  - No short-selling of stocks
  - Achieve the corresponding reduction in carbon intensity

Tangency Portfolio w/ 20% Carbon Intensity Reduction

- **Objective:** Maximise the Sharpe ratio
- **Constraints:**
  - Portfolio weights sum to 1
  - No short-selling of stocks
  - Achieve a 20% reduction in carbon intensity

Tangency Portfolio w/ 20% Carbon Intensity Reduction & Sector Balance

- **Objective:** Maximise the Sharpe ratio
- **Constraints:**
  - Portfolio weights sum to 1
  - No short-selling of stocks
  - Achieve a 20% reduction in carbon intensity
  - Sector proportions cannot vary more than 30% from those of the market portfolio

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Comparison of Portfolio Statistics & Properties

Portfolio	Return		Volatility		Sharpe Ratio	Num of Companies	Num of Sectors	Benchmark Portfolio	Tracking Error
	Monthly	Annual	Monthly	Annual					
Market	0.0143	0.1854	0.0549	0.1901	0.9009	100	10		
Market w/ 10% CI Reduction	0.0142	0.1840	0.0549	0.1901	0.8946	100	10	Market	0.00%
Market w/ 20% CI Reduction	0.0142	0.1839	0.0549	0.1901	0.8943	100	10	Market	0.00%
Market w/ 50% CI Reduction	0.0140	0.1816	0.0549	0.1901	0.8837	58	9	Market	0.01%
Tangency	0.0298	0.4230	0.0453	0.1571	2.2792	14	8		
Tangency w/ 20% CI Reduction	0.0274	0.3835	0.0438	0.1516	2.1706	12	7	Tangency	1.33%
Tangency w/ 20% CI Reduction & Sector Balance	0.0226	0.3083	0.0443	0.1535	1.7701	16	10	Tangency	2.72%

From the summary table of portfolio performance, it is clear that the returns profile of the market portfolio can be very closely replicated within each of the various carbon intensity constraints, with the tracking error for each of the portfolios being less than 0.01%. Consequently, the return, volatility & Sharpe ratio of the constrained portfolios were not severely impacted by the constraints. This indicates that an ESG conscious investors' ability to achieve market level returns is not severely hampered by limiting their portfolio's carbon intensity. One item of note is that when limiting the portfolio's carbon intensity to 50% of that of the benchmark results in less diversified portfolio, with investments across only 58 of the 100 sampled companies, and 9 of the 10 sampled sectors.

However, a drop in performance can be seen in the portfolios looking to maximise the Sharpe ratio. There is a slight dip in return, and a reduction in volatility when we constrain the portfolio's CI to 80% of the market portfolio's figure. This leads to a moderate drop in the Sharpe ratio achieved. There is a more severe drop-off in performance when we implement the sector balance constraint. Monthly returns drop by about 0.7%, with volatility of monthly returns drop by about 0.1%, leading to a Sharpe ratio which is about 0.5 lower than the tangency. The tracking error on these portfolios were 1.33% & 2.72% respectively, however, as the objective of these is to maximise the Sharpe ratio rather than match the returns of the unconstrained portfolio, this is not too much of an issue.

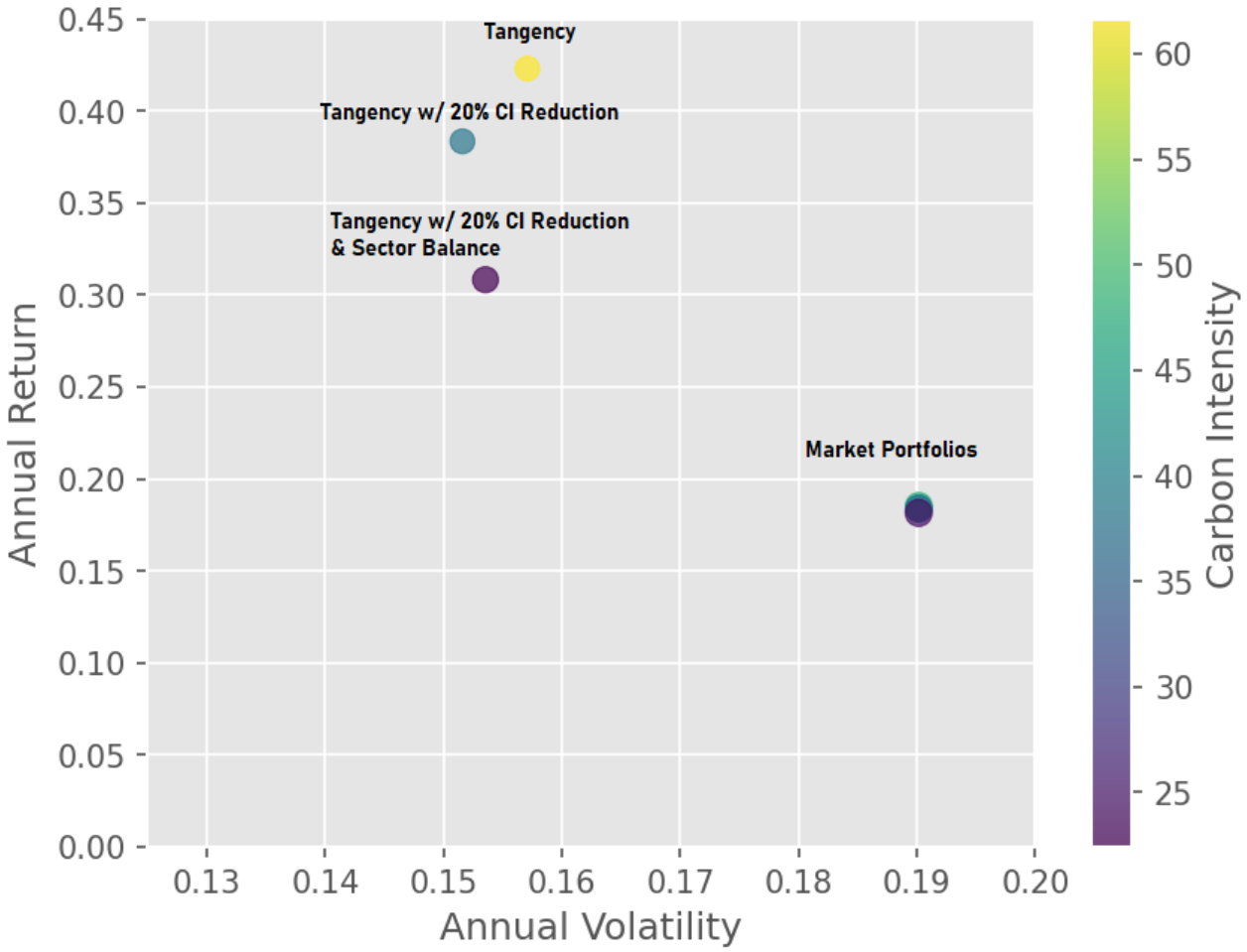

Figure 1 Risk-return profile for each of the constructed portfolios, coloured by WACI

Portfolio ESG Performance Comparison

Portfolio	Carbon Intensity	ESG Score	Social Pillar Score	Environmental Pillar Score	Governance Pillar Score
Market	47.67	73.41	75.56	68.99	73.63
Market w/ 10% CI Reduction	42.14	73.15	74.95	69.00	73.51
Market w/ 20% CI Reduction	37.72	73.40	75.15	69.26	73.70
Market w/ 50% CI Reduction	23.83	74.69	76.23	71.00	74.63
Tangency	61.66	61.77	64.11	45.28	72.48
Tangency w/ 20% CI Reduction	38.14	62.46	62.42	43.15	75.57
Tangency w/ 20% CI Reduction & Sector Balance	22.41	68.59	69.03	53.27	78.03

Each of the market-tracking portfolios have Environmental Pillar Scores which increase as the carbon intensity constraints become more severe, indicating that the constraint is leading to a reduction in carbon performance. For the portfolios with a 10% & 20% reduction in CI however, the scores achieved are not massively different from the benchmark and as such, could be attributed to random chance. In fact, other than for the 50% reduced CI portfolio, none of the ESG measurements seem to deviate hugely from that of the benchmark there doesn't seem to be any significant relationship in this respect. The scores achieved by the 50% reduced CI portfolio are uniformly higher than those of the other portfolios.

For the Sharpe-ratio maximising portfolios, the constrained portfolios both achieve higher scores for ESG & Governance, but the portfolio without an industry balance constraint fails to beat the tangency portfolio in terms of Social & Environmental scores. The sector-balanced portfolio has significantly higher scores than its comparable portfolios across all metrics. Another item of note is that, despite the fact that the CI of the sector-balanced portfolio has only been limited to 80% of that of the market portfolio, the optimal portfolio has a CI which is roughly 53% lower.

Sector Composition Analysis

Portfolio	Basic Materials	Consumer Cyclicals	Consumer Non-Cyclicals	Energy	Financials	Healthcare	Industrials	Real Estate	Technology	Utilities
Market	4.74%	9.22%	15.14%	3.39%	5.19%	15.64%	14.61%	4.10%	26.72%	1.25%
Market w/ 10% CI Reduction	5.08%	10.19%	15.09%	3.74%	4.85%	15.00%	13.19%	4.21%	27.47%	1.18%
Market w/ 20% CI Reduction	5.13%	9.98%	15.47%	3.80%	4.96%	15.29%	12.93%	4.17%	27.37%	0.91%
Market w/ 50% CI Reduction	5.30%	8.66%	17.39%	4.11%	4.92%	16.33%	12.21%	3.88%	27.19%	0.00%
Tangency	6.69%	2.67%	0.00%	28.83%	8.05%	4.45%	38.18%	0.58%	10.55%	0.00%
Tangency w/ 20% CI Reduction	4.15%	3.24%	0.00%	16.58%	16.29%	10.84%	35.17%	0.00%	13.72%	0.00%
Tangency w/ 20% CI Reduction & Sector Balance	6.17%	6.45%	10.60%	4.41%	6.75%	19.69%	19.00%	4.96%	20.36%	1.62%

Unsurprisingly, the sector composition for the constrained market portfolios are generally in line with those of the benchmark, with the heaviest deviations being the increasing trend in the weights of the basic materials, consumer non-cyclicals, energy sectors, and the decreasingly trend in weights in the industrials & utilities sectors as the severity of the CI constraint is increased. An increasing trend in the weights here, indicates that an investor can usually safely divest themselves of stocks in these sectors, without hampering their ability to match the returns offered by the market portfolio. The

remaining sectors show no significant trend in either direction.

Once again, the differences in makeup are much more prevalent in the Sharpe-ratio optimized portfolios. There is a much lower proportion of investments in the energy, industrials & basic materials sectors. Conversely, a much greater emphasis is placed on financials, healthcare & technology sectors when including the CI constraint, indicating that these the trade-off between Sharpe ratio & CI is better for companies in these sectors. With the industry-balanced portfolio much greater sector diversity is achieved. It can be seen that weights in basic materials, energy, financials, industrials & utilities are at the upper bounds of the permitted sector weights, while consumer cyclicals & consumer non-cyclicals are at their lower bounds.

Sector Analysis for ESG Performance

The following section will encompass a comparison of the contributions of each sector to the ESG scores of the market portfolio & the market-tracking portfolio with a 20% CI reduction. The proportions of each score contributed to by each sector is summarized in the table below.

	ESG		Social		Environmental		Governance	
Sector	**Market**	**Constrained**	**Market**	**Constrained**	**Market**	**Constrained**	**Market**	**Constrained**
Basic Materials	4.11%	4.38%	3.53%	3.70%	4.34%	4.77%	5.00%	5.22%
Consumer Cyclicals	8.66%	9.43%	9.58%	10.50%	9.82%	10.50%	6.94%	7.65%
Consumer Non-Cyclicals	17.12%	17.52%	16.04%	16.49%	18.81%	19.14%	17.61%	18.04%
Energy	3.40%	3.75%	3.46%	3.91%	3.53%	3.82%	3.27%	3.58%
Financials	4.02%	3.80%	3.67%	3.52%	1.42%	1.37%	5.18%	4.87%
Healthcare	16.97%	15.97%	17.13%	16.21%	17.23%	16.03%	16.51%	15.56%
Industrials	14.22%	12.84%	13.52%	12.06%	14.10%	12.71%	15.32%	13.99%
Real Estate	3.47%	3.65%	3.61%	3.74%	3.32%	3.54%	3.63%	3.83%
Technology	26.66%	27.67%	27.98%	28.80%	26.11%	27.16%	25.15%	26.26%
Utilities	1.37%	0.99%	1.49%	1.07%	1.31%	0.96%	1.39%	1.01%

The consumer-cyclicals, & technology sectors comprise a much more important contribution to the constrained portfolio ESG scores than the benchmark, with industrials, & healthcare being more important to the benchmark. These relationships are seen across each of the corresponding sub-scores.

In order to get a better idea as to why this may be the case, a breakdown of the average sub-factors comprising the CI metric & the average ESG scores for companies within each sector are provided in the following tables.

Sector	**Mean Revenue (USD Millions)**	**Mean Scope 1 Emissions (tCO_2e)**	**Mean Scope 2 Emissions (tCO_2e)**	**Mean Carbon Intensity**
Basic Materials	7,422.27	841,427.50	592,138.60	254.67
Consumer Cyclicals	14,282.77	583,783.14	274,239.93	97.21
Consumer Non-Cyclicals	162,294.92	1,977,954.60	2,424,978.96	21.34
Energy	8,039.53	2,014,040.03	443,999.14	394.77
Financials	12,768.66	5,422.17	11,521.33	1.24
Healthcare	24,178.51	79,337.79	74,601.45	11.88
Industrials	10,451.23	1,790,023.68	105,468.55	148.90
Real Estate	1,556.82	12,466.66	276,543.68	84.74
Technology	15,889.02	18,770.57	50,991.55	7.00
Utilities	3,785.00	107,794.50	253,271.00	95.31

Sector	ESG Score	Social Score	Environmental Score	Governance Score
Basic Materials	58.75	52.50	57.07	72.74
Consumer Cyclicals	67.94	73.34	67.04	61.97
Consumer Non-Cyclicals	62.06	58.92	62.84	67.35
Energy	62.69	63.30	58.96	65.86
Financials	51.03	48.28	19.44	65.56
Healthcare	66.43	72.43	62.79	62.58
Industrials	61.25	59.57	51.96	70.41
Real Estate	64.61	63.20	60.69	70.51
Technology	63.99	72.74	52.20	62.03
Utilities	77.34	80.05	74.71	78.90

It is clear from the above the reduction in investments in the industrials sectors is because it performs poorly both in terms of CI, and in terms of ESG scoring, meaning it will have lower weighting in the portfolio along with the lower average ESG scores of the included companies meaning they contribute less to the overall portfolio scores. The argument for the technology and consumer cyclicals sectors are more mixed, with technology having very low mean CI scores, but performing fairly middle of the road in terms of ESG, and consumer cyclicals being the converse. Healthcare remains somewhat of an anomaly with relative strong performance across both metrics, but still seeing a reduction in it's contributions to the constrained portfolio.

Conclusion

Overall, this report has found that using carbon intensity can used by investor's without hampering the performance of their portfolios, depending on the objectives/desired returns profile. Constraining WACI does not seem to have any detrimental effects on a portfolio's ability to track the returns of a market portfolio, however when applied to a portfolio which seeks to optimise the trade-off between risk & return, we do see somewhat of a fall in performance.

Other than for portfolio's which severely constrained WACI, the relationships between lower CI and improvements in ESG scores were not particularly strong. There are many potential factors behind this, such as a lack of standards within the industry in terms of the publishing of carbon emissions information, the non-robustness of ESG scores as a metric for assessing the sustainability of a company, or potentially the failure of WACI as a metric for assessing the environmental impact of a company.