Introduction

Before diving into the empirics and theory of the report, it's worth stepping back and acknowledging the contributions of everyone involved:

Skirnir – Valuation impact on strong ESG performance - DCF sensitivity analysis; reshoring / nearshoring of manufacturing; green shipping corridors and alternative fuels; transition companies (including but not limited to their current weaknesses, improvement plans and the risk-reward trade-off); comparing ESG-industrials and non-ESG industrials via Shiny and showing our results; electrification of the heavy industry

Joshua – Strong ESG performance – Impact on stock price volatility; correlation between ESG adoption and ROE; ESG score vs financial returns – charted; benchmarking and comparables methodology; predictive modelling

Kieran – Friendshoring & trade alliances; tax credits, green subsidies and tariffs; regulatory arbitrage risk, geopolitical resource scarcity; supply-chain vulnerabilities; green bond issuance and lower borrowing costs.

Jake – Circular economy vs linear economy; ESG KPIs (carbon intensity, water use efficiency, executive ESG-linked compensation; Trump tariffs; ESG standardisation; electrification and high-speed freight; margin expansion of low-margin manufacturing firms; comparing ESG-industrials and non-ESG industrials via Shiny and showing our results.

Mourya –AI-optimised logistics; margin expansion of low-margin manufacturing firms**.**

One of the key focal points of the report is to interrogate the financial implications and strategic significance of ESG integration within the Industrials sector, an area often overlooked in favour of high-visibility, low-emission sectors. We aim to move beyond the surface level ESG questions, rather answering a deeper set of questions: *Does ESG performance translate into measurable financial upside? To what extent does sustainability act as a valuation lever, volatility hedge, or governance signal? And crucially, can ESG metrics be operationalised as robust investment inputs rather than reputational footnotes?*

After the valuations sector, we explore the report expands its lens to sector-wide adoption drivers, macroeconomic trends and statistics. ESG adoption is contextualized within broader forces: regulation, technology and cost curves. We attempt to structure with consistent logic; firstly defining the trend, giving some economic rationale and some supporting theory, then giving key headwinds and/or tailwinds, and relevance to investors. The final analytical layer covers strategy and risk: regulatory arbitrage and hedging strategies, inconsistency among ESG ratings, and supply-chain vulnerabilities.

Contents:

Valuations

Valuation impact on strong ESG performance: DCF Sensitivity Analysis (Task 1)

Introduction

The Discounted Cash Flow approach is a valuation method that estimates the value of an investment using its future expected cash flow. The analysis will examine how different Weighted Average Costs of Capital (WACC) impacts Free Cash Flows (FCF), Terminal Value (TV), Enterprise Value (EV), and intrinsic value per share.

Typically, ESG firms are regarded as more stable due to lower operational risk and lower financing costs leading to potentially higher FCF, whereas non-ESG firms have higher risk premiums meaning lower FCF. The general equation for FCF is shown below:

$$FCF = EBIT \times (1 - Tax\ Rate) + Depreciation - CAPEX - \Delta Working\ Capital$$

The terminal value represents the future value of a business beyond the explicit forecast period. Measuring the terminal value uses the Perpetuity Growth Model which assumes the firm is to operate indefinitely and expects to grow at a stable rate forever. The general equation for TV is shown below:

$$TV = \frac{FCF_{t+1}}{WACC - g}$$

This leads to enterprise value, which represents total firm valuation, which is the sum of discounted cash flows and terminal value. The general equation is shown below:

$$EV = PV_{FCF} + PV(TV)$$

Finally, intrinsic value per share is derived using equity value and shares outstanding, where equity value is enterprise value minus net debt. The general equation is shown below.

$$Intrinsic\ Value\ per\ Share = \frac{Equity\ Value}{Shares\ Oustanding}$$

WACC and EV/EBITDA Multiple

The WACC represents the average rate of return a company is expected to pay its shareholders containing a blend of cost of equity and debt whilst being weighted to their respective portions in the firm's structure. An EV/EBITDA Multiple is a measure of a company's enterprise value compared to its earnings before interest, tax, depreciation, and amortisation. As stated earlier, companies with strong ESG performance often enjoy a lower WACC or higher FCF.

But how does WACC affect the EV/EBITDA Multiple?

- **Increased EV** – as WACC falls, the present value of future cash flows increases, present value of terminal value increases, increasing EV, increasing the multiple
- **Stable EBITDA** – if the denominator of the multiple remains constant whilst EV rises then the multiple increases.

The industrials sector is a broad sector containing various industries and sub-industries. Specialised companies range from manufacturing and production to transportation and logistics. Therefore, various industries and sub-industries have various EV/EBITDA multiples. A particular example I will be focusing on is Caterpillar Inc. (CAT), which operates in the machinery industry and more specifically under construction and mining equipment. CAT is notorious for creating industrial-grade diesel and natural gas engines. Therefore, CAT does have a large carbon footprint. However, their role in energy transition makes use of increasing alternative fuel capabilities such as biodiesel, hydrogen, and even hydrotreated vegetable oil. As a result, it would be quite interesting to visualise how CAT reaches these goals may lead to a lower WACC as they meet ESG standards.

The current EV/EBITDA multiple of CAT is 11.3 with an enterprise value of $193.122 billion and EBITDA of $17.091 billion. Compared to the machinery industry, an average of 17.29, it falls behind.

How does CAT's EV/EBITDA multiple change as WACC falls?

WACC (%)	EV/EBITDA Multiple	Enterprise Value (in billions)
8.8 (Current)	11.3	$193.122
8.0	12.58	$215.10
7.0	14.39	$246.07
6.0	16.81	$287.45

Data as of 13/3/25

As shown above, as WACC decreases, investors require lower returns, therefore future cash flows are discounted less, increasing firm valuation and the EV/EBITDA Multiple.

On the DCF analysis and using the equations above, a lower WACC doesn't directly affect FCF. However, discounting using the WACC makes them worth more in present value. Therefore, FCFs remain constant in analysis but the present value increases. As shown in the table above, the EV changes drastically largely due to TV being a large portion of a firm's DCF valuation. Therefore, the impact of a lower WACC on TV is significant and can be shown in the table below using the equation:

$$TV = \frac{FCF_{t+1}}{WACC - g}$$

WACC (%)	Terminal Value (in billions)
8.8 (Current)	$143.35
8.0	$164.38
7.0	$200.91
6.0	$258.31

With the data given, FCF at the end of Q4 2024 was around $8.820 billion. Using the equation and assuming a long-term growth rate of 2.5%, the TV increases significantly as shown above when WACC falls. As TV largely affects EV and EV affects intrinsic value per share, we can expect the same result as shown below:

WACC (%)	Intrinsic Value per Share ($)
8.8 (Current)	371.45
8.0	422.50
7.0	496.80
6.0	596.30

Overall, we visually see that CAT's cost of capital is influenced by ESG progress (alternative fuels, sustainability). Further ESG adoptions and progress results in a lower WACC, lower operational risk. This leads to higher EV/EBITDA multiple, increasing firm valuation. Therefore, DCF analysis confirms that WACC reductions lead to a significant intrinsic value appreciation for shareholders. Although returns lower as WACC falls, capital gains significantly increase. A fall from 8.8% to 6% leads to a 60.5% gain on intrinsic value. Furthermore, we can see that the current stock price of CAT is $333.31, an upside based on DCF of 11.4% or in Layman's terms, undervalued.

Strong ESG performance - Impact on stock price volatility

Environmental, Social and Governance (ESG) refer to a set of criteria used to evaluate a company's operations concerning their environmental sustainability approach, social responsibility and governance practices. Depending on how well they achieve their goals within these 3 elements or mitigate concerns and risks, companies tend to receive an ESG ratings – these ratings are assessments of a company's performance across different non-financial metrics, such as environmental impact, social responsibility and governance practices.

These ESG ratings are generally seen by investors as indicators of long-term sustainability and risk exposure. Firms with strong ESG performances are often perceived as lower risk investments since they are better equipped to handle market changes such as regulatory changes. This stability could result in lower price volatility, as investors show more confidence in the firm's long-term outlook.

Conversely, firms with poor ESG ratings may face higher regulatory risks for example, leading to greater uncertainty and thus higher volatility in their stock price.

This analysis was seen in several research papers.

Firstly, Zhou & Zhou (2021) selected ESG rating data from MSCI with better differentiation, adopts multiple regress and dummy variables, and adopt the Differences-in-Differences (DID) model, using COVID-19 as an exogenous event. The results found that the stock price volatility of companies with good ESG performance is lower than that of companies with poor performance.

Additionally, despite COVID-19 exacerbating volatility in company stock price fluctuations, the companies with good ESG performance faced mitigated increases in stock price volatility.

Secondly, Hassan (2020) selected 44 firms from 2010 to 2018 available in Refintiv. The study mainly uses stock price volatility and a market beta of Refinitiv as a proxy for stock price volatility. Refinitiv measures stock price volatility as the degree of stock price variations over 12 months, according to the last 52 weeks' price. The study used fixed-effects panel regression models to test the hypothesis. Fixed effects estimation was considered to remove the unobserved endogeneity bias. They then test the hypothesis again by applying the pooled ordinary least squares and random effects regression model to check the consistency of the results. The null hypothesis was "Higher ESG performance significantly reduces the stock price volatility of the textile and apparel firms" and the alternate hypothesis was "Firm size significantly moderates the relationship between ESG performance and stock price volatility of the textile and apparel firms". Within this study, they supported the hypothesis that "Higher ESG performance significantly reduces the stock price volatility of the textile and apparel firms".

Thirdly, Lundberg & Jakobsson (2018) firstly collected Thomson Reuters ESG Score which is "designed to transparently and objectively measure a company's relative ESG performance, commitment and effectiveness across 10 main themes (emissions, environment product innovation, human rights, shareholders etc)". After conducting Panel Data Analysis, they concluded that high ESG performance leads to lower share price volatility between the years 2009 and 2016 on the S&P 500 Firms studied.

Case Study 1: Microsoft – Strong ESG Performance and Reduced Stock Price Volatility

Microsoft holds an ESG risk rating of 17.2 which is considered low risk, an AAA rating from MSCI and a Refinitiv Score of 84/100 where 100 is considered the best. These consistent high ratings have positioned Microsoft among the most ESG resilient firms in the technology sector.

The success that Microsoft had with ESG performance came from their structural, proactive and measurable commitments. Firstly, it achieved carbon neutrality in 2012 and has pledged to become carbon negative by 2030 whilst aiming to remove all historical emissions by 2050. On the social side, Microsoft published its workforce representation data and promotes inclusive hiring practice whilst contributing to digital equity. With regards to governance, its board is fully independent, and it separates chair and CEO roles, allowing transparency whilst maintaining strong shareholder engagement.

Microsoft's beta rating is 0.89. The beta value is a measure of how much a stock's price moves relative to the overall market. A beta of 1 means the stock tends to move in line with the market – for example, if the market rises by 5%, the stock would be expected to rise by 5%. A beta that is greater than one suggests the stock is more volatile than the market – if the market rises by 5% the stock may increase by more than 5% implying that falls in the market results in a bigger fall for the stock. Finally, a beta below 1 suggests that the stock is less volatile than the market. Contextually, since Microsoft's beta rating is 0.89, it suggests that if the market were to increase by 10%, the stock would typically rise by 8.9%.

Within the technology industry, major technology competitors are not performing as well as Microsoft. Alphabet Inc has an ESG risk rating of 24.9, categorizing it as a medium risk. Amazon's ESG risk rating is 26.1, also placing it in the medium risk category. The beta values of Alphabet and Amazon are 1.09 and 1.25 respectively suggesting lower ESG ratings (higher risk) results in higher stock price volatility.

However, companies such as Adobe and SAP, despite having an AAA MSCI rating, their beta values are 1.02 and 1.05 respectively, contradicting the research analysis above. The main reason stems from the idea that ESG is a platform for investors and not a determinant of stock behaviour itself.

High ESG

Firm	ESG Score	Beta	Standard Deviation
Schneider Electric	AA	0.85	18.2%
Siemens AG	AA	0.90	19%
Texas Instruments Inc.	AA	1.05	22.5%
JB Hunt Transport Services Inc.	AA	0.95	20%
Grifols	BBB	1.10	23%

Low ESG

Firm	ESG Score	Beta	Standard Deviation
Caterpillar Inc.	BB	1.2	25%
Lockheed Martin Corporation	BB	1.15	24.5%
General Electric Company	BB	1.3	26%
Raytheon Technologies Corporation	BB	1.25	25.5%
Northrop Grumman Corporation	BB	1.10	23.5%

ESG and Financial Performance ROE

- Through a Panel Vector Autoregression (PVAR) model using Generalised Method of Moments (GMM), Qureshi, Akbar, Akbar & Poulova (2021) found that ESG performance and ROE share a negative bidirectional relationship – higher ESG performance was associate with lower ROE suggesting that ESG initiatives impose short-term financial costs on firms. Conversely, stronger ROE led to improved future ESG scores, indicating that financially successful firms are more capable of investing in sustainability. These finds support the negative synergy theory where ESG and ROE influence each other in opposing directions over time
- Lucia, Pazienza & Bartlett (2020) through machine learning and ordered logistic regression found that ESG practices exert a statistically significant influence on the ROE. Firms with sustainable development policies and higher employment productivity were more likely to fall into higher ROE deciles – diversity and opportunity policies increased the probability of a firm being in the top ROE deciles by 11% while sustainable development policies contributed to an increase of up to 12%.
    - However, it also identified ESG factors that correlated with lower ROE performance. This includes the presence of

environmental management teams, environment training programmers and CSR governance board committees

- Buallay (2018) found through a random effects panel regression analysis that overall ESG disclosure, which is the public reporting of a company's performance and practices, has a positive association higher ROE. The study found that banks with higher ESG scores tended to demonstrate higher ROE outcomes, with a coefficient of 0.301 being significant at the 1% level.
- Junius (2020) found through random effects panel regression analysis of 271 listed firm across 4 ASEAN countries that ESG performance had no statistically significant effect of ROE since the p-value was 0.661 implies that there was no relationship between ESG Performance and ROE
- Koundouri, Pittis & Plataniotis (2022) found through comparative sector based financial ratio analysis that companies with high ESG performance tend to show higher ROE than non-ESG companies. Using data from STOXX Europe ESG Leaders 50 index and comparing it with firms from the EURO STOXX 50 Index, the study found that in sectors such as Construction and Materials, ESG leaders had an average ROE of 26% compared to just 5% in non-ESG firms. Similarly, in Healthcare, ESG leaders achieved 32% ROE, while non-ESG peers posted 18%.

Corporate Sustainability Impact on ROE

- Odhanwala & Bodhanwala (2018) found through fixed effects panel regression model that corporate sustainability has a positive and statistically significant relationship with ROE. More specifically, firms categorized as high ESG compliant (HESGC) reported an average ROE of 25.51%, compared to 14.62% for low ESG compliant (LESGC) firms.
- Weber (2017) found through random effect panel regression and Granger causality analysis that corporate sustainability has a positive and statistically significant effect on ROE among Chinese banks. The sustainability score is based on both environmental and social performance. The coefficient was 1.075 on ROE, which is significant at the 1% level.
- Tarigan & Valerie (2023) found through heteroscedasticity-corrected pools OLS regression that ROE has a positive and statistically significant influence on Corporate Sustainability Performance (CSP)

ESG Value Creation Mechanisms

- ESG value creation refers to the ways in which ESG practices contribute to a firm's financial performance, risk profile and long-term competitiveness. Instead of using ESG as a compliance cost or ethical obligation, recent research has framed it as a strategic tool that enhances shareholder value. ESG initiatives can help reduce costs therefore offering firms a pathway to align with responsible practices. Examples Include:

1. Risk Mitigation: ESG practices enable firms to manage non-financial risks that may result in financial consequences. These include environmental liabilities, reputational damage and regulatory non-compliance. Friede (2015) suggests that by integrating ESG frameworks into governance, this allows firms to better prepare and identify and respond to disruptions, such as supply chain instability or environmental incidents. ESG focused firms are also less likely to face fines or public backlash, maintain operational continuity and stakeholder trust. This creates ESG value by reducing volatility in earnings and preserving firm value over time.
2. Revenue Growth: ESG can also drive performances by allowing firms to capture demand for sustainable goods and services. Currently, consumers favour ethical brands, whereas B2B customers (a form of transaction between businesses such as a manufacturer and a wholesaler or a wholesaler and a retailer) are building ESG criteria into supplier selection. Companies with strong ESG reputations benefit from enhanced brand loyalty and are better positioned to enter or expand in emerging green markets, as suggested by Lins, Servaes & Tamayo (2017). This creates ESG value by expanding market share and strengthening customer loyalty. ESG aligned firms generate revenues from new growth areas while reinforcing their long-term brand equity

Identify 2 to 3 ESG Leaders and Laggards – ESG Score through MSCI and ROE For The Last 3 Years

This section will aim to complement existing academic evidence on ESG and ROE relationships be using real world comparative analysis.

To ensure consistency and comparability, all companies that will be used are from the Integrated Oil & Gas sector. ESG Scores will be obtained from MSCI ESG ratings, ranging from AAA being leader to CCC = laggard.

Selected Companies:

ESG Leaders	ESG Rating (MSCI)	ESG Laggards	ESG Rating (MSCI)
Equinor ASA (Norway)	AAA	PetroChina Co. Ltd (China)	B
TotalEnergies SE (France)	AA	ONGC (India)	B

ESG ROE & Revenue Growth

Company	ROE 2021	ROE 2022	ROE 2023	Revenue Growth (2021 – 2022)	Revenue Growth (2022-2023)
Equinor	21.95%	53.25%	24.51%	+68%	-28%
TotalEnergies	14.35%	18.37%	18.32%	+42.6%	-16.8%
PetroChina	11.10%	11.39%	11.13%	+24%	-7%
ONGC	5.49%	16.99%	15.05%	+62%	+31%

Analysis:

- Equinor is an MSCI AAA-rated firm. They demonstrate a clear alignment between ESG leadership and strong financial performance. Between 2021 and 2022, Equinor's ROE more than doubled from 21.95% to 53.25%, before declining to 24.51% in 2023. This sharp increase in ROE coincides with a 68% surge in revenue, while the decline in ROE mirrors a 28% fall in revenue. This direct relationship suggests that Equinor's shareholder returns are underpinned by profitability rather than accounting manipulation.
- TotalEnergies is rated AA by MSCI. The firm's ROE increased from 14.35% in 2021 to 18.37% in 2022 is coincided with a 42.6% increase in revenue. In 2023, despite a 16.8% decline in revenue, ROE remained relatively stable at 18.32%. This may suggest that the firm maintained strong operational efficiency and cost control, which allows it to preserve profitability even during a revenue downturn
- PetroChina is rated B by MSCI. The firm's ROE remained broadly unchanged over the three year period, rising marginally from 11.1% in 2021 to 11.39% in 2022 before falling to 11.12% in 2023. This occurred despite a 24% increase in revenue between 2021 and 2022 and a 7% decline the following year. The lack of ROE responsiveness to revenue changes suggests limited capital efficiency which may indicate that PetroChina may not have effectively translated top-line growth into improved shareholder returns, which is consistent with the performance risk often associate with lower ESG-rated firms
- ONGC is rated B by MSCI. The firm's ROE rose from 5.49% in 2021 to 16.99% in 2022 before declining slightly to 15.05% in 2023. This is associated with a 62% growth between 2021 and 2022, and a further increase of 31% in 2023. This consistency between ROE and revenue trends suggest that ONGC's improved returned were driven by operational profitability rather than financial restructuring.

- Overall, the data suggests that firms with higher ESG ratings tend to deliver stronger ROE performances i.e. higher ROE. Both Equinor and TotalEnergies rated AAA and AA respectively achieved higher ROE levels which corresponded with revenue growth, suggesting that returns were driven by profitability rather than financial engineering. This is further supported by the absence of any equity reduction or abornmal changes to capital structure. This was implied when ROE changes moved in tandem in revenue instead of diverging from it. If the ROE had increased while revenue remained flat or declined, it could suggest financial engineering where firms artificially boost returns by reducing the equity base. Since no divergence occurred, this suggests that revenue was the source of ROE growth

Green bond issuance and lower borrowing costs

Sustainable investments produce positive social impacts, allowing promising green companies access to raise much needed capital to develop. Green bonds are the most popular instrument. They are publicly traded and attract investors due to their low risk.

By placing a green label on corporate bonds, companies send out the message that they are committed to being ethical and are conscious about their impact on the environment. Investors find this attractive, with the company gaining a reputation in corporate social responsibility, which is perceived by investors as a safer investment, more trustworthy, and will be more willing to invest, even at the cost of inferior returns (see poll results below). This increase in investor demand drives better stock performance.

NN IP Poll on Green Bonds;

- Most popular instrument among institutional investors, 45% say the bonds make the greatest positive impact.
- 44% say the greatest barrier to green bond investing is the perception of inferior returns .
- Greenwashing is the next greatest fear, 38%.
- Lastly, insufficient market capacity, 19%

However, there are costs to green investments. They are often held to a much higher standard, influencing the financing costs of such a project. In order to qualify for green bond issuance, 3rd party verifications are required (e.g. low carbon transport criteria). Higher standards are certainly expected due to the impact on the environment, and the incentives for companies to greenwash their products to reel in more business.

R Zhang tested for the green premium (Greenium), matched green bonds with conventional bonds using propensity scores, using 1010 green bonds matched with conventional bond counterparts in China. On average, the yield spread of green bonds is 24.9bps lower than conventional bonds, meaning that firms with a high CSR / ESG profile are able to issue bonds at a lower cost. This was found significant at the 95% confidence level.

The key drivers for green bond capital:

Once a company decides it wishes to adopt green financing policy, there are information disclosure requirements which are, as mentioned before, much more thorough than those of conventional bonds, lowering information asymmetry. It has been established in prior works that higher cost of capital can be caused by information asymmetry. Companies with higher information asymmetry are perceived as riskier, due to the uncertainty surrounding their projects, and vice versa. Thus, lowering this will result in a reduction in the cost of capital due to increased investor confidence.

Investors tend to follow norms, and some institutional investors look to avoid companies that are seen as unethical, such as tobacco, alcohol, and gaming companies. The negative sentiment around these products often deters investors. Environmental issues have become much more prevalent as of recent, and investors are increasingly looking towards CSR / ESG rated firms. As mentioned before, when a company issues green bonds, they are sending out that message that they are committed to the fight against unsustainable and environment-damaging practices. As more investors follow these companies and invest, the market liquidity improves. Prior works show that a company's cost of capital can decrease due to the increased liquidity of its securities, thus by improving the security liquidity, green bonds reduce the cost of capital.

As mentioned throughout, investors perceive companies with lower CSR / ESG profiles as higher risk. By issuing green bonds, companies can improve their CSR / ESG profile, and the cost of capital will lower alongside the decreased perception of risk.

In Chinese markets, over 2/3rds of green bonds are rated at AAA. Higher bond ratings reflect the quality of the bond, meaning that the issuer has a strong capacity to meet their financial obligations, and the risk of defaulting is lowered. These assets are seen as predictable and stable, which are very attractive for investors seeking to diversify their portfolio and limit their risk exposure.

However, these results are found purely in Chinese markets. Other studies show that whilst a green bond premium does exist, and usually quite consistently, the yield spread can range from 2-5bps as found by Zerbib in 2019. A more recent study done by Chih-Yueh Huang (2023) found that over many studies, the bps ranges from 7.8 – 34, and occurs in different markets. Even defining 'green' can be challenging as different countries deal with different amounts of environmental impact (China's most pressing issue is air pollution, whereas in the EU and US this issue is not as extreme). Huang concludes that whilst a green premium does exist, it varies widely on the markets, and that there is still a lot of room for development in the models used to test the green premium.

Even so, issuing green bonds does appear to lower the cost of capital for a company (even if marginal). But the issuing of green bonds goes further then investors. It's a message that in the long-run, the company is committed to its ESG endeavours, making the company itself an attractive security for investors, as well as attracting consumers who wish to purchase from responsible companies.

US Federal Reserve Study 2022 – Found an average of 8bps lower than conventional bonds, thus issuers pay lower interest on their green bonds, marking an almost 5% decrease in borrowing cost to the issuer. However, this does not consider the other costs associated with green bonds and the projects they fund, such as higher compliance standards and logistical / monitoring costs.

European Central Bank Working Paper 2022 – Found that green bonds issued by credible companies benefit from a significant green bond premium, and that external reviews of green bond projects help to attain this level. Provides the data below:

	Conventional Bonds	Green Bonds	Difference
Coupon Rate	1.570	1.046	0.524
Yield Spread (bps)	59.214	52.634	6.58

248 Green & Conventional Bonds used from 2016 – 2021 in the Euro-Area

These studies show that pinpointing the ‘greenium’ is incredibly difficult, with too many variables to be considered. We have established that there are several factors that are involved in lowering the cost of capital for firms. Whilst issuing green bonds is one of these factors, it is certainly not advised to be the only metric used when assessing whether to invest in a company. There should be a thorough consideration of trustworthiness, is the company making an impact, or using green bonds as a form of greenwashing.

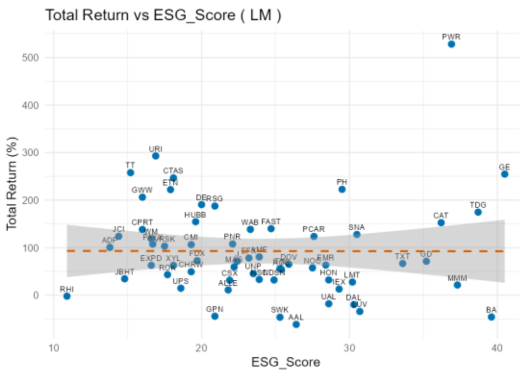
ESG risk vs performance

In contemporary capital markets, ESG considerations serve as a proxy for gauging how efficiently a firm internalises externalities; at Oakwood we are intrigued whether these metrics reflect genuine operational resilience or constitute to greenwashing. ESG represents a distinct dimension of firm quality that might reduce unanticipated legal or reputational costs, hence the motivation is to test whether ESG data holds explanatory power relative to other established factors present in Fama French factor models and other firm profitability literature.

Firstly, we downloaded an ‘ESG score’ dataset from Kaggle of all the constituents of the S&P500, however in the analysis we merely consider the Industrials sector. Through leveraging the quantmod package, we were able to pull time-series data from Yahoo Finance; we pulled historical prices between the specified bounds (1st January 2015 and 7th April 2025) and extracted the adjusted closing prices to avoid the noise of splits and dividends. We computed total returns by calculating a percentage change in the stock price at the start date and the end data. Note that the date is changeable by the user in the Shiny interface, although for the sake of our analysis we look at 1st January 2020 onwards.

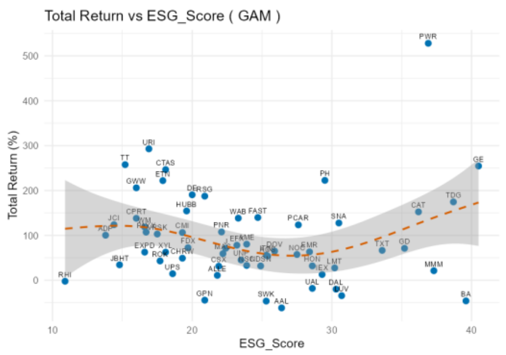
For the modelling approach, our analysis explores both the standard linear model and the generalised additive model. The GAM step introduces non-linearity, which captures the possibility of ESG scores taking a non-linear distribution. Within the analysis, one should see this visually through a smooth GAM spline, together with confidence intervals. Please note that temporal variations in ESG are not accounted for; in a more advanced study, we would track ESG scores year-over-year and match them with annualised returns for a panel model.

Furthermore, we assume that no confounding variables dominate the ESG-return relationship, although this would need to be investigated in reality. Finally, the gaussian identity is indicative of normal error distribution around the fitted curve, using a standard linear leak function.



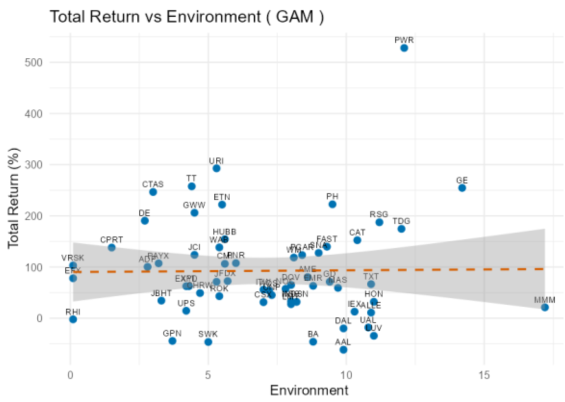
The slope coefficient is negligible, and the p-value exceeds the marginal threshold of 0.1, indicative of no evidence ESG score influences returns linearly, warranting model expansion.

ESG combined:

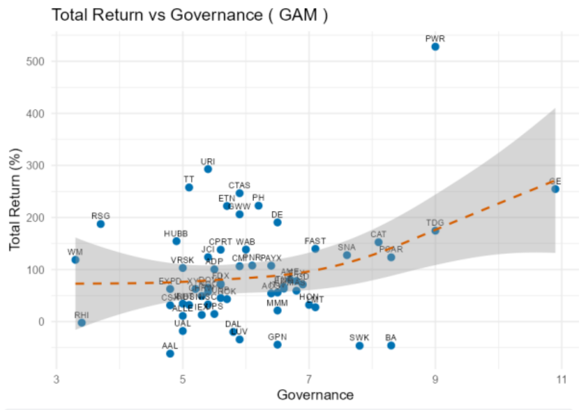


If the ESG score were to be 0 (i.e 0 risk) between 1st January 2020 and 28th March 2025, the model's average predicted return is 92.7%. The smooth term has an estimated degrees of freedom score of 3.16 indicative of the function's shape being non-linear, using 3 degrees of freedom to capture curvature. The smooth term takes a p-value of 0.084, indicative of a marginal effect, thus we have mild statistical evidence of a non-linear relationship. Deviance explained lies around 16%, much higher than the 2-3% in the earlier model.

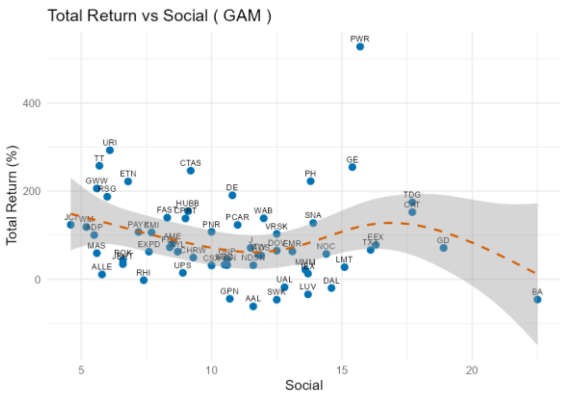
We can see there is a dip in predicted returns at moderate ESG scores, then a ramp up at higher ESG scores, although the confidence band is fairly wide, indicative of uncertainty in the relationship. To further improve the model specification in the future, as stock returns often have heavy tails, following a 'random walk' return distribution, we could explore heavy-tailed families to determine whether outliers strongly influence the results.



The deviance explained jumps to 38.1% when isolating for environmental effects, suggesting environment as a smooth function captures a much bigger chunk of variability in returns. It seems that environment also correlated with management quality, future cost savings and goodwill, potentiating omitted variable bias and endogeneity. The EDF jumps to 8.56, with a term F-value of 3.07, a p value less than 0.01, suggesting strong evidence that environment correlates in a curvilinear manner. However, the plots don't really show anything significant, indicative that environment-related changes are standard rather than a differentiator for profit.



The smooth curve has an EDF score of 5.96, indicative of the model using 6 parameters to shape the function. The p-value is below the 95% significance level at 0.024, suggesting significant evidence the governance dimension influences returns non-linearly. The deviance explained is at 28.4%, a healthy proportion of the data is explained. For lower governance scores, the curve starts at around a 93% return then dips for firms with middle governance scores (80-120% range). As governance increases, the curve slopes upwards, indicative of governance improvements correlating with progressively higher returns.



Finally, for the social component, the EDF F-value does not meet the marginal threshold of 10%; the p-value is instead 0.13. There is nothing meaningful we can add from this section. We cannot rule out that the pattern of peaks and troughs are through chance. Due to social score complexity, direct impact on returns might be more long-term or subtle than immediate environmental or governance factors.

ESG KPI's – Carbon intensity, water use efficiency, executive ESG-linked compensation

Preface

Carbon intensity attempts to quantify a firm's GHG emissions relative to economic output, typically expressed as CO_2 emitted per unit of financial output (per $1m revenue), which provides a normalised basis for comparing environmental impact across firms. Please see the general formula below:

$$Carbon\ Intensity = \frac{Total\ CO_2\ emissions}{Economic\ Output}$$

As industrials is typically regarded a more carbon-intensive sector, increased attentiveness has been place on carbon-intensity metrics. Carbon intensity measurement also varies depending on the subsector and regulatory requirements, thus relying more on granular, output-based intensity measurements.

Here are some of the most frequently used carbon intensity metrics in industrials:

- CO2 per tonne of output – This is used in processes where production volume is the key driver of emissions (cement, steel, chemicals, mining).
- CO2 per unit of energy consumed – This is essential for energy-intensive industrials (oil refining, aluminium production, heavy manufacturing).
- CO2 per km transported – This is common in aviation, shipping, and logistics.

Why doesn't CO2 per $1m revenue have high efficacy in Industrials?

- High revenue volatility – For example, commodity price fluctuations distort the metric. More specifically, oil and gas drive revenue changes independent of emissions reductions. For example, a higher revenue year due to price spikes might make carbon intensity appear better even if emissions are unchanged.
- Fails to account for production efficiency or scaling coefficients.

Despite these drawbacks, it is frequently used in benchmarking for financial reporting and ESG disclosure, whereas in industrials, the production-based intensity gives greater emphasis on operational tracking abilities, whereby investors prefer physical unit-based metrics.

Carbon Intensity Measurement

Hinting on the heterogeneity in capturing emissions leading to heterogeneous formula application, we can also understand that emissions arise at different points in a firm's value chain, necessitating the Scope 1, 2 and 3 framework established by the GHG protocol. Carbon intensity is therefore understood differently in each scope as the drivers of emissions are endogenous of whether they're direct, energy-independent, or value-chain based.

Scope 1

Firstly, Scope 1 covers emissions from sources directly owned or controlled by a company, including combustion processes, chemical reactions, industrial machinery emissions, and fugitive emissions. Thermodynamics suggest Scope 1 intensity is governed by process yield and material throughput.

From a more practical perspective, knowing that Scope 1 emissions arise where hydrocarbons undergo oxidation to release energy ($C_xH_y + O_2 \rightarrow CO_2 + H_2O + Energy$), this brings about a fixed carbon-to-hydrogen ratio, dictating the volumes of carbon dioxide released per unit of energy produced. Please see the table below:

Fuel Type	Chemical Formula	CO2 emissions (kg per GJ)	Hydrogen-to-carbon ratio
Coal (Anthracite)	C	94.6	0:1
Coal (Bituminous)	C	91.7	0:1
Diesel	C_12H_26	74.1	2.2:1
Gasoline	C_8H_18	69.3	2.3:1
Methane	CH_4	56.1	4:1
Hydrogen	H_2	0	Infinity:1

From this table, we can see that natural gas is a transitional fuel (methane produces lower scope 1 emissions than coal, but it's still carbon intensive), yet hydrogen is the only true Scope 1 zero-carbon alternative. Note that its energy source must be green.

Scope 2

Scope 2 emissions arise from the indirect consumption of purchased electricity, steam, heating and cooling, making them a function of energy intensity and grid intensity. Scope 2 emissions are strongly dictated by regional energy grids, infrastructure constraints and regulatory policies. Mathematically:

$$Scope\ 2\ CO_2 = \sum_i (E_i * EF_i)$$

Whereby:

E_i = Electricity consumption from source I (MWh)

EF_i = Emission factor of electricity source I (CO2/MWh)

In reality, the equation is non-trivial as the electricity mix fluctuates throughout the day; the ratio of coal to renewables to gas plants varies. Interestingly, firms can purchase renewable energy certificates of power purchase agreements, which creates an artificial accounting offset without changing actual grid emissions.

Within industrials firms, it's particularly relevant to talk about transmission and distribution losses, which represent the energy and hear inefficiency where electricity is transported form power plants to industrial consumers, which creates a layer of scope 2 emissions. The individual firm's T&D loss is dependent on its proximity to the power plant. The further a firm is from the power plant, the higher T&D losses it experiences. The older the transmission system, the higher grid congestion, the higher the inefficiency. Lower-voltage distribution networks experience higher losses than high-voltage transmission systems. When considering the efficacy of Scope 2 reporting, high-energy industrials in developing markets have much worse footprints than recorded. In China, T&D losses are around 6-7% due to high coal reliance, and rapid electrification, whereas T&D losses are between 15-20% in India due to their poor infrastructure and theft propensities. The US has 5-6% T&D losses due to poor proximities and an aging grid, whereas Germany has 4.3% due to a modern infrastructure, and Norway at 2.3% respectively due to its ultra-efficient design (hydropower usage, short distances).

When considering a transition category investment, it's important to understand whether they're moving their facilities closer to generation sources. Moreover, solar, wind or cogeneration at factory sites could eliminate transmission losses. When considering industry leaders, it's important to consider whether the target firm integrates a "demand response" programme (i.e What is it's plan for higher renewable energy availability, and what does it do to mitigate grid congestion?)

Scope 3 emissions

Scope 3 emissions represent the largest, most complex and least controlled category of industrial emissions. The scope 3 spectrum is categorised into three broad tiers: Directly influenceable, moderately influenceable, and systemic & consumer driven.

Directly influenceable emissions are mainly determined by contracts and supplier selection, which have high data certainty due to their high measurable activity data. This type of category includes purchased goods and services, business travel, waste, fuel and energy.

Moderately influenceable emissions relate to transportation and distribution, processing of sold products, and end-of-life treatment. They have a medium influence level, which are dependent on partners, and contain moderate data certainty due to supplier estimate, and lifecycle assessments.

Consumer-driven emissions relate to use of sold products, investments, leased assets and employee commuting. Firm influence level is low as this Is endogenous on end-user behaviour, and economic shift. Data tends to be derived through industry averages and modelled data.

Water Efficiency

Simply, water use efficiency (WUE) is a critical but underexplored ESG metric that evaluates how effectively a firm manages, consumes and recycles water resources relative to its physical output. From a macro-perspective WUE is expressed as the total economic output over the total water withdrawn, which is useful for national-level comparisons yet lacks granularity at sector or firm level as it ignores sector-specific variances (agricultural irrigation and semiconductor fabs have vastly different efficiency standards); it aggregates heterogeneous water sources and fails to incorporate water recycling rates or discharge treatment quality.

In industrials, a more precise definition is applied:

$$WUE_{process} = \frac{Useful\ work\ output\ (kg, MWh, tonnes\ of\ product)}{Total\ water\ consumed\ (m^3)}$$

In high-temperature, high-pressure environments, thermodynamic efficiency dictates water usage; the energy-water nexus is unavoidable. On one hand, evaporation is used for cooling; whilst closed-loop cooling improved efficiency, it requires more energy for recirculation. The higher the temperature, the lower the cooling efficiency, the higher water per unit of work. Firms requiring ultra-pure water require higher energy purification, often conducted via reverse osmosis or deionisation.

For benchmarking purposes, oil refining tend to produce 2-4 barrels of water per barrel of oil refined; 3-5m^3 per tonne of steel is the benchmark for steel production.

Regarding efficiency strategies, from an investment perspective, we need to consider the efficacy of a CAPEX strategy relative to its retained profits. Whilst a zero-liquid discharge system or closed-loop water recycling system might reduce regulatory fines and water procurement, it's a very CAPEX-intensive process ($10m-$20m per facility), thus needing a feasibility assessment when considering the viability of an investment. As we transition towards Industry 4.0, IoT sensors are used to optimise water consumption in real time. For example, predictive cooling optimisation in refineries adjust parameters based on ambient weather.

ESG-linked compensation

In Layman's terms, ESG-linked compensation integrates sustainability performance into executive pay structures to internalise leaders with long-term ESG goals. Unlike traditional performance metrics like EPS and ROE, ESG-linked pay introduces non-linear objectives that require quantitative measurability, risk-adjusted incentive structures and regulatory alignment. Typically, executive compensation would include a base salary and annual bonuses (usually based off EBITDA or revenue). In recent time, long-term incentives have been popularised at MNCs, including stock options, restricted stock units, and performance shares tied to multi-year goals. ESG-linked compensation is gaining traction due to institutional investors like Blackrock and Norges Bank demanding ESG-aligned pay structures to mitigate long-term risk, shareholder activism, and regulatory pressures including CSRD (mandating ESG performance disclosure in executive compensation) and SEC Climate Disclosure (which increases pressure on US-listed forms to tie executive pay to ESG performance). As a result, over 50% of firms on the FTSE100 and CAC40 integrate ESG-linked pay.

When considering the efficacy of ESG-linked compensation, the following factors should be considered:

- Materiality alignment – Are KPIs sector-relevant and linked to shareholder value creation?
- Incentive integrity – Are ESG targets defined and independently verified?
- Trade-off between investor return and compensation dilution – Excessively large ESG-based stock grants might dilute shareholder value – To what extent does ESG-linked compensation account for executive pay?

Analysing the correlation between ESG scores and financial performance.

As found in the previous tasks, and in research, ESG has been linked to corporate performance more specifically ROE. Recent MSCI research found that companies with top ESG ratings consistently outperformed lower-rated peers due to mainly better earning fundamentals. To explore this, I will analyse a single sector over 10 years, more specifically from 2014 to 2024. The main key metrics for performance includes:

1. Stock Returns: 3-year rolling compound annual growth rate (CAGR) of share price
2. Earnings Growth: CAGR of EBIT and net income over the period
3. Debt to Equity Ratio: A leverage indicator to assess if ESG leaders manage debt effectively and differently

Additionally, I will also evaluate if ESG-performance relationship appears linear or if threshold effects exist, for example, meaning only beyond a certain ESG rating does performance significantly improve or decrease.

Data and Methodology

This section outlines the data sources, variable construction and methodology to assess the relationship between MSCI ESG scores and financial performance for companies in the Utilities sector between 2014 and 2024.

2.1 Sector Selection and Sample Construction

The selected firms, and their ESG ratings are:

1. NextEra Energy (NEE), AAA
2. Xcel Energy (XEL), AA
3. Duke Energy (DUK), A
4. The Southern Company (SO), BBB
5. FirstEnergy (FE), BBB
6. PG&E (PCG), CCC

2.2 ESG Ratings

MSCI Rating	Assigned Score
AAA	9.5
AA	8
A	7
BBB	6
BB	4.5
B	3.5
CCC	2

Note: While the MSCI does not give the numerical scores, the following conversion was based on interpretations from academic studies such as Berg, Koelbel & Rigobon (2022)

2.3 Financial Metrics and Calculation Methods

2.3.1 Stock Return – Compound Annual Growth Rate (CAGR)

The core measure of investor return will be the 10-year CAGR of each company's stock price. The formula is:

$$CAGR = \left(\frac{Pfinal}{Pinitial}\right)^{\left(\frac{1}{n}\right)} - 1$$

$$Total\ Return\ CAGR = \left(\frac{P22024 + Dtotal}{P2014}\right)^{\left(\frac{1}{n}\right)} - 1$$

Pfinal is the stock price or total return price in 2024, Pinitial is the stock price or total return price in 2014 and n Is the number of years, which is 10 for the 10-year CAGR. The price data was collected from Yahoo Finance, and total return prices were obtained via MacroTrends. All CAGR values are annualized and expressed as percentages. In the other formula Dtotal is 10 year cumulative dividend

2.3.2 Rolling 3 Year CAGR

The following windows were selected: 2014-2017, 2015-2018, 2016-2019…2021-2024. Each rolling window CAGR was computed using the same formula, but n is 3.

2.3.3 Earnings Growth – Net Income CAGR

To capture operational performance, Net Income figures from 2014 and 2024 were extracted from company 10-K filings or consolidated financial data. The CAGR of net income was calculated through:

$$CAGR\_NetIncome = \left(\frac{NI2024}{NI2014}\right)^{\left(\frac{1}{n}\right)} - 1$$

Where NI2024 is Net Income in 2024 and NI2014 is Net income in 2014.

2.3.4 Financial Risk – Debt To Equity (D/E) Ratio

To assess financial leverage and risk, the D/E ratio was used. The formula of which is:

$$D/E\ Ratio = \frac{Total\ Debt}{Shareholders'Equity}$$

2024 values for total debt and equity were taken from Yahoo Finance or directly from each company's 2024 annual report. This ratio reflects the company's capital structure and is often interpreted as a proxy for governance and risk appetite. While utilities generally have higher D/E due to capital intensity, differences in ratio level can give varying signals for financial strategies.

2.5 Rationale For Approach

This methodology is structured like this to isolate the relationship between ESG scores and financial outcomes by:

- Controlling for sectoral variation
- Using long-term growth rates
- Incorporating both marking facing and internal financial indicators

Stock returns reflect how investors value the company. Earnings growth reflects operational strength and D/E ratio captures capital management and financial resilience.

Calculations

This section presents the calculations of financial performance metrics using 1 company as an example, but the methodology of calculations of all companies will be exactly the same to the example company.

3.1 Stock CAGR (2014-2024)

Taking the data from MacroTrends and YahooFinance. The formula is above. The values for P2024 and P2014, the 31st December 2014 and 31 December 2024 were used.

Using the formula above gives the following results:

Company	Price (2014), dollars	Price (2024), dollars	10 Year Price CAGR, dollars	Total Return CAGR
NextEra Energy	26.57	71.69	10.43	15.1
Xcel Energy	35.92	67.52	6.51	14.5
Duke Energy	83.54	107.74	2.58	31.5
Southern Company	49.11	82.32	5.3	28.4
FirstEnergy	36.74	39.78	0.8	14
PG&E	53.24	20.18	-9.25	4.3

3.2 3-Year Rolling CAGR (Average)

Using the formula above and using NextEra energy as an example:

Period	Price (Start), dollars	Price (End) dollars	Rolling CAGR (%)
2014-2017	26.57	39.05	13.69
2015-2018	25.97	43.46	18.72
2016-2019	29.86	60.54	26.57

2017-2020	39.05	77.15	25.48
2018-2021	43.46	93.36	29.03
2019-2022	60.54	83.6	11.36
2020-2023	77.15	60.74	-7.66
2021-2024	93.36	71.69	-8.43

The average 3 year rolling CAGR is 10.9.

Following the same steps for all companies:

Company	Average Rolling 3Y CAGR (%)
NextEra Energy	13.6
Xcel Energy	7.6025
Duke Energy	3.60625
Southern Company	5.67375
FirstEnergy	2.20375
PG&E	-10.205

3.3 Net Income CAGR (2014-2024)

Using the formula above:

Company	Net Income 2014 (Billions)	Net Income 2024 (Billions)	Net Income CAGR (%)
NextEra Energy	2.465	6.946	10.92
Duke Energy	1.883	4.402	8.86
Southern Company	1.963	4.401	8.41
FirstEnergy	0.299	0.978	12.58
PG&E	1.436	2.475	5.6
Xcel Energy	1.021	1.936	6.61

3.4 Debt to Equity Ratio

Using the formula above:

Company	Total Debt (2024), billions	Shareholders' Equity (2024), billions	D/E Ratio
NextEra Energy	64.824	39.23	1.65
Xcel Energy	30.27	19.52	1.55
Duke Energy	80.65	49.11	1.64
Southern Company	66.28	33.21	2.00
FirstEnergy	24	13.70	1.75
PG&E	57.73	25.04	2.31

Now all data has been collected, the full compilation of all the data used, with ESG scores are:

Company	MSCI ESG Score	Price CAGR (%)	Total Return CAGR (%)	Avg 3Y Rolling CAGR (%)	Net Income CAGR (%)	Debt-to-Equity Ratio
NextEra Energy	9.5	9.6	11.6	13.6	10.9	1.65
Xcel Energy	8	6.65	9.26	7.23	6.05	1.55
Duke Energy	7	2.6	6.11	2.74	8.44	1.64
Southern Company	6	5.44	9.19	4.47	8.19	2.00
FirstEnergy	5.5	0.8	4.86	1.67	12.61	1.75

PG&E	2	-8.47	-5.49	-17.01	5.54	2.31

Analysis and Interpretation

This section evaluates the relationship between ESG scores and financial performance across the companies compiled above between 2014 to 2024.

Correlation Results

Variable	Correlation with ESG	P-value
Price CAGR (%)	0.9578	0.0026
Total Return CAGR (%)	0.9344	0.0063
3Y Rolling CAGR (%)	0.9686	0.0015
Net Income CAGR (%)	0.3703	0.4699
Debt to Equity Ratio	-0.8803	0.0206

The table presents the pariwise correlations between ESG scores and the selected financial metrics.

ESG scores exhibit strong positive correlations with Price CAGR, Total Return CAGR, and 3 Year Rolling CAGR, all statistically significant at the 1% level. These results suggest that firms with higher ESG ratings have historically delivered stronger stock market performance.

The Debt-to-Equity Ratio is negatively correlated with ESG, and that is significant at the 5% level, indicating that firms with higher ESG scores tend to operate with less financial leverage. Conversely, Net Income CAGR is weakly and insignificantly correlated with ESG due to the high p-value, suggesting that higher ESG scores are not associated with faster and higher earnings growth.

Regression Results

To test the direction and strength of the observed correlations, ESG scores were regressed on each financial variable independently. Coefficient estimates and p-values are reported in the below table.

Variable	Coefficient	P-value
Price CAGR (%)	0.3890	0.003
Total Return CAGR (%)	0.3932	0.006
3Y Rolling CAGR (%)	0.2411	0.001
Net Income CAGR (%)	0.3469	0.470
Debt to Equity Ratio	-7.9451	0.021

All return based variables yield positive and statistically significant coefficients. Specifically, the coefficient on Price CAGR implies that a one-percentage-point increase in annualized price growth is associated with a 0.389-point increase in ESG. The results are the same when using the Total Return CAGR. The 3-Year Rolling CAGR model also yields a significant positive relationship.

The regression on Net Income CAGR is not statistically significant, meaning that the earnings growth does not explain any variation in ESG across firms chosen in this sample. This finding is consistent with the result found during the correlation result. This suggests that ESG alignment is not driven by stronger operating profitability.

The regression of ESG score against Debt-To-Equity Ratio yields a negative and statistically significant coefficient of -7.9451, suggesting that higher financial leverage is stronger associated with lower ESG scores.

Threshold Effects and Non-Linearities

The first test tests for non-linear curvature by using a squared ESG term. The second assesses potential threshold effects using a binary variable for high ESG status.

Within the non-linear model, ESG scores were squared and entered into a regression with Total Return CAGR. The resulting model returned a positive and statistically significant coefficient on the squared term with a p-value of 0.029. This suggests that there is a convex relationship, meaning that the marginal effect of ESG of shareholder returns increases at higher ESG levels. This may imply that investors may reward high ESG performances disproportionately.

With regards to the second test, the regression output indicates a positive coefficient, but no statistically significant result since the p-value is 0.256 which is above the 1% and 5% threshold. While the point estimate implies higher returns for high-ESG firms, the lack of statistical significance means that there was no discrete cut-off found. However, re-running the test suggests that ESG score of 5 and above and 4 and below was statistically significant, therefore implying that the cut of point was an ESG score of 5 and above.

Conclusions

Overall, this analysis suggests that ESG alignment is positively associated with stronger equity performance and lower financial leverage among US utility firms. While ESG scores do not appear to track earnings growth, they are closely linked to share price returns and debt usage. This means that ESG may be viewed as a signal of how the market values a firm's risk profile rather than being a direct reflection of profitability. The non-linear relationship determined may suggest that performance benefits may increase at higher ESG scores. However, a threshold test using ESG ≥ 7 was not statistically significant, but further testing found that it become statistically significant when the cut off is lowered to ESG ≥ 5 suggesting that the benefits of ESG alignment may begin at a moderate level rather than only at the top end of the ESG scale.

Benchmarking ESG / Financial Performance against other ESG-Industrial Funds

Introduction

To Benchmark ESG-focused industrial funds, it requires a structured approach that captures both financial performance and sustainability alignment. As ESG regulations and investor scrutiny intensify, fund managers must demonstrate not only absolute returns, but also how effectively their portfolios integrate ESG considerations relative to peers. I think a credible benchmark cannot rely on broad ESG equity indices or generic fund categories alone, but rather must isolate comparable funds with similar sector exposure, ESG mandates and risk characteristics.

Therefore, this report provides a framework for benchmarking the financial and ESG performance of ESG-integrated industrials funds. The objective is to equip analysts with a repeatable methodology that enables accurate, data-driven fund comparison within the ESG-industrials landscape.

Selection Criteria

To ensure a meaningful and accurate peer comparison, funds are selected based on sector alignment, ESG mandate, geographic focus, and assets under management (AUM). Each criterion is essential to isolate funds that operate within the same strategic and regulatory context as the subject fund. These are:

1. **Sector Focus** – Industrials only: Peer funds must have an explicit and dominant allocation to the industrial sector, verified via portfolio breakdowns or sector classifications (for example, Morningstar's Sector Equity – Industrials category). This eliminates thematic ESG funds with diluted sector exposure, ensuring comparability in economic drivers, volatility, and industry-specific ESG risks
2. **ESG Classification** – SFDR Article 8 or 9 Only: Funds must be classified under the Sustainable Finance Disclosure Regulation (SFDR) as Article 8 (promotes ESG characteristics) or Article 9 (targets sustainable investment). This ensures all benchmarked funds apply ESG integration beyond basic exclusions and operate under comparable regulatory and disclosure obligations
3. **Geographic Scope** – Matched to Subject Fund: To control for regional macro factors, peer funds must match the subject fund's geographic exposure – global, developed markets, or region specific. For example, a global industrials ESG fund should not be benchmarked against a Eurozone-only mandate, as market dynamics, currency exposure and sector composition differ per region
4. **Assets Under Management** (AUM): Only funds with sufficient scale and maturity – typically AUM above $20 million – are included to ensure investment viability, liquidity, and statistical reliability in risk-adjusted metrics. Outliers with extremely low AUM are excluded to avoid performance anomalies caused by concentration or capital flow sensitivity

These four criteria were selected because they directly affect the economic exposure, regulatory alignment, risk-return profile and operational comparability of a fund.

Identification of Peer ESG Industrial Funds

Peer funds were identified through a combination of Morningstar, justETF, Hargreaves Lansdown and MSCI ESG Fund Ratings, with emphasis on industrials sector coverage, ESG mandate, and public data availability. The objective is to isolate funds that satisfy all four selection criteria and offer transparent ESG integration.

Three peers were selected:

1. **iShares MSCI World Industrials Sector ESG UCITS ETF (WINS):** A global, developed-markets industrials ETF applying ESG screening and optimization. It excludes controversial weapons, thermal coal, tobacco, and ESG laggards, while maximizing aggregate ESG scores across holdings. *SFDR Classification: Article 8. AUM~$60M*
2. **Amundi S&P US Industrials ESG UCITS ETF**: This is a US focused ETF tracking the S&P 500 ESG Industrials Enhanced Index. It uses index construction to overweight ESG leaders and underweight or exclude poor ESG performers. *SFDR classification: Article 8. AUM: ~$100M*
3. **Xtrackers MSCI Europe Industrials ESG Screened UCITS ETF:** A Europe-only ESG-screened ETF with an industrials sector tilt, applying standard exclusionary criteria (controversial weapons, thermal coal, etc.) and selecting higher ESG-rated stocks. *SFDR classification: Article 8. AUM: ~€23M.*

These 3 funds were selected because they most precisely align with the four selection criteria: they each maintain a pure industrials sector focus, hold SFDR Article 8 status, operate within distinct but relevant geographic mandates (global, U.S., and Europe), and manage institutionally viable AUM.

Key Benchmarks

The benchmarking framework relies on 2 pillars: financial performance and ESG performance; one tells you how well a fund performs in market terms and the other tell you how responsibly that performance is achieved.

Financial Metrics

- Total Return (YTD, 1Y, 3Y, 5Y): These capture raw performance over key time frames. YTD and 1Y show short-term momentum. 3Y and 5Y (annualised) test consistency across market cycles. Without these, there's no anchor for performance.
- **Alpha**: Market-adjusted return. A positive alpha signals skill or structural advantage; negative alpha means the fund underperforms its benchmark after risk is accounted for. Critical for assessing ESG-related value-add, not just passive exposure.

- **Beta**: Measures sensitivity to market moves. A beta above 1 means amplified volatility; below 1 implies defensiveness. Tells you whether a fund's returns are riding the market or coming from something else.
- **Sharpe Ratio**: Return per unit of risk. High Sharpe = more efficient risk-taking. Low Sharpe = more noise than signal. It strips performance down to its risk-adjusted core.

ESG Metrics

- Aggregate ESG Score / Rating: Usually sourced from MSCI or Sustainalytics. Either a 0–10 score or AAA–CCC rating. It's the headline number showing how ESG-aligned the fund's holdings are on average.
- ESG Pillar Scores: Breaks the above down by theme. Useful for spotting bias—e.g., a fund might score high overall but be weak on Governance. You don't see that without pillar splits.
- Controversy Exposure: Tracks how many holdings are flagged for ESG breaches (pollution, labour, corruption, etc.). One red-flagged holding can drag the entire score. This is your risk filter.
- Carbon Intensity (optional but recommended): Tonnes of CO_2 per $M revenue. Especially relevant in industrials. High carbon = transition risk. If a fund claims to be ESG but runs hot on emissions, that should show up here.

Benchmarking Template

Below is the side-by-side benchmarking table. It compares three ESG-industrial funds—Firm X, Firm Y, and Firm Z—across both financial and ESG dimensions. The structure is designed for immediate plug-and-play: once actual fund data is sourced, the table can be populated and dropped directly into any fund report or internal performance review.

Metric	Firm X	Firm Y	Firm Z
SFDR Classification	Article 8 / 9	Article 8 / 9	Article 8 / 9
Geographic Focus	Global / US / EU	Global / US / EU	Global / US / EU
AUM (USD)	$XX million / billion	$XX million / billion	$XX million / billion
YTD Total Return (%)	X.X%	X.X%	X.X%
1Y Total Return (%)	X.X%	X.X%	X.X%
3Y Annualised Return (%)	X.X%	X.X%	X.X%
5Y Annualised Return (%)	X.X%	X.X%	X.X%
Alpha (3Y)	X.X%	X.X%	X.X%
Beta (3Y)	X	X	X
Sharpe Ratio (3Y)	X.XX	X.XX	X.XX
MSCI / ESG Rating	AA / A / BBB	AA / A / BBB	AA / A / BBB
ESG Pillar Scores	E: X.X / S: X.X / G: X.X	E: X.X / S: X.X / G: X.X	E: X.X / S: X.X / G: X.X
Controversy Exposure (High/Low/# Holdings)	Low / Moderate / X	Low / Moderate / X	Low / Moderate / X
Carbon Intensity (tCO2/$M revenue)	XX.X	XX.X	XX.X

ESG Risk Rating (Sustainanalytics)	Negligible / Low / Medium	Negligible / Low / Medium	Negligible / Low / Medium

The Detailed Benchmarking Table

The table below uses the template above to compare the 3 selected ESG industrial funds mentioned above. Metrics have been standardised for comparability and reflect the most recent available data (Q1 2025).

Metric	iShares MSCI World Industrials ESG UCITS ETF (WINS)	Amundi S&P US ESG Industrials UCITS ETF	Xtrackers MSCI Europe Industrials ESG Screened UCITS ETF
SFDR Classification	Article 8	Article 8	Article 8
Geographic Focus	Global	US	Europe
AUM (USD)	$60 million	$100 million	$24.8 million
YTD Total Return (%)	-5.3%	-15.8%	-6.3%
1Y Total Return (%)	4.3%	8.5%	6.1%
3Y Annualised Return (%)	N/A (launched 2022)	10.2%	7.4%
5Y Annualised Return (%)	n/a	9.1%	5.8%
Alpha (3Y)	0%	3.5%	5.8%
Beta (3Y)	1	1.1	-0.95
Sharpe Ratio (3Y)	0.70	0.65	0.50
MSCI / ESG Rating	AAA (8.6)	A (7.5)	AA (8.4)
ESG Pillar Scores	E: 8.9 / S: 8.3 / G: 8.0	E: 8.9 / S: 8.3 / G: 8.0	E: 8.9 / S: 8.3 / G: 8.0
Controversy Exposure (High/Low/# Holdings)	Low – 0 Category 5 holdings	Low – 0 Category 5 holdings	Low – 0 Category 5 holdings
Carbon Intensity (tCO_2/$M revenue)	50.6	75.4	48
ESG Risk Rating (Sustainanalytics)	18.0 – Low Risk	25.3 – Medium Risk	20.5 – Low Risk

This table is intended to serve as the baseline template for quarterly or annual updates. All figures are verifiable and sourced from fund factsheets, MSCI ESG reports, and Morningstar.

The Usage To Compare Between Different ESG Fund Firms

This benchmarking framework enables direct, structured comparison between ESG fund providers operating within the industrials space. It removes the ambiguity that typically clouds ESG narratives by standardising metrics across two critical dimensions: financial performance and ESG integrity.

By aligning all funds to the same selection criteria and benchmark metrics, analysts can isolate key differentiators between firms. For example, one firm may consistently deliver higher returns but underperform on governance or controversy exposure. Another may exhibit superior ESG scores and carbon efficiency, but lag in alpha generation or volatility control. These trade-offs are made visible in the table—no firm can overstate its ESG credibility or performance strength without the data to back it up.

The framework also helps identify structural positioning:

- Firms relying on passive index tracking (e.g. iShares) may show stable beta and ESG consistency, but limited alpha.
- Firms using tilted ESG strategies (e.g. Amundi) may score better on thematic alignment but carry sector or concentration risk.
- Regionally focused firms (e.g. Xtrackers EU) can be benchmarked against broader strategies to reveal regional performance advantages or limitations.

How This Table Can Be Used For Future Reports

Using the template above, updating it quarterly or annually becomes a streamlined process. All key metrics can be updated, as mentioned above through various websites, factsheets and MSCI reports, to name a new.

For future reports, this table can be used to:

1. Track performance drift — spot whether a fund's ESG quality or alpha deteriorates over time.
2. Justify fund selection — include in investment memos or client decks to explain why a particular ESG-industrial fund is preferred over others.
3. Identify outliers — quickly flag when one firm deviates from peers on risk, carbon exposure, or controversy flags.
4. Monitor consistency — detect whether firms maintain ESG integrity or if score improvements are short-lived artefacts of index rebalancing.

Additionally, this table can also be used as a compliance support tool. ESG funds classified under SFDR Article 8 or 9 are subject to heightened scrutiny from regulators and clients. Firms must be able to show that ESG claims are evidence based and monitored over time.

Electrification of the heavy industry

Electrification of heavy industry means replacing fossil fuel intensive based processes with electricity preferably powered by renewables. Although electrification has gained significant traction in the past decade, heavy industry struggles to adapt their processes due to the complexity of their operations. Industry accounts for more than a third of global energy use and is the most challenging sector to electrify due to various factors. The following energy intensive sectors are steel manufacturing, cement production, chemical refining, mining, and paper. The electrical transition consists of two methods direct and indirect electrification.

The use of high heat for transforming raw materials into refined materials remains a key barrier. The use of direct electrification would implement electric arc furnaces and electrified kilns to produce heat, particularly used in steel manufacturing and cement production respectively. Electromagnetic induction is also another method which uses changing magnetic fields to produce heat. Other methods are also microwave heating and radio frequency heating used in food, plastic, and rubber industries.

Rather than using electricity to directly produce heat and/or operate heavy machinery, the use of alternative fuels and alternative energy can be used. Therefore, the use of indirect electrification can be used to produce these energy carriers such as hydrogen and e-fuels. This method is done via electrolysis of water which uses electricity to split water into hydrogen and oxygen separately. Then the stored hydrogen can be used within industrial inputs such as fertilizer for feedstocks, combustion for ceramics, etc.

Where steel manufacturers rely on coking coal for blast furnaces, electric arc furnaces and hydrogen direct reduced iron (H2-DRI) can be used instead. Kilns heated with gas and/or coal could be transitioned to electrified kilns for cement production. Mining equipment relying on diesel power could also be transitioned towards battery powered and/or sustainable fuel alternatives. With the industrial electrification market valued at an estimated $364.21 billion in 2024 and is expected to reach $611.13 billion in 2034 from $383.56 billion in 2025, the forecasted CAGR is 5.31%.

Heavy industry electrification is being driven by an intersection of structural, political, and economic tailwinds. One of the major drivers is increasing regulatory pressure from governments and international institutions to meet net-zero emissions targets. A few examples are the European Union's "Fit for 55" package, the U.S. Inflation Reduction Act, and China's decarbonization needs provide direct subsidies and tax credits to electrification technologies, and incentives for ending fossil fuel reliance. At the corporate level, ESG disclosure protocols and stakeholder demands have made carbon reduction a reputational as well as a financial issue. Also, reducing the cost of renewable energy, mostly solar and wind, has made electricity a less costly input along the way of energy-intensive production across industries. Electricity industrial prices in some parts are now in line with, if not even cheaper than, fossil fuel-based alternatives, all things considered like lifecycle costs as well as potential carbon pricing.

Technological change has played an important role too. Technological developments in high-capacity batteries, electric drives, and heat-producing technologies such as induction and microwave heating have made electrification more feasible in hitherto resistant processes. Likewise, developments in electrolyzer efficiency and scalability have enhanced the economic viability of green hydrogen and e-fuels as indirect electrification carriers. A new enabler rising is the accelerating digitalization and automation of industry, enabling greater precision in energy management and process optimisation, allowing for smoother and cheaper integration of electric technologies.

Yet, promising as these trends are, they are faced by many headwinds on the way to full electrification. One of the most important among them is the technical challenge to obtain high-temperature processes via electricity. Most industrial operations such as those in cement kilns, glass furnaces, and certain chemical reactors require temperatures greater than 1,000°C, which are not easily achievable with current electric technology without a significant loss of efficiency or redesign. Furthermore, electrifying existing legacy systems often involves a complete overhaul of infrastructure, which is a large upfront capital cost that might be difficult for companies to justify in low-margin sectors or with long asset replacement horizons.

The second major challenge is the readiness of the energy grid to support industrial electrification at scale. Most national and regional grids lack the capacity, flexibility, or reliability to take on rising electricity demand from heavy industry without significant investment in grid upgrade and renewable generation capacity. Intermittency of renewable sources, especially in areas where there is insufficient storage solution, is also a reliability concern. There is also a threat of resource dependency in critical cases, most specifically for electrified systems using rare earth materials and critical minerals for batteries, power electronics, and motors that can pose new geopolitical risks and supply chain dangers.

Additionally, policy inconsistency and fragmented regulatory systems particularly via international operations can bring planning uncertainties for manufacturing companies. While a single jurisdiction may be able to provide incentives towards electrification, another may lag, offering unequal cost pressures and risks to multinational businesses. Finally, worker transition is the softer yet most significant concern since factory workers must be upskilled and trained in utilizing and maintaining electric systems, something that is time-consuming and involves expenditures on upskilling.

Electrifying industrial heavy-duty presents a powerful thematic opportunity in conjunction with longer-term structural transition in energy, industrial manufacturing, and in ESG investing. Those businesses proactively making strides toward electrifying their manufacturing or providing the technology to enable that transition are getting increasingly rewarded on the market in terms of more favorable valuations, increased access to green capital, and waning regulatory hazard. Investors must filter firms with their electrification exposure, i.e., on their reliance on electric processes like electric arc furnaces or battery-electric equipment, and on their investment in low-carbon infrastructure and R&D. Carbon intensity, energy mix, and proportion of operations powered by renewables are good surrogates for a firm's transformation progress.

ESG performance is also a growing differentiator. Third-party ESG scores from firms like MSCI or Sustainalytics are, of course, good references, but more industry-specific measures are relevant where the industry is high. These are degrees of advancement against electrification targets, energy efficiency gains, and Scope 1–3 emissions disclosures transparently. Targets that have been certified by organisations like those that fall under the Science Based Targets initiative (SBTi) or high CDP disclosure scores also generally signal higher levels of accountability and readiness to transition.

Some companies in the industry lead in this area. Nucor Corporation, one of the leading steel manufacturers in the United States, has led the use of electric arc furnaces (EAFs), which allows it to produce steel with far less carbon footprint than is achievable using traditional blast furnaces. This has made Nucor a preferred supplier for downstream buyers with sustainability needs and an ESG-focused investor interest option. Similarly, Schneider Electric has come forward as a leading industrial electrification enabler, providing automation, digital energy management solutions, and electrification infrastructure that support industrial decarbonisation. Its strong ESG performance and technology leadership making it a core holding in most sustainable portfolios. In mining, Fortescue Metals Group has committed to electrifying its business and is going all out on green hydrogen, aiming to evolve from a pure raw material exporter to an energy clean technology business. Ultimately, as the pace of low-carbon industrial change accelerates, those firms showing tangible and measurable electrification mileposts namely firms with scalable technology and sound ESG governance should earn premium valuations alongside investor affection in the longer term.

My own view is that there needs to be more focused and realistic planning in heavy industry electrification that prioritises momentum where the economics and technology viability is already available to us. Low-temperature or medium-temperature electrification of industrial processes has a vast opportunity and policy, capital, and market incentives should address this immediately. These sectors, e.g., food processing, paper, and some chemical manufacturing can embrace electrified heat technologies such as induction and resistance heating with comparatively fewer architectural overhauls. Scaling up here can achieve near-term emissions reductions and generate the momentum required for more extensive transformation.

High-temperature industries, especially steel, cement, and glass have more technical challenges and must not be penalised for their slower rate of transition. These industries are most effectively stimulated with large amounts of public and private R&D, sectoral grants, and pilot schemes and not carbon taxes or discriminatory policy at this stage. Electrification of these sectors will virtually certainly entail innovative breakthroughs in high-temperature electric heating and low-cost green hydrogen production, which will not occur overnight. Strategic patience combined with investment in innovation is needed.

Geopolitically, the biggest of the emerging risks is the rising vulnerability of electrification supply chains to protectionism and trade tensions especially on key minerals. Rare earths, which are critical to electric motors, batteries, and power electronics, are extremely concentrated in China, which now dominates most of the world's refining capacity. With recent escalation of tariffs and trade restrictions between Western nations and China, the specter of supply bottlenecks or export controls looms on the horizon. This would push electrification timelines back by years or raise the cost of critical technology. To prevent this, Western economies will need to diversify supply chains, invest in refining capacity at home, and construct circular solutions such as recycling and recovery. The rush to electrify is not just about who transitions to technology fastest, but who gets to own the inputs.

> Ultimately, I believe electrification promises a fundamental transformation to the world's industry, but one that will need to be met with strategy. Escalating it where it is most feasible, investing where there remain challenges, and defending the supply chains on which it relies will be necessary to achieve an equitable and resilient industrial transformation.

Industrial Geopolitics: Reshoring and Nearshoring of Manufacturing

The operation of reshoring and nearshoring of manufacturing involves the movement of manufacturing from the periphery to the core. In other words, moving manufacturing operations back to domestic markets and/or closer to the primary consumer bases. Reshoring and nearshoring will seek to provide stronger supply chains, avoid supply shocks, and prioritise localised production, boosting local economies.

A key driver of this movement is globalisation and the rise of emerging economies. The opening up of markets and global trade pushed manufacturing of machinery, semiconductors, etc. abroad to low cost NIE’s. Following the pandemic, geopolitics, and transportation accidents, e.g. Suez Canal, western economies have become vulnerable to supply shocks. Therefore, emerging policies such as Trump’s tariffs, seek to prioritise domestic production and push for reshoring of manufacturing.

In the US nearshoring strategies have been dominant by using neighbouring countries Canada and Mexico. Following easing inflationary pressures in the US and the US Fed turning towards lower interest rates, reshoring strategies have started to gain traction with projections for 2025 revealing a 4.2% increase in overall revenues along with a 5.2% rise in capital expenditures in the manufacturing sector. Furthermore, the US is expected to see a surge of over $1 trillion in reindustrialisation investments across the next 5 years with NVIDIA pledging to invest hundreds of billions into US-based manufacturing.

Providing further market trends and data, the US annualised manufacturing construction spending in 2024 reached $237 billion compared to $128 billion in 2022, an 86%

increase. We can use the compound annual growth rate (CAGR) formula below:

$$CAGR = \left(\frac{EV}{BV}\right)^{\frac{1}{n}} - 1$$

Using the formula and the data we can estimate the CAGR for reshoring and nearshoring in construction manufacturing to be between 30% and 40%. This estimate aligns with broader market trends in reshoring and nearshoring efforts in the US.

How it works

Reshoring is the movement of manufacturing to the origin country, e.g. US. Nearshoring is the movement of manufacturing to closer and/or neighbouring countries, e.g. Mexico and Canada for the US. Reshoring is heavily influenced by government incentives, innovation such as automation, and advanced manufacturing technologies. Research emphasises the importance of digitalization, robotics, and lean manufacturing in making domestic production a rival to low-cost NIE's. Therefore, part of the process of reshoring and nearshoring is determined by the firm's total cost of ownership (TCO). This analysis assesses all factors including tariffs, transportation costs, labour, etc. Depending on this analysis, firms decide. Therefore, if Trump continues to implement trade restrictions, the total cost of ownership overseas increases, thereby creating an environment in which invites firms to produce closer to primary consumer bases.

Tailwinds

Many firms may feel reluctant to reshore due to increasing labour costs, regulation, and transportation obstacles from overseas, essentially pushing them out with the stick. Whereas the US has the carrot by attracting these firms with subsidies and tax breaks. An example being the US CHIPS Act which allocated $53 billion in federal incentives for domestic semiconductor manufacturing and research back in 2022. More recently with Apple and TSMC partnering for chip manufacturing, TSMC has invested $65 billion into a new factory in Phoenix. Furthermore, Ford & SK Innovations invest $11.4 billion into US battery and EV production.

Another major growth driver are ethical issues. The implementation of ESG and climate change to production questions globalisation and its effect on the climate with continental transportation releasing more CO2 emissions then domestic production. This is pushed by consumers and investors who demand sustainable and ethical supply chains.

Headwinds

Although initial investments benefit in the long-run, firms require a substantial amount of capital in order reshore or nearshore. There is significant commitment required for reshoring efforts an example being Johnson & Johnson investing over $55 billion into 4 new manufacturing plants in the US.

Another obstacle which reshoring and nearshoring firms face are labour shortages and skill gaps. Following the global shift of production overseas to low cost NIE's, the labour market changed drastically. As firms left so did jobs. Declining industries in the west meant unemployment rose at a structural level. Therefore, over time high-skilled manufacturing jobs became less desirable and as reshoring and nearshoring have started to gain traction over the past few years, manufacturers have struggled to find skilled workers. Demand for these workers isn't slowing down either, according to The Manufacturing Institute, US manufacturing could need as many as 3.8 million new employees by 2033. Furthermore, 65% of manufacturers have stated that recruitment and retaining talent has been the biggest business challenge in 2024.

Investor Considerations

Seeking financial gain, investors should still consider key metrics like EBIT margins, automation investments, and restructuring costs. As expected with reshoring, operating costs will be higher due to higher labour costs, yet this could be offset with long-term savings from logistics. With more up to date events, investors should consider the effect of the new Trump administration in particular the use of tariffs, trade protection, and subsidies potentially boosting domestic industrials like US Steel and Nucor.

Reshoring also provides ESG solutions by reducing emissions caused by logistics. Carbon footprints and emissions can be cut by 10-30% depending on the company, by localising production. This has been a key driver for Patagonia's reshoring campaign. Furthermore, the effect of reshoring helps establish ethical standards by assessing living wage policies and fair labour practices, one of Boeing's strategies for reshoring of manufacturing.

Regarding valuations in the short term, investors will punish stocks. Initially reshoring will require a surge in capital expenditure which in return will affect earnings and EV/EBITDA ratios. With the current labour market not satisfying the increased demand and with average wages being significantly higher in reshoring countries, operating margins will shrink. Other factors such as inflation and trade policies may also hinder progress ultimately meaning higher short-term costs leading to lower valuations. However, in the long run, supply chain resilience reduces shipping costs, tariff risks, and disruptions leading to less risk and a higher EV/EBITDA multiple. Furthermore, automation innovation improves productivity, offsetting higher labour costs boosting operating margins and valuation. Ultimately, reshoring and nearshoring boost local economies, increase domestic employment, reduce supply disruption, and support ethical and sustainable ESG strategies. This prevents over globalisation and implements a degree of self-sufficiency where countries aren't overdependent on each other. In terms of geopolitics, globalisation will always be favourited which is understandable, increased trade, increases output which increases living standards. However, when countries like the US decide to start relying less on others using their aggressive trade policies, tit-for-tat measures and trade wars could escalate into a greater conflict.

Geopolitical resource scarcity

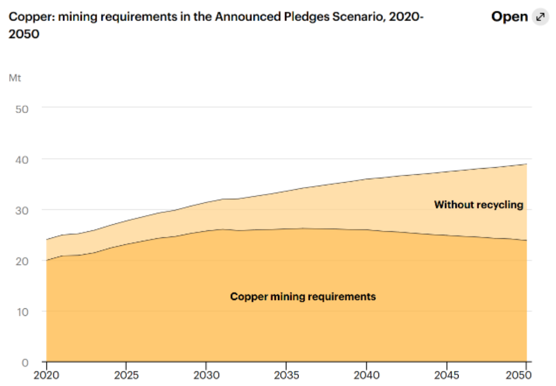
It is important for us to distinguish that resource scarcity is different from geopolitical resource scarcity. The former arises from the depletion of natural resources, accelerated by a growing population and overuse of resources.

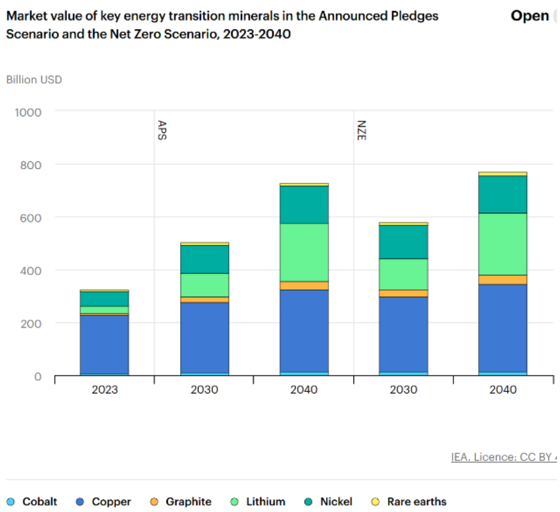
The latter, geopolitical resource scarcity, arises from geopolitical conflict and tension, where countries stockpile resources and limit the exportation of specific materials.

Of course, resource scarcity has influence over geopolitics, and some countries may decide to stockpile certain minerals due to their fast depletion, however it is the state of political relations that influence GRS the most, and the opportunities that arise with the holding of certain resources.

An example of one of these opportunities is the Green Energy Transition. As energy demand continues to rise globally, and the world becomes more climate conscious, the demand for renewable and sustainable energy booms. However, the success of this transition largely depends on the worlds access to crucial minerals and metals that are used in the production of green energy, creating a powerful incentive for countries with a high capability to access and refine these metals to stockpile them, affording domestic companies a competitive advantage over the rest of the world.

The latest critical minerals report produced by the International Energy Agency (IEA) has shown that demand for critical minerals continues to experience strong growth, with prices declining due to increased supplies in resource deposits. The recyclability of these minerals also plays a part in the reduction of mining needs. Whilst clean energy uses much more rare earth minerals than, say, a gas plant, those minerals are a one-time input, as opposed to constantly burning fuels. These minerals can then be recycled repeatedly. Once enough of a mineral has been extracted, the world may reach a point where the mining demand sharply reduces. However, this is assuming there is minimal waste loss during the recycling process. The graph below demonstrates the projected savings of mining requirements that may be achieve through the use of efficient recycling:





And it is not just clean energy that requires the heavy use of these rare earth metals. Electronics, electric vehicles, and overall decarbonisation requires the use of metals like copper, lithium and iridium, which go towards batteries.

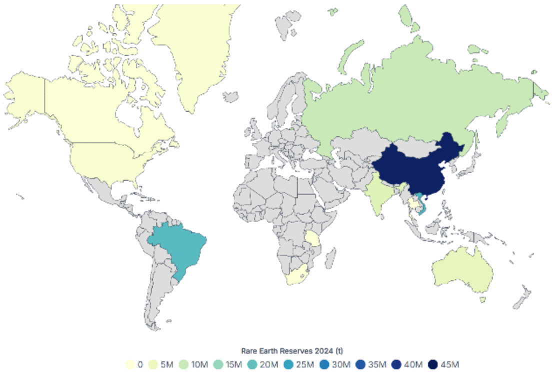
An especially crucial metal is lithium. This is the lightest metal on earth, and is required in most new technologies and electronics, creating a boom in demand, with the IEA predicting that the demand for lithium will increase ninefold by 2040. However, the exposure to deposits and the refining capabilities for this metal is not equal across all countries. The border region between Argentina, Bolivia and Chile are rich in the element, accounting for around 75% of the worlds identified natural lithium deposits. This area is known as the lithium triangle and has been subjected to growing tensions and at points, conflict, between the indigenous population, who seek to prevent the harm caused by mining on their land, and the mining companies.

But whilst this area is where the lithium is in its rawest form, the actual refinement and processing of the ore is championed by China. They have built up infrastructure to facilitate their dominance in the refining process, accounting for around 70% of these rare earth metals production, and holding about 90% of the global processing cap. metals. On the 4th April, Beijing announced the restrictions of exporting 7 different rare earth metals which are used across the energy, defence and automotive industries in response to the ongoing trade war with the US. Exporters must now get licences from the Chinese government to export. Typical customer stockpiles last around two months, thus if the US-China trade war continues to escalate, then almost every company is likely to be affected, with China essentially severing the entire rare earth mineral global supply.

The west is now looking to catch up, with the Trump Administration seeking to domesticate production using tariffs and possible trade agreements. One of the more ambitious moves has been the US expressing their desire to set up / own Greenland after it was reported that the territory contains vast, untapped deposits of rare earth minerals, oil, and gas deposits.

Australia, holding the worlds 3rd largest reserves in rare earth metals, may benefit greatly from the US-China trade war, especially now the restrictions on Chinese exports has taken place, there is a prime opportunity for Australian mining companies to capitalise on the huge supply gap. However, there is still the issue of the refining of these ores, with the next course of action to establish either domestic processing plants or establishing reliable processing supply chains overseas. Australian mining company shares such as Lynas Rare Earths Ltd have seen incredible recent growth and may have found themselves as the worlds next best solution to the Chinese dominance issue.

However, some argue that the west has failed, and that isn't entirely wrong. According to the European Commission, the EU, a global powerhouse and the second largest economy, does not produce any rare earth metals themselves, and imports 98% of this from Chinese importers. To shift the global dominance over crucial materials away from China, countries need to establish refining facilities rather than focusing on the extraction of raw ore. Companies and countries can extract as much ore as possible, however without the proper facilities, they will likely be sending it to China.



Overall, it will be important for investors to closely monitor the processing capability of different countries to determine which geographical locations to invest into. It will also be essential to monitor the political climate, especially the current trade war heating up between the US and China, as these are huge powers in global trade, and have the ability to influence the accessibility and demand of certain materials, such as rare earth metals. I would advise that we seek to take into account the possibility of long term recycling contributing to a decrease in demand for newly extracted metals, thus my focus would be in processing and refinements companies that are seeking to establish secure, efficient plants outside of China, as these will be part of the very limited options available around the globe for countries and companies to send their raw ore to, where the value in the product is actually created.

Friendshoring and trade alliances

Defined, friendshoring is the rerouting of supply chains to countries that are perceived as politically and economically safe / low risk in order to avoid disruption to the flow of business and to become less reliant on politically unstable countries for sourcing materials.

Or

A preference for sourcing materials and production from countries that share similar cultural, economic and political values such as democratic institutions, religion, geographical proximity, aligned views on peace and ESG principles. Based on strategic, long-term partnerships between two countries, diversifying the supply chain and reducing dependency on single monopolistic countries (e.g. China +1 Strategy)

So.. What exactly is tradeshoring?

Shifts from a traditional focus on maximising profit in the long run to strengthening the resilience of supply chains, whereby supply chains can respond efficiently to significant disruption changes and events without falling into long stagnant periods and crisis. Companies, rather than seeking to minimise production costs, may now wish to ensure the security and agility of supply chains, even if this results in higher costs.

The idea of 'Friendshoring' popularised by former US Treasury Secretary Janet Yellen "deepening relationships and diversifying US supply chains with more trusted partners". Friendshoring was actively pushed by the Biden administration, especially to reduce the US dependency on China, whom Trump had imposed tariffs on the term before. Whilst these tariffs in 2018 could be seen as incentivising companies to move away from a Chinese supply chain to more trusted partners, Trumps actions in 2025 appears to undermine this view. Rather, it appears Trump seeks to completely domesticate production within the US.

Friendshoring partners must be chosen carefully. Companies must consider the cost and availability of labour, costs of building infrastructure, the legal environment / possible red tape issues, and the distance from the home country / country of sale. Studies have shown that friendshoring strategies are likely to be less efficient in general and can lead to a real output loss in the range of 0.1% - 4.7%. Thus, it is crucial that companies thoroughly evaluate the possible longevity of investing into a friendshoring strategy. It is not a short-term solution to a currently volatile environment, but rather a long-term plan to permanently diversify supply chains.

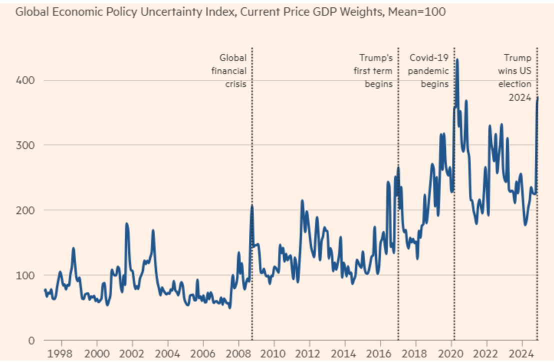
Friendshoring can be implemented in a variety of ways. Formal trade agreements, the implementation of incentives such as tariffs, subsidies for certain sectors, investment in both domestic and foreign companies / sectors. It may also be incentivised simply through the values of the government, public and investors.

Investors are continuously seeking firms with higher ESG profiles (Starks et al). If investors observe firms moving away from countries which may have lax regulations on ESG principles, such as emission controls and strict labour welfare laws, they are likely to consider such a firm a more attractive investment as higher ESG profiles are considered an excellent corporate standard. Irresponsible firms are also perceived to have a higher level of risk, thus 'responsible' firms that seek to strengthen its supply chains in order to avoid unexpected disruptions quickly become an attractive investment possibility.

Drivers;

Driver	Impacts & Solutions
Endemic / Pandemic concerns	Global supply chain disruptions, resulting in shortages of certain products. To combat this, companies will seek to establish robust supply chains.
Conflicts & Wars	Disruptions to supply chains, uncertainty in the reliability of a country to remain complaint and cooperative. The establishment of close, friendly relations with trustworthy countries is essential to the certainty of supply chains.
Political factors	Certain economic and political policies, such as trade wars and the rise of protectionism, create security concerns for a country. By reducing dependency on single source suppliers like China, a country can reduce their risk exposure.

Cultural values	With a steady shift towards climate consciousness, countries need to provide incentives to companies to conduct cross-border business with other countries that share certain ESG sentiments.
Economic uncertainty	Especially pertinent under the highly protectionist Trump Administration. In periods of high uncertainty, companies will seek to diversify production and supply chains across multiple locations to hedge against geopolitical uncertainty. (see graph below)



Headwinds;

Headwind	Impact & Solutions
High initial costs	There are a range of costs associated with diversifying a companies supply chain to other countries. There may also be long-term costs, such as higher labour costs due to increased worker welfare. Companies need to determine if they have the required capital to be able to expand their production.
Limited options	'Friendly' nations may not have the required infrastructure to support a company's production. There are also the issues of finding a nation that aligns sufficiently with the other country's values, leaving very few options available.
Political uncertainty and retaliation	In response to a country seeking to reduce their economy's dependency on a single source, the monopolistic country may retaliate with tariffs and trade restrictions, increasing global tensions.
Current uncertain climate	With the high level of uncertainty off the back of Trumpian policies, companies may wish to hold back on making definitive moves in their structure in order to let the dust settle. It is almost impossible to predict when the 'best' time would be to take action, discouraging companies from taking any action at all.

Friendshoring in Europe;

A survey done by the European Bank for Restructuring and Development (EBRD) asked leading companies in the Eurozone about risks in the supply chain.

The survey showed that companies are becoming increasingly inclined to relocate production sites within and outside the EU over the next 5 years. There is a particular focus on moving production geographically closer to the end consumer / country of sale to strengthen resilience of their supply chains and cut transportation time / cost.

42% of companies surveyed also stated that they are considering such a strategy. Geopolitical risks such as Covid-19 and the Russia-Ukraine war play an important role in these relocation decisions, shifting sentiment from maximising profit by producing in the cheapest location possible, to ensuring the stability of production.

The UK and India have also re-entered into negotiations for a free trade deal. With India forecasted to become the worlds third largest economy within just a few years, securing a strong relationship offers incredible potential for both parties. This follows on from the March 2024 free trade agreement with the European Free Trade Association, which committed US$100 billion in investments and the creation of millions of direct jobs within India over the next 15 years.

<u>Friendshoring in the US;</u>

As mentioned previously, the Biden administration sought to deepen economic relationships with 'trustworthy' countries whilst reducing dependency on China and Russia. One key area targeted was the production of semiconductors, which are vital to numerous industries such as;

- Electronics
- Automotive manufacturing
- Defence
- Fight against the climate crisis

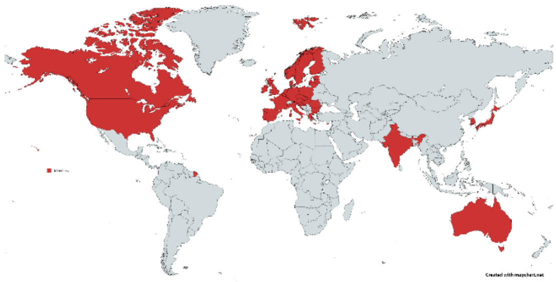
China controls a significant portion of the critical rare materials essential in the production of semiconductors. A huge step taken by the US was the formation of the Minerals Security Partnership (MSP) in June 2022. The MSP aims to "accelerate the development of diverse and sustainable critical energy minerals supply chains".

Minerals covered but not limited to;

Mineral	Practical Usage
Lithium	EV batteries / Energy / Consumer electronics
Cobalt	Battery longevity / Aerospace applications
Nickel	EV batteries / Steel production
Manganese	Steel production / Energy / Water treatment
Graphite	Battery anodes / Lubricants in industrial applications
Gallium	Semiconductors / Solar cells
Germanium	Fibre optics / Medical applications
Antimony	Flame retardant / Semiconductors / Energy
Copper	EV wiring / Renewable energy / Semiconductors

All these minerals are essential across the entire industrials sector. They all have unique uses which, when used in conjunction, offer efficient production that can be shifted towards a more sustainable supply chain. Thus, it is incredibly important to have a diverse range of suppliers of these materials that share similar sustainability sentiments to truly work towards green production.

Current partners include;



Recently entered discussions with numerous African countries to discuss opportunities for investment in socially responsible mining projects.

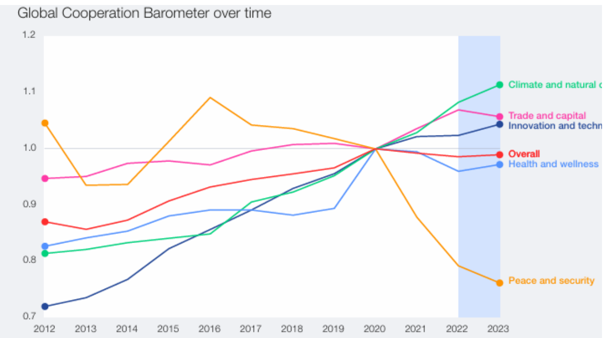
Trump appears to be hyper-focused on attaining these rare minerals, likely due to their application in high-tech industries such as electric vehicle manufacturing, defence and AI. He has expressed an interest in gaining control over areas of Greenland, which a survey carried out by the European Commission in 2023 showed contained 25 of the 34 minerals that are deemed to be "critical raw materials", much of which has remained largely untapped due to legal issues and indigenous opposition.

Taiwan Semiconductor Manufacturing Company (TSMC) has also expressed their interest in investing US$100 billion into fabrication plants within Arizona, as well as seeking closer partnerships with major customers (Nvidia, AMD, Intel, Broadcom) in a move that seemingly aims to placate Trump, possibly in hopes of maintaining their dominance over the semiconductor production market. Some have argued that if TSMC were to fall behind in their dominant semiconductor market share (62%), then China may see this as an opportunity to increase aggression due to the potential lack of reliance the US would have in Taiwan semiconductor production, known as the 'silicon shield'.

It will also be important to closely watch the potential US-Ukraine mineral deal because of the negotiations to bring the Russia-Ukraine war to an end. Bear in mind, this deal does not currently allow the US access to the minerals themselves, but rather revenue generated by their extraction.

<u>Brief global cooperation overview</u>

Global cooperation has been shown to have flatlined in recent years, due to the rise in political uncertainty. Climate cooperation levels continue to trend up steadily, which is aimed at decreasing emissions, and the levels of climate finance flows continue to reach new highs. However, this is the extent of the positivity in global cooperation. Analysts claim that global security is fast reaching a crisis point off the back of continuous conflicts and war, with the international community seemingly incapable of preventing new conflicts from emerging.



Special Mention – How do recent imposed tariffs from the US influence the Industrials division?

Trump introduced a mechanistic formula aimed at neutralising bilateral trade deficits through the following expression:

$$\Delta\tau_i = \frac{x_i - m_i}{\varepsilon * \varphi * m_i}$$

Whereby:

$\Delta\tau_i$ = Tariff required on country i.
x_i, m_i are US exports and imports into country i.
ε = Import price elasticity of demand
φ = the pass-through rate of tariffs into import prices.

Traditional trade policy which historically adjusted tariffs through geopolitical bargaining or retaliation under WTO rules, this approach is purely arithmetic and micro-founded, treating bilateral trade deficit as a solvable function of price responsiveness and imposes tariffs at a level that would erase net exports from that country, shifting from reactive trade defence to calibrated macroeconomic rebalancing, whereby tariffs are tools for current account engineering rather than sectoral protection.

Markets reacted with defensiveness. The S&P500 is down 13.7% YTD, making it the 6^{th} worst first-quarter decline in nearly a century. High-beta sectors reliant on cross-border values chains, particularly semiconductors and auto components have suffered disproportionately, as the formula disproportionately penalises economies with large net exports to the US. In this context, firms with domestically integrated, entropy-minimising operations are being re-rated for their resilience.

This outlook naturally looks grim, however in any market, there will always be emerging winners. Here's how I believe Industrials might be affected:

Supply Chain Convexity:

Firstly, under a tariff regime, previously uncompetitive domestic suppliers gain price parity or advantage over tariffed imports. When analysing a company, it's increasingly important to evaluate the dual-sourcing or interchangeable input architecture efficacy of supply chains. The agility is now priced as a premium relative to before. Input substitutability therefore becomes a proxy for option value, contributing to supply chain convexity, the ability to adapt supply chain in response to shocks.

CAPEX-heavy firms are making a comeback…

Secondly, within a low tariff world, labour arbitrage and just-in-time manufacturing rewarded asset-light models, yet this recent shift exposed the fragility of asset-light firms. CAPEX-heavy industrials which were previously punished for lower ROIC may now regain competitiveness as they control production, embed value domestically, and bypass tariffed intermediaries. As a result, CAPEX intensity becomes a hedge rather than a drag in a protectionist regime.

Digital Twins as Strategic Tools:

More generally, in a geopolitical landscape with heightened volatility, I believe demand for "digital twins" rises. Essentially, these replicate supply-chains using real-time data from IoT, logistics and ERP systems. As a throwaway comment, to hedge against future geopolitical risk, we will begin to see demand for digital twins. Firms with existing digital twins under the tariff volatility can stress-test various permutations, can utilise predictive analytics allocating working capital, and can better model geospatial risk. The digital twin is a non-linear information advantage; firms that implement this earlier can pre-optimise their response, yielding lower friction than competitors.

In summary, when pitching, investors need to consider whether a company has:

1) Multiple suppliers (dual sourcing) and swappable inputs (modular design)
2) Digital twins (potential edge case adding to the intrinsic value per share)
3) Locally embedded firms vs global corporates (seen as resilient relative to dated)

How does Oakwood respond?

To account for the changes to the macroeconomic landscape, the following changes to valuations:

- Introducing a volatility-adjusted COGS driver – Those with single supply-chain dependency, apply higher COGS volatility, whereas those with multiple sources and quick interchangeability, dampen COGS inflation assumption.

- For modular firms – Apply a reduced CAPEX:revenue ratio over the longer-term (3-5 years) due to extended asset life, lower retooling CAPEX in response to design shocks.

- For firms with digital twin, forecast a working capital efficiency gain through better inventory and receivables management. Another way this effect might be captured is through a gradual compression to days inventory outstanding and days payables outstanding (DIO vs DPO)

- Applying a "shock-absorption coefficient" in scenario planning – Firms with digital twin capability re-optimise logistics in shorter lead times, resulting in lower cash burn and NPV uplift in negative operating scenarios.

Green subsidies, tax credits, and tariffs

Tax credits, green subsidies and tariffs are all mechanisms used by governments in the fight against climate change. The purpose of these mechanisms is to provide economic incentives for companies, and in turn consumers, to shift their practice towards sustainability.

Markets incentivise companies to produce unsustainably. When negative externalities are created, a company can chose to ignore the damage caused, or they can look to internalise the eternality. However, by internalising an externality, the company is taking on additional external costs and thus will have higher costs than competitors. Thus, to maintain a fair market, government intervention may be required to ensure that companies who produce sustainably, or are willing to take on costs, are not put at a disadvantage to those who don't.

The aforementioned tools differ from the common use of Pigouvian tax, where governments simply tax activities that produce negative externalities on society, such as pollution. Whilst the aim of this tax is to hold polluting companies responsible for their harm, this cost is often passed onto consumers whilst the company maintains its profit level. Whilst a company is indeed incentivised to find alternative ways to produce their chosen good / service, firms may be comfortable simply increasing their prices, which in turn shrinks the market. Thus, more specified mechanisms that not only punish irresponsible firms, but encourage and help companies to develop their sustainability leads to a much more effective timeline and use of government funds.

Green Subsidies

A green subsidy is a direct investment by the government in companies with the aim of supporting sustainability projects, research and development schemes, and a wide range of eco-friendly projects that cut emissions and limit the damage done to the environment from a company's activities. They differ from Pigouvian taxes in the sense that they create a much stronger incentive for a company to take advantage of such schemes, directly supporting the company in innovating their production. This not only allows companies to limit their negative externalities, overall increasing societal welfare, but also allows responsible companies to gain an advantage over competitors by accessing funding to strengthen their sustainable production, avoiding Pigouvian taxes in the long run. Consumers also benefit from lower costs for sustainable products.

An example of this would be the use of the Inflation Reduction Act 2022 passed by the United States. This Act contained around US$500 billion to be put towards domestic schemes covering but not limited to:

- Transportation
- Residential buildings
- Commercial buildings
- Manufacturing
- Carbon capture
- Key industrial processes.

This Act also covered certain tax credits. However, the Act is now in danger of being gradually dismantled by the Trump Administration, who seek to promote the use of fossil fuels over sustainable energy.

Tax Credits

Whilst this mechanism falls under the wide scope of subsidies, they do not involve direct financial assistance. Rather, tax credits reduce a company's tax liability, and in return the company will engage in government-approved practices that hold a positive impact on the environment. The most common type of tax credit incentives research and development (R&D) to innovate within a certain sector.

R&D is a driver of development, trying to find new ways to conduct the business process within a company, such as more efficient production, creating less pollution, etc. However, for a company, investing in R&D is incredibly uncertain, high-risk, and takes a long time. Benefits may not be seen for years, if at all, as it is the innovation of something new that may not even be applicable in practice, thus companies may be unwilling to invest in R&D independently whilst paying the same amount of tax alongside the process.

By taking advantage of tax credits, companies are able increase their R&D spending in exchange for a reduction in the amount of tax paid. This difference is a more efficient use of funds for a company, which, like green subsidies, are likely to benefit in the long run from gaining a competitive advantage. Simply put, its much more efficient for a company to invest in R&D rather than pay that money in taxes, where there is no benefit to be had.

A study conducted by PWC in 2018 found that the industrials sector is in the top 5 largest spenders on R&D, accounting for 10.6% of the total US$ 781.8 billion spent on R&D in 2018. Whilst these figures fluctuate year by year, with healthcare and technology competing for the top spot, the industrials sector is likely to maintain a sizeable amount of spending into R&D.

Tariffs

As we have seen on the domestic level, a government has multiple tools available to ensure compliancy with sustainability goals. However, attempting to apply these goals across the globe becomes much more difficult. Some countries may favour their competitive strength over their climate consciousness.

The Paris Agreement is a prime example of this in theory, however as of March 2025, only 8% of the countries subscribed have produced plans for their domestic emission reduction. On a global scale, countries can often behave like companies, a self-serving entity seeking to create the most value for its stakeholders, thus there is little economic incentives to apply climate goals strictly.

Therefore, governments can turn to trade measures to protect against unfair competition with countries who are not as committed to climate goals. Tariffs, specifically import tariffs, are used to target unsustainably produced goods with the aim of reducing negative externalities, as tariffs create higher costs, discouraging the purchase of said good, in turn encouraging alternative suppliers / methods of production.

In a paper produced for the World Trade Organisation, Renee Wehkamp proposes that countries should apply low / no tariffs on countries that either have the same sustainability standard as the importing country or on products that meet a specific sustainability requirement, even if the goods are produced in a country that has worse standards for sustainable production. On the other hand, high tariffs should be imposed on companies that do not meet the specific requirements. By following such a framework, a government can incentivise sustainable production and supply chains, whilst setting the entire burden on the company themselves, rather than punishing an entire country.

Of course, applying tariffs on any country, even for a noble reason such as the fight against irresponsible production, is likely to erode relations between countries. This has become especially prevalent in today's current global market as seen from the Trump Administrations actions. Whilst those tariffs are not climate-focused, they still portray the dangers of finding the delicate balance in global trade measures.

The European Union is introducing it’s Carbon Border Adjustment Mechanism in 2026, a tariff system on carbon intensive products, covering key resources in the industrials sector:

- Iron & Steel
- Cement
- Aluminium
- Electricity

The CBAM seeks to accelerate decarbonisation and prevent 'carbon leakage', where EU companies move carbon-intensive production abroad to escape the stricter EU climate policy.

Issues & Comments

All these tools can be utilised by governments, however they come at a cost. To have green subsidies, a country must have the sufficient funds to be able to support sustainable projects. Tax credits create an opportunity cost for a government, where they are losing out on potential revenue from tax. This may negatively impact consumers if taxes in other areas of policy are increased to offset the loss. And tariffs will increase the cost of obtaining materials for production, which companies will usually pass onto consumers, driving up costs. All these issues are especially detrimental to developing economies, who may not have the domestic infrastructure, government funding, or social pressure to pursue a greener economy. It is left to global powers to set the goals, leaving those with smaller voices to fall in line.

When assessing companies, it is important to have regard to their sustainability promises. Greener firms are more attractive, especially if an investor can be relatively certain of the company's commitment to their goals. Thus, by looking to see which companies are currently taking advantage of the incentives described, one can in part determine a firm's commitment to sustainability. And those companies that are investing in R&D are more likely to see long-term benefits in reducing their social harm than those who simply accept the costs of their negative externalities. Overall, I believe that whilst all these mechanisms are important in incentivising a shift to sustainable production, they should not be used in a disproportionate manner in assessing the validity of a company. Rather, it would be helpful to research in depth into what a company's views on sustainability are, and their previous actions towards reaching these goals, as these incentives provide tax loopholes for companies who have little regard in improving their sustainability metrics, which could be interpreted as a form of greenwashing.

Industry 4.0 – Predictive Modelling

Introduction

Predictive modelling (often termed predictive analytics) refers to using data, statistical algorithms, and AI/machine learning techniques to identify patterns and forecast future events or behaviors (IBM 2024). In industrial contexts this can range from predicting machine failures to forecasting product demand. Economic forecasting, in turn, focuses on projecting future economic conditions – for example, market demand, input costs, or macroeconomic indicators – using quantitative models. With advances in artificial intelligence (AI), these forecasts increasingly leverage machine learning to improve accuracy and adapt to complex data.

The growing importance of AI-driven predictive modelling in industry is tied to several trends. First, digital transformation and Industry 4.0 have flooded firms with data from sensors, machines and business processes. Manufacturing now generates more data annually than most sectors (estimated 1,812 petabytes per year), prompting firms to seek "smart" technologies to exploit these datasets. Within this section is AI based forecasting tools, which can analyze this big data in ways traditional methods could not, therefore uncovering new insights and patterns to aid decision making.

Predictive Modelling directly supports ESG-conscious innovation by enabling efficiencies that reduce waste and emissions. It also drives long-term operational efficiency which improve profitability and stability of industrial firms. Additionally, it also contributes to risk-adjusted performance, as better forecasts help companies anticipate and buffer against risks, leading to more resilient financial outcomes.

Theory

Foundational Forecasting Models: Traditional forecasting in industry has relied on statistical models like ARIMA (Auto-Regressive Integrated Moving Average) and related time-series methods. ARIMA extrapolates future values from past patterns under assumptions of linearity and stationarity. They work well for stable, seasonal trends but have limitations in capturing non-linear or sudden changes. Econometric models have also been used for economic forecasting – for example, vector autoregressions or structural models incorporating economic indicators.

In the current era, modern AI techniques can assist in addressing these issues. For example, deep learning models can approximate highly complex functions. For forecasting problems, recurrent neural networks (RNNs) and long short-term memory networks (LSTMs) have shown the ability to learn temporal dynamics and non-linear interactions that elude simpler models. More recently, hybrid approaches that combine statistical forecasting with machine learning have proven very powerful – notably, the winning method of the M4 forecasting competition was a hybrid of exponential smoothing and an RNN, outperforming either approach alone (Makridakis et al. 2020). These hybrids suggest how AI can enhance traditional models, by capturing subtle patterns.

Overcoming Traditional Limitations: A key advantage of AI models is their capacity to ingest diverse data sources beyond just a single time series. Research shows that incorporating multiple drivers (economic indicators, sensor readings, weather, etc.) improves forecast accuracy in volatile environments. For example, Punia and Shankar (2022) demonstrated that adding contextual macro-economic variables to a demand forecast model significantly improved its accuracy compared to using a univariate (past sales only) model. In other words, when markets or operations are in flux, purely extrapolative models often break down. Hasheminejad et al. (2022) similarly found that conventional forecasting methods “generally do not work when the market is constantly fluctuating,” whereas machine-learning models that consider many variables can adapt better. AI models excel at detecting complex, non-linear relationship in data. By learning from large historical datasets, AI systems can uncover hidden drivers and leading indicators. One study notes that researchers are now using a median of 14 input variables in machine-learning demand prediction models (with some models using hundreds of features), reflecting the richer information AI is able to leverage (Meisenbacher et al. 2022, in Punia & Shankar 2022 review).

Case Studies

Case Study 1 – AI for Demand Forecasting

A case study by Punia and Shankar (2022) examined demand forecasting for a fast-moving consumer goods manufacturer. They compared a baseline ARIMA model to a neural network that incorporated macroeconomic indicators (like consumer confidence and input prices) and internal data (promotions, inventory levels). The AI-enhanced model improved forecast accuracy by about 15% and was especially superior during volatile periods (e.g. when a sudden economic shock hit demand). This theoretical application showed that by using AI to integrate external economic signals, the company could better anticipate demand swings that a univariate model would miss. As a result, the firm could adjust production plans faster, avoiding overstocking during downturns and stockouts during recoveries.

Case Study 2 – Predictive Modelling in Production

Academic researchers have also applied AI inside the factory. For example, Hasheminejad et al. (2022) present a case where an automotive assembly line's output was forecast using an LSTM neural network. The LSTM model was trained on historical production data along with upstream supply metrics and machine sensor readings. It outperformed a classical regression forecast, particularly in predicting short-term slowdowns due to supply disruptions. By capturing non-linear lag effects (like the impact of a vendor delay on output two weeks later), the AI model provided early warnings of production bottlenecks. This theoretical case demonstrated how AI-based predictive modelling could be used by plant managers to proactively reallocate resources or maintenance schedules before a drop in output occurred. In essence, the neural network learned a richer representation of the production system's behavior, overcoming the rigid assumptions of traditional linear models.

How the Industrial Sector Would Implement It

Bringing AI-based predictive modelling from theory into practice in the industrial sector requires focusing on high-impact use cases and building the technological backbone to support them. Several key implementation areas have emerged:

- **Predictive Maintenance**: Perhaps the most widespread application, predictive maintenance uses AI to predict equipment failures before they happen. By analyzing sensor data (vibrations, temperatures, pressures, etc.) from machines, algorithms can identify early warning signs of wear or faults and schedule maintenance at optimal times. This reduces unplanned downtime and maintenance costs. For instance, in heavy manufacturing, AI-driven predictive maintenance has been shown to cut overall maintenance costs by ~20% and reduce unplanned downtime by up to 50% (McKinsey 2020). These gains come from avoiding catastrophic breakdowns and extending machinery life through timely interventions. Many industrial firms start their AI journey here since the ROI can be clearly measured in reduced downtime hours.

- **Energy Optimisation**: AI can analyze energy consumption patterns in a plant or facility and forecast future usage, enabling smarter energy management. By predicting peaks and lows, AI systems help operators adjust heating/cooling, machine run times, or microgrid usage to save power. In process industries, predictive models can optimize furnace or oven settings to achieve required output with minimal energy. Digital twins (virtual models of physical assets or processes) often play a role here: a digital twin of a factory's energy profile combined with AI allows scenario testing – e.g. how to maintain output if one generator goes down – and fine-tuning in real time. Companies like Schneider Electric deploy such solutions; for example, Schneider's EcoStruxure platform uses ML algorithms to optimize energy loads in industrial sites, achieving energy efficiency improvements on the order of 10–15% in some deployments (Schneider Electric 2022). Beyond cost savings, these optimizations directly support sustainability by cutting greenhouse gas emissions.
- **Production Scheduling and Process Optimisation**: AI-based predictive models can greatly enhance production planning and scheduling. Traditional scheduling is often static, but AI can forecast production bottlenecks or quality issues and dynamically adjust schedules. For example, an AI system might predict that a certain machine will slow down next week (due to wear or a tricky production batch) and proactively reallocate some tasks to other machines to meet the production target. Similarly, in multi-step manufacturing processes, predictive modelling can help optimize throughput – ensuring each stage gets the right inputs at the right time to avoid idle time or queues. A practical case is Siemens using AI in its electronics factory: Siemens has reported using machine learning to automatically reschedule production lots on its lines in response to predicted equipment constraints, which increased throughput and labour

productivity (Siemens 2021). The result was a more agile factory floor that could self-optimize based on predictions, something impossible with fixed schedules.

- **Supply Chain and Demand Forecasting**: Manufacturers are using predictive models to forecast customer demand, supplier lead times, logistics delays, and inventory levels with greater accuracy. This helps avoid both overstocking and stockouts. AI can also optimize shipping routes and distribution. A notable example is Schneider Electric, which applied machine learning to its global supply network of 240 factories and 110 distribution centers. By analyzing hundreds of thousands of transportation options and constraints, Schneider's predictive model identified optimal product flows and routes. The outcome was a reported €8 million in annual transportation cost savings and improved container utilization (Best Practice AI 2019). This kind of ROI demonstrates the power of AI in streamlining complex industrial supply chains. In volatile times (e.g. pandemic-related disruptions), such AI foresight in supply chains is especially valuable to mitigate risk.

Implementing these use cases requires enabling technologies and infrastructure:

- **IoT and Data Integration**: Foundational to all the above is the Industrial Internet of Things (IIoT) – networks of sensors and connected devices on factory floors, in vehicles, and across supply chains that feed data to AI systems. Without IoT data (vibration readings, energy meters, production counts, etc.), predictive models have little to work with. Companies must invest in sensor hardware and connectivity (often industrial wireless or 5G) to stream data from legacy machines that were not originally digital. Integrating these diverse data streams is equally critical: firms need data platforms to aggregate and clean information from many sources (operations data, enterprise systems, external market data) into a unified "data lake" for analysis. This often entails building or adopting cloud-based data warehouses and using industrial protocols/gateways to link old equipment to the network.
- **Cloud Computing and Edge Computing**: The heavy computational demands of AI models (especially deep learning) mean that scalable cloud infrastructure is often needed. Many industrial AI implementations use cloud platforms to store big data and train complex models. Cloud services also facilitate collaboration – e.g. sending machine data securely to a cloud AI service that returns a health prediction. At the same time, edge

computing is gaining traction for latency-sensitive tasks: an edge AI device (located on the factory site) can process sensor data and generate immediate alerts (say, shutting down a machine about to fail) without needing to send everything to the cloud. Many architecture designs use a hybrid: critical real-time inference at the edge, heavy model training or fleet-wide analytics in the cloud. Companies like GE and Siemens have developed such edge/cloud combos (e.g. GE's Predix Edge or Siemens Industrial Edge) to ensure that AI predictions are both fast and globally informed.

Company Case Studies (Practical Implementation & ROI)

1. **Siemens AG**: Siemens has been a frontrunner in integrating AI into industrial products and its own factories. One example is Siemens' deployment of predictive analytics in its Amberg Electronics Plant (a flagship "smart factory"). By using AI algorithms via its MindSphere IoT platform, Siemens monitors production in real-time and predicts quality issues or equipment needs. This contributed to a remarkable 99% reliability rate and high automation efficiency in the plant. Siemens also offers these solutions to customers – notably through its acquired subsidiary Senseye, which provides AI-driven predictive maintenance. According to Siemens, clients using Senseye have seen substantial ROI; an American Society of Mechanical Engineers study found an average 250% ROI on predictive maintenance projects industry-wide (ASME 2019, cited in Siemens 2023). In practice, this means for every $1 invested in AI-maintenance, $2.5 is gained back (through reduced downtime, extended asset life, etc.). Siemens has reported cases like a food & beverage plant that used its AI system to predict motor failures and achieved near-perfect uptime, or a rail operator that reduced train delays by forecasting component wear. These successes underscore that when implemented at scale, predictive modelling directly boosts productivity and lowers costs, yielding tangible financial returns for industrial operators.
2. **Schneider Electric**: Schneider Electric is another industrial leader that has embraced AI for both its clients and internally. One compelling case is supply chain optimization within Schneider's own operations. Schneider applied machine learning models to its global logistics network, which encompasses 240 manufacturing plants and 110 distribution centers worldwide. The AI models analyzed vast datasets on shipping routes, costs, and constraints – on the order of 100,000+ transportation lanes and 130,000+

routing constraints. By crunching these numbers, the AI could predict the most efficient paths to move products and materials through Schneider's supply chain. The result was a redesign of logistics that led to €8 million in annual savings in transportation costs, primarily through better route choices and load optimization (e.g., consolidating shipments to improve container utilization). This represents a significant ROI, considering it was achieved by software analytics without major capital spend – essentially pure efficiency gains. Additionally, Schneider has deployed predictive analytics in energy management for clients: for example, its AI-based advisory services helped a manufacturing client predict and prevent an electrical failure that could have caused a factory fire (Schneider Electric 2023). That not only saved millions in prevented damage but also averted safety and environmental incidents – aligning with Schneider's emphasis on using digital tech for safety and sustainability. These case studies highlight that with focused applications (like logistics or electrical maintenance), AI modelling can unlock substantial value even in well-established industrial companies.

Other major industrial players like General Electric (GE) and Siemens Energy have similarly offered AI-driven services – e.g. GE's Predix platform for power plant optimization, Siemens Energy's AI for turbine performance – with mixed results, which we discuss in the risk section. Overall, however, the pattern is that when AI predictive models are thoughtfully applied to specific pain points (downtime, energy cost, throughput, etc.), they tend to deliver strong ROI and become a source of competitive advantage in the sector.

Risk vs Benefits

Adopting AI-based predictive modelling in the industrial sector comes with a balance of significant benefits and notable risks. Companies and investors must weigh these to make informed decisions.

Category	Benefits	Risks
Operational Efficiency	Reduced unplanned downtime (up to 50%) Optimised maintenance and production schedules Higher asset utilisation and throughput	High upfront CapEx for IoT, AI infrastructure, and talent ROI may take time or be unclear without defined KPIs
Cost Reduction	Lower maintenance and energy costs Reduced inventory holding costs through better	Integration with legacy systems is complex and costly Fragmented or poor-quality data can lead to inaccurate or failed predictions

	demand forecasting Leaner, smarter operations	
ESG Performance	Energy savings → emissions reduction (5–10% typical) Safer working environments via predictive safety Waste reduction and cleaner ops	AI models may lack transparency ("black box" risk) Optimisation may unintentionally pressure workers or stretch machinery/environmental limits
Agility and Resilience	Real-time forecasting enables proactive responses Scenario simulations with digital twins Greater resilience to market volatility	Overreliance on AI models can be risky if false positives/negatives occur Requires constant model monitoring and validation
Governance & Transparency	Enhanced governance if AI maturity is high (e.g. ethics frameworks, board oversight) Regulatory	Lack of AI oversight can lead to compliance breaches Cybersecurity vulnerabilities increase with cloud/IoT infrastructure

	alignment with sustainability goals	
Human Capital	Enables augmentation of workforce capabilities Opens opportunities for digital skill development	Industrial AI talent shortage Resistance from existing workforce if not trained or engaged Cultural pushback against algorithmic decision-making
Case Evidence	Examples: Siemens, ABB, Schneider show strong ROI and scalability Enel, Bosch, Thyssenkrupp demonstrate measurable improvements	GE Predix failure shows risk of overextension, lack of focus "Pilot purgatory" risk if projects don't scale beyond testing phase

Investor Considerations

Consideration	Details
Strategic Alignment and ESG Integration	Check if AI adoption is tied to company-wide strategy and ESG goals. Look for mentions in sustainability reports, alignment with SDGs, and how digital initiatives support emissions reduction or safety.
KPIs and Operational Metrics	Review KPIs such as unplanned downtime reduction, inventory

	turnover, energy intensity, and margin improvements. Demand forecast accuracy and AI-driven maintenance cost reductions are key indicators.
AI Maturity and Governance	Assess AI governance structures: presence of Chief Digital Officer, board oversight, ethical AI principles, and regulatory preparedness (e.g., EU AI Act compliance).
ESG Ratings and Frameworks	Use frameworks like MSCI ESG, SASB, and GRI to benchmark performance. Look for disclosures showing improvement in emissions, safety, and digital transformation contributions to ESG ratings.
Benchmarks and Recognition	Identify if the company is recognised in WEF Lighthouse Network or other innovation awards. These validate leadership in AI integration and operational excellence.
Long-Term Competitive Advantage	Look for proprietary AI capabilities, patent filings, or digital service revenue. Consider whether the company's use of AI is a sustainable moat versus peer adoption levels.
Transparency and Disclosure	Evaluate whether the company provides detailed and regular updates on AI implementation, including case studies, KPIs, and governance measures, in investor calls or public filings.

Margin expansion through IoT..

Margin expansion in traditionally low-margin manufacturing firms is becoming increasingly achievable, specifically through data-driven automation, supply chain digitisation and more intelligent product systems. This section of the report explores the factors contributing to this emerging thematic, with a focal point around cyber-physical systems.

Firstly, we are transitioning towards cyber-physical systems (CPS). A "CPS" is a framework integrating physical processes, like mechanical manufacturing systems, and cyber capabilities, like computational algorithms. Physical processes and cyber capabilities are interlinked to form a feedback-enabled adaptive system. CPS architecture tends to include, but not limited to; embedded sensors, real-time data transmission, edge and cloud computing integration, and feedback control loops.

Interdisciplinary by nature, CPS are predicated by various foundational pillars. Firstly, control theory addresses how one can influence the behaviour of dynamic stems through feedback loops.

(Kalman , 1960) conceptualised Kalman Filtering, which would be used in state estimation for systems with noisy inputs; in cyber-physical systems, this underpins a sensors fusion in robotics and autonomous systems. For example, Kalman Filtering would be used to estimate a robotic arm's true position amongst mechanical noise. Within CPS, the linear Gaussian processes for feedback estimation used in Kalman Filtering is extended to either the EKF or UKF (Extended Kalman Filter and Unscented Kalman Filter respectively) to deal with non-linearities in complex systems. In Layman's terms, this helps reconstruct the true state of the system given noisy observations, answering the question of "Where am I?" given noise.

In contrast, another form of Control Theory is that of optimal control frameworks. Firstly, Pontryagrin's maximum principle states the first-order necessary conditions for optimality, using the Hamiltonian as the Central tool (not to be confused with classical Hamiltonian from physics):

$$H(x, u, \lambda, t) = L(x, u, t) + \lambda^T f(x, u, t)$$

Whereby:

$x(t)$ = The state variable, describing where the system is
$u(t)$ = The control input, the variable we can manipulate
$L(x, u, t)$ = The running cost (Lagrangian) which describes how expensive or rewarding a particular combination of state and control is at time t.
$f(x, u, t)$ = System dynamics, which refers to how the state evolves under the control
$\lambda(t)$ = Costate variable, which acts like a Lagrange multiplier, telling us how much the cost changes if you were to perturb, or marginally changing the $x(t)$ state.

The Costate variable is a subtle powerhouse as it carries time-evolving information about opportunity cost, akin to shadow price on capital "If I had a bit more capital now, how much more value could I extract by final time?".

Conversely, Richard Bellman devised Dynamic Programming as a means to solve multi-stage decision processes, where the outcome depends not only on present actions but also on the sequence of future decisions. This deviates from classical optimisation whereby decisions are involved over time, thereby optimising the sequence requires thinking recursively. It thinks in the sense of "To solve a problem, you must solve its subproblems first, but only once, and remember the result; this avoids redundant computation, allows time-dependent problems to be broken down into stages, and allows backward recursion as a means to solve complex control problems.

He introduced the value function, which is the minimum cost to go from a given state x to the final goal, assuming optimal decisions from that point onward, modelled:

$$V(x) = \min[L(x, u) + V(f(x, u))]$$

.. which becomes part of the Hamilton-Jacobi-Bellman partial differential equation:

$$c + \min\left[L(x, u, t) + \frac{\partial V}{\partial x} . f(x, u, t)\right] = 0$$

Whereby:

$V(x, t)$ represents the value function, telling us the optimal cost-to-go from any state x at time t.

$\frac{\partial V}{\partial T}$ represents the rate at which future value is decaying

$L(x, u, t)$ is the instantaneous running cost what is costs to be in state x without taking action u at time t.

$\frac{\partial V}{\partial x} . f(x, u, t)$ represents the value drift; how changes in the state affect the value of the system as it evolves under control u.

Regarding specific examples where CPS has been implemented effectively, firstly Siemens utilises its MindSphere platform; in alignment with Pontryagin's Maximum Principle, Siemens deploys model predictive control systems that simulate and optimise control trajectories based on dynamically evolving constraints, which minimises energy use and component wear in real time. The control decisions are made using embedded estimators inspired by Kalman filtering. The use of digital twins allows Siemens to simulate responses virtually before physical implementation, which reduces commissioning times and CapEx misallocations. This integration of feedback loops led to energy savings exceeding 20% complemented with reductions in unplanned downtime.

Next, Bosch's Homburg facility provides an interesting CPS case study. By embedding real-time sensors and adaptive control into the physical machinery, Bosch created a system governed by continuous feedback loops and state estimation logic. The smart factory used decision systems applying trajectory-optimising logic consistent with Pontryagin-type frameworks. Bosch saw a 25% reduction in waste complemented with a 10% improvement in overall equipment effectiveness, demonstrating how real-time optimisation converts physical asset intensity into margin leverage.

Green Shipping Corridoors and Alternative Fuels:

Green shipping corridors are specified maritime routes where zero-emission options are supported by policy, infrastructure, and technology. Green corridors are important for the decarbonisation of shipping, which accounts for nearly 3% of all greenhouse gas emissions according to the International Maritime Organization. Green corridors are driven by ambitious environmental regulation, consumer and investor demand for green supply chains, and innovation in alternative fuels technology.

Increased push for alternative fuels in green shipping corridors affects shipbuilding and retrofitting, port infrastructure, and logistics and supply chains. The use of ammonia, hydrogen, and biofuels such as biodiesel are increasing, supporting the use of alternative fuels whilst port infrastructure must provide the necessary fuel bunkering for alternative energy vessels. Whilst freight is on the move, logistic companies must adapt to specified maritime routes to minimise emissions.

The push for green shipping technologies market is projected to grow from $22.31 billion in 2024 to $140.74 billion by 2032. Using a CAGR, the forecast period is set to see a 25.89% compound annual growth rate. Demand for sustainable fuels is expected to triple by 2050, seeing the most increasing demand coming from aviation and maritime. Also, the rise of e-fuels has been implemented to enhance collection of biomass feedstocks for agricultural land, another constraint on global net-zero emissions targets. Furthermore, according to the United Nations Conference on Trade and Development, maritime trade is set to grow annually by over 2% between 2024 and 2028. Although with recent tariffs enforced by the Trump Administration we may see uncertainty under global trade of goods. The use of tariffs will seek to encourage domestic production and investment, reducing the trade deficit in goods, which was $1.203 trillion in 2024.

Green shipping corridors work by establishing coordinated global partnerships between governments, shipping companies, fuel providers, and port authorities. The corridors enable the use of low and zero-emission vessels and ensure infrastructure readiness for alternative fuels. Hydrogen and ammonia fuels are gaining popularity due to their zero-carbon footprint. Nonetheless, infrastructure concerns are there since they are unsustainable and hard to store. Biofuels are made of renewable materials such as algae and waste oils, giving them a short-term advantage but long-term scalability is a cause for sustainability. Methanol powered ships are becoming popular as well because of their favorable low-carbon alternative and ease of storage compared to hydrogen. Increased use of alternative fuels and a full transition to green shipping corridors can reduce maritime emissions by 30% by 2050 according to a study by the International Council on Clean Transportation.

The uptake of green shipping lanes is initiated mainly by regulatory pressure, market forces, and technological innovation. The International Maritime Organization’s (IMO) 2023 greenhouse gas strategy calls for 50% emissions cut by 2050, and the European Union’s Fit for 55 packages include carbon pricing of shipping. ESG investors and large retailers are increasingly demanding lower carbon supply chains, driving a strong demand for sustainable maritime operations. Advances in technology regarding fuel cell technology, digital route optimisation, and eco-friendly methods of fuel production are also reducing cost barriers, making green shipping corridors more feasible.

Government subsidies and incentives further stimulate green corridor transitions. The United States Inflation Reduction Act and certain European Green Deal Initiatives finance port investment and investigation of alternative fuels. In addition, public-private initiatives like the Clydebank Declaration brings governments together with industry stakeholders to support the development of green shipping corridors worldwide.

These drivers are not without certain barriers in widespread application. High initial expenditure remains the primary hurdle, with retrofitting ships and building new infrastructure being extremely costly, usually excluding smaller shipping companies. Access to and scalability of alternative fuels such as hydrogen and ammonia are also challenging, as current volumes of production fall below forecast demand. Regulatory fragmentation represents another level of complexity, as global standards differ and generate uncertainty among global shipping companies. Moreover, safety matters concerning the storage and handling of alternative fuels must be resolved prior to their mass deployment. The prolonged vessel operating life that is often over 20 to 30 years also limits speed of technology adoption. Finally, traditional fossil fuels remain cheaper in most instances, and hence financial viability remains a key consideration to the shift.

For investors to make determinations on firms in the green shipping sector, there are multiple aspects to look at. Readiness for adoption is an important metric, with firms that are moving aggressively into alternative fuel technology and ship modernisation poised to gain in the long term. ESG scores and key performance indicators (KPIs) are important metrics used to measure a firm's dedication to sustainability. Carbon intensity (in terms of CO_2 per ton-mile), fleet modernising rates, and strategic partnership with fuel providers are some of the most relevant measures.

Financial viability is also a top-of-mind issue. Companies must reconcile investment in green technologies with retaining profitability. Investors would need to look at financial reports for assurance that companies have the money necessary to invest in infrastructure without compromising their long-term financial integrity.

Recommended ESG measures for rating firms in this sector are Carbon Intensity Indicator (CII) scores, Scope 1, 2, and 3 emissions reporting, and percentage investment in R&D of sustainable fuels.

Green shipping lanes are a sea change for the maritime industry, with the potential to remake global trade flows. Green shipping lanes would provide first movers with long-term competitive edge as carbon taxation and ESG requirements converge to become more stringent. Green corridors would, in the long run, reshape geopolitical alliances by delinking energy dependence from fossil fuel-rich regions. Investors should keep a close eye on the development of alternative fuels' scalability because a breakthrough in the storage of hydrogen or ammonia would unlock huge value in the industry.

Task 20 – Electrification and High-speed Freight

At its core, logistics is a spatial-temporal optimisation problem. In applied operations research, the core idea around the temporal value of freight is that the time in transit has a quantifiable economic cost, not least due to depreciation of perishable goods, but because capital is being tied up in inventory.

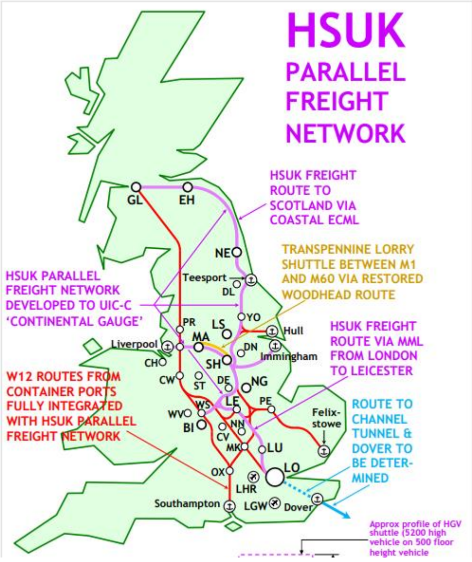
Secondly, network theory provides the mathematical tools to model the spatial-temporal optimisation problem. ‘Nodes’ are fixed locations such as plants, warehouses, terminals and fulfilment centres, whereas ‘Edges’ are connections between nodes, representing pipelines, flows and routes. Each edge carries attributes like time, cost, reliability, and capacity. Within logistics, the ‘edge weight’ reflects fuel usage, emissions and monetary cost. ‘Inter-node transfer function’ represents the performance of moving goods between nodes, which is subject to constraints like congestion, scheduling or intermodal handoff friction, whereas ‘Hub-and-Spoke architecture’, conceptualised, is where a central hub serves as a pivot point for multiple spoke nodes, which centralises complexity although can create bottlenecks without high-speed links.

Finally, logistics utilises ‘economies of speed’, which is analogous to economies of scale; they arise when increased velocity across a logistics chain reduces system-wide inefficiencies, reducing asset time, warehouse backlog and stockouts. As the intention-action gap of economies of speed are marginalised, the system benefits from a logistics yield curve, a higher ROI per unit of capital employed.

High-speed freight rail (HSFR) is a cross-disciplinary fusion of transport economics, supply-chain design, spatial economics and industrial systems engineering. Some relatable contemporary examples include SNCF in France, which adapted TGVs for mail transport operating at over 250km/h, operational from 1984 to 2015; Deutsche Bahn, which trialled express parcel services on ICE tracks; China Railway Express, whicvh currently leads in scalable HSFR logistics, which has modified carriages on high-speed passenger lines supporting e-commerce shipments between megacities; and Mercitalia, a private operator in Italy, which supports the ultra-fast movement of parcels and perishable goods.

Rather than replacing bulk rail or air freight, HSFR aims to fill the “missing middle” which provides fast, cost-efficient, lower emission connectivity between regional industrial nodes. Key industry drivers include Just-in-Sequence manufacturing, whereby component delivery needs to be precise and in a timeframe opposed to being just “on time”; increased nearshoring and regionalisation (caused partially by tariff and post-COVID bottlenecks), whereby industrials are shifting to regional production ecosystems, HSFR compresses intra-regional lead time. Furthermore, industrials are under pressure to decarbonise scope 3 emissions; HSFR offers a carbon dioxide per kilometer reduction of 80-90% vs air freight and around 50% versus diesel road haulage whilst maintaining competitive delivery times.

In terms of strategic deployment, HSFR utilises corridor-based logic, focused on between 300km – 1000km ranges where value-density justifies speed and predictability. Additionally, HSFR is being coupled with digital twins and predictive freight platforms which allows logistics to move from static routing to adaptive synchronisation.



(Above: UK current freight network)

Actionable insights

- Oakwood should consider exposure to firms involved in the electrification value-chain (catenary system providers, battery-electric traction manufacturers for freight locomotives, rolling stock leasing companies transitioning to green assets)
- HSFR is not only a logistical decision, but also an ESG procurement lever – Watch out for GreenPath initiative in the UK, Deutsche Bahn and Varamis Rail.
- As HSFR compresses delivery cycles, freeing working capital and boosting ROIC, industrials able to shift logistics to HSFR demonstrate leaner inventories and stronger asset turnover, improving balance sheet agility in macroeconomic turmoil

Special Edition: Predictive modelling in aerospace logistics

Firstly, aerospace supply chains are high-stakes, with thousands of suppliers and millions of parts per aircraft; delays or failures to even minor components are catastrophic in cost and safety. Firms are using time-series forecasting via neural networks, particularly RNN and LSTM models for demand.

Recurrent Neural Networks are designed to model sequential dependencies by maintaining a hidden state that is a function of the current input and the previous state, which enables the model to "remember" past inputs and make a temporally aware embedding of the sequence. In contrast, long short-term memory networks enhance standard RNNs by introducing gated memory cells; they regulate the flow of information across time steps, which addresses the vanishing gradient problem through allowing long-range dependencies, which is critical in aerospace as supply-demand shifts might lag by months.

The equation allows LSTM models to distinguish between short-term anomalies and long-term trends:

$$Cell\ State\ Update: C_t = f_t \odot c_{t-1} + i_t \odot \widetilde{C_t}$$

For example this would allow forecasting of seasonal part demand and sudden supplier shutdowns. Where inventory holding costs are huge and lead times long, the LSTM-based forecast allows anticipation of non-linear demand surges with more precision than a standard ARIMA or exponential smoothing model. The LSTM model also allows probabilistic forecasting when wrapped in Bayesian architecture, providing confidence intervals around forecasts for risk-adjusted planning. Both Boeing or defense contractors tend to use the SAP A&D platform with customisable AI add-ons, reducing supplier risk. Key platforms are usually integrated with enterprise systems. Other vendors include Airbus' Skywise platform, developed with Palantir, allows connection of real-time aircraft and supply data to allow predictive analytics across airlines and OEMs.

Waste-to-energy innovations, co-processing of waste, recycling of landfills

Circular Economy vs Linear Economy

Issues with traditional linear economic models:

Firstly, linear models follow a "take → make → use → dispose" motion, which neglects entropy generated during each stage. Put simply, entropy is the amount of energy not available to do useful work. In supply chains, a higher entropy corresponds to higher waste heat, lower efficiency, and greater environmental dissipation. Within neoclassical models, exergy destruction (as a result of entropy generated) is disregarded, treated indefinitely substitutable. In contrast, the second law of thermodynamics suggests that one cannot create order without increasing disorder elsewhere. Consequently, entropy is externalised, whereby processes are pushed into environmental sinks (think landfills, oceans, atmosphere), rather than closed resource loops.

Secondly, industrial processes transgress three boundaries devised in (Rockström et al, 2009)'s Planetary Boundaries Model, which highlights critical sysem processes necessary to maintain a "safe operating space" for humanity: Exceeding natural assimilation rates, altering feedback loops, and decoupling from regenerative cycles.

Simply, assimilation capacities refer to the rate a world can absorb or neutralise pollutants without inducing systemic damage. Industrial processes within linear models produce waste faster than it could be integrated by geochemical cycles. For example, industrial nitrogen fixation exceeds the natural nitrogen cycle's capacity to denitrify, leading to aquatic zones. CO_2 emissions exceed the ocean's buffering capacity leading to ocean acidification and coral bleaching. As an analogy, this is comparable to pouring heat into a system faster than it can radiate it; the system destabilises as entropy accumulates.

Feedback loops in Layman's terms are the homeostatic mechanisms which maintain a dynamic equilibrium. Firstly, 'buffers' exist, which refer to ecological dampeners that absorb, delay or stabilise fluctuations; they're crucial to maintaining equilibrium. Whilst forests act as climate stabilisers via evapotranspiration, cloud formation, carbon sequestration, and albedo regulation, the deforestation in the Amazon Rainforest weakens its' ability to generate its own rainfall through vegetation-atmosphere coupling. Secondly, 'amplifiers' refer to elements that exacerbate change and push systems further from equilibrium. For example, whilst arctic ice has a high albedo, which reflects solar radiation, as it melts due to global warming, darker ocean water is exposed which absorbs more heat. The more darker ocean water is exposed, the greater a self-reinforcing warming loop. Industrials particularly contribute to this phenomenon through fossil fuel combustion and black carbon deposits from diesel and biomass burning, which darken ice surfaces. Finally, for completeness, some industrial proposals attempt to mask symptoms of systemic instability without directly addressing the root cause. For example, stratospheric aerosol injection (releasing sulphur dioxide into the stratosphere) reduces incoming solar radiation, cooling the earth artificially, which delays warming but doesn't address CO_2 accumulation an alters precipitation patterns. If stratospheric aerosol injection were suddenly stopped, the system experiences termination shock; rapid rebound warming occurs due to suppressed feedback simultaneously reactivating.

Finally, industrials disrupt regenerative cycles, which refer to natural, closed-loop systems maintaining Earth's homeostasis; examples of key cycles include the carbon cycle, nitrogen and phosphorus cycles, the water cycle, and biodiversity cycles. Firstly, industrials deviate from these cycles as industrial chemistry produces novel entities, substances with no evolutionary precedent. Examples include PVC, synthetic dyes and microplastics. Whilst these materials are thermodynamically stable, they are biologically inert; nature cannot decompose of assimilate them within relevant timeframes. As a result, biological cycles are disrupted, and novel substances accumulate in soils, oceans, and organisms. From an opportunity cost perspective urbanisation, infrastructure, landfills and industrial estates seal land off from biological productivity, reducing ecological dimensionality. Combined, these factors compress nature's ability to self-repair and evolve.

So, now that we understand lots about the pitfalls of linear systems, how does Oakwood Fund Management categorise leaders, transitions and laggards?

Category	Characteristics
Leaders	Likely to have a built-in entropy-aware design (recyclable, modular) Actively engaged in systemic loop closing Exploiting waste streams as inputs Investing in material traceability and digital twins to minimise information loss
Transition Firms	Currently operating with linear models but actively shifting towards circular systems Might be deploying pilot schemes Working on regenerative assets but lack full-scale integration
Laggards	High-entropy outputs, no viable re-entry pathway Reliance on novel entities and material waste CAPEX locked into landfill-dependent systems Limited engagement with planetary boundaries framework

What are the key takeaways for portfolio companies?

Entropy reduction can be seen as an enhancement in operational alpha

Entropy reduction slows down the rate by which order degrades through designing for modularity, reparability and disassembly, which keeps materials in closed-loop, high-grades states and recovers usable energy from waste streams. When firms close loops and reduce waste, they extract more output per unit of input. As a result, entropy-aware firms operate closer to thermodynamic optimality, producing more economic value before they reach the waste threshold. Secondly, whilst entropy-intensive forms rely on long-distance material flows and single-point extraction nodes, entropy-reducing firms rely more on locally sourced secondary materials; they use design for circularity to recover internal waste, and they have more resilient supply loops. As a result, lower entropy systems are less structurally fragile. They adapt better to shocks as their material metabolism is locally circular rather than globally linear.

Regulatory arbitrage is diminishing

Within a linear economy, industrial actors offload material waste into unpriced ecological sinks like landfills and oceans; ignore or underreport Scope 3 emissions, and operate across jurisdictions with variable environmental enforcement, capitalising on regulatory asymmetry. The 'arbitrage' is a function of pushing thermodynamic disorder into ecosystems whereby no economic cost was priced into its degradation.

There are various mechanisms closing the arbitrage. Firstly, EU green taxonomy is a classification system defining which economic activities can be labelled "environmentally sustainable under EU2020/852. This acts as a technical screening tool to guide investment flows towards low-entropy activity. To qualify, the firm needs to significantly contribute to at least one environmental objective, whilst not doing significant harm to the others, comply with minimum social safeguards, and align with technical thresholds. The policy is thermodynamically grounded as the taxonomy implicitly rewards exergy efficiency, whereby it favours activities that preserve material and energy quality, penalising high-entropy, irreversible processes. As an implication, taxonomy is turning entropy into a discipline for green capital access. Firms failing to meet circularity, emissions, and waste thresholds face green capital exclusion.

Secondly, carbon border adjustment mechanism is a trade mechanism imposing a carbon price on imports of goods from countries with less stringest climate policies. This is scheduled to fully apply from 2026, although reporting obligations began in 2023. For the initial phase, the covered sectors included cement, iron & steel, aluminium, fertilisers, hydrogen, and electricity. Importers must purchase CBAM certificates equivalent to the carbon price they would have paid under EU ETS. To avoid double taxation, if the exporting country has a carbon pricing mechanism, credits are adjusted. This essentially internalises thermodynamic disorder, whereby firms can no longer evade ecological consequences operating beyond regulatory borders. In some sense this can be seen as entropy harmonisation at the geopolitical scale.

Finally, scope 3 reporting makes entropy visible as it recognises disorder not confined to factory waste, including emissions from product use, leased assets, and supplier inefficiencies, which highlights where thermodynamic disorder is hidden in the chain, rewarding firms that can trace, reduce or reintegrate the losses.

Zero Waste Manufacturing

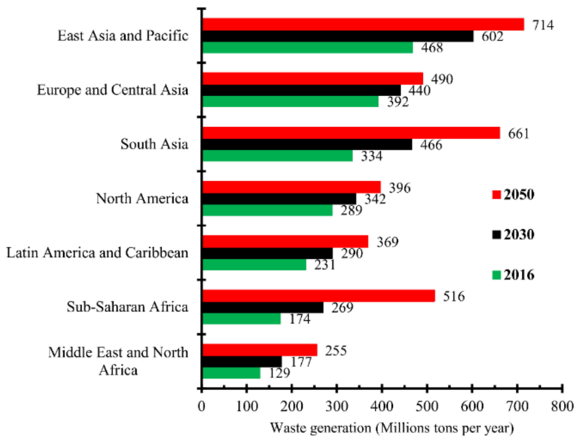
Zero Waste Manufacturing (ZWM) is the methods of production that aim to create sustainability across the entire supply chain. This is not simply reducing waste during production either, but also extends to the products lifespan, and its recycling capability after it has been 'consumed' and needs to be disposed of. Ultimately, it is the responsible utilisation and recycling of resources, aiming for total elimination of waste. This process is often seen as one way of achieving a circular economy, whereby the life cycle of products and production is extended.

There are various factors that need to be taken into consideration by a company when seeking to shift towards ZWM. These include:

- Reduce – minimising the use of materials by refining and optimising production, cutting out any unnecessary steps that may be a waste of resources or energy.
- Reuse – recycling materials and ensuring that machinery is able to be maintained and usable for as long as possible. This is especially prevalent with products that use rare earth metals, as these can be used over and over, reducing the reliance on large, single exporters of the material.
- Innovation – research and development into new technologies in order to create production methods and machinery that is more efficient in using materials, more energy efficient, or more robust, increasing the longevity of the machine's lifespan.

In order to achieve these goals, many strategies can be implemented according to the company's needs and preferences. Leaner manufacturing methods, sustainable research and development, shift to green and renewable energy, these are all examples of different business practices and common attitudes that result in a shift towards total ZWM.

The reasons why a company may wish to look into ZWM are diverse. Looking to get ahead of regulatory changes that may force them to adopt new measures, attempts to increase their ESG and Sustainability profiles, actual concern for the environment, the uncertainty around the availability of resources from politically unstable countries, or even the idea of being self-reliant in their own company structure, creating a more robust supply chain, and eventually leading to lower costs for extracting / sourcing new raw materials.



As the figure above shows, the World Bank Group estimates that by 2050, global waste production will reach 3.4 billion tons, with much of these predicted figures being obtained through research done about waste collection in wealthy nations, leaving developing nations unaccounted for, meaning this figure is likely to be much higher.

Examples of ZWM:

Toyota Motor Corp.

Toyota, already established with a Kaizen lean manufacturing system, has achieved a nearly 96% recycling / reuse of its manufacturing waste. The company was also a founder of the US Green Building Council, which aims to implement ZWM strategies in order to support sustainable buildings.

Ford

Recently launching their first carbon neutral electric vehicle plant in Cologne, this is a major step in the company's plan to obtain carbon neutrality by 2050. This is in conjunction with their other activities, including aims to achieve zero waste to landfills in their European plants, and their aims to use only recycled plastics by 2035.

Unilever

Unilever has been a pioneer in this area for a while, already achieving zero waste to landfills across multiple factories. Aiming to achieve net zero emissions by 2039, over a decade ahead of the 2050 goals set out by the Pais Agreement. And this seems obtainable for the company, with hundreds of millions of dollars being invested per year in decarbonisation programmes, and energy efficiency schemes.

Waste will likely always be present; however, this doesn't mean that ZWM as a concept is unachievable. It simply requires that companies reduce their waste output as much as possible. However to do this, there needs to be stronger incentives rather than simply reducing a company's impact on the environment for reputational reasons. Regulatory bodies and governments need to offer stronger incentives for reducing waste. Whilst some incentives exist in the form of tax credits and subsidies, promoting sustainability, they often are geared towards research and development in new technologies for increasing the emission efficiency of production, and leaving solid waste under accounted for. A paper by Omojola Awogbemi even suggests that governments should be investing in education to make the public aware of the implications of climate change and waste, as consumers do not appear to be willing to adopt sustainable lifestyles and changes to products if it even marginally negatively affects their current lifestyle and expectations. The governments role in incentivising and holding companies responsible for their waste mitigation actions will be of great importance to their decisions in implementing ZWM strategies.

Benefits of such strategies include the obvious positive impact on the environment, including a reduction in the need for new materials, meaning that extraction sites around the world will not be as destructive to local communities. Economically, there ae cost-saving benefits, leaner production results in less supply chain risk, quicker production timelines, and easier logistics for a company. I believe that this approach towards sustainability will become more important as the uncertainty in politics and dominance that China has over the rare earth metal stockpiles will result in the increased need to recycle newer technologies, as this may very well be more cost-effective for companies, especially due to the ban China has placed on certain metal exports. When looking at investment opportunities, it will be important to identify industries where ZWM is likely to be adopted effectively, rather than speculating on possible technologies in development.

Product as a Service models

Product-as-a-service is a particular business model whereby the company retains ownership of the product, whilst it sells its use or outcomes as a service, rather than selling the product outright. The customer pays for the performance the product delivers rather than the good itself. The firm would remain responsible for maintenance, upgrades and end-of-life management, diverting away from the make >> use >> dispose model through maximising product utilisation and longevity. In this sense, through decoupling value delivery from outright product ownership, product durability is internalised to the producer, enhancing resource efficiency.

Scheinder Electric realised many industrial clients wanted sustainable energy solutions without bearing high CAPEX of buildings and microgrid maintenance costs, resulting in a derived demand for Energy-as-a-service, a PaaS approach where customers pay for the outcome rather than purchasing the infrastructure. As a result, Scheinder considered a JV with The Carlyle Group, forming AlphaStruxure. Strategically, customers avoids upfront costs meaning AlphaStruxure funds the microgrid assets. The JV structure also allows Schneider and Carlyle to retain asset ownership, and combine expertise (Schneider's expertise in digital control platforms and Carlyle's expertise in financial structuring), resulting in a monthly or usage-based fee, increasing customer flexibility. This shifts something that would've been traditionally regarded as CAPEX into OPEX.

Secondly, Rolls-Royce was one of the pioneers of the PaaS model, originally dubbed "power-by-the-hour", and later formalised to TotalCare service agreements. At the time, most OEMs sold engines outright and profited from spare parts and maintenance, whereas Rolls-Royce inverted the logic through charging airlines per hour of engine operation and assuming responsibility for engine upkeep. Mechanistically, billing is shifted to being outcome-based; they pay a fixed fee for each hour the engine operates, paying thrust rather than the physical engine. Rolls-Royce is consequently responsible for proactive repairs. If the engine fails, the OEM bears the brunt rather than the airline. To keep on top of maintenance, this required a network to ensure timely maintenance, repairs, and minimal downtime for airlines. From an ESG perspective, Rolls Royce' profitability under TotalCare is endogenous of the extent of breakdowns. Therefore, the greater the engine life, the better the profitability, which inherently promotes better materials engineering and design efficiency. TotalCare is particularly unique in the sense that airlines want lower costs, derived to lower fuel burn and lower emissions. As a result, Rolls Royce invests in more efficient engines which pass through to reduced cost and entropy; a mutually beneficial example of how PaaS drives continuous R&D in sustainability. Finally, through retaining ownership, Rolls Royce is able to titanium and nickel alloys at the end of an engine's life, which are then refurbished, improving lifecycle circularity.

These are interesting case studies, but what does this mean for us when considering a stock pick?

- Firstly, when evaluating PaaS in industrials, these usually take the form of long-term service contracts, which should exhibit highly predictable cash flows. For the provider, a strong PaaS contract should enhance the resilience of cash flows, smoothing earnings volatility opposed to lump-sum sales. As a result, we consider the contract length, escalation clauses, and termination conditions of such.
- When considering the stickiness of a PaaS deal, a highly sticky customer base would translate into a low churn rate. Consequently, when analysing, we look for the renewal rates and customer satisfaction rates as proxies for how well PaaS offerings are perceived. It's important to contextualise this temporally, whilst also using comparables to establish a benchmark.
- Interestingly, for firms using PaaS, they remain closely involved with the assets operations, resulting in potential complementary packages. As a result, when looking historically at revenue streams, it's important as an investor to look at the rate of modular expansion of service offerings. For firms with higher service offerings, we should expect a higher average revenue per unit, resulting in higher revenue CAGR.
- End-of-life management is naturally a concern as minimal waste can translate into enhanced margins, thereby reducing total cost of ownership per asset. As an investor we consequently consider the recoverable value of components.
- Within Industrials, downtime is costly for clients. Service-level agreements usually stipulate a minimum uptime (usually 98% or 99%) or performance thresholds; failure to meet such metrics triggers penalties or renegotiations. We pay special attention to the contractual penalty structure, evaluating whether they are proportionate to potential downtime costs and the efficacy of monitoring systems (i.e Is the firm using predictive analytics for sensitivity analysis? Is the firm utilising IoT sensors for real-time analytics to address issues pre-emptively?).
- Finally, when considering the financial structuring within Industrials PaaS, we would want to consider the proportion of debt and equity financed for the deal, due to providers often bearing the upfront cost of manufacturing, resulting in strained balance sheets. Alternatively, firms bundle service contracts into SPV's which shift risk, freeing up balance sheet capacity.
- Overall, to calculate an appropriate IRR for the long-term payback on PaaS assets, an investor needs to carefully account for maintenance costs, redeployability at contract end, and contract renewal assumptions.

3-4 examples of transition companies

The industrials sector has several companies that are actively pushing for ESG transformations, aiming to align with the evolving market and meet regulatory expectations through enhanced sustainability. Utilizing Quiver Quantitative, an insider trading website of US Government Officials, I have tracked stock transactions worth mentioning that may prove to be significant whilst following ESG transitions. The following companies are Ford Motor Company, Caterpillar Inc., and Honeywell International Inc.

Ford Motor Company (F)

Current Share Price: $10.03 per share

Market Cap: $40.2 billion

P/E Ratio: 7.5

EPS: $1.34

Dividend Yield: 4.5%

As part of the automotive industry, Ford has a heavy reliance on the traditional internal combustion engine for vehicle sales. Ford's current weakness is seeking global demand for their EV vehicles, particularly in Europe. This is important because if Ford want to push beyond their domestic markets, they must comply with tighter regulations in Europe regarding emissions.

As part of their improvement plans Ford have decided to commit $22 billion through 2025 to develop EVs. As part of this electrification investment, Ford plan on developing the new Mustang Mach-E and the electric F-150, Ford's flagship truck. Further embracing ESG standards, Ford plans on reaching carbon neutrality by 2050, implementing various cleaner energy sources and materials within production, achieving supply chain sustainability.

This aggressive push into the EV market could help Ford plant their feet and compete with Rivian's trucks, Tesla's Cybertruck, and other manufacturers pushing for electrification. Successful implementation could lead to a dominant position in the EV market and even further in the automotive industry as whole. However, global demand for EVs continues to increase but growth is slowing down potentially harming future sales and dependence on this investment. This is because of consumer taste and more importantly price differences between EVs and traditional combustion engines. Furthermore, there is a greater discussion about how the production of EVs has a greater carbon footprint than that of traditional vehicles.

An example of a member of congress trading Ford is Republican Representative Tim Moore of North Carolina who currently holds a position worth over $250,000 with a current return of 15.61% over the past 3 months.

Caterpillar Inc. (CAT)

Current Share Price: $329.80

Market Cap: $162.75 billion

P/E Ratio: 15.44

EPS: $22.05

Dividend Yield: 1.66%

As part of heavy machinery production and usage, CAT has a heavy dependence on fossil fuels resulting in high emissions. In 2023 CAT emitted 1.44 million metric tons of CO_2 with a GHG intensity of 21.47 metric tons of CO_2.

For improvement plans CAT seeks to expand into hybrid and electric powered heavy equipment. Also, the use of alternative fuels has become popular following the development of the new C13D engine platform, a hydrogen hybrid powertrain. The new powertrain will provide 20% increased power, and 25% increased low-speed torque compared to the previous generation of CAT's diesel engines. These targets and goals will ultimately help improve efficiency goals by reducing carbon footprint and align with consumer demand following tightening restrictions on emissions.

Following increased ESG adoption, CAT will drive long-term revenue growth as demand for low-emission machinery continues to grow. The development of the new C13D engine will run on biodiesel, hydrogen, and is planned to run on other natural gases, making it a versatile powertrain, potentially increasing its demand globally. Early investments in sustainability will further improve CAT's competitive edge in the heavy machinery and mining industries.

An example of insider trading of CAT is Republican Representative Marjorie Taylor Greene of Georgia who holds a position worth over $135,000 with a return of 30% over the past 3 years.

Honeywell International Inc. (HON)

Current Share Price: $211.75

Market Cap: $132.63 billion

P/E Ratio: 23.28

EPS: $9.10

Dividend Yield: 2.0%

As a multinational conglomerate, Honeywell has a heavy reliance on energy-intensive industrial processes. Since the turn of the century, Honeywell has drastically improved efficiencies in production. However, scope 3 emissions remain a challenge despite operational carbon neutrality goals. Scope 3 emissions are indirect emissions that occur in a company's value chain but are not directly owned or controlled by the company. An example of this is the lifecycle emissions of Honeywell's refrigerants and insulation materials.

For Honeywell's improvement plans carbon neutrality remains a key target for facilities along with expanded Scope 3 target emissions. Collaboration with the U.S. Department of Energy seeks to commit a 50% reduction in Scope 1 & 2 GHG emissions by 2030. Therefore, committing to both direct and indirect emissions, complementing Honeywell's broader sustainability strategy. Regarding Honeywell's products, 60% of sales stem from ESG-oriented solutions. An example being global warming-potential refrigerants under the brand Solstice which reduce carbon emissions by 99% compared to traditional hydrofluorocarbons. Also being a conglomerate, Honeywell will continue to make portfolio adjustments via strategic acquisitions to enhance sustainability, for example, Solstice.

Honeywell does have a strong balance sheet with a diversified portfolio whilst making ESG adjustments, which makes it an easy and effective target when it comes to becoming a shareholder. Its strong ESG initiatives aligns with regulatory trends and could enhance revenue streams while reducing long-term energy costs and carbon taxes.

Regulatory Arbitrage Risk:

A practice in which companies use loopholes and differences in regulation systems in order to create benefit for the company. This is done through the avoidance of certain limits and charges said regulations impose. Perhaps the most widely known example is the use of tax havens, using a country with low tax rates to achieve tax efficiency for the business.

Whilst the use of such loopholes is not in itself illegal, it is certainly an ethical issue, and regulatory bodies are constantly seeking to tighten their regulations. This poses a threat for companies and investors alike, as companies engaging in regulatory arbitrage often spend substantial resources in order to maintain the benefits they are receiving. Thus, if a regulatory body closes a loophole, the company may be forced to undergo a degree of restructuring or risk being excluded / punished for their noncompliance. For those invested in such a company, their risk becomes much higher, as this restructuring will take time, capital, and create logistical issues.

It can be considered a type of rent-seeking behaviour, which means an entity (company) seeks to increase their own wealth without contributing to the wealth / benefit of society, resulting in social harm. When companies engage in such behaviour, they are seeking to maximise their profit without adding to society through the payment of taxes, innovation, or ethical business practices. The implications of this behaviour can be incredibly harmful for society:

Harm	Impact
Misallocation of Resources & Reduced Economic Efficiency	Companies engaging in rent-seeking will often value the benefits gained for the company and will favour maintain them over the innovation and improvement of their products.
Harm to Competition	By actively seeking these loopholes, unethical companies gain a competitive advantage over those who prioritise sustainable and ESG aligned practices.
Loss of Government Revenue	By avoiding tax liabilities, companies are reducing the amount of revenue a country's government is able to raise, thus reducing the amount of funding that may be used to better a country's society.
Reduced Trust in Institutions	Investors may perceive the use of loopholes as the failure of the government and regulatory bodies to efficiently control companies, eroding the rule of law and the confidence in world leaders.

When a company is operating across multiple countries, then it is highly likely that the company will face multiple regulatory bodies. If these bodies have the possibility of being substitutional, then the possibility of regulatory arbitrage opens, and companies can choose which regulator they adhere to that benefits them the most. This allows the company a stronger defence if they have been accepted by one regulator already. This is an example of the Tiebout model, where entities move jurisdictions to best cater to their preferences, optimising their personal utility. Whilst this could be seen as a benefit, allowing the free market to operate as intended, it opens countries up to regulation wars, where the regulatory authority needs to determine their priority, allowing the business to operate in their country by relaxing rules, or protecting the environment, even at the cost of business.

Bear in mind that the risk of regulatory arbitrage is not equal across all sectors. Below is a table that compiles the ESG risk factors for various sectors, which I have given a risk rating based on the severity of each risk associated;

Risk Rating	Sector	Risks
High Risk	Mining & Resource Refinement	**Resource Depletion** – due to the need of a wide variety of natural minerals in the industrial sector, there is the risk of depleting the planets natural reserves of each element. The mining of these resources often results in the exploitation of labour, as deposits are found in countries that have inadequate human rights protections. **Pollution** – the refinement of minerals and construction of industrial-related goods typically results in high levels of carbon emission output. And with the difficulty in reporting Scope 3 emissions (which are often not required at all), companies may not be able to accurately report on their impact. Instead, companies may choose to operate in jurisdictions that don't require this at all.

High Risk	Oil & Gas	**Pollution** – the use of fossil fuels significantly contributes to the release of carbon emissions, accelerating climate change. There is also the risk of accidents during the extraction process, such as oil spills and gas explosions, both of which have a risk of fatality for humans and animals. **Regulatory risk** – The increase in requirements for stringent health & safety measures, as well as emissions disclosure, may lead to companies seeking to move operations to jurisdictions where the rules are not as strict. This in turn creates the opportunity for exploitation of labour and the destruction of the immediate extraction area, potentially displacing the local population.
Medium Risk	Agriculture	**Pollution** – the use of pesticides and artificial fertilizers has historically been common, and arguably necessary, to produce food. However, these chemicals leak into the soil and water supply, greatly damaging the local ecosystem. **Regulatory risk** – companies may seek to engage in unsustainable farming across multiple countries, knowingly disregarding the fact that the land may be left uncultivable, in order to avoid limitations on the types of chemicals used.
Medium Risk	Construction & Materials	**Pollution** – many building companies are exposed to high emission risks, as the refinement and transportation of materials requires high fuel usage. **Labour risk** – construction companies tend to have thorough incident reporting systems and educational programmes for employees, however the industry as whole still exposes employees to potential incidents.
Low Risk	Sustainable Finance Service	This sector, whilst not a typical polluter, still has exposure to emission release, accelerated due to the digitisation of their service. Large data services and the use of AI requires huge amounts of energy. Their main risk is through the disclosure of information around their assets. With the increasingly stringent information disclosure requirements, investment firms need to ensure that they are reporting honestly and transparently.

European Influence on Regulation

It’s important to acknowledge that the EU has a high level of influence on global standards. This is a phenomenon known as the Brussels Effect, whereby the EU holds the ability to influence the standards held by non-members and companies alike. When the EU introduces a regulation, other countries may adopt these policies as their own due to the success of the single market. Companies may also adopt these policies into their own structure globally due to the fear of being excluded from the single market, even when operating in countries that hold less stringent requirements.

The EU has also been at the forefront of ESG-related regulation over the past decade, creating and incentivising ESG-focused regulatory bodies to streamline the reduction in carbon emissions. Below is a table of just some of the most important advancements in this area of law that the EU has established.

Title of Directive	Impact
Corporate Sustainability Reporting Directive (CSRD)	Replaced and enhanced the NFRD. Aims to standardise sustainability reporting across the EU. Covers over 50,000 companies, requiring

	them to report on sustainability risks, the potential impacts of the business on the environment, social issues, and diversity. Companies must also report any mitigatinf actions they have taken to improve their impact on society.
Corporate Sustainability Due Diligence Directive (CSDDD)	Applying to large EU and non-EU Companies that have significant operations within the single market, requires companies to integrate due diligence into their policies and identify any potential impacts they may have. They must also publicly communicate their efforts to being ethical.
Sustainable Finance Disclosure Rules (SFDR)	Creates a standardised framework for disclosing sustainability related information, reducing information asymmetry and allowing investors to make better informed decisions. Firms must integrate these risk assessments into their investment decisions.
EU Taxonomy for Sustainable Activities	Aims to create a consistent environment for sustainable economic activities, establishing a list of sustainable economic activities in order to facilitate sustainable investment.
Carbon Border Adjustment Mechanism (CBAM)	Main aim is to reduce carbon leakage, where companies move carbon-intensive production to countries that have a lack of regulation in this area. Requires importers to obtain and purchase CBAM certificates, and report on the embedded emissions in the imported products, which are verified through accredited entities.

All these directives are set to be fully put into action within the next three years. Thus, companies must act quickly to adhere to these requirements in order to maintain their European presence, which in nominal terms ranks as the second largest economy in the world.

The United Kingdom has also implemented the Sustainability Disclosure Requirements, which require large UK companies to disclose sustainability risks and opportunities, cracks down on greenwashing companies and introduces investment labels for sustainable products to enhance consumer confidence when making investment decisions. The labels are as follows;

Sustainability Impact™ Sustainability Focus™
Sustainability Improvers™ Sustainability Mixed Goals™

Sustainability Focus – 70% of the assets must meet a credible standard of ESG sustainability

Sustainability Improvers – assets that are currently not sustainable, but aim to improve their sustainability over time

Sustainability Impact – investments into solutions to problems affecting the environment / people

Sustainability Mixed Goals – label applies where a mix of sustainability objectives is present in a product.

These labels all come with their own specific disclosure requirements, allowing investors to make decisions based on their personal level of commitment and objectives towards sustainable investing. Each class seeks to tackle ESG issues overall, but by allowing a range of assets at different sustainable levels, there is the opportunity to diversify across a range of commitments.

Outside of Europe, California has passed two new laws, SB 253 & 261, that requirecompanies to disclose carbon emission data and sustainability risks.

SB **253** – Requires companies with revenues higher than US$1 billion operating in California to provide comprehensive emission reports, including all three emission scopes. This is a huge step in information disclosure due to the lack of scope 3 emission report requirements found in most other countries. Whilst this step will greatly reduce information asymmetry for investors, companies may struggle to calculate their scope 3 emissions due to the ambiguity and complexity of them.

SB 261 – Requires large companies with revenues higher than US$500 million operating in California to provide a climate risk reports every two years. This must include the actions taken by the company in mitigating their impact on the environment and announced to the public, following in the stead of the EU's CSDDD.

Comments

It's advised that we should seek to invest in companies that are getting ahead and being compliant with regulatory bodies, avoiding rent-seeking behaviour. They tend to be more ethical and are less likely to be burdened by long-term tightening regulatory policy. These companies take initiative, showcasing their commitment to aligning ESG policies with their company structure. By adhering to the more stringent regulations, they are likely to be able to operate across more jurisdictions that may have more relaxed policy. Of course, this may come at a cost to the companies profit in the short-term and put the company at a technical disadvantage to rent-seeking companies, however global trends point towards the continuation of stringent ESG aligned regulations being imposed.

Companies that are CBAM compliant, and that adhere to EU regulations and disclosure rules should be favoured due to the Unions influence on regulation precedent. By maintain our attention on these companies, we can avoid the possibility of investing in non-committed companies who seek to take advantage of unethical loopholes, as well as reducing our exposure to greenwashing firms. Whilst the short-selling of non-compliant companies may be a viable investment option, I personally suggest that this is avoided due to the uncertainty of the global market off the back of the US trade war. With the possibility of companies losing market share in the US, they may be more willing to restructure in accordance with the EU's stringent policies. Thus, long positions in companies that are CBAM compliant or companies that are making reputable investments in ESG-friendly schemes and projects will carry much less risk.

Companies that promote contribution to the welfare of the environment and society will be much more equipped to thrive in a ESG aligned regulatory environment.

ESG Standardisation

ESG Standardisation – The problem

In theory, ESG ratings should guide investors towards more responsible companies, although in practice ESG scores vary dramatically between rating agencies, reflecting a lack and need for standardisation. (Liu, 2022) modelled the log number of quantitative ESG metrics disclosed (number of ESG metrics) against ESG divergence. Across all model specifications, including firm-level controls, agency, industry, and fixed effects, the p values were all lower than the 1% significance threshold, implying more quantitative ESG disclosure increases divergence. When disaggregating the environmental, social, and governance pillars, it was found environmental and social disclosures lead to rating divergence at the marginal 90% confidence interval and stronger 95% confidence interval respectively, whereas governance does not, calling into question the efficacy of such ESG sources.

From another lens, cross-agency correlation estimates amongst ESG ratings for the same firm range from 0.3 – 0.5; by contrast, credit ratings from different agencies usually correlate above 0.95, indicating far greater consensus, reflecting subjectivity and methodological inconsistency within ESG assessment.

What are the sources of ESG rating inconsistencies?

Firstly, ESG agencies often include different sets of issues within their rating frameworks. The "scope divergence" in this sense might mean that two agencies are legitimately measuring ESG performance, but they are talking about two non-identical constructs. For example, if agency A factors in corporate lobbying within its governance score, but agency B doesn't consider lobbying at all, a company heavily engaged in lobbying will be viewed differently between the two ratings. This variability in coverage reflects heterogeneous views and theories regarding the definition of sustainability, reinforced by (Chatterji et al, 2016)'s observation of evaluators "defining CSR in different ways". Even today, there is no single authority defining which criteria belong in which ESG rating, leading each provider to craft its own mix of indicator.

Secondly, methodological weighting contributes to the unobserved heterogeneity contributing to the divergence. The "weight divergence" occurs as agencies assign different varying importance to ESG factors when aggregating into an overall score. (Mayor, 2019) from MIT observes that the three most important categories for different weighting agencies are the same, although weighting differences statistically explain less of the variance than the scope issues aforementioned. This poses an interesting question – How does one trade off performance in an environmental domain versus a social domain? This is a normative judgement, contrasting financial metrics having accepted weights in models for credit risk. S&P global ESG scores apply a double materiality approach, considering both financial materiality and societal impact materiality, whereas other frameworks merely consider financial materiality, usually rooted within FASB and SASB traditions.

Double materiality was initially introduced in the EU NFRD, which explicitly bifurcated the lens. From an outside-in (financial materiality) approach, we are questioning how ESG factors impact enterprise value, whereas from an inside-out (environmental and societal materiality) approach, we look at how the firm's operations affect society and the environment.

Thirdly a further inconsistency arises in how ESG attribute is measured in practice, relating to measurement divergence. This means that even if two agencies agree that a particular issue matters, they might use two different proxies to quantify performance on that issue. For example, evaluating labour practices could use either workforce turnover rate or number of labour-related controversies as the key metric, although these indicators highlight different aspects, one being an outcome metric, the other highlighting incidents, which might lead to different conclusions about whether a company has "good" labour practices. This accounts for around 50% of discrepancy in score. Interestingly, in many cases agencies choose metrics based on proprietary research, indicative of no uniform yardstick for performance. Finally, some indicators are focused on policies and outputs (what a company says or implements), whereas others focus on outcomes (actual results) exacerbating the divergence.

Underscoring the aforementioned, there seems to be difference in objectives, value systems and resulting purpose. Some agencies take a value-based approach, oriented towards investors' needs, rating companies based on how ESG factors influence financial performance or risk, whereas others take a more values-based approach, exploring the company's impact on society irrespective of immediate financial implications.

What does this mean for our assessment of ESG within a target firm?

- As corelation between ESG agencies are low, each offers partial information. As a result, we triangulate across multiple ESG providers – MSCI, Sustainalytics, and S&P global). We compare E,S,G subscores independently, identify outliers, and weight each rating based on our methodological alignment – In this case, we are very interested in financial risk so upweight MSCI.
- Industrials possess greater inter-agency ESG divergence particularly in the E and S pillars due to regional operations, local regulation and CAPEX profiles, so we focus on subscores in addition to ESG scores (aforementioned in the circularity section of the report).
- Often, ratings miss plant-level compliance and environmental violations, so we focus on pulling environmental permits and breach records, ISO 14001 and ISO45001 certifications, and audit reports.
- Industrials tend to face high stranded-asset potential, so when modelling financial risk, it's important to model the effects of scope 3 exposure and carbon taxes.
- To innovate how 'ESG' is collected, many ESG failures stem from localised events. As a result, we could build some NLP tools targeting local news sources, and NGO / activist mentions

Greenwashing and Supply Chain Vulnerabilities

Supply chain vulnerabilities:

In order to understand supply chain vulnerability (SCV), we must also understand similar terms relating to the supply chain.

Supply Chain Resilience:

> This is the ability of a company's supply chain to adapt, withstand, absorb, or recover from disruptions to the supply chain.

Supply Chain Vulnerability:

> This is how susceptible a supply chain is to harm from threats and disruptions. It is the characteristics of the supply chain, and is a precondition to supply chain risk.

Supply Chain Risk:

> These are the actual events that affect the goals of the supply chain, thus causing the company loss. It is the likelihood and potential impact of disruptions to the supply chain.

It is essential that companies are able to assess SCVs in order to make better decisions to offset the impact of disruptions, making their supply chain more robust. This has become especially prevent with the increase in outsourcing parts of the production process as a result of globalisation. Historically, companies have sought to maximise efficiency and minimise cost, and this is often done through sourcing materials and production to countries where labour is cheaper, and where materials are more abundant.

Supply Chain Vulnerability Drivers:

Supply chains are structured in nodes, with each node linked. These nodes are points in the production process where goods, information, or services are processed, such as warehouses, ports, distribution hubs, etc.

The more nodes in a supply chain, the more complex it becomes, increasing its exposure to disruptions. The management and logistics behind the supply chain also increases in difficulty alongside the increase in nodes. Thus, if a product requires many different components in its production, there will be a higher number of nodes involved.

This is referred to as Supply Chain Complexity, which is the main driver of SCV. Managing this complexity is an action that is essential to managers, with many companies seeking to limit the complexity through vendor rationalisation. Whereby they seek to refine their supplier base. This is done by reducing the amount of suppliers, incentivising them to compete with each other in order to retain business. They may offer lower prices, faster turnarounds, etc. An example of this is seen in the producing of motor vehicles, where producers now ask suppliers to assemble larger modules of the vehicle which is then shipped to an assembly point, rather than attempting to produce the entire vehicle by the company alone.

By reducing supply chain complexity, the logistical complexity also decreases, allowing easier oversight and management, ensuring a smoother operation.

List of SCVs:

External Environmental Vulnerabilities - beyond the supply chains control

- Force majeure events / Natural disasters
- War / Terrorism (Prevalent example is the Houthi attacks on the Red Sea, driving up shipping and vessel insurance costs, forcing some to reroute, increasing delivery times. Shipping traffic through the Suez Canal (accounts for 10-12% of global maritime trade) had halved in March 2024 compared to the year prior, with vessels taking different routes which may not have the long-term infrastructure to support such a shift in use (Cape of Good Hope traffic doubled). As of the time of writing, the US has seemingly escalated the situation using air strikes. This situation should be closely monitored and taken into consideration)
- Implication of new laws / Regulation
- Industry / Market pressures (need for quick transportation, need to remain competitive)
- Epidemics / Pandemics
- Damage to infrastructure (e.g. explosions at a shipping hub)
- Political instability (especially prevalent due to outsourcing reliance)

Project Organisational Vulnerabilities

- Labour strikes / Disputes
- Communication breakdowns (lengthens the decision-making process)
- Lack of skilled workforce
- Loss of trust / Fraud

Procedural Vulnerabilities

- Transport disruptions (high traffic, jams such as the blockage of Suez Canal, customs clearance time, transport capacity)
- Quality loss (materials damaged in transportation, especially risky in the transportation of sensitive products such as electronic components)
- Variations (very costly as supply chains tend to be fixed, and can be hard to adjust on the fly)
- Systems breakdowns (machines)
- Safety hazards

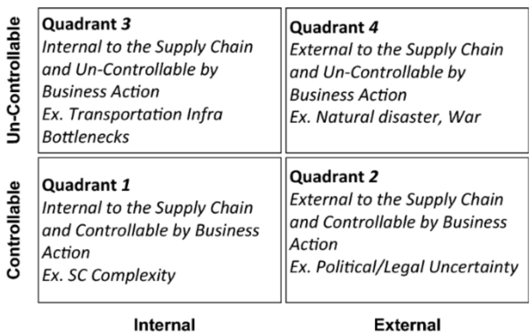
Technological Vulnerabilities

- Information loss
- Failure
- Information misuse
- IT system failure / Inadequacy

Financial Vulnerabilities

- Liquidity / Credit issues
- Poor management of monetary assets
- Price fluctuation / exchange rate fluctuations
- Liability claims
- Economic crisis

Companies also now face the added pressure of ensuring they are ESG complaint, whether this be through law or stakeholder perception. Thus, incorporating ESG practices is now an essential part of the manager's job. However, there is often a trade-off between maximising efficiency, ensuring ESG-friendly practices are implemented, and minimising the vulnerability of supply chains. One impacts the other, with the latter two likely to raise costs.



Greenwashing:

Whilst there are several definitions for greenwashing, TerraChoice defines it as "the act of misleading consumers regarding the environmental practices of a company, or the environmental performance and positive communication about environmental performance". Put simply, greenwashing is when a company provides a false sentiment / information to appear more environmentally friendly.

Stakeholders, in general, demand transparency from firms about their environmental impact. It is well established that investors and stakeholders are more aware of current climate issues and often seek out companies that have high ESG profiles. Government bodies and pressure groups have also pushed companies to put climate friendly processes in place.

In a survey produced by PWC (May 2024), it's found that consumers are willing to pay, on average, 9.7% more for sustainably produced goods. Whilst current sentiments on the sustainability of companies often fluctuates, it is well established that ESG-friendly products are often able to exploit a consensus that such products are worth paying more for. There is also the fact that investors perceive companies with a high ESG profile as 'safer' investments and attract a variety of benefits regarding raising capital / stock price liquidity.

There are a vast variety of greenwashing examples and strategies. Possible examples:

Claim Greenwashing – explicitly or implacably referring to the environmental benefits of a product to create a misleading claim.
False claims – claims that are simply fabricated
Omission of important information that allows evaluation of the truth of the claim.
Ambiguity – claims that are intentionally left with a broad definition.
Boasting about sustainable actions that are required by law.
Diversion – claiming that the production of a product will benefit the world in other ways (i.e. claims in favour of oil production due to the creation of jobs, infrastructure in poor areas, etc. Often these promises are unrealised as well)

Executional Greenwashing – does not use claims, but rather other avenues of evoking misled eco-friendly sentiment for a company.
Use of colours – using colours such as green and blue throughout product and advertising, colours which have a subconscious connection to the environment.
Sounds and Imagery – The use of nature and animal sounds in advertising. Using natural backdrops, renewable energy imagery such as wind farms, etc. All these types of imagery again impact consumers into making an eco-friendly connection to the company, without making any direct claims.
Whilst these above examples may seem to be a far reach in terms of the impact on a firm's perception when compared to outright claims, it is found that non-expert consumers are especially swayed by this 'guerilla' greenwashing.

Bluewashing – similar to greenwashing but targeted towards the company's commitment to social issues. Deceives stakeholders into believing that the company is ethical and is often used in conjunction with greenwashing. Again, this has a positive impact on the company's perceived ESG profile, in turn increasing a consumer's willingness to pay higher prices for the product.

Supply chain vulnerabilities in an ESG context:

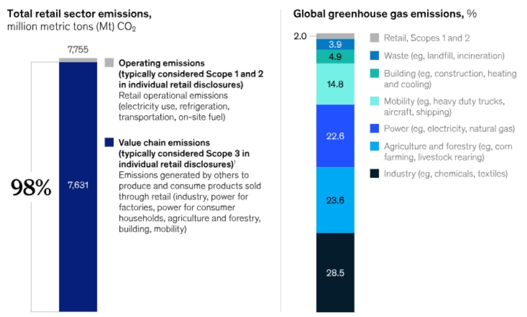
When it comes to the reporting of a company's environmental impact, specifically in terms of emissions, there are 3 scopes;

- Scope 1 – the direct emissions the company causes
- Scope 2 – emissions from energy bought
- Scope 3 – emissions tied to other activities, such as supply chains.

Whilst companies are urged to report all the scopes, many jurisdictions make the reporting of scope 1 & 2 emissions compulsory (e.g. the UK only requires companies to disclose the first 2 scopes). Scope 3 emissions are much harder to categorise, and have the potential to emit more emissions than the first two.

This leaves the company in the position of whether it would be in their interest to disclose their scope 3 emission impact, offering the opportunity to hide away any unfavourable practices. Thus, investors should be especially cautious when looking at which companies they seek to select. If a company only discloses what is required of it, then this may be an attempt at a form of greenwashing through omission, which is especially dangerous if the company has focused efforts on minimising their scope 1 & 2 emissions, with little regard to scope 3 emissions.

McKinsey estimated that scope 3 emissions typically represent around 90% of a company's total emissions (varies heavily by sector)



Note: Gasoline retail was not included in calculations. Figures may not sum to 100%, because of rounding.
[1]Aggregate and sector emissions were considered on a regional basis rather than on a company-by-company basis, and double counting was avoided.
Source: "Climate change," Walmart, updated December 15, 2023; "Global greenhouse gas overview," United States Environmental Protection Agency, updated April 11, 2024; "The net-zero transition: What it would cost, what it could bring," McKinsey Global Institute, January 2022; *Walmart climate transition analysis*, Planet Tracker, November 3, 2023; *Walmart, Inc. - Climate change 2021*, CDP Disclosure Insight Action, 2021

McKinsey & Company

Regulators are seemingly pushing to eliminate such exploitation; however the disclosure of scope 3 emissions still remains largely voluntary. And with an uncertainty and rollbacks on company DEI & ESG programmes, the forward progress being made in the fight against climate change may be much harder to materialise. (e.g. BP cuts spending on renewable energy by 70%, showcase of sentiment).

Concluding Remarks

In summary, writing this report was thoroughly enjoyable whilst enhancing intellectual rigour for all of the team. As a result, we came to the following findings:

ESG must be treated as a capital efficiency indicator, not just a risk filter… At Oakwood, we've traditionally approached ESG through a risk-management lens, treating it as a volatility dampener and governance enhancer. This report challenges us to reframe ESG as a proxy for capital efficiency.

- The observed inverse correlation between ESG and leverage, as well as the non-linear link to stock CAGR, suggests that ESG scores encapsulate balance sheet strength and managerial foresight, not just "green PR"
- As a result, we integrate ESG into our screening not just post-selection but upstream, during capital structure analysis.

Non-linear ESG effects require strategy tailoring… The empirical non-linear relationship evident from the GAM analysis shows diminishing marginal ESG benefits below a certain threshold, and outsized returns only above ESG ≈ 5. Oakwood's portfolio, whilst ESG-conscious, might not consistently apply threshold- based filtering in its thematic allocations. As a result, Industrials invests in ESG momentum in addition to ESG quality floors.

ESG KPIs should be industry-calibrated rather than uniformly applied…

The report's deep-dive into carbon intensity metrics, scope differentiation, and grid transmission loss introduces a sophistication we've yet to operationalise at Oakwood.

- Currently, Oakwood's ESG analysis often relies on composite scores or top-down screens, which risk mischaracterising whereby intensity metrics are domain-specific
- To further improve, we can build KPI dashboards, rather than fully relying on generic ESG indices.

Appendix

Full code for task 5:

```
# ------------------ LIBRARIES ------------------

library(readr)

library(dplyr)

library(quantmod)

library(tidyquant)

library(ggplot2)

library(tidyr)

library(broom)

# ------------------ STEP 1: LOAD & FILTER ESG DATA ------------------

# Load file from your Downloads folder

esg_raw <- read_csv("C:/Users/jakes/Downloads/SP 500 ESG Risk Ratings.csv")

# Clean and filter to Industrials sector

esg_clean <- esg_raw %>%

  filter(Sector == "Industrials") %>%

  select(

    Ticker = Symbol,

    Company = Name,

    Sector,

    Industry,

    ESG_Score = `Total ESG Risk score`

  ) %>%

  filter(!is.na(ESG_Score))

cat("✅ Filtered", nrow(esg_clean), "industrial firms with ESG scores.\n")

# ------------------ STEP 2: FETCH STOCK PRICE DATA ------------------

fetch_prices <- function(tickers, start_date = "2015-01-01", end_date = "2025-04-1") {

  results <- list()
```

```
  for (ticker in tickers) {
    cat("⏳ Fetching:", ticker, "\n")
    tryCatch({
      data <- getSymbols(ticker, src = "yahoo", from = start_date, to = end_date, auto.assign = FALSE)
      adj_close <- Ad(data)
      df <- data.frame(Date = index(adj_close), Price = coredata(adj_close))
      names(df)[2] <- ticker
      results[[ticker]] <- df
    }, error = function(e) {
      cat("⚠️ Skipping", ticker, "-", e$message, "\n")
    })
  }
  if (length(results) == 0) return(data.frame())
  combined <- Reduce(function(x, y) full_join(x, y, by = "Date"), results)
  return(combined)
}
price_data <- fetch_prices(esg_clean$Ticker)
price_data <- price_data %>% drop_na()
# ------------------ STEP 3: CALCULATE TOTAL RETURNS ------------------
if (nrow(price_data) > 0) {
  first_row <- price_data[1, -1]
  last_row <- price_data[nrow(price_data), -1]
  total_return <- (last_row - first_row) / first_row * 100

  returns_df <- data.frame(
    Ticker = colnames(total_return),
    Total_Return = as.numeric(total_return)
  )
```

```
  # Merge with ESG data
  esg_final <- left_join(esg_clean, returns_df, by = "Ticker") %>%
    filter(!is.na(Total_Return))
    cat("✅ Merged with returns for", nrow(esg_final), "tickers.\n")
    # ------------------ STEP 4: REGRESSION ------------------
  model <- lm(Total_Return ~ ESG_Score, data = esg_final)
  print(summary(model))
    # ------------------ STEP 5: VISUALISE ------------------
  ggplot(esg_final, aes(x = ESG_Score, y = Total_Return, label = Ticker)) +
    geom_point(colour = "#0072B2", size = 3) +
    geom_smooth(method = "lm", se = TRUE, colour = "#D55E00", linetype = "dashed") +
    geom_text(vjust = -0.8, size = 3) +
    labs(
      title = "Total Return vs ESG Score (S&P 500 Industrials)",
      x = "ESG Risk Score",
      y = "Total Return (%)"
    ) +
    theme_minimal(base_size = 14)
} else {
  cat("⚠️ Not enough data to compute returns. Try again with more valid tickers.\n")
}
#--------UI---------
library(shiny)
library(readr)
library(dplyr)
library(quantmod)
library(tidyquant)
library(ggplot2)
```

```
library(tidyr)

library(broom)

library(bslib)

# Load ESG data

esg_raw <- read_csv("C:/Users/jakes/Downloads/SP 500 ESG Risk Ratings.csv")

# Clean and filter to Industrials sector

esg_sub <- esg_raw %>% filter(esg_raw[[4]] == "Industrials")

esg_final <- data.frame(

  Ticker      = esg_sub[[1]],

  Company     = esg_sub[[2]],

  Sector      = esg_sub[[4]],

  Industry    = esg_sub[[5]],

  ESG_Score   = as.numeric(esg_sub[[8]]),

  Environment = as.numeric(esg_sub[[9]]),

  Governance  = as.numeric(esg_sub[[10]]),

  Social      = as.numeric(esg_sub[[11]])

) %>% na.omit()

# UI

ui <- fluidPage(

  theme = bs_theme(bootswatch = "flatly"),

  titlePanel("ESG Risk Factors vs Stock Performance"),

  sidebarLayout(

    sidebarPanel(

      selectInput("esg_factor", "Select ESG Factor:",

                  choices = c("ESG_Score", "Environment", "Governance", "Social"),

                  selected = "ESG_Score"),

      dateRangeInput("daterange", "Select Date Range",

                     start = "2015-01-01", end = Sys.Date(),
```

```
                    min = "2010-01-01", max = Sys.Date()),
        actionButton("run", "Run Analysis")
      ),
      mainPanel(
        plotOutput("esgPlot"),
        verbatimTextOutput("regressionSummary")
      )
    )
)
# Server
server <- function(input, output) {
  observeEvent(input$run, {
    fetch_prices <- function(tickers, start_date, end_date) {
      results <- list()
      for (ticker in tickers) {
        tryCatch({
          data <- getSymbols(ticker, src = "yahoo", from = start_date, to = end_date, auto.assign =
FALSE)
          adj_close <- Ad(data)
          df <- data.frame(Date = index(adj_close), Price = coredata(adj_close))
          names(df)[2] <- ticker
          results[[ticker]] <- df
        }, error = function(e) {
          message("Skipping ", ticker, ": ", e$message)
        })
      }
      if (length(results) == 0) return(data.frame())
      combined <- Reduce(function(x, y) full_join(x, y, by = "Date"), results)
      return(combined)
```

```
}

price_data <- fetch_prices(esg_final$Ticker, input$daterange[1], input$daterange[2])
price_data <- price_data %>% drop_na()

if (nrow(price_data) > 0) {
  first_row <- price_data[1, -1]
  last_row <- price_data[nrow(price_data), -1]
  total_return <- (last_row - first_row) / first_row * 100

  returns_df <- data.frame(
    Ticker = colnames(total_return),
    Total_Return = as.numeric(total_return)
  )

  esg_merged <- left_join(esg_final, returns_df, by = "Ticker") %>%
    filter(!is.na(Total_Return))

  fmla <- as.formula(paste("Total_Return ~", input$esg_factor))
  model <- lm(fmla, data = esg_merged)

  output$esgPlot <- renderPlot({
    ggplot(esg_merged, aes_string(x = input$esg_factor, y = "Total_Return", label = "Ticker"))
+
      geom_point(colour = "#0072B2", size = 3) +
      geom_smooth(method = "lm", se = TRUE, colour = "#D55E00", linetype = "dashed") +
      geom_text(vjust = -0.8, size = 3) +
      labs(
        title = paste("Total Return vs", input$esg_factor),
```

```
            x = input$esg_factor,
            y = "Total Return (%)"
          ) +
          theme_minimal(base_size = 14)
      })

      output$regressionSummary <- renderPrint({
        summary(model)
      })
    } else {
      output$esgPlot <- renderPlot({
        plot.new()
        text(0.5, 0.5, "⚠ Not enough data to compute returns.")
      })
      output$regressionSummary <- renderPrint({
        "No valid price data available."
      })
    }
  })
}

# Run App
shinyApp(ui, server)
```