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MPhil in Management Science

**Corporate Sustainability Performance: Analysing Sustainability Initiatives
in Multinational Corporations Through a Hybrid Meta-analysis and
Predictive Modelling Approach**

A dissertation submitted to University of Strathclyde Business School,
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List of Acronyms

1. MNC: Multinational Companies/Corporations
2. CSP: Corporate Sustainability Performance
3. ESG: Environmental, Social, and Governance
4. KPI: Key Performance Indicator
5. TSMC: Taiwan Semiconductor
6. RMSE: Root Mean Squared Error
7. MAE: Mean Absolute Error
8. R^2 : Coefficient of Determination or R-squared
9. GRI: Global Reporting Index
10. SASB: Sustainability Accounting Standards Board
11. TFCF: Task Force on Climate-related Financial Disclosures
12. SBTi: Science Based Targets initiative
13. GHG: Greenhouse Gas
14. CSR: Corporate Social Responsibility
15. UNSDG: United Nations Sustainable Development Goals
16. SDG: Sustainable Development Goals
 - a. SDG 5 – Gender Equality
 - b. SDG 6 – Clean Water and Sanitation
 - c. SDG 7 – Affordable and Clean Energy
 - d. SDG 12 – Responsible Consumption and Production
 - e. SDG 13 – Climate Action
 - f. SDG 16 – Peace, Justice and Strong Institutions

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Abstract

In recent years, the imperative for corporate sustainability has gained significant traction, with Multinational Companies (MNCs) increasingly acknowledging their responsibility to support global sustainability agendas, particularly the United Nations Sustainable Development Goals (UNSDGs). Prior studies largely focus on descriptive assessments of sustainability performance, meanwhile there is limited empirical evidence exists on the predictive capability of company-level ESG disclosures in explaining and forecasting corporate sustainability performance (CSP). Therefore, this thesis addresses this gap by assessing the relationship between sustainability initiatives and CSP within MNCs and evaluates the usefulness of predictive modelling in projecting future sustainability outcomes.

Subsequently, Environment, Social, & Governance Key Performance Indicators (ESG KPIs) that were manually taken from corporate sustainability reports between 2017 and 2023 are synthesised by the meta-regression component. This method aggregates quantitative variables, such as environmental, social, and governance factors, to assess their empirical links with CSP across several sectors instead of examining secondary studies. This offers a methodical, cross-company review of how sustainability initiatives impact external ESG assessments and reflect operational performance.

Moreover, machine learning techniques include Random Forest, Extreme Gradient Boosting (XGBoost), Least Absolute Shrinkage and Selection Operator (LASSO regression), Decision Tree, and Support Vector Regression (SVR), are employed to generate predicted CSP scores and compare against actual outcomes. By capturing both linear and non-linear patterns in ESG datasets, these models analyse complicated relationships that are frequently missed by conventional statistical techniques. This study evaluates the accuracy and robustness of predictive methods for projecting future CSP outcomes by comparing model performance using assessment criteria like Root Mean Squared Error (RMSE), Mean Absolute Error (MAE), and Coefficient of Determination or R-squared (R^2).

Finally, the study shows how predictive analytics can help with strategic planning and sustainability evaluation through hybrid approach. It also offers new insights into the relationship between Corporate Sustainability Performance (CSP) in Multinational Corporations (MNCs) and ESG-related key performance indicators (KPIs) reported in sustainability reports. The results demonstrate that prediction accuracy differs among machine learning models and indicate quantifiable relationships between specific ESG KPIs and CSP. In comparison to linear methods, ensemble-based and non-linear approaches produce predicted

CSP scores with greater accuracy among the five models used. This study provides a forward-looking analytical viewpoint that helps MNCs, investors, regulators, and other stakeholders make more informed sustainability-related decisions in line with global sustainability agendas by contrasting actual and anticipated CSP outcomes.

Keywords: Corporate sustainability, Multinational Companies (MNCs), United Nations Sustainable Development Goals (UNSDGs), meta-regression analysis, predictive modelling, sustainability initiatives, machine learning, ESG, ESG KPI

Corporate Sustainability Performance: Analysing Sustainability Initiatives in Multinational Corporations Through a Hybrid Meta-analysis and Predictive Modelling Approach

CHAPTER 1

Introduction

1.1 Introduction

Sustainability has evolved from a voluntary corporate responsibility programme to an important strategic objective for Multinational Companies (MNCs), driven by global legislative developments, investor expectations, and the urgent need to address environmental and social concerns (DESA, 2022); (Pizzi, et al., 2020). As businesses align their operations with the United Nations Sustainable Development Goals (UNSDGs), particularly those related to climate action, gender equality, and strong governance, accurately assessing corporate sustainability performance (CSP) has become increasingly important (Hummel & Szekely, 2021); (Hacıhasanoğlu, et al., 2024). Since companies with better sustainability performance frequently outperform peers in market value and financial outcomes, corporate sustainability initiatives are becoming important indicators of a company's long-term resilience, ethical standing, and competitiveness in the market (Zhou, et al., 2022); (Chang, et al., 2022). These programs cover everything from workforce diversity and governance frameworks to emissions reduction and the use of renewable energy (Govindan, et al., 2019); (Wang, et al., 2016).

However, the field is still characterised by inconsistent disclosure policies, varying interpretations of sustainability measures, and methodological challenges when evaluating ESG (Environmental, Social, and Governance) results, despite notable progress in sustainability reporting (Hummel & Szekely, 2021); (Meiden & Silaban, 2023). Even though popular third-party ESG ratings, such as those produced by LSEG (Refinitiv), provide organised evaluations of sustainability performance, there are still problems with measurement divergence, rating variability, and constraints in conventional evaluation techniques (Doğa, et al., 2025); (Chowdhury, et al., 2023). This is because ESG disclosure quality affects stakeholder trust and overall performance, it is still challenging to assess how quantitative sustainability activities improve CSP outcomes (Chowdhury, et al., 2023); (Subramaniam, et al., 2024).

Consequently, to address these gaps, this study employs a hybrid analytical strategy that blends meta-regression methods with machine learning predictive modelling. Despite its

potential to improve the accuracy of sustainability and company value estimation (Doğa, et al., 2025), previous research emphasises the limited use of machine learning techniques in examining CSP relationships (Sharma, et al., 2024); (D'Amato, et al., 2023); (De Lucia, et al., 2020). Therefore, using manually gathered ESG KPIs from sustainability reports of MNCs between 2017 and 2023, the analysis guarantees data consistency across enterprises, sectors, and reporting years. This method is in line with findings that CSR committees and robust governance structures enhance ESG transparency and performance (Subramaniam, et al., 2024).

While the accuracy and generalisability of predicting sustainability trajectories are assessed using predictive modelling techniques like Random Forest, XGBoost, LASSO regression, Decision Tree, and Support Vector Regression, the meta-regression component evaluates the influence of environmental, social, and governance indicators on sustainability performance, supporting evidence that ESG elements, especially social initiatives, have a significant impact on firm value (Tahmid, et al., 2022).

In essence, this integrated perspective acknowledges that a single approach cannot fully capture the complexities of sustainability performance. In line with earlier research highlighting the necessity of multidimensional assessment of sustainability initiatives, meta-regression offers empirical insights into KPI–rating relationships while machine learning enables the modelling of non-linear patterns, complex interactions, and temporal dynamics (Hacıhasanoğlu, et al., 2024); (Diñcer, et al., 2024). Altogether, these analytical elements provide to a more comprehensive understanding of how sustainability measures affect CSP in various industries. By doing this, our study enhances methodological rigour in sustainability research, promotes more transparent and reliable sustainability assessment processes across Multinational Companies, and provides insights consistent with UNSDG progress (Pizzi, et al., 2020); (Hummel & Szekely, 2021).

1.2 Background of Study

Corporate sustainability has become a crucial component of strategic decision-making for Multinational Companies (MNCs) due to rising stakeholder expectations, regulatory obstacles, and the global push to meet the Sustainable Development Goals (SDGs). As customers, investors, and lawmakers place a greater value on ethical business practices, sustainability initiatives have become significant elements in determining long-term performance and market competitiveness (Zhou, et al., 2022); (Chang, et al., 2022). Superior sustainability performance

has been associated with higher corporate value due to enhanced staff involvement, improved stakeholder trust, long-term growth, and favourable financing conditions (Chang, et al., 2022). These patterns demonstrate the growing demand for accurate and robust quantitative approaches to evaluate CSP and understand how ESG-driven initiatives affect both financial and non-financial outcomes.

Given the importance of evaluating CSP, it is equally important to determine the most appropriate organisational context in which to examine the relationship between ESG KPIs and CSP. In this regard, MNCs are considered more suitable than small and medium-sized enterprises (SMEs). As argued by (Ajwani-Ramchandani, et al., 2021), MNCs offer an appropriate environment for sustainability research with their significant environmental impact, global resources and capabilities, well-established corporate social responsibility (CSR) and ethical strategies, and exposure to reputational risks when stakeholder expectations are not fulfilled. Additionally, (Kolk, et al., 2017) highlighted the economic strength of MNCs, while (Ajwani-Ramchandani, et al., 2021) emphasised the alignment of MNC objectives with state policies as an important characteristic influencing their contribution towards the SDGs. However, SMEs typically have fewer resources than larger firms (Lu & Beamish, 2001); (Eller, et al., 2020) making the efficient allocation of available resources essential for sustaining business performance (Matysiak, 2018). Therefore, it is more difficult for SMEs to obtain breakthrough technology due to their limited skills and market presence (García-Álvarez de Perea, 2019). Consequently, (Zanten & Tulder, 2018) stated that MNCs appear to be better positioned to address sustainability challenges because they benefit from established normative institutions that primarily emphasise self-regulation.

Building upon the significant role of MNCs in advancing sustainable development, the 2030 Agenda for Sustainable Development acknowledges the vital role of private businesses in driving progress towards the SDGs (UN, 2015). According to (Kolk, et al., 2017), MNCs play a significant role in influencing three macro-level areas that indirectly contribute to the achievement of several SDGs; energy and climate change (SDGs 7 and 13), peace (SDG 16), and poverty and inequality (SDGs 1 and 10). Similarly, previous studies have examined MNC contributions towards the SDGs through sustainability themes such as innovation (Cordova & Celone, 2019); (Michelino, et al., 2019); (Waal, et al., 2021), energy (Ajwani-Ramchandani, et al., 2021); (Kaartemo & Gonzalez-Perez, 2020); (Patchell & Hayter, 2021), and social aspects (Bowie, 2019); (Breinbauer, et al., 2019); (García-Alaminos, et al., 2021)

demonstrating that environmental, social and governance dimensions are commonly used to evaluate corporate contributions to sustainable development.



Figure 1 United Nations Sustainable Development Goals (UNSDGs)

Accordingly, this study operationalises corporate sustainability initiatives using ESG KPIs that correspond to selected SDGs. These indicators provide measurable proxies for examining how sustainability initiatives relate to corporate sustainability performance and are incorporated into the proposed conceptual framework of this study.

ESG KPIs	Sustainability Dimension	SDGs	Justification
Emission Reduction	Environment	SDG 13	Measures corporate climate mitigation efforts.
Energy Consumption	Environment	SDG 7	Reflects energy efficiency and responsible energy use.
Renewable Energy	Environment	SDG 7	Indicates transition towards clean energy.
Water Consumption	Environment	SDG 6	Measures sustainable water resource management.
Waste Generated	Environment	SDG 12	Represents responsible production and waste reduction.
Female Employees Globally	Social	SDG 5	Reflects organisational commitment to gender equality and workforce diversity.

Board Independence	Governance	SDG 16	Supports transparent, accountable and effective governance.
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Table 1 Justification on the ESG KPIs Operationalisation

Despite the growing interest in ESG performance, the empirical research environment reveals persistent limits in methodological reliability. Research that uses traditional linear statistical methodologies sometimes ignores the complex and non-linear correlations that characterise sustainability data (Sharma, et al., 2024); (D'Amato, et al., 2023). Furthermore, the impact of governance structures, legislation, and stakeholder pressures on sustainable performance is further demonstrated by the adoption and reporting of SDG-related activities across enterprises (Martínez-Ferrero & García-Meca, 2020); (Hummel & Szekely, 2021); (Hacıhasanoğlu, et al., 2024). Additionally, the absence of industry standardisation and inconsistent SDG disclosures, however, continue to be problems that limit the comparison of sustainability results and contribute to construct validity difficulties (Pizzi, et al., 2020). As noted by (Schmidt & Hunter, 2015) and (Garson, 2020) in the context of cross-study synthesis, differences in measurement frameworks can distort estimated relationships between sustainability initiatives and CSP, which is why these discrepancies reflect broader concerns about methodological reliability.

On the other hand, the Global Reporting Initiative (GRI), Sustainability Accounting Standards Board (SASB), and European Sustainability Reporting Standards (ESRS) are examples of sustainability reporting frameworks that have tried to meet the requirement for uniform disclosures though significant restrictions still exist. Despite its comprehensiveness, the GRI framework frequently produces broad disclosures that lack in-depth understanding of important sustainability concerns and lacks clear thresholds for materiality evaluation (Puroila & Mäkelä, 2019); (Zharfpeykan & Akroyd, 2023). Similarly, SASB's financially significant indicators improve comparability; nonetheless, measurement issues persist due to differences in industry interpretation and uneven worldwide adoption (IFRS, 2017); (Cini & Ferrari, 2024). According to (Agosto, et al., 2023) and (Berg, et al., 2022) these discrepancies lead to methodological uncertainty and raise questions about the reliability of combining ESG KPIs generated from several frameworks in empirical analysis.

Conversely, these reporting difficulties are reflected in the ESG rating ecosystem, where different approaches are used by data providers like Bloomberg, Refinitiv, and MSCI, leading to low inter-rating correlations (Abhayawansa & Tyagi, 2021); (Berg, et al., 2022). According

to (KPMG, 2020), there are more than 160 ESG grading systems in use worldwide, each with its own weighting schemes, presumptions, and indicator scopes. Because of this, endogeneity, measurement inaccuracy, and methodological opacity are common problems with ESG ratings that make them less valuable to researchers and investors (Kotsantonis & Serafeim, 2019); (Christensen, et al., 2021); (Lai & Zhang, 2022). Determining actual sustainable performance is made more difficult by the complexity and diversity of ESG measurements, which increases the risk of misinterpretation and ineffective resource allocation (Goyal, et al., 2015); (Glavič & Krajnc, 2005). Consequently, (Schmidt & Hunter, 2015) highlighted difficulties including measurement inaccuracy, reliability discrepancies, and publication bias which are problems that are especially pertinent in ESG research since disclosure quality and indicator definitions varied greatly among GRI, SASB, and LSEG frameworks.

Nevertheless, several methodological limitations have been identified in conventional statistical methods. As (Wolf, 1986) noted for quantitative synthesis, when underlying statistical assumptions or publication biases are ignored, quantitative synthesis risks becoming a mechanical exercise detached from theoretical foundations, ultimately producing skewed or overstated effect estimates. Moreover, the findings of (Abdullah, et al., 2024) and (Subramaniam, et al., 2024) indicate that conventional statistical methods tend to reveal linear connections while potentially overlooking intricacies in large datasets. Furthermore, (Gruber, 2017) added that in datasets characterised by multicollinearity, standard linear regression models can produce highly variable coefficient estimates, reducing the stability and reliability of the model. Therefore, this instability may subsequently increase the risk of overfitting (De Lucia, et al., 2020). Finally, (Doğa, et al., 2025)'s found that traditional models generally assume fixed, linear relationships, potentially overlooking the complex associations between ESGC and market value.

Some of these methodological constraints have been suggested to be addressed by recent developments in Machine Learning (ML) and Artificial Intelligence (AI). In sustainability assessment, machine learning models can identify non-linear trends, capture intricate interconnections, and increase predicted accuracy (Saydam, et al., 2024). Advances in ESG score prediction and interpretability through feature importance and Shapley value analysis have been demonstrated by methods like Random Forest, Support Vector Regression, decision trees, and advanced text analytics (e.g., BERT models for ESG news extraction) (Sokolov, et al., 2020); (Borms, et al., 2021); (D'Amato, et al., 2023). ML techniques, however, provide unique methodological difficulties. Highly flexible models run the danger of overfitting,

decreased generalisability, and poor interpretability, which are particularly troublesome in ESG research because of data sparsity, skewness, and uneven industry coverage, as noted by (Castellani & Rajaram, 2021). (Garson, 2020) and (Pelham, 2013), who stress the significance of resolving non-normality, multicollinearity, model instability, and hierarchical structure violations in regression-based analyses, share these concerns. Lastly, these problems are further demonstrated by prior research using ML for ESG prediction. For instance, (Cini & Ferrari, 2024) highlight the trade-off between parsimony and complexity, pointing out that an excessive number of predictors may improve accuracy but compromise the interpretability of the model. Similarly, (D'Amato, et al., 2023) and (Doğa, et al., 2025) show that predictive performance differs greatly between sectors, regions, and ESG subclasses, supporting (Garson, 2020) claim that heterogeneity and imbalanced group structures might skew estimation. All these research point to ongoing deficiencies in methodological consistency and the necessity of reliable validation techniques including cross-validation, rolling temporal windows, and sensitivity analysis (Garson, 2020); (Castellani & Rajaram, 2021).

Overall, the literature shows that while sustainability research has come a long way, there are still a lot of methodological inadequacies. The validity of sustainability assessment is compromised by differences in ESG definitions, measuring systems, reporting standards, and rating systems. While machine learning techniques have the risk of overfitting and interpretability issues, traditional regression procedures frequently fail to identify complicated patterns due to the non-linear interactions in the ESG KPIs data. These conflicts highlight the need for robust, open, and hybrid methodological frameworks that combine sophisticated computer methods with statistical synthesis. Therefore, to fill these gaps, the current study evaluates the association between ESG KPIs and corporate sustainability performance using a hybrid technique that combines machine learning and meta-regression. Through human data verification, normalisation, and multi-model validation, this method addresses known limits in sustainability research while adhering to positivist quantitative principles by emphasising objectivity, statistical rigour, and replicability. This study intends to contribute a more robust, comprehensible, and empirically reliable model for evaluating sustainability trajectories across multinational organisations by firmly establishing the analytical framework in both theoretical understanding and methodological discipline.

1.3 Problem Statement

Although corporate strategy now includes sustainability initiatives, it is still very difficult to effectively assess how these programs affect corporate sustainability performance (CSP).

The adoption of many frameworks (such as GRI, SASB, and TCFD) has fragmented current sustainability reporting, leading to variations in measurement boundaries, disclosure depth, and indicator definitions among businesses and sectors. These discrepancies make it difficult to compare and undermine the reliability of stated ESG data. Considering it is the only metric available to investors who want to factor in sustainability data into their strategic investment decisions, external ESG ratings, such as those from LSEG (Refinitiv), Thomson Reuters, and Bloomberg, are often used as equivalents for CSP. However, there are methodological issues with these ratings, such as measurement divergence, low transparency, uneven indicator weighting, and rating biases. Consequently, there is still a lack of understanding regarding the connection between external sustainability assessments (ESG ratings) and internal sustainability initiatives (ESG KPIs). Realistic sustainability trajectories are difficult to describe because traditional statistical methodologies, which predominate in previous studies, frequently presume linearity and ignore intricate linkages and sector-specific trends.

Furthermore, there is still little integration of predictive analytics into sustainability performance studies, even with the increasing availability of quantitative ESG data. Additionally, it is possible to increase forecasting accuracy, identify non-linear relationships, and make sustainability indicators easier to understand with machine learning approaches. Applying these methods to company-level ESG KPIs and connecting them to CSP outcomes, however, still has a methodological gap.

These problems emphasise the need for a more reliable, integrated method that can assess and forecast CSP. In the absence of such a strategy, companies, investors, and lawmakers are unable to clearly demonstrate how sustainability initiatives support long-term success and the advancement of the UNSDGs. By using a hybrid technique that blends machine learning predictions with meta-regression analysis, this study fills this gap by offering a thorough evaluation of sustainability practices among MNCs.

1.4 Research Aim and Objectives

The overall aim of this research is to examine the impact of sustainability initiatives on corporate sustainability performance (CSP) in multinational corporations (MNCs), and to assess the extent to which ESG-based indicators can be used to explain and predict sustainability performance outcomes.

The following are the research objectives based on the research questions to support this study:

1. To assess how sustainability initiatives affect corporate sustainability performance (CSP) in multinational corporations (MNCs) by utilising a meta-regression analytic approach to examine the connections between company-level ESG Key Performance Indicators (KPIs) and ESG ratings from third-party data provider.
2. To evaluate machine learning-based predictive models' accuracy, robustness, and generalisability in predicting MNCs' sustainability trajectories by using suitable statistical methods and performance validation measures.

1.5 Research Questions

The following are the research questions that support this study:

1. How are multinational companies' (MNCs) sustainability initiatives, as operationalised through ESG Key Performance Indicators (KPIs), associated to Corporate Sustainability Performance (CSP) as reflected in LSEG ESG ratings?
2. To what extent can machine learning-based predictive models accurately forecast sustainability trajectories for MNCs, and how reliable and generalisable are these forecasts across different sectors?
3. Which environmental, social, and governance (ESG) KPIs show the strongest associations with corporate sustainability performance across international corporations?
4. Which machine learning approaches achieve the highest predictive accuracy and robustness when forecasting corporate sustainability performance using ESG KPIs?

1.6 Significance of Study

This research contributes empirical, methodological, and practical value to the growing field of corporate sustainability performance by offering a comprehensive analysis of how sustainability initiatives influence CSP outcomes among Multinational Companies.

Primarily, the study advances empirical understanding by directly linking company-level ESG KPIs such as emissions reduction, energy consumption, renewable energy, water consumption, waste generation, female employees globally, and board independence to CSP as measured by LSEG's ESG ratings. By manually extracting ESG KPI data from sustainability reports, this research ensures consistency and reliability, overcoming limitations associated with third-party data divergence and incomplete reporting.

Consequently, the hybrid methodological approach of the study enhances the analytical rigour of sustainability research. The synthesis of ESG KPI–CSP correlations across different companies is made possible by the inclusion of meta-regression analysis, which captures heterogeneity and changes in effect sizes. By assessing how well machine learning algorithms predict sustainability trends, the predictive modelling component adds even more methodological depth. A strong foundation for evaluating both explanatory linkages and predictive potential is offered by this dual approach.

Moreover, the results provide useful information for Multinational Companies looking to enhance sustainability performance and correspond to the UNSDGs. The study enables more focused sustainability initiatives, better resource allocation, and improved transparency practices by determining which ESG variables show significant connections with sustainability ratings. The findings also emphasise the significance of integrated sustainable governance processes, consistent ESG KPI measurement, and transparent reporting.

Finally, the study shows how predictive models can improve the dependability of sustainability assessments, which helps investors and policymakers make decisions. Corporate and regulatory stakeholders' long-term planning, risk assessment, and investment screening can all be strengthened by more precise CSP trend forecasts.

All things considered, this study advances the understanding of the methodological, operational, and strategic aspects of sustainability performance. It promotes the development of more cohesive sustainability reporting standards, fortifies evidence-based decision-making, and advances global progress towards accomplishing the UNSDGs by connecting explanatory and predictive insights.

CHAPTER 2

Literature Review

2.1 Introduction

Corporate sustainability initiatives have become increasingly influential in shaping company performance, with both customers and investors placing greater value on responsible business practices. While research consistently shows that superior sustainability performance can enhance market value and financial outcomes through improved employee engagement, customer trust, and competitive advantage, significant gaps remain in our understanding especially regarding how comprehensive ESG (Environmental, Social, and Governance) factors and machine learning techniques can enhance the precision of corporate sustainability valuations. This chapter explores the evolving landscape of sustainable initiatives, examining the determinants of SDG adoption, the standardisation challenges of sustainability reporting frameworks, the reliability of ESG ratings, the impact of regulatory and stakeholder pressures, and how advanced analytics may offer more robust and actionable insights for companies striving to meet rigorous sustainability expectations.

2.2 The Influence of Sustainable Initiatives on Corporate Sustainability Performance

Corporate sustainability initiatives have gained increased recognition from customers and investors; thus, the relationship between corporate sustainability performance and market success has been a prominent area of research. Companies exhibiting superior sustainability performance generally surpass their counterparts in market value, attributed to improved financial outcomes (Zhou, et al., 2022), stemming from increased employee engagement, enhanced relationships with customers and suppliers, elevated long-term growth and dividends, along with advantageous financing costs (Chang, et al., 2022).

Few studies have used machine learning techniques in this field, despite the fact that a large portion of the literature currently in publication has looked at the connection between corporate sustainability performance and financial results, typically measured through accounting- and market-based indicators like Earnings Before Interest and Taxes (EBIT), Return on Assets (ROA), Return on Equity (ROE), and firm profitability.

For example, (Sharma, et al., 2024) employ artificial intelligence and machine learning techniques to improve forecasting accuracy in complex and non-linear energy markets,

demonstrating that advanced models outperform traditional methods when predicting financially relevant outcomes such as price trends. Furthermore, (D'Amato, et al., 2023) investigate the relationship between ESG scores and firm profitability, measured by EBIT, using machine learning models and interpretability tools, and find that ESG indicators serve as meaningful predictors of financial performance. Similarly, (De Lucia, et al., 2020) apply a combined machine learning and inferential approach to predict financial indicators, including ROA and ROE, and provide evidence of a positive association between ESG practices and financial performance, particularly in relation to environmental innovation and human capital factors.

Additionally, most existing studies emphasise profitability measures rather than comprehensive indicators of company value. As a result, there is limited understanding of how sustainability initiatives affect a firm's overall corporate sustainability valuation. Thus, to address this gap, (Doğa, et al., 2025) research's focused to improve the accuracy of company value estimates using LSEG's Corporate Sustainability Performance ratings, which include Environmental (E), Social (S), Governance (G), and ESG Controversies (C) indicators. Their research employs sophisticated machine learning algorithms to enhance these estimates. Additionally, (Doğa, et al., 2025) emphasise the importance of including ESGC elements into market value prediction models as their research results imply that Europe and America are more important than other regions in terms of business sustainability performance indicators (E, S, G, and C).

(Chowdhury, et al., 2023) cited that ESG disclosure improves corporate sustainability performance because they discovered that clear ESG disclosure, which provides accurate information about a business, improves the likelihood of gaining stakeholders' trust and, eventually, improves company performance. In essence, financial institutions will be able to forecast their borrower's ESG rating and make loan decisions based on the rating, while investors and portfolio managers will be able to make investment decisions based on that rating.

In accordance with (Subramaniam, et al., 2024), Corporate Social Responsibility (CSR) reporting committees greatly improve an organisation's ESG performance. Higher recycling metrics between 2017 and 2021, a rise in green innovation practices (apart from the energy sector), and increases in average environmental and disclosure ratings are indicative of this. These results show that organisations with reporting committees typically adopt more open reporting procedures, satisfying stakeholder requests for increased accountability. Subsequently, the author added CSR committees enhance transparency and accountability through rigorous disclosure practices and prioritise strategic resource allocation toward

sustainable initiatives, directly impacting environmental performance and improving risk profiles in risk management by identifying and mitigating environmental risks.

A study conducted by (Tahmid, et al., 2022), that social initiatives improve the firms' value and performance among the ESG initiatives, followed by environmental and governance initiatives based on the ESG score results from the regression analysis study. The following author further mentioned that firms' employ ESG activities as part of their strategy planning to give shareholders more information about corporate conduct and investments as investors are drawn to successful ESG activities, which increases their propensity to purchase and make investments. Similarly, (Flammer, 2015) found that employee satisfaction is the underlying mechanism behind the improvement in profitability based on the long-term effect result that shows labour productivity rises significantly in the years after the employee satisfaction channel vote. Evidently, social initiatives have significant impact to the firms as compared to environmental and governance initiatives.

2.3 Factors that influence the adoption of Sustainability Reporting to comply with Sustainable Development Goals in Multinational Companies

The 17 Sustainable Development Goals (SDGs) established by the United Nations provide a comprehensive roadmap for achieving a sustainable future by 2030. Committed efforts to address global concerns make these SDGs particularly significant (DESA, 2022) (UN, 2015). While the adoption and reporting of SDG-related activities are increasingly seen as integral to organisational strategies, the quality and detail of such disclosures remain a concern. (Hummel & Szekely, 2021) observed ongoing progress in how companies report on the SDGs in their annual reports, but they also highlighted persistent gaps, particularly a lack of quantitative information and forward-looking projections underscoring the need for greater rigor in the depth and quality of SDG disclosures. This gap in comprehensive and reliable reporting points to an incomplete understanding of the factors that drive thorough SDG adoption and communication. In line with this, (Hacıhasanoğlu, et al., 2024) argued for more robust research to unravel the multitude of influences shaping organisations' engagement with the SDGs and to explore how these determinants manifest across different sectors and regions. (Pizzi, et al., 2020) asserted that the SDGs necessitate companies to adopt sustainable practices and incorporate sustainability data into their reporting mechanisms to tackle critical global sustainability issues. Addressing these gaps requires not only understanding the importance of SDG reporting but also identifying and strengthening the underlying factors such as regulatory

environment, competitive advantage, and stakeholders' expectation that enable effective disclosure:

a. Regulatory Environment

The effectiveness of SDG reporting and commitment is influenced by the regulatory environment, including corporate governance structures, transparency requirements, and the use of standardised reporting frameworks. Research by (Martínez-Ferrero & García-Meca, 2020) demonstrates that the internal corporate governance of a corporation was analysed in connection with its commitment to the SDGs. According to the results, when a company has better corporate governance, including elements like board composition, attendance, and chief executive officer independence, it is more likely to report on the SDGs in its sustainability reports. Similarly, (Pizzi, et al., 2020) findings indicate a favourable correlation between a company's SDG reporting scores (SRS) and several determinants; such as the report's length, knowledge of non-financial reporting, and the presence of independent directors on the board, with environmentally sensitive industries scoring at the highest level. Subsequently, (Hacıhasanoğlu, et al., 2024) claims that by revealing their SDG-related activities, companies may show their dedication to sustainability, follow regulations, encourage sustainable practices, improve accountability and transparency, and enhance their reputation and brand value. In contrast with (Sachs, et al., 2019) findings, where six initial transformation were identified that are required to achieve the SDGs: a shift in the educational system; a guarantee of health and well-being; a focus on renewable energy; the sustainable management of natural and artificial resources; and the use of technology to create a sustainable digital revolution through a process of decoupling and circularity. However, it appears that MNCs' initiatives are ineffective in enacting all these changes.

b. Competitive Advantage

On the other hand, another factor that influence the adoption of SDGs in MNCs were discussed by (Elalfy, et al., 2021) (Izzo, et al., 2020) indicate that the SDGs are more likely to be included in reporting by larger organisations, publicly traded firms, and sectors with greater sustainability consequences. Similarly, (Govindan, et al., 2019) chose six industries with the filter criteria was that the company must be a small or medium-sized business (SME) or a major supplier to multinational corporations (MNCs) because, as with any strategy, MNCs or big players can implement sustainable development practices more easily, while SMEs frequently struggle because of their limited resources, capital, and expertise. As stated by (Pizzi, et al., 2020) from (United Nations, 2015), SDG 17 (Partnerships for the Goals), SDG 12, and specifically SDG target 12.6, "requires Member States to encourage companies, especially

large and transnational companies, to adopt sustainable practices and to integrate sustainability information into their reporting cycle” including a call to action for the private sector (UN, 2015). Additionally, (Abdelhalim & Gamal Eldin, 2019) agree that the introduction of the Sustainable Development Goals (SDGs) in the post-2015 development agenda established by the UN emphasises Goal 17 (Partnership for the Goals), focuses on strengthening global multi-stakeholder partnerships for sustainable development that drive and disseminate knowledge, expertise, technology, and financial resources to facilitate the SDGs initiatives. Overall, (Wang, et al., 2016) shared about how the phrase "sustainable development" has changed in the journalistic discourse in this day and age and that means businesses have begun disclosing information about their environmental performance, including waste management, energy efficiency, and the utilisation of natural resources and raw materials, giving them a competitive edge.

c. Stakeholders Expectations

Beyond regulatory environment and competitive advantage, the internal landscape of effective leadership and stakeholders' expectation also determines whether SDGs translate from strategy into action. (Hacıhasanoğlu, et al., 2024) highlight the importance of consistently reporting sustainability-related issues and incorporating them into annual reports to facilitate effective SDG implementation. Their findings illustrate the factors influencing sustainability reporting, the impact of annual reports on sustainability outcomes, and approaches to strengthening alignment between stakeholder perspectives and the Sustainable Development Goals. Future research is necessary to delve deeper into the metrics of SDG reporting, even though (Hummel & Szekely, 2021) findings on the positive relationships between stakeholders and SDG reporting. Subsequently, stakeholder engagement is vital for effective measurement of environmental performance as was emphasised by (Meiden & Silaban, 2023). Engaging with stakeholders allows organisations to understand their concerns, expectations, environmental sustainability priorities, gather valuable insights, gain legitimacy, and build trust in their environmental performance (Meiden & Silaban, 2023). According to stakeholder theory, (Diñcer, et al., 2024) findings indicate that corporations ought to prioritise environmental disclosures, taking into account their causal impact on economic and social dimensions to meet the diverse objectives of stakeholders.

2.4 Development and Standardisation of Sustainability Reporting Framework

As more organisations strive to achieve the Sustainable Development Goals, it is increasingly important for them to provide transparent and reliable reports on their progress. To share their sustainability initiatives, businesses often use specialized reporting systems. Widespread use of accountability tools has encouraged both theoretical and practical discussions about regulating sustainability reporting, with the goal of improving transparency in financial markets (Caputo, et al., 2021); (Jackson, et al., 2020). However, comparing sustainability reports is difficult because these reports are often based on different standards and frameworks, and there are few strict requirements on what should be included.

To address these challenges, financial institutions and regulators have started debates about the future of sustainability reporting. A significant step in standardising disclosures is the introduction of the European Sustainability Reporting Standards (ESRS) (European Commission, 2023). Before preparing a sustainability report, it is recommended that companies conduct a materiality assessment to identify which ESG issues are most relevant to their business and stakeholders (Hajek, et al., 2024). To ensure consistency and comparability, companies are encouraged to use globally recognised standards such as the Global Reporting Initiative (GRI), the Sustainability Accounting Standards Board (SASB), or the Task Force on Climate-related Financial Disclosures (TCFD)'s recommendations (Hajek, et al., 2024).

a. Global Reporting Initiative (GRI) Framework

The GRI standards are the first internationally recognised guidelines for sustainability reporting, created by the Global Sustainability Standards Board (GSSB) since 1997 (GSSB, 2025) as an independent functioning organisation under GRI's sponsorship, with members from a variety of backgrounds and have different viewpoints on sustainability reporting. As explained by (Elalfy, et al., 2021), the Global Reporting Initiative (GRI), which was founded in 1997 in response to the United Nations Environment Programme, seeks to use responsible reporting methods to assist governments, corporations, and institutions in comprehending and communicating their effects on global sustainability issues. Furthermore, (Sethi, et al., 2017) explained the Global Sustainability Standards Board (GSSB) of GRI has been creating reporting requirements since 2014 and these guidelines have evolved across four generations (G1, G2, G3, and G4) to the present GRI Standards, which were introduced in 2017. Within the GRI framework, which promotes standardised sustainability reporting to address global sustainability impacts (Elalfy, et al., 2021) a materiality matrix serves as a visualisation tool to display the relative importance of sustainability issues identified in assessments (Puroila &

Mäkelä, 2019). To identify and disclose its distinctive sustainability impacts, each company needs to perform a comprehensive material assessment (Puroila & Mäkelä, 2019). However, the materiality matrix does not normally indicate the threshold for identifying what to include and exclude (Puroila & Mäkelä, 2019). In September 2020, the four main sustainability reporting frameworks (CDP, GRI, SASB, and TCFD) issued a statement announcing their plan to standardise their indicators to achieve complete reporting and the growing need to comprehend how businesses contribute to the SDGs (World Economic Forum, 2020). Finally, (Zharfpeykan & Akroyd, 2023) study reveals that attempts by organisations like the Global Reporting Initiative (GRI) to improve voluntary sustainability reporting through revised standards, a focus on key issues, and tools like the materiality matrix have not encouraged companies to shift from reporting on many topics to providing detailed insights on critical ones. (Zharfpeykan & Akroyd, 2023) further added, without mandatory requirements, these efforts may not lead to noticeable improvements, as companies may not prioritise these changes.

b. Sustainability Accounting Standards Board (SASB)

Although GRI places a strong emphasis on impact materiality and wide stakeholder engagement, various frameworks have been developed to meet investor demands for financially significant sustainability data such as SASB, one of the most widely recognised. SASB standards guide industry-specific organisations in identifying and reporting sustainability-related risks and opportunities that could reasonably be expected to affect financial performance over the short, medium, or long term (IFRS, 2017). For example, material disclosure is defined by the SASB as information that would materially change an investor's perception of the company's information mix (Cini & Ferrari, 2024).

Recent update from International Sustainability Standards Board (ISSB), especially the IFRS S1 mandate that businesses incorporate SASB Standards into their reporting to identify and reveal sustainability-related risks and opportunities (IFRS, 2023). Following this, (Pizzi, et al., 2024) indicated that multinational businesses may consider adopting the SASB as a first step toward the IFRS Foundation's conceptual framework.

2.5 Challenges and Advances in ESG Ratings: Reliability, Methodology, and the Role of AI in Sustainability Assessment

Over the years, standardised frameworks such as GRI and SASB have significantly improved the quality and consistency of sustainability reporting, providing data that is subsequently evaluated by ESG rating agencies and data providers. This section examines the

reliability and methodological rigor of ESG ratings, highlighting how data providers interpret disclosures and the challenges this creates for meaningful assessment. As noted by (Cini & Ferrari, 2024), Environmental (E), social (S), and governance (G) are the three main pillars of ethical finance that the name ESG seeks to integrate. The author further added concerns like pollution and climate change are the focus of the E pillar, which also assesses a company's efforts in waste management, energy and resource efficiency, and gender policies; the S pillar covers workplace safety and gender policies; and the G pillar is related to elements like board independence and legal compliance.

Furthermore, there may be inconsistencies and uncertainty regarding a company's actual ESG performance if there are many ESG ratings for it. More than 160 ESG ratings and data sources are available, according to a recent KPMG survey (KPMG, 2020). These agencies include Bloomberg, Thomson Reuters, S&P, and others, and their ESG ratings can differ. (Abhayawansa & Tyagi, 2021) have demonstrated that there is little correlation between the ESG ratings that are given by different sources. The absence of standardisation in ESG measurements and the poor connection between ESG ratings from various sources were discussed by (Agosto, et al., 2023). Moreover, ESG rating agencies are frequently attacked for their possible conflicts of interest, misaligned methodology, lack of standardised procedures, and lack of transparency (Kotsantonis & Serafeim, 2019). These approaches are further examined for problems like the incapacity to identify unethical acts like social washing and greenwashing (Drempetic, et al., 2020); (Abdi, et al., 2022) and the lack of comparability brought on by the absence of reporting standards (Berg, et al., 2022). (Dwivedi, et al., 2023) asserts that businesses find it challenging to use these indicators for decision-making because of the lack of uniformity and openness in these data sources. In any case, there are many applications for ESG measures, ranging from assessing a business's environmental performance to influencing investment choices. Subsequently, the author also mentioned that these data sources measure ESG using various methodologies, which can lead to significant differences in rankings because ESG ratings are complicated and have few relationships. Therefore, determining the significance of ESG sustainability becomes a challenging undertaking due to the abundance of indicators available for evaluating organisations' ESG performance. (Goyal, et al., 2015) stated that the attainment of sustainable development goals may be hampered by this complexity, which may lead to difficulties and possibly inefficient resource allocation. As a result, decision-makers looking to allocate resources effectively must prioritise and simplify the numerous sustainability indicators (Glavič & Krajnc, 2005).

To address these challenges of complexity and inconsistency, recent advances in artificial intelligence and machine learning offer promising solutions for analysing, simplifying, and standardising ESG assessment processes. For instance, (Saydam, et al., 2024) discovered that the use of machine learning techniques was crucial in revealing subtle facets of the environmental innovation, diversity, and ESG scores that were difficult to identify using traditional linear analysis. Notably, when taking similar predictors into account, different machine learning algorithms, such as rpart, SVM, partykit, evtree, and ensemble models (such as boosted regression) have demonstrated better performance than multinomial logistic regression (Saydam, et al., 2024). Furthermore, (Dwivedi, et al., 2023) asserts that a number of businesses have resorted to artificial intelligence (AI) systems in order to get past the difficulties associated with analysing ESG data as these systems can help businesses assess risks, uncover opportunities that may be hidden, carry out intricate tasks, and let sustainable investors sift through vast amounts of data in order to find both possible risks and opportunities. Furthermore, machine learning has become increasingly popular as a methodological strategy for forecasting and elucidating market dynamics in the financial industry (Henrique, et al., 2019). Subsequently, machine learning algorithms are designed to identify patterns and support decision-making by learning from data through a structured training process. In this context, machine learning models extract patterns from historical data by iteratively adjusting their parameters, enabling the system to improve predictive performance over time. Although these researchers have different goals and variables, (D'Amato, et al., 2021); (D'Amato, et al., 2022); (Lee, et al., 2022); (Raza, et al., 2022) have all employed machine learning to predict the ESG score using balance sheet and income statement data. With the goal to make these models more interpretable, (D'Ecclesia, et al., 2024) uses various interpretation tools that enable the examination of a machine learning model's operation, which are still little utilised in the literature on sustainability measurement.

However, despite these methodological advancements, significant limitations remain; most notably the challenges of endogeneity, data reliability, and causal inference that continue to compromise the robustness and interpretability of ESG ratings. For example, possible endogeneity problems provide difficulties and constraints when researching the relationship between financial performance and ESG ratings (Lai & Zhang, 2022). Furthermore, it can be challenging to establish causal linkages and produce erroneous correlations when data used for ESG ratings are impacted by external or correlated factors (Tang, et al., 2022). Similarly, (Berg, et al., 2022) (Christensen, et al., 2021) studies show that technical flaws in accounting metrics and ESG data impact their results. Lastly, based a thorough analysis of institutional investors

worldwide by (Eccles, et al., 2017) the lack of trustworthy and accurate information about how companies are performing on their material environmental, social, and governance (ESG) components is the main barrier to their decision-making process.

Although they are frequently criticized for their inability to accurately assess the sustainability level of securities and regardless of comparisons between ESG ratings from different providers, it is important to note that many studies point to other advantages on higher scores of ESG ratings (Berg, et al., 2022). According to (Clément, et al., 2025), ESG ratings are extensively employed as key financial instruments for constructing portfolios that emphasise environmental, social, and governance considerations, as well as for assessing firms' performance in these dimensions, particularly within the context of responsible investing. Despite the significant methodological opacity and inconsistency surrounding ESG ratings, they continue to gain prominence in both academic research and professional practice, becoming indispensable tools for investors, particularly institutional investors (Ahmad, et al., 2024). Evidence from (Cini & Ferrari, 2024) suggests that most studies developing machine learning models for ESG rating prediction utilise Refinitiv (LSEG) data because it is among the most accessible and cost-effective ESG datasets available. Further demonstrating the widespread use of Refinitiv (LSEG) data, (D'Amato, et al., 2022) employed its ESG ratings as the measure of corporate ESG performance in a Random Forest (RF) regression model to evaluate the predictive power of balance sheet variables for companies in the STOXX 600 Index between 2011 and 2020. Overall, ESG ratings are the only metric available to investors that want to include sustainability data into their strategic investment choices (Cini & Ferrari, 2024).

While Refinitiv (LSEG) ESG Ratings include information disclosed in corporate sustainability reports, they are developed using a proprietary assessment methodology that incorporates a substantially broader range of ESG indicators, along with standardisation and weighting processes. As a result, the ESG KPIs chosen for this study represent only a subset of the broader evaluation framework instead of a direct reconstruction of the overall LSEG ESG Rating. Despite ongoing concerns surrounding methodological opacity, inconsistencies in rating methodologies, and limited comparability across ESG providers, ESG ratings remain a widely accepted measure of corporate sustainability performance in both academic research and professional practice. While these limitations warrant cautious interpretation, their extensive use in investment analysis and machine learning models supports their continued research relevance. Accordingly, Refinitiv (LSEG) ESG ratings provide a suitable and defensible proxy for measuring corporate sustainability performance in this study.

2.6 Leveraging Machine Learning Techniques to Evaluate Corporate Sustainability Performance

Given the limitation in ESG assessment and varied methodological strengths in prior context, it is now essential to examine how emerging machine learning techniques can address the identified limitations and advance the field of corporate sustainability performance assessment.

As stated by (Lee & Kim, 2023), there are a lot of research being done these days on ESG, a measure of business non-financial activity. From the findings of (Abdullah, et al., 2024), conventional statistical methods tend to reveal linear connections and might overlook intricacies in large data sets. On the other hand, complex, non-linear dynamics are captured by machine learning approaches such as decision tree regressors that renowned for being easily interpreted, highlighting important characteristics and connections, and offering clear, useful insights; and ARIMA models that accurately predict time series data by taking autocorrelations, trends, and seasonality into consideration (Subramaniam, et al., 2024). That said, there is little ESG research that uses machine learning and deep learning, even though there are a lot of interest in and research on ESG in many fields. Nonetheless, a lot of businesses and organisations are currently attempting to use machine learning technology for ESG investing, ESG information collecting, disclosure data analysis, and corporate report analysis (Macpherson, et al., 2021).

Through the application of Random Forest regression and linear regression, (Sharma, et al., 2024) confirmed that adding ESG data as input variables results in a high prediction accuracy when forecasting the values of growth metrics, like stock returns. (Chen & Liu, 2020) suggested a method for deriving ESG alpha and used ESG scholar data to construct an autonomous transaction strategy. Algorithms like linear regression, LASSO regression, ridge regression, SVR, RF, and long short-term memory (LSTM) were trained using a combination of financial indicators and ESG scholar data; ensemble approaches were used to extract the alpha. Moreover, (Borms, et al., 2021) filtered ESG news documents to integrate company-specific ESG news-based indicators into ESG investments featuring keyword-based extraction, word embeddings for semantic expansion, lexicon-based sentiment analysis enhanced by contextual adjustments, and a rigorous filtering process. Additionally, (Sokolov, et al., 2020) built an ESG index employing news and social media data in the study using BERT, a large-capacity corpus pretraining language model. (Subramaniam, et al., 2024) asserts that Shapley values allow the predictive power of each feature to be assessed. On top of that, (D'Amato, et

al., 2021) and (Frost, et al., 2023) evaluated structural variables using Bloomberg ESG scores using the random forest algorithm.

According to (Dwivedi, et al., 2023) a corporation's actual performance should not be inferred solely from ESG ratings. However, the authors contend that by encouraging companies to adopt more environmentally and socially sustainable practices, ESG frameworks can still have an impact on corporate reputation and decision-making, hence promoting a fairer economy. In addition, the author added by assisting corporations in becoming more socially and environmentally sustainable, they can have an impact on a company's reputation and decision-making, so promoting a more equitable economy. According to (Subramaniam, et al., 2024), machine learning techniques have several benefits over conventional approaches. For instance, while ML models reveal hidden patterns and relationships, linear regression only shows direct relationships and frequently overlooks complex, non-linear interactions. Since data from these sources can be standardised to enable more precise and significant predictions, (Dwivedi, et al., 2023) showed that a robust ESG-ML model yields a relevant ESG grade and that machine learning models can be helpful in forecasting ESG ratings.

(Dwivedi, et al., 2023) has effectively created a machine learning model to forecast business entities' ESG scores. High goodness of fit is demonstrated by the gradient boosting algorithm's RMSE value of 3.47. When making ESG investments, this method of forecasting ESG scores for other corporations where such scores are unavailable can be applied, and a strategy can be created using a cutoff value of such a score. Investors are increasingly including non-financial aspects into their risk analysis and corporate growth evaluations. (Dwivedi, et al., 2023) suggested to assist investors make better judgments about their portfolios, machine learning (ML) models that forecast ESG scores are a very helpful tool. This is because investors may benefit from a tool that has a wide range of alternative data.

Research on identifying whether data are ESG-related is currently lacking, as datasets that are relevant to ESG are either too small or do not fall under any of the ESG sub-elements (Pontes, et al., 2022). Finally, (Dwivedi, et al., 2023) discovered that the absence of a common taxonomy for the various ESG variables is a major issue when evaluating ESG data. This implies that data suppliers must choose models and account for variables like risk, industry, and nation that impact how accurately ESG ratings and pillar scores are predicted.

2.7 Theoretical Discussion

Building upon this overview of machine learning's role in advancing corporate sustainability performance evaluation, it becomes essential to explore the underlying

theoretical frameworks that complicate and inform the practice of evaluating corporate sustainability.

Firstly, stakeholders become key forces behind corporate social responsibility when Environmental, Social, and Governance (ESG) efforts are integrated into a company's financial plan. (Diez-Cañamero, et al., 2020) enlightened that ESG score is a crucial evaluation indicator. Additionally, companies create value for a number of stakeholders, such as the government, civil society, workers, and local communities, in addition to their shareholders (Bradford, et al., 2017) ; (Tao, et al., 2020) ; (Garcia-Sanchez, et al., 2014) ; (López-Concepción & Gil-La, 2022). Therefore, stakeholder theory supports the expectation that firms responding effectively to stakeholder demands through ESG initiatives are more likely to demonstrate stronger corporate sustainability performance.

On the other hand, (Jensen & Meckling, 1976) contended that agency theory places more emphasis on ownership structure, particularly how distributed ownership affects the requirement for thorough information disclosure to balance the interests of management and shareholders. Another study by (Rajesh, 2024) observed some insights into strong corporate governance and showed that the main measures of organisations' governance performances were based on the stewardship theory and agency theory. Accordingly, agency theory suggests that stronger governance-related ESG practices should contribute positively to corporate sustainability performance by reducing information asymmetry and improving accountability.

Meanwhile, (Chowdhury, et al., 2023) emphasised that the legitimacy theory depends on the organisation's capacity to meet society expectations and desires. Thus, an organisation aims to acquire or enhance legitimacy by prioritizing societal requirements. Following that, (Drempetic, et al., 2020) backed up the notion by asserting that an investment company's legitimacy with the community is earned once the investment obtains the society's acceptance. Investment firms employ sustainability ratings to show investors that they are a legitimate corporation with moral business practices. Consequently, legitimacy theory provides a rationale for expecting organisations with stronger ESG practices and disclosures to exhibit higher sustainability performance.

In addition, (Chowdhury, et al., 2023) illustrated from the institutional theory that an organisation's adoption of ESG practices is a result of pressure from institutions like autonomous organisations, non-governmental organisations, or the larger social structure, which influences the organisation's existence. The amalgamation of institutional and stakeholder theory elucidates the extensive institutional pressures that compel firms to implement sustainability reporting practices, thereby enhancing the comprehension of the

motivations driving ESG-related disclosure decisions (DiMaggio & Powell, 1983). Subsequently, institutional theory supports the expectation that organisations responding to institutional pressures through ESG practices will demonstrate improved sustainability performance.

Considering businesses deliberately use information distribution to resolve knowledge gaps with external parties, signalling theory emphasises factors including firm size, auditor type, profitability, gearing, and industry developments as vital determinants of disclosure (Spence, 1973). (Diñcer, et al., 2024) indicated that prioritizing reporting along sustainable dimensions is consistent with the conclusions made by the three theories that were discussed: legitimacy, signalling, and stakeholders. The author added that businesses may strategically prioritise their reporting efforts, meet the various needs of stakeholders, demonstrate their commitment to the SDGs, and preserve their legitimacy in a larger social context by knowing how sustainability disclosure criteria relate to one another. From this perspective, sustainability disclosures act as positive market signals that are expected to be reflected in stronger corporate sustainability performance.

Furthermore, (Zhou, et al., 2022) explained how resource-based theory logically explains how ESG performance as a resource can enhance the company's output, result in strong financial performance, and lower the likelihood of environmental mishaps like pollution. Additionally, the resource-based theory highlights that companies should concentrate on generating competitive heterogeneity with the aim to increase their firm performance and value through their sustainability performance (ESG scores) (Xie, et al., 2019). Alas, ESG and competitive advantage have a concave relationship, according to (Bhandari, et al., 2022), who use the resource-based approach and the stakeholder capitalism theory. Accordingly, (Bhandari, et al., 2022) argue that the resource-based view of existing resource base traits for sustainable competitive advantage ignores the critical component of "ESG friendliness" in a resource. Finally, resource-based theory provides the strategic justification for expecting ESG capabilities to contribute positively to long-term corporate sustainability performance.

Collectively, these theories demonstrate how firms implement sustainability practices to enhance performance, legitimacy, and competitive advantage as explained in Section 2.3. More importantly, they offer the theoretical foundation for the hypotheses formulated in this study. Theories related to stakeholders, legitimacy, institutions, signaling, agency, and resource-based view indicate that companies implementing stronger sustainability measures are more likely to attain better corporate sustainability results through improved relationships with stakeholders, higher governance quality, enhanced organisational legitimacy, and effective

resource development. Therefore, these theories substantiate H₁, which investigates the connection between ESG KPIs and CSP outcomes. Additionally, they serve as an interpretive framework for comprehending the empirical results, especially in cases where industry differences may indicate variations in stakeholder expectations, institutional pressures, governance frameworks, and organisational resources. Although the theories clarify the anticipated relationship between ESG KPIs and CSP, H₂ takes a methodological approach by investigating if machine learning models can effectively forecast corporate sustainability performance based on ESG-related metrics.

2.8 Empirical Foundation

Having established the theoretical foundations that explain why firms adopt ESG practices and how these practices are expected to influence CSP, this section reviews empirical studies that have tested these theoretical propositions using statistical and machine learning approaches. While the theories explain the conceptual drivers of ESG adoption, the empirical literature demonstrates how these relationships have been operationalised, measured, and evaluated across different organisational and industry contexts. Consequently, the empirical evidence provides the methodological and analytical foundation for the hypotheses examined in this study.

Following this, summarisation of heavily used articles including the gap, methodology to address the gaps and findings are discussed.

Area	Articles	Methodology/Approach	Identified Gap
Predictive Modelling of ESG/CSP	(Dwivedi, et al., 2023); (Chowdhury, et al., 2023); (Cini & Ferrari, 2024)	Machine learning models (Random Forest, Gradient Boosting, Artificial Neural Network, Support Vector Machine; cross-validation; classification/ regression	Heavy reliance on ESG scores; limited use of operational KPIs
ESG Rating Construction & Measurement	(Berg, et al., 2022)	Correlation, fixed-effects regression, taxonomy harmonisation	Focus on rating divergence, not firm

			sustainability performance
ESG KPI-Performance Relationship	(Subramaniam, et al., 2024); (Saydam, et al., 2024)	Machine learning and regression; forecasting/predictive models	Limited integration of operational KPI measurement
Sustainability Disclosure & SDG Alignment	(Diñcer, et al., 2024); (Pizzi, et al., 2020); (Izzo, et al., 2020)	Content Analysis; Ordinary Least Squares (OLS); Decision-Making Trial and Evaluation Laboratory (DEMATEL)	Symbolic disclosure; weak link to measurable outcomes
Methodological Foundation for ESG Analysis	(D'Amato, et al., 2021)	Random Forest regression and classification; temporal dynamic modelling; feature importance analysis; financial-based predictors	Heavy reliance on financial balance sheet variables; limited integration of operational ESG KPIs or sustainability initiative data

Table 2 Summary of heavily used articles

Overall, the empirical literature demonstrates that ESG initiatives, governance practices, sustainability disclosures, and stakeholder engagement are associated with corporate sustainability performance, although the strength and consistency of these relationships vary across organisational and industry contexts. Nevertheless, previous studies have predominantly relied on aggregated ESG ratings, financial indicators, or disclosure-based measures, with relatively limited attention given to operational ESG KPIs and their predictive capability. Consequently, this study extends the existing literature by integrating operational ESG KPIs with meta-regression, machine learning, and document contextual analysis to evaluate both the explanatory relationships and predictive capability of ESG initiatives in influencing corporate sustainability performance.

2.9 Conceptual Framework

Drawing upon the theoretical perspectives discussed in Section 2.7 and the empirical evidence reviewed in Section 2.8, the conceptual framework integrates the explanatory and predictive dimensions of this study. The theoretical perspectives provide the conceptual

rationale for expecting ESG KPIs to influence CSP, while the empirical literature informs the operationalisation of ESG KPIs, predictive modelling techniques, and the measurement of CSP. These elements are synthesised into the conceptual framework presented below.

Furthermore, as derived from the GRI and/or SASB frameworks, ESG KPIs operationalise corporate sustainability processes into quantifiable indicators disclosed in corporate sustainability reports. These indicators operationalise key aspects of firms' ESG practices and provide the empirical basis for examining the relationship between sustainability initiatives and corporate sustainability performance, while also serving as predictive inputs for forecasting ESG ratings.

Moreover, ESG KPIs serve as the independent variables in this study, while ESG ratings obtained from Refinitiv (LSEG) represent the dependent variable and proxy for CSP. As a standardised proxy for corporate sustainability performance, these ratings provide the basis for evaluating the relationship between ESG KPIs and CSP. ESG KPIs are conceptualised as explanatory variables for examining their relationship with ESG ratings and as predictive inputs for forecasting variations in ESG ratings over time. The predictive capability of the models is assessed using standard accuracy metrics, including root mean squared error (RMSE), mean absolute error (MAE), and the coefficient of determination (R^2). These metrics are not treated as dependent variables; rather, they are used to assess the predictive accuracy and robustness of the models in estimating corporate sustainability performance trajectories. By integrating explanatory and predictive perspectives, the framework enables both the identification of influential ESG KPIs associated with CSP and the evaluation of their predictive capability for forecasting ESG ratings.

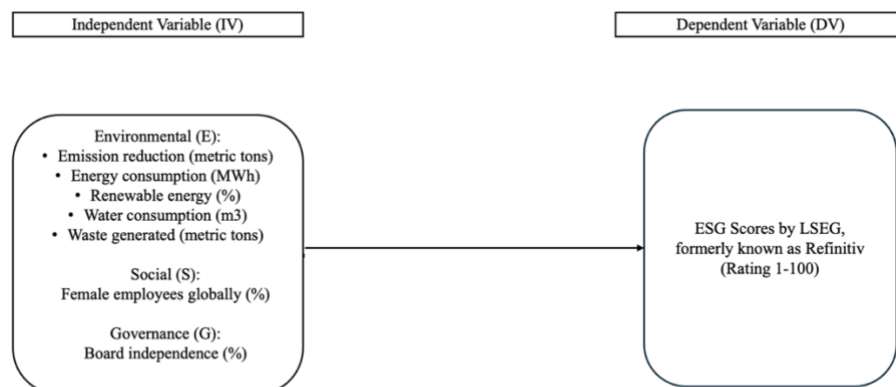


Figure 2 Proposed conceptual framework of this study

Lastly, through the combination of explanatory and predictive dimensions, this integrated framework provides a thorough approach to assessing the effects of ESG activities and determining the best forecasting models, which is in line with the study's goals and premises.

a. Framework Relevance to Hypotheses

The conceptual framework informs the development and testing of the study's hypotheses by specifying the directional relationship between environmental, social, and governance (ESG) key performance indicators (KPIs) and corporate sustainability performance, as measured by ESG ratings. Based on the framework, the hypotheses are formulated to examine whether variations in ESG KPIs are associated with corresponding changes in ESG ratings, thereby testing the explanatory influence of ESG practices on observed corporate sustainability performance.

In addition, the framework supports hypotheses related to predictive analysis by positioning ESG KPIs as predictive inputs for forecasting ESG ratings over time. These hypotheses assess the extent to which ESG KPIs can reliably predict sustainability performance trajectories over time. By linking ESG KPIs to both observed and predicted ESG ratings, the framework ensures that the hypotheses are empirically tested through both explanatory relationships and predictive accuracy, consistent with the study's objectives.

H₁: ESG KPIs have a positive relationship with corporate sustainability performance.

This hypothesis is rooted in the explanatory dimension of the framework. ESG KPIs covering environmental (e.g., emissions, energy, water, waste), social (e.g., diversity), and governance (e.g., board independence) are expected to contribute significantly to improved sustainability performance. By adopting recognised reporting standards such as GRI and SASB, the framework enables the consistent measurement of ESG initiatives across multinational corporations. The alignment with standardised indicators allows for robust cross-company and cross-industry comparisons. Testing H₁ through this framework ensures that the empirical analysis directly evaluates whether corporate sustainability initiatives, when systematically quantified, correlate with higher ESG ratings from reputable sources such as Refinitiv (LSEG). Thus, the framework operationalises the theoretical expectation that stronger ESG practices contribute to superior CSP, enabling this relationship to be empirically tested.

H₂: Machine learning models can accurately predict corporate sustainability performance as proxied by ESG ratings

As for the second hypothesis, it corresponds to the predictive dimension of the framework. While H_1 focuses on explaining current relationships, H_2 extends the analysis to the forecasting of sustainability trajectories. The predictive dimension of the framework incorporates machine learning models including Random Forest, XGBoost, LASSO regression, Decision Tree, and Support Vector Regression (SVR), with performance assessed using RMSE, MAE, and R^2 . By embedding these models, the framework enables the systematic comparison of predictive capabilities, addressing the research gap where traditional regression techniques have dominated prior studies. Testing H_2 evaluates the capability of machine learning models to accurately forecast ESG ratings using the selected ESG KPIs as predictive inputs. This extends the explanatory analysis by assessing whether ESG-related information can reliably predict corporate sustainability performance over time.

By aligning H_1 and H_2 with explanatory and predictive dimensions, respectively, the framework bridges the gap between ESG disclosure and measurable outcomes. The explanatory pathway examines whether corporate sustainability initiatives are associated with higher ESG ratings, while the predictive pathway evaluates the capability of machine learning models to forecast ESG ratings over time. Together, these hypotheses ensure that the study addresses both the current and future dimensions of sustainability, reinforcing the framework's relevance to advancing research and practice in corporate sustainability.

2.9.1 Alignment of Research Objectives, Research Questions and Hypotheses

Table 1 shows that Research Questions 1 and 3 collectively address Research Objective 1 and hypothesis 1 (H_1) by exploring the relationship between sustainability initiatives, as measured by ESG KPIs, and CSP, as well as identifying the ESG KPIs with the strongest associations to CSP. Research Questions 2 and 4 address Research Objective 2 and hypothesis 2 (H_2) by assessing the predictive capabilities, robustness, and comparative performance of machine learning models for anticipating sustainability trajectories. As a result, the four research questions give a detailed operationalisation of the two main hypotheses investigated in this study.

Research Objective	Research Questions	Hypothesis Correspondence
RO1: To assess how sustainability initiatives affect	RQ1: How are MNCs sustainability initiatives, as operationalised through	H_1

CSP in MNCs by utilising a meta-regression analytic approach to examine the connections between company-level ESG KPIs and ESG ratings from third-party data provider.	ESG KPIs, associated to CSP as reflected in LSEG ESG ratings?	
	RQ3: Which ESG KPIs show the strongest associations with corporate sustainability performance across international corporations?	H ₁
RO2: To evaluate machine learning-based predictive models' accuracy, robustness, and generalisability in predicting MNCs' sustainability trajectories by using suitable statistical methods and performance validation measures.	RQ2: To what extent can machine learning-based predictive models accurately forecast sustainability trajectories for MNCs, and how reliable and generalisable are these forecasts across different sectors?	H ₂
	RQ4: Which machine learning approaches achieve the highest predictive accuracy and robustness when forecasting corporate sustainability performance using ESG KPIs?	H ₂

Table 3 Alignment of Research Objectives, Research Questions and Hypotheses

2.10 Chapter Summary

In summary, this chapter has demonstrated that strong sustainability initiatives are linked to improved corporate performance, reputation, and stakeholder trust, yet the field faces ongoing methodological and reporting challenges. The discussion highlighted that the quality of sustainability disclosures, driven by regulatory environments, competitive strategies, and stakeholder expectations, remains highly variable despite the proliferation of frameworks like GRI and SASB. Furthermore, ESG ratings, while valuable, are hampered by inconsistencies and data limitations, reinforcing the need for advanced machine learning techniques that can deliver deeper and more reliable analysis. By integrating theoretical perspectives such as stakeholder, legitimacy, and agency theories, the chapter underscores the importance of both innovation and transparency in sustainability assessment, ultimately suggesting that meaningful progress lies in the thoughtful alignment of standards, rigorous analytics, and responsive engagement with global sustainability goals.

CHAPTER 3

Data Collection & Methodology

3.1 Introduction

Building upon the insights established in Chapter 2, this chapter delineates the research methodology employed to examine the correlation between corporate sustainability initiatives and corporate sustainability performance, focusing specifically on ESG dimensions and the utilisation of machine learning techniques. Given the gaps identified in the literature, such as inconsistencies in sustainability reporting frameworks, limitations in the reliability of ESG ratings, and the underutilisation of advanced analytics, this study adopts an *empirical meta-regression approach* rather than a traditional literature-based synthesis. Specifically, the analysis aggregates and examines ESG KPIs from multiple MNCs across a seven-year period (2017–2023).

Additionally, unlike conventional meta-regression which synthesises effect sizes derived from independent published studies, this study applies meta-regression principles to firm-level ESG data. Each multinational corporation is treated as an individual analytical unit from which correlation coefficients between ESG KPIs and ESG ratings are estimated. These correlation coefficients are subsequently synthesised to evaluate the overall relationship between ESG KPIs and corporate sustainability performance while accounting for between-company heterogeneity. Accordingly, the term empirical meta-regression is used to reflect the application of meta-analytic techniques to internally derived company-level effect estimates rather than effect sizes extracted from prior literature.

3.2 Research Design

This study employs a quantitative research strategy that combines explanatory and predictive methodologies to analyse the correlation between ESG KPIs and corporate sustainability performance. Therefore, to determine which ESG KPIs have the greatest impact, the explanatory approach applies empirical meta-regression analysis to synthesise company-level correlation estimates and examine the relationship between ESG KPIs and ESG ratings. At the same time, the predictive approach evaluates how well ESG KPIs can predict corporate sustainability trajectories using machine learning models such as Random Forest, XGBoost, LASSO regression, Decision Tree, and Support Vector Regression (SVR). This integrated approach guarantees a thorough examination of both theoretical connections and actual

predictive efficacy, addressing deficiencies noted in the literature concerning the dependability of ESG ratings, discrepancies in reporting systems, and the restricted application of advanced analytics.

Additionally, R software serves as the primary analytical tool for this research due to its strong capabilities in statistical computing, data visualisation, and machine learning integration. Moreover, R is an open-source programming environment that offers a versatile and repeatable framework for managing big ESG datasets, carrying out intricate meta-analytic synthesis based on company-level correlation estimates, and effectively creating prediction models. Its vast library ecosystem, which includes XGBoost for predictive modelling, Random Forest, and metafor for meta-analysis and caret, provides robust data analysis and guarantees precision and transparency in statistical results. On that note, R's flexibility makes it easy to combine explanatory and predictive techniques, which makes it ideal for sustainability studies that call for both sophisticated forecasting and rigorous inferential testing.

The application of meta-regression and predictive modelling in sustainability research is supported by prior works (Chowdhury, et al., 2023); (Suprihadi & Danila, 2024); (Ali, et al., 2024) which highlight the increasing use of firm-level ESG data to derive cross-sectional insights and forecast sustainability trajectories. Building upon this foundation, the present study extends existing methods by integrating meta-regression principles with predictive machine learning models to evaluate both explanatory and predictive dimensions of corporate sustainability performance.

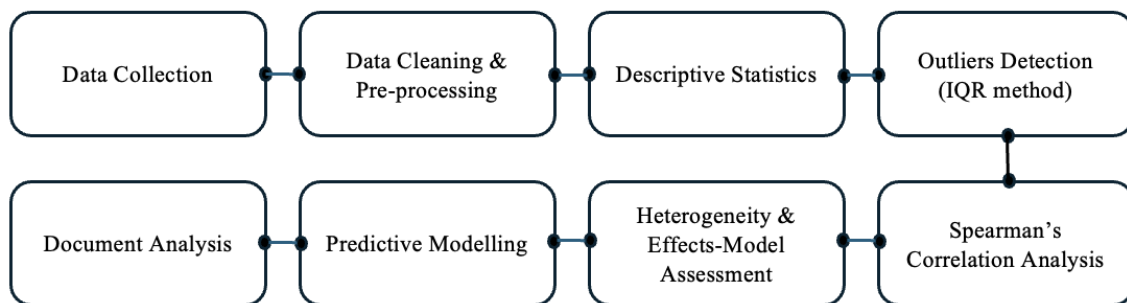


Figure 3 Research design structure

a. Data Collection

i. Sample Population

First, with the objective to improve the generalisability of the results, the sample population for this study consists of MNCs that are listed in the Fortune Global 500 (FG500)

and the Dow Jones Industrial Average (DJIA) that represent a variety of industries and sectors. Accordingly, a purposive sampling strategy was adopted, whereby companies were deliberately selected based on predefined inclusion criteria, including consistent ESG KPI disclosures, the availability of LSEG ESG ratings, and representation across multiple industry sectors. Although the sample is not intended to be statistically representative of all MNCs, it was designed to provide broad sectoral representation and enable meaningful cross-sector comparisons. Two stages of data gathering were carried out: the first phase concentrated on DJIA enterprises, while the second phase broadened to include FG500 companies. ESG KPI information for DJIA companies was gathered in the first phase between March and April. Only 10 firms from the consumer staples/discretionary, financial, IT, industrial, and healthcare sectors consistently reported the necessary ESG KPI data from 2017 to 2023, even though the DJIA has 30 listed companies. However, The Coca-Cola Company was later excluded due to the absence of reported ESG ratings from LSEG starting in 2022. After it was determined that just 70 sample observations were provided by DJIA firms alone, the second round of data gathering was conducted between August and September. Additional samples were taken from the FG500 to bolster the dataset for reliable machine learning analysis. The selection process began with identifying companies that had been awarded consecutively from 2017 to 2023. Out of 500 companies, 361 met this criterion. From these, 192 companies were shortlisted based on their alignment with the required sectors. After further screening of sustainability reports, 15 companies were finalized for inclusion.

According to the availability of annual sustainability reports, full ESG KPI disclosures from 2017–2023, and matching ESG ratings from Refinitiv (LSEG) for the same time frame, companies were chosen. All sampled companies were guaranteed to offer adequate and comparable data for meta-regression analysis and predictive modelling by these inclusion criteria, whereas organisations with inconsistent or inadequate ESG reporting were eliminated by these exclusion criteria. This carefully defined sampling approach enables a robust statistical analysis, and a comprehensive evaluation of sustainability practices are clustered by sector.

Accordingly, a purposive sampling strategy was adopted, whereby companies were deliberately selected based on predefined inclusion criteria, including consistent ESG KPI disclosures, availability of LSEG ESG ratings, and representation across multiple industry sectors. Although the sample is not intended to be statistically representative of all

multinational corporations, it was designed to provide broad sectoral representation and enable meaningful cross-sector comparisons.

The selected companies and their respective sectors are listed in Table 2.1 as follows:

	Sector	Companies
1.	Industrials	3M Company Caterpillar Inc. Hitachi Siemens Vinci
2.	Healthcare	Amgen Merck and Co. UnitedHealth Group AbbVie Novartis
3.	Financials	Goldman Sachs American Express Allianz Santander MetLife MS&AD Insurance
4.	IT	NVIDIA Corp. Compal Electronics Google (parent company: Alphabet Inc.) Intel Samsung Taiwan Semiconductor
5.	Consumer Goods (Discretionary)	Nike Nissan Motor

Table 4 List of selected companies and its business sector

ii. Variables & Measurements

Essentially, the secondary data collection involves the manual extraction of ESG KPIs from sustainability reports, ESG datebooks, annual reports, and proxy statements of the sampled companies for the period 2017 to 2023. These indicators, which are the independent variables, are in line with the Sustainability Accounting Standards Board (SASB) and Global Reporting Initiative (GRI) frameworks and concentrate on the environmental, social, and governance (ESG) aspects.

At the early stage of this research, a broader set of variables was considered within each ESG dimension. However, sustainability reports do not consistently disclose the same types of variables across companies due to differences in business nature, methodological approaches, and levels of engagement with sustainability reporting requirements. For instance, the proportion of female employees in management (%) is a social KPI that is not commonly reported across firms. As a result, the variable is removed so that research can move forward.

In contrast to the governance dimension, proxy statements and governance disclosures predominantly contain qualitative information. As a result, the percentage of independent board members was selected as a governance KPI, as it is a measurable and comparable indicator. A score of 100% board independence indicates that all board members are independent, which may reduce potential conflicts of interest within the company.

The unit of analysis comprises the following components:

Environmental KPIs

- Emission reduction (metric tons): Measures a company's efforts to reduce greenhouse gas (GHG) emissions through initiatives such as energy efficiency improvements, renewable energy adoption, and carbon capture technologies. Emissions are classified under Scopes 1, 2, and 3, and aligned with the Science Based Targets initiative (SBTi) framework.
- Energy consumption (MWh): Denotes the total energy used, measured in megawatt-hours, reflecting operational efficiency and energy management practices.
- Renewable energy (%): Represents the proportion of total energy derived from renewable sources such as solar, wind, and hydropower.

- Water consumption (m³): Measures the total volume of water used in operations, serving as an indicator of resource management and conservation efforts.
- Waste management (metric tons): Refers to the total waste generated and the extent of recycling, recovery, or safe disposal practices implemented by the company.

Social KPIs

- Female employees globally (%): Represents the proportion of female employees within the company's total global workforce, indicating gender diversity and inclusion initiatives.

Governance KPIs

- Independent board members (%): Indicates the proportion of board members who are independent of company management, serving as a measure of governance transparency and accountability.

Next, the ESG ratings from Refinitiv (LSEG) represented the dependent variable for company sustainability performance. Upon request, the University of Strathclyde's Department of Accounting and Finance supplied this information, which comprises the overall ESG scores for the chosen businesses between 2017 and 2023. Although the LSEG ESG Rating is based on corporate sustainability disclosures; however, this study reduces potential construct overlap by choosing a limited set of seven independently derived ESG KPIs rather than replicating the complete LSEG rating methodology. The LSEG ESG Rating is determined through numerous underlying indicators categorised across various environmental, social, and governance domains, along with unique weighting and normalisation processes. In contrast, this research evaluates whether a small selection of operational ESG KPIs, chosen for their reporting consistency and theoretical significance, correlates with overall corporate sustainability performance as indicated by the LSEG ESG Rating. Therefore, the independent variables do not recreate the dependent variable but instead explore to what degree the selected sustainability initiatives account for variations in a wider external ESG perspective.

Furthermore, there were missing data for some companies during the data collection process. The missing data were from Google particularly the social KPI and for Taiwan

Semiconductor, there were no renewable energy use (%) reported in the corporate sustainability report. Fortunately, these missing data were found from a data provider platform Statista with the reported sources from the companies respectively. Therefore, these data were extracted and collected to replace the missing data required from sustainability reporting. Consequently, Figure 3 shows the distribution of Google employees worldwide from 2014 to 2024 while Figure 4 shows the share of renewable energy use of Taiwan Semiconductor from 2015 to 2024.

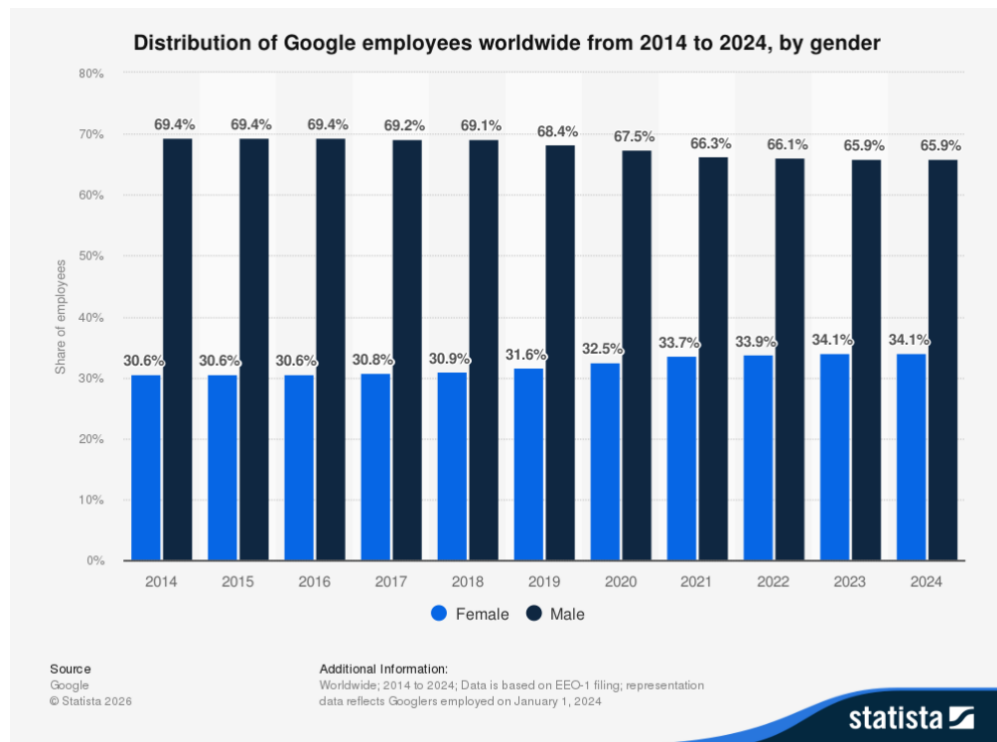


Figure 4 Distribution of Google employees worldwide from 2014 to 2024 by gender
(source: <https://www.statista.com/statistics/311800/google-employee-gender-global/>)

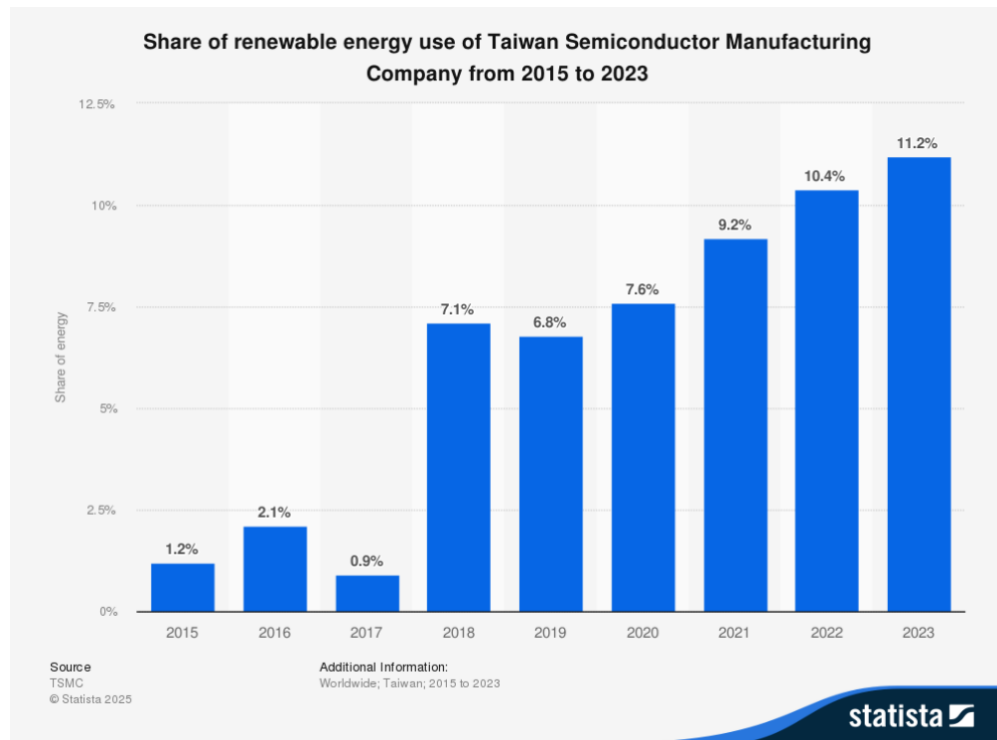


Figure 5 Share of renewable energy use of Taiwan Semiconductor from 2015 to 2024

(source: <https://www.statista.com/statistics/1178867/taiwan-semiconductor-manufacturing-company-share-of-renewable-energy-use/>)

Lastly, the raw ESG dataset was collected in Microsoft Excel, and the data is formatted with no decimal points to maintain data consistency before performing the data cleaning and pre-processing.

b. Data Cleaning & Pre-Processing

Data pre-processing was performed to guarantee the dataset's reliability, consistency, and analytical robustness prior to executing statistical and predictive analyses. Moreover, systematic data-cleaning procedure was put in place using R software since ESG data collected from sustainability reports may contain missing data due to publication faulty, different reporting formats, and measurement differences between companies.

- Handling Missing Value

The initial step was to find and eliminate any missing values from all the variables. Missing value counts were analysed for every column using the `colSums(is.na(df))` method. The dataset was filtered out of companies who have insufficient information for any of the ESG KPIs from 2017 to 2023. By ensuring that all ensuing analyses were founded on comprehensive

and comparable observations, this method avoided the possibility of skewed correlation or predictive values resulting from imputation or inconsistent reporting.

- Remove Companies with Missing Value

Companies who did not provide all their ESG information during the observation period were eliminated to improve internal validity. By ensuring that every company included in the sample had access to a complete seven-year dataset, this step made it possible to evaluate ESG performance trajectories longitudinally.

- Renaming Column Names

For uniformity in naming across scripts and datasets, column names were manually standardised (for example, Emission.Reduction..Metric.Tons. to Emission_Reduction). Syntax errors were avoided during analysis and repeatability was enhanced by using consistent naming standards.

- Data Type Adjustments

The conversion of all numerical variables (such as emissions, energy, and water) to the proper data format allowed for precise computation of both descriptive and inferential statistics. For the purposes of grouping during meta-regression analysis and visualisation, the Year variable was kept as an integer and the Company as a character type.

- Data Distribution through graphs by Sector

Following cleaning, the dataset was displayed using ggplot2 to create sector-level trend graphs. The 2017–2023 timeframe for each ESG KPI was plotted for companies categorised by sector (e.g., Industrials, Financials, Healthcare). Through visual assessment, sectoral differences in sustainability practices, possible anomalies, and temporal trends were identified. The creation of these plots verified data integrity prior to further research by confirming that data patterns matched anticipated industry activity.

3.3 Methodology

This section describes the hybrid methodological framework that examines the association between ESG KPIs and corporate sustainability performance (CSP) among multinational corporations (MNCs) by combining predictive modelling with meta-analytic

synthesis. Furthermore, statistical accuracy and consistency is guaranteed as quantitative data taken from sustainability reports from 2017 to 2023 was examined using R software. Descriptive statistics, outlier detection, correlation analysis, heterogeneity and effects model assessment, and predictive modelling are all components of the technique, which enables both predictive evaluation of future performance trends and empirical assessment of ESG–CSP correlations. Every step of the analysis is described in depth in the ensuing subsections.

a. Descriptive Statistics

Following typical quantitative research methodologies, descriptive statistics were calculated to summarise the central tendencies and distributional characteristics of each company's ESG KPI and corporate sustainability performance (Chowdhury, et al., 2023). The analysis measured mean, median, standard deviation, minimum, maximum, quartiles (Q1, Q3), and the 95th percentile (P95) to capture both central tendency and dispersion. Next, statistical correctness and reproducibility is sustained as all calculations were carried out using R software. The P95 statistic was especially significant because ESG datasets frequently show right-skewness due to of the predominance of high-performing companies in particular industries (Chowdhury, et al., 2023). For later visualisation and inferential analysis, the descriptive statistics were exported as a CSV file. This first stage laid a strong basis for subsequent predictive modelling by offering a thorough summary of variable dispersion, central tendency, and asymmetry.

b. Outliers Detection (IQR method)

Prior to correlation and prediction studies, the dataset's robustness and reliability were checked by employing the Interquartile Range (IQR) approach to identify any outliers (Uddin, et al., 2024). Especially when working with diverse cross-company variables, this method is in line with accepted procedures in ESG and sustainability performance research. R was used to import the cleaned dataset (`final_ESGdatasector_cleaned.csv`) and use the `dplyr` tool to process it. Type-related discrepancies were avoided by explicitly converting data types to numeric or character representations. The dependent variable (LSEG ESG Score) and each of the ESG KPIs (Emission Reduction, Energy Consumption, Renewable Energy, Water Consumption, Waste Generated, Female Employees (Global), Independent Board) were analysed separately for each of the sampled companies.

Following that, the first (Q1) and third (Q3) quartiles were computed for every variable, and $Q3 - Q1$ was the definition of the IQR. In essence, based on the observations either above $Q3 + 1.5 \times IQR$ or below $Q1 - 1.5 \times IQR$ are identified as possible outliers. In addition, the script also stored contextual information (e.g., whether the minimum or maximum exceeded thresholds) and estimated the deviation magnitude of each extreme value from the computed bounds in addition to flagging. Lastly, an output table was created and exported as `outlier_detection_results.csv`, which contained all the results, including quartiles, IQRs, lower and upper bounds, and descriptive outlier remarks.

Essentially, each flagged observation was contextually evaluated to distinguish between legitimate extreme values and real data anomalies. For instance, sudden emission reductions brought on by technology advancements, instead of immediately eliminating these instances. This well-rounded strategy maintained the dataset's analytical integrity while preserving the authenticity of significant sustainability performance disparities.

c. Spearman's Correlation Analysis

The first hypothesis (H_1), which posits that sustainability initiatives, operationalised through ESG KPIs, positively influence corporate sustainability performance in MNCs, was initially examined using Spearman's rank correlation coefficient (ρ). This non-parametric method was employed to assess the strength and direction of the association between ESG KPIs and corporate sustainability performance prior to further meta-regression analysis. Spearman's correlation was selected due to its suitability for ordinal and non-normally distributed ESG data and its robustness to outliers and non-linear relationships (Liu, et al., 2024).

Pairwise correlations between the dependent variable, the LSEG ESG Score, and the individual ESG KPIs (Emission Reduction, Energy Consumption, Renewable Energy, Water Consumption, Waste Generated, Female Employees (Global), and Independent Board) were calculated for each company in the dataset. The analysis iteratively estimated ρ values and accompanying p-values using R's `cor.test()` function.

Subsequently, 95% confidence intervals were computed using Fisher's z-transformation and then back-transformed to the correlation scale to guarantee the statistical reliability of the estimates. Hence, undefinable correlations are prevented through observations with inadequate variability, where either variable had zero variance were disregarded. Additionally, the script used `tryCatch()` to gracefully manage any missing data or other computational warnings, maintaining legitimate findings for all firms.

For each ESG KPI within each organisation, all correlation results including ρ , p-values, and 95% confidence intervals were combined and exported as `spearman_correlations_with_ci.csv`. The strength and consistency of the ESG–CSP interactions were indicated by the direction and magnitude of ρ . By reducing the impact of data inconsistencies and guaranteeing trustworthy cross-company comparisons, Spearman's non-parametric approach enhanced internal validity in compared to Pearson's correlation.

d. Heterogeneity Testing & Effects Model Assessment

Using the `metafor` package in R, heterogeneity analysis was performed to investigate cross-company differences in the degree of correlation between ESG KPIs and CSP. Spearman correlation coefficients were calculated between the LSEG ESG Score and the chosen ESG KPIs for every organisation. Before meta-analytic estimate, Fisher's z-transformation was implemented for every correlation value to stabilise variances and approximate normalcy.

Following meta-analytic principles, the Cochran's Q statistic, I^2 statistic, and τ^2 (tau-squared) variance component were computed using restricted maximum likelihood (REML) estimation (Ali, et al., 2024). In essence, significant heterogeneity was shown by a statistically significant Q statistic and I^2 values greater than 50%, indicating that sampling error alone could not account for variation in effect sizes. To account for both within- and between-company variance, a random-effects model was utilised in certain situations; in other circumstances, a fixed-effects model was employed.

Consequently, each company's pooled effect size was converted back to the original Spearman correlation coefficient (pooled ρ) from Fisher's z. The dependability of the mean effect sizes was then evaluated by computing 95% confidence intervals. The findings were displayed in a summary table that included information on model selection, pooled correlation estimates, and heterogeneity metrics (Q, I^2 , and τ^2). In an effort to graphically represent the direction and amplitude of ESG–CSP interactions across KPIs, forest plots were also created for each organisation. Lastly, supplemental bar charts gave a clear visual depiction of the overall trends and variability in ESG–CSP links by summarising I^2 heterogeneity levels and pooling correlations across all companies.

e. Predictive Modelling

The second hypothesis H_2 , according to which ESG KPIs can forecast business sustainability outcomes, was addressed using a predictive modelling framework developed

using five supervised machine learning algorithms implemented in R. Decision Tree (DT), Support Vector Regression (SVR), Least Absolute Shrinkage and Selection Operator (LASSO Regression), Random Forest (RF), and Extreme Gradient Boosting (XGBoost) were among the algorithms. Given their combined capacity to represent both linear and intricate non-linear patterns in sustainability data, these algorithms were subsequently selected (Uddin, et al., 2024); (Lee & Kim, 2023); (Hajek, et al., 2024); (Supriyadi & Danila, 2024).

Now, several key steps were followed in the predictive modelling method. The first step was standardising the dataset's ESG-related KPIs (formatting and metrics selection) to guarantee comparability across businesses and time periods. For the reason to retain chronological order and evaluate out-of-sample predictive performance, the dataset was chronologically divided into training (2017–2021) and testing (2022–2023) subsets. Following training on the training subset, the models were verified on the test subset.

After that, the `cv.glmnet()` method was used to train LASSO regression using ten-fold cross-validation to get the ideal regularisation value (λ) that minimises prediction error. Recommendations for similar sustainability analytics applications were followed by applying experimentally obtained default hyperparameters to the other algorithms, Decision Tree, Random Forest, XGBoost, and SVR. For instance, `ntree = 100` and `mtry = 3` for Random Forest; `eta = 0.1` and `max_depth = 3` for XGBoost; `kernel = radial` for SVR; each model's configuration was changed to balance accuracy and computational efficiency, even if thorough grid search tuning was not carried out.

Lastly, the coefficient of determination (R^2), mean absolute error (MAE), and root mean square error (RMSE) were the three main metrics used to assess the model's effectiveness. While lower RMSE and MAE values suggested higher prediction accuracy, higher R^2 values indicated stronger explanatory power. While Random Forest and XGBoost models revealed intricate, non-linear connections among ESG predictors, Decision Tree models provided explicit representation of decision routes for interpretability. By penalising less significant variables, LASSO regression further helped to reduce dimensionality and manage multicollinearity.

All things considered, the multi-model framework offered a thorough analysis of algorithmic efficacy in forecasting corporate sustainability performance. A comparative summary table was created from the findings of each model, allowing for interpretative analysis of predictive strength across models as well as performance benchmarking. This strategy strengthened the analytical basis for assessing sustainability trajectories within multinational corporations by combining predictive analytics and inferential rigor.

3.4 Document Analysis for Contextual Validation of ESG KPIs (Additional Analysis)

This study incorporates a document analysis component to provide contextual justification for the quantitative findings derived from ESG KPIs. As the quantitative analysis relies exclusively on firm-reported ESG data extracted from sustainability reports, it is essential to supplement the statistical results with descriptive, evidence-based insights drawn directly from the original disclosures.

The primary purpose of the document analysis is twofold. First, it serves to validate the reliability and credibility of the extracted ESG KPI values by ensuring that reported numerical changes are supported by verifiable sustainability initiatives, policies, or operational actions disclosed by the companies. Second, it provides contextual explanations for variations, anomalies, or abrupt changes in ESG KPIs, which may arise due to operational adjustments, external shocks, regulatory developments, or firm-specific strategic decisions.

Sustainability reports and publicly available corporate disclosures for each multinational corporation (MNC) in the sample were systematically reviewed for the period covering 2017 to 2023. The analysis focused on identifying narrative disclosures related to environmental, social, and governance initiatives that corresponded to the ESG KPIs used in the quantitative dataset. Particular attention was given to disclosures describing sustainability programmes, policy commitments, governance structures, investments, operational changes, and strategic initiatives that could plausibly explain observed KPI trends.

To ensure consistency and transparency, the document analysis followed a structured review process. Relevant sections of sustainability reports, including environmental performance, social responsibility, governance practices, and strategic sustainability commitments were examined annually for each company. These disclosures were then compared against year-to-year changes in ESG KPIs to assess whether numerical trends aligned with reported corporate actions. This approach ensured that the dataset relied on substantiated disclosures rather than proxy measures or secondary ESG ratings.

The document analysis also plays a critical role in interpreting years where the quantitative data exhibit notable fluctuations. For instance, during periods affected by external disruptions such as the COVID-19 pandemic, changes in ESG KPIs may reflect short-term operational conditions rather than long-term strategic improvements. By incorporating contextual evidence from corporate disclosures, the study distinguishes between KPI changes driven by temporary operational disruptions and those resulting from sustained sustainability strategies.

Furthermore, the document analysis supports the interpretation of descriptive statistics, trend analyses, and correlation results presented in the empirical chapters. By linking ESG KPI movements to documented sustainability initiatives, the study enhances the explanatory depth of the quantitative findings and mitigates the risk of misinterpretation arising from reliance on numerical indicators alone.

Overall, the integration of document analysis strengthens the methodological robustness of the study by ensuring alignment between quantitative ESG data and qualitative corporate disclosures. This contextual justification enables a more accurate assessment of how sustainability initiatives influence corporate sustainability performance and supports a nuanced interpretation of ESG-driven outcomes across multinational corporations.

3.5 Reliability & Validity of Data

The precision, consistency, and believability of the data used in this study were all dependent on validity and reliability. By using consistent processes for data extraction, cleaning, and analysis, reliability was preserved. Consequently, to avoid inconsistencies resulting from third-party data suppliers, all ESG metrics were manually extracted from business sustainability reports. Lastly, R scripts and coding practices were documented and executed twice to ensure that each observation was subjected to the same computation and analytical reasoning, and internal consistency was strengthened with further statistical analysis that validated data repeatability and stability.

Validity guaranteed that the measures used in the study appropriately represented the constructs being examined. The chosen ESG KPIs were aligned with recognised frameworks, such as the Dow Jones Sustainability Index (DJSI) and the Global Reporting Initiative (GRI), to attain construct validity. Furthermore, internal validity was further strengthened through appropriate statistical analyses, including meta-regression analysis and Spearman's correlation, which provided evidence that the observed associations were statistically supported. Next, including international companies from a variety of industries resulted the external validity reinforcement and the findings' applicability to a larger corporate setting was improved. Overall, by taking these steps together, the research's quantitative and qualitative components were guaranteed to maintain high methodological rigor.

3.6 Ethical Consideration

All facets of this investigation were directed by ethical considerations to guarantee openness, equity, and adherence to professional and academic norms. There were no direct human engagement or sensitive data involved because the study only used publicly available data. As a result, formal institutional review board ethical clearance was no longer required. However, moral values like objectivity, honesty, and integrity were strictly upheld. Regardless of whether the results confirmed or refuted the assumptions, they were reported objectively, and data were managed carefully to avoid selective reporting or misrepresentation.

Additionally, the study followed the guidelines for academic integrity and correct credit, making sure that all secondary materials, frameworks, and tools were properly referenced. The study ensured that the research procedure adhered to the highest standards of ethical behaviour by complying with the University's Research Ethics Policy and the European Code of behaviour for Research Integrity (ALLEA, 2017).

3.7 Limitations

Several limitations are noted, even though this study used rigorous analytical and methodological techniques. The main restriction is to the uniformity and accessibility of ESG data across companies and reporting periods. Ensuring full comparability was made difficult by variations in reporting techniques, data granularity, and disclosure criteria. Despite all efforts to standardise data through cleaning and verification, bias in reporting may still exist to some extent. Additionally, a relatively short observation period of sustainable progress is captured by the study's temporal scope, which runs from 2017 to 2023. The results may not accurately reflect the long-term effects of sustainability and corporate social responsibility programs.

Finally, the qualitative component, which has a lot of interpretive value but was not defined for use into statistical models, is another drawback. Thematic findings are therefore more often used as contextual reinforcement than as quantifiable factors. Additionally, machine learning-based predictive models may not translate well to smaller businesses or circumstances peculiar to a given location because they are based on the traits of huge international organisations. Finally, self-presentation bias may arise from voluntary ESG reporting since businesses may prioritise positive results over negative ones. Recognising these restrictions enables a clear interpretation of the findings and lays the groundwork for

future advancements in the field.

3.8 Chapter Summary

The analytical framework for investigating the connection among corporate social responsibility, sustainability initiatives, and corporate sustainability performance has been introduced in this chapter. The research problem was thoroughly understood because to the mixed-methods design, which combined quantitative and qualitative techniques. Therefore, empirical proof is shown through the connections between sustainability performance and ESG KPIs, the quantitative component comprised descriptive statistics, correlation analysis, empirical meta-regression analysis, and predictive modelling. The contextual document analysis, on the other hand, provided interpretive information about how corporations convey their sustainability pledges.

The study maintained methodological rigor and credibility by paying close attention to validity, reliability, and ethical issues. Despite acknowledged limitations, the analytical methodology effectively addressed the research's two hypotheses: i) that ESG KPIs may forecast future sustainability trajectories ii) and that they have a significant correlation with corporate sustainability ratings by LSEG. The conclusions drawn from these techniques serve as the basis for the next chapter, which provides a detailed presentation and interpretation of the empirical data.

CHAPTER 4

Data Analysis and Findings

4.1 Introduction

This chapter presents the results obtained from the data analysis procedures outlined in Chapter 3. The findings are organised according to the two main research objectives: first, to examine the relationship between Environmental, Social, and Governance (ESG) key performance indicators (KPIs) and corporate sustainability performance (CSP) across multinational corporations; and second, to evaluate the predictive accuracy of selected machine learning models in forecasting sustainability outcomes using ESG KPIs. The analyses include descriptive statistics, outlier assessments, correlation and meta-regression results, and predictive modelling outputs. Collectively, these findings provide both explanatory and predictive insights into the influence of ESG initiatives on corporate sustainability trajectories.

4.2 Descriptive Statistics

The descriptive statistics for the dataset spanning the years 2017–2023 are shown in this section. Emission Reduction, Energy Consumption, Renewable Energy, Water Consumption, Waste Generated, Female Employees Globally, Independent Board, and the LSEG ESG Score are among the characteristics examined. For every company, descriptive statistics were calculated to shed light on the distribution, dispersion, and central tendency of the data. Each variable's mean, median, minimum, maximum, standard deviation, first and third quartiles (Q1 and Q3), and 95th percentile (P95) values are included in the summary.

The R script (refer Appendix 6) used the dplyr package to automate summary calculations and export the results to a CSV file. This procedure ensures consistency and accuracy in the descriptive computation across multiple firms and years.

4.2.1 Interpretation of Descriptive Results

The following subsections examine these descriptive patterns across sectors to identify emerging trends in environmental, social, and governance practices. This analysis provides a foundation for evaluating the relationship between ESG initiatives and corporate sustainability performance (CSP) with Spearman's correlation analysis.

Essentially, descriptive statistics is interpreted with the following guidance for each variable and described according to sectors:

i) Industrial

In this research, there are 5 companies that are under industrial sectors which namely 3M Company, Caterpillar Inc, Hitachi, Siemens and Vinci. The descriptive statistics are measured through mean, median, min, max, SD, p95, Q1, and Q3 accordingly. In addition, the results are then compared across companies to explore which companies drive the sustainability effort and ESG practices effective and efficiently.

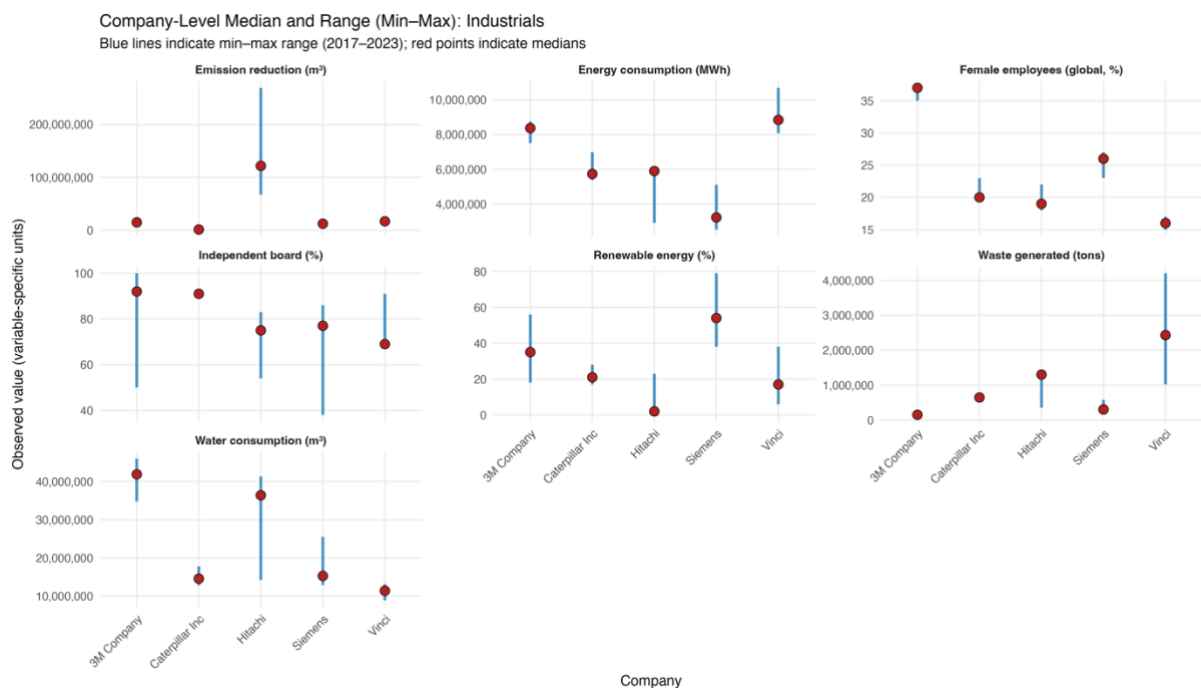


Figure 6 Minimum–maximum range plot with median indicator for Industrial sector

3M Company

The descriptive statistics for 3M Company indicate generally low year-to-year variation across most sustainability indicators between 2017 and 2023, suggesting stable reporting and consistent performance over the observation period.

Emission reduction averaged 15,070,000 and ranged from 13,226,000 to 16,180,000, indicating low variability across years. Energy consumption shows a similar pattern, with a mean of 8,300,000 and a narrow range between 7,510,000 and 8,750,000, reflecting stable annual energy use. Renewable energy consumption exhibits greater dispersion, averaging

38.43 and ranging from 18 to 56, indicating moderate year-to-year variation. Water consumption remained relatively stable, with a mean of 41,700,000 and values spanning from 34,800,000 to 46,000,000. Waste generation was consistent throughout the period, averaging 158,000 and ranging from 147,000 to 177,000, which reflects low variation across years.

In the social dimension, female employee representation averaged 36.29% and varied narrowly between 35% and 37%, indicating a highly stable workforce gender composition.

Greater variability is observed in governance. Board independence averaged 86.14% and ranged from 50% to 100%, indicating substantial variation relative to other indicators. This suggests changes in board composition over time, although no causal inference is drawn from the descriptive results.

Overall, 3M Company demonstrates low variability across most environmental and social indicators, alongside more pronounced variation in renewable energy usage and board independence.

Caterpillar Inc.

Examination of Caterpillar Inc.'s sustainability indicators over the period 2017–2023 reveals relatively stable performance across environmental, social, and governance dimensions, with only limited year-to-year fluctuation observed in most variables.

Over the study period, emission reduction averaged 1,773,428.57, with recorded values ranging from 1,500,000 to 2,260,000, indicating low variability across years. Energy consumption followed a similar pattern, averaging 6,066,944.57 and varying between 5,380,556 and 6,988,889, which reflects moderate but controlled changes over time. Renewable energy usage also remained broadly consistent, with a mean value of 22.14 and observed values spanning from 17 to 28, suggesting limited dispersion in adoption levels. A comparable level of stability is evident in water consumption, which averaged 14,946,968.71 and ranged from 12,870,400 to 17,791,435, indicating modest variation in annual water use. Waste generation likewise remained steady throughout the observation period, with an average of 654,173.14 and values confined to a narrow range between 610,377 and 702,273.

In the social dimension, female employee representation averaged 21.29% and fluctuated only slightly between 20% and 23%, pointing to a stable workforce gender profile over time. Governance indicators exhibit even greater consistency, as board independence averaged 91.29% and varied marginally from 90% to 92% across the study period.

In conclusion, the descriptive evidence indicates low to moderate variability across Caterpillar Inc.'s sustainability indicators between 2017 and 2023, reflecting a broadly consistent sustainability performance and disclosure profile.

Siemens

Siemens AG's sustainability indicators over the period 2017–2023 indicates a generally consistent performance profile across environmental, social, and governance dimensions, although the degree of year-to-year variation differs across individual measures.

Emission reduction averaged 13,663,714.29 during the study period, with values ranging from 11,459,000 to 18,177,000, indicating moderate variation across years. Energy consumption followed a similar pattern, averaging 3,488,170 and ranging between 2,532,499 and 5,111,666, which suggests controlled but noticeable fluctuation over time. Renewable energy adoption recorded a mean of 55.57 and ranged from 38 to 79, reflecting moderate variability in annual uptake rather than a uniform pattern across the observation period. Water consumption averaged 16,627,142.86 and varied between 12,930,000 and 25,520,000, indicating moderate dispersion and year-to-year changes in water use. Waste generation displayed a comparable pattern, with an average of 363,985.71 and observed values spanning from 256,200 to 580,000, suggesting observable variation across years rather than minimal fluctuation.

In the social dimension, female employee representation remained relatively stable, averaging 25.43% and ranging narrowly from 23% to 27%, indicating low variability over the study period. Governance outcomes exhibit greater dispersion, as board independence averaged 72% and ranged from 38% to 86%, indicating substantial variation in board composition across years.

Overall, Siemens AG's descriptive results indicate consistent sustainability reporting between 2017 and 2023, alongside low variability in social indicators and moderate to substantial variation in several environmental and governance measures.

Hitachi

Across the period from 2017 to 2023, Hitachi Ltd.'s sustainability indicators exhibit differing degrees of stability, with several measures showing limited fluctuation while others display substantial year-to-year variation.

Emission reduction recorded an average of 129,530,000 during the observation period, with values spanning from 67,340,000 to 269,240,000. This wide range indicates substantial

variation in annual emission outcomes rather than a tightly clustered performance. Energy consumption, in contrast, remained comparatively stable, averaging 5,185,400 and ranging between 2,924,000 and 6,028,100, which reflects moderate but controlled variation over time. Renewable energy adoption demonstrates the highest degree of volatility among the environmental indicators. With an average value of 6.29 and observed values extending from 0 to 23, the data indicate pronounced year-to-year fluctuation rather than a consistent adoption trajectory. Water consumption averaged 31,417,142.86 and ranged from 14,230,000 to 41,340,000, indicating substantial dispersion in annual water use despite generally continuous reporting. Waste generation shows comparatively lower variability, with an average of 1,129,428.57 and values between 356,000 and 1,384,000, suggesting controlled but observable fluctuation across years.

In the social dimension, female employee representation remained highly stable, averaging 19.29% and varying narrowly between 18% and 22%. Governance outcomes exhibit greater dispersion, as board independence averaged 71.43% and ranged from 54% to 83%, indicating noticeable changes in board composition over the observation period.

In summary, the descriptive evidence for Hitachi Ltd. highlights a combination of stability in social indicators and moderate to substantial variation in environmental and governance measures, particularly emission reduction and renewable energy adoption.

Vinci

Over the period from 2017 to 2023, Vinci SA's sustainability indicators generally exhibit stable patterns, with low year-to-year variation across several environmental, social, and governance measures, alongside more noticeable fluctuation in selected indicators.

Emission reduction averaged 17,702,807.29 and ranged from 16,129,011 to 21,382,281, indicating moderate variation across years. Energy consumption shows a similar profile, with a mean of 9,043,582.29 and values spanning from 8,082,242 to 10,686,843, suggesting relatively stable operational energy use over time. Renewable energy adoption averaged 20.43 and ranged from 6 to 38, reflecting moderate year-to-year variation rather than uniform adoption across the observation period. Water consumption remained relatively consistent, averaging 11,304,272.14 and ranging between 8,914,846 and 13,140,699, which indicates controlled variation across years. Waste generation averaged 2,461,766.14, with observed values between 1,021,735 and 4,205,464, suggesting noticeable but regulated fluctuation over time.

In the social dimension, female employee representation was highly stable, averaging 16% and varying narrowly between 15% and 17%, indicating low variability throughout the study period. Governance indicators show greater dispersion, as board independence averaged 74.43% and ranged from 67% to 91%, indicating observable changes in board composition across years.

Overall, Vinci SA's descriptive results indicate relatively low variability across social indicators and moderate variation in several environmental and governance measures. These findings suggest generally consistent sustainability performance and disclosure practices between 2017 and 2023.

ii) Healthcare

In this research, there are 5 companies that are under healthcare sectors which namely Amgen, Merck & Co., United Health Group, AbbVie, and Novartis. The descriptive statistics are measured through mean, median, min, max, SD, p95, Q1, and Q3 accordingly. In addition, the results are then compared across companies to explore which companies drive the sustainability effort and ESG practices effective and efficiently.

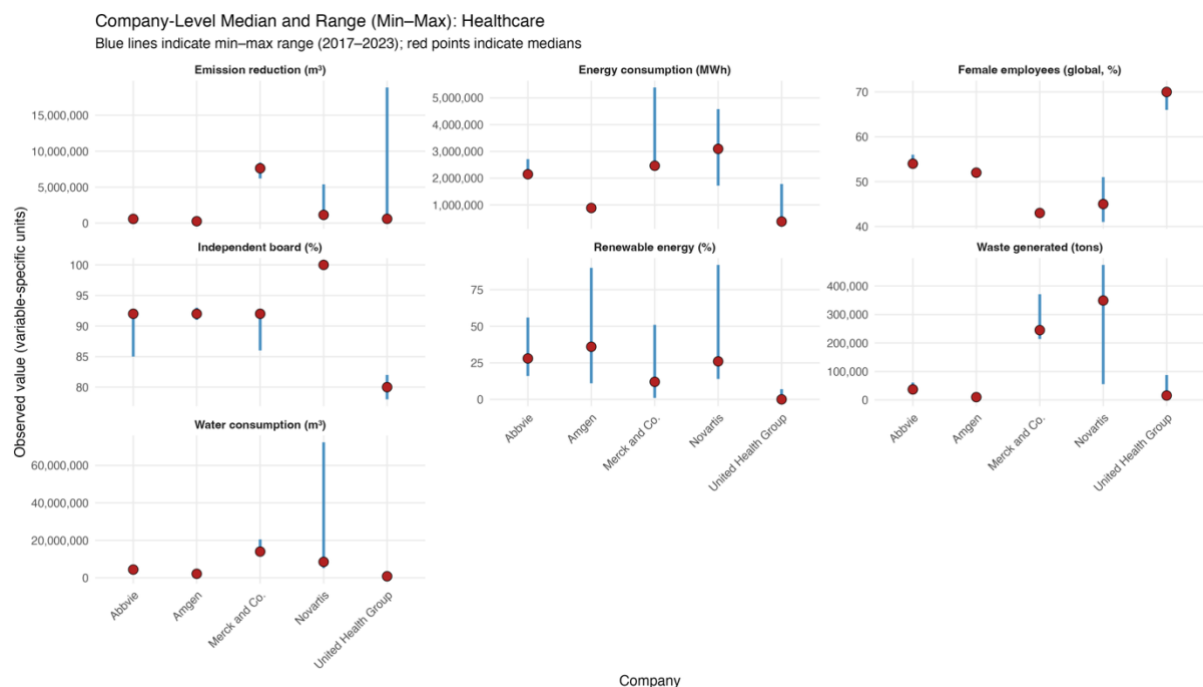


Figure 7 Minimum–maximum range plot with median indicator for Healthcare sector

Amgen

Within the healthcare sector, Amgen's sustainability indicators are characterised by a high degree of consistency across most measured variables, with only limited dispersion observed over the study period.

Environmental indicators largely reflect this stability. Emission reduction recorded an average value of 233,285.71, with observations ranging from 165,000 to 296,000, indicating low year-to-year variation. Energy consumption follows a similarly narrow pattern, averaging 898,499.43 and remaining within a confined range of 833,618 to 1,030,286. Renewable energy usage, however, displays comparatively greater dispersion, with a mean of 40.29 and values spanning from 11 to 90, suggesting moderate variability relative to other environmental measures. Water consumption averaged 2,183,285.71 and varied only modestly between 2,042,000 and 2,355,000, while waste generation averaged 7,709.14 and ranged from 1,982 to 10,289, indicating generally stable outcomes despite some spread in annual values.

Social and governance measures exhibit the greatest consistency. Female employee representation remained tightly clustered around an average of 52%, with values between 51% and 53%, reflecting minimal fluctuation. Board independence also remained highly stable, averaging 91.86% and ranging narrowly from 91% to 93%, indicating limited change in governance composition over time.

Overall, Amgen's descriptive results point to low variability across most sustainability indicators, with moderate dispersion confined primarily to renewable energy usage.

Merck & Co.

Within the healthcare sector, Merck & Co.'s sustainability indicators exhibit generally stable patterns over the period 2017–2023, with most measures showing limited dispersion and consistent year-to-year reporting.

Emission reduction averaged 7,519,128.57 during the observation period, with values ranging from 6,211,000 to 8,418,000, indicating low variability across years. Energy consumption shows a broader spread, averaging 3,643,396.14 and ranging between 2,337,000 and 5,385,149, which reflects moderate variation rather than tightly clustered outcomes. Renewable energy usage averaged 15.14, with observed values spanning from 1 to 51, indicating noticeable year-to-year fluctuation in adoption levels. Water consumption averaged 16,171,428.57 and ranged from 12,100,000 to 20,500,000, suggesting moderate variation in annual water use over the study period. Waste generation remained comparatively stable, with

an average of 264,142.86 and a relatively narrow range between 214,000 and 371,000, indicating limited dispersion across years.

Social and governance indicators demonstrate greater consistency. Female employee representation averaged 43.29% and varied narrowly between 43% and 44%, reflecting minimal year-to-year change. Board independence averaged 91.14% and ranged from 86% to 92%, indicating a stable governance structure with modest variation over time.

Overall, Merck & Co.'s descriptive statistics indicate low variability across social and governance measures and low to moderate variation across environmental indicators. These findings point to generally consistent sustainability performance and disclosure practices between 2017 and 2023. As this analysis is descriptive in nature, no causal interpretation is drawn from the observed patterns.

UnitedHealth Group

The sustainability indicators for UnitedHealth Group display a heterogeneous pattern over the period 2017–2023, with substantial year-to-year variation observed in several environmental measures alongside greater stability in social and governance indicators.

Emission reduction shows pronounced dispersion across the observation period, averaging 6,845,947.71 and ranging widely from 300,960 to 18,855,106. This broad range indicates substantial variability in annual emission outcomes rather than a consistent performance trajectory. Energy consumption exhibits a similar pattern, with a mean of 927,369.29 and values spanning from 365,005 to 1,782,846, reflecting moderate to high variation across years. Renewable energy usage remains low on average, with a mean value of 2 and observed values between 0 and 7, indicating irregular adoption and high relative variability. In contrast, water consumption demonstrates greater consistency, averaging 974,285.71 and ranging from 560,000 to 1,810,000, which suggests controlled variation over time. Waste generation, however, displays considerable dispersion, with an average of 30,939.57 and values extending from 7,398 to 87,452, indicating substantial year-to-year fluctuation in waste outputs.

Social and governance indicators are comparatively stable. Female employee representation averaged 69.29% and varied narrowly between 66% and 71%, indicating low variability across the study period. Similarly, board independence averaged 80.57% and ranged from 78% to 82%, reflecting a stable governance structure with limited annual change.

Overall, UnitedHealth Group's descriptive statistics reveal a mixed sustainability profile, characterised by substantial variability in several environmental indicators and greater consistency in social and governance measures.

AbbVie

Across the 2017–2023 observation period, AbbVie’s sustainability indicators are characterised by a high degree of consistency, with most environmental, social, and governance measures displaying limited year-to-year variation.

Emission reduction averaged 607,835.57 and ranged from 572,287 to 698,900, indicating low variability over time. Energy consumption follows a similar pattern, with an average of 2,252,028.86 and observed values between 1,978,000 and 2,709,962, suggesting controlled and stable energy use across years. Renewable energy adoption shows greater dispersion relative to other environmental indicators, averaging 31.43 and ranging from 16 to 56, which reflects moderate variation in annual adoption levels. Water consumption remained stable throughout the study period, averaging 4,597,142.86 and ranging from 4,060,000 to 5,220,000, indicating low variability in water use. Waste generation also exhibited limited fluctuation, with an average of 43,757.14 and values spanning from 30,200 to 60,900, suggesting generally consistent waste outputs across years.

In the social dimension, female employee representation remained highly stable, averaging 54.29% and varying narrowly between 53% and 56%, which reflects minimal year-to-year change. Governance indicators similarly show strong consistency, as board independence averaged 91% and ranged from 85% to 92%, indicating a stable governance structure over the observation period.

Overall, AbbVie’s descriptive statistics indicate low variability across most sustainability indicators, with moderate variation observed primarily in renewable energy usage. These results suggest consistent sustainability performance and disclosure practices between 2017 and 2023. As this analysis is based solely on descriptive statistics, no causal interpretation is inferred from the observed patterns.

Novartis

Novartis exhibits a mixed sustainability profile over the 2017–2023 period, with several indicators showing stable year-to-year patterns alongside substantial variability in selected environmental measures.

Emission reduction displays pronounced dispersion, averaging 2,696,268.43 with values ranging widely from 519,400 to 5,395,300. This broad range indicates substantial year-to-year variation rather than a consistently clustered performance. Energy consumption, by contrast, appears more stable, with an average of 3,028,010 and observed values between

1,722,222 and 4,577,766, suggesting controlled variation across the study period. Renewable energy adoption averaged 40 and ranged from 14 to 92, indicating noticeable year-to-year fluctuation in adoption levels. Water consumption exhibits the highest degree of variability among the environmental indicators, averaging 17,171,428.57 with values spanning from 5,200,000 to 72,300,000, reflecting substantial dispersion in annual water use. Waste generation shows comparatively lower variability, averaging 268,682.86 and ranging from 55,400 to 474,000, which indicates moderate fluctuation over time.

In the social dimension, female employee representation averaged 46.43% and varied between 41% and 51%, reflecting moderate but stable variation across years. Governance indicators are notably consistent, as board independence remained at 100% throughout the entire observation period, indicating no variability in governance composition.

Overall, Novartis's descriptive statistics indicate relatively stable performance across social and governance measures, alongside moderate to substantial variation in several environmental indicators, particularly emission reduction and water consumption.

iii) Financial

In this research, there are 5 companies that are under financial sectors which namely Goldman Sachs, American Express, Allianz, Santander, MetLife, and MS&AD Insurance. The descriptive statistics are measured through mean, median, min, max, SD, p95, Q1, and Q3 accordingly. In addition, the results are then compared across companies to explore which companies drive the sustainability effort and ESG practices effective and efficiently.

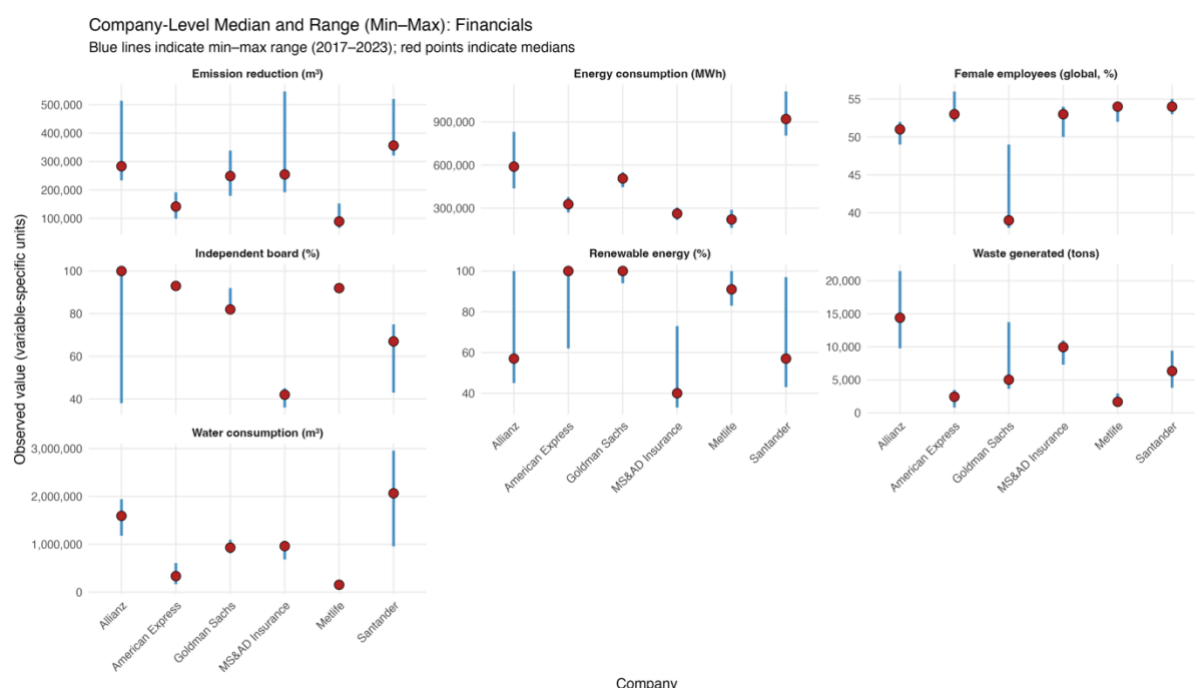


Figure 8 Minimum–maximum range plot with median indicator for Financial sector

Goldman Sachs

The descriptive statistics for Goldman Sachs indicate a generally stable sustainability profile over the 2017–2023 period, with most indicators exhibiting limited year-to-year variation and consistent reporting patterns.

Emission reduction averaged 259,188, with observed values ranging from 179,157 to 338,876, indicating relatively modest dispersion across years. Energy consumption also remained stable, averaging 507,881 and ranging between 445,881 and 549,940, which suggests limited fluctuation in operational energy use. Renewable energy utilisation was consistently high, averaging 98.14%, with values confined to a narrow range between 94% and 100%. Water consumption averaged 945,688 and varied from 810,529 to 1,093,979, indicating controlled variation over time. In contrast, waste generation displayed greater dispersion relative to other indicators, averaging 7,655 and ranging from 3,638 to 13,743, highlighting comparatively higher year-to-year variability.

From a social and governance perspective, female employee representation averaged 40.71%, with values between 38% and 49%, reflecting moderate variation across the observation period. Board independence remained high and stable, averaging 84% and ranging from 82% to 92%, indicating consistent governance structures.

Overall, Goldman Sachs demonstrates low to moderate variability across most environmental, social, and governance indicators, with waste generation standing out as the most variable metric.

American Express

The sustainability indicators for American Express display a largely stable pattern over the 2017–2023 period, with limited year-to-year dispersion across most environmental, social, and governance measures.

Emission reduction averaged 147,909.86 and ranged from 98,879 to 191,725, indicating moderate but controlled variation over time. Energy consumption followed a similarly consistent pattern, with an average of 331,847.86 and observed values between 269,898 and 376,988. Renewable energy utilisation remained high throughout the period, averaging 94.57% and ranging from 62% to 100%, suggesting sustained engagement with renewable sourcing despite some variation across years. Water consumption averaged 387,782.29, with values spanning from 166,171 to 609,310, reflecting moderate variability but no evidence of extreme fluctuations. Waste generation remained comparatively stable, averaging 2,276.71 and ranging between 806 and 3,472, indicating limited dispersion over the observation period.

From a social and governance perspective, female employee representation averaged 53.57% and varied narrowly between 52% and 56%, reflecting a stable workforce gender composition. Board independence remained consistently high, averaging 92.43%, with values confined to a narrow range between 91% and 93%.

Overall, American Express demonstrates low variability across most sustainability indicators, suggesting consistent performance and reliable disclosure between 2017 and 2023.

Allianz

An examination of Allianz SE's descriptive statistics reveals that most sustainability indicators exhibit low to moderate year-to-year variation, with dispersion concentrated in selected dimensions rather than uniformly across measures.

In this context, emission reduction averaged 343,307.71 and ranged from 233,657 to 514,351, reflecting moderate variation that nonetheless remained within a controlled range throughout the study period. A comparable pattern is observed for energy consumption, which averaged 625,857.43 and varied between 437,321 and 831,085, suggesting generally stable operational energy use with limited fluctuation over time. Renewable energy utilisation, while

displaying a wider range of values from 45 to 100 and averaging 66, similarly remained relatively contained across years, indicating an overall consistency in renewable sourcing despite observable annual variation. This pattern of stability extends to water consumption, which averaged 1,567,300.57 and ranged from 1,178,788 to 1,940,030, as well as to waste generation, which averaged 15,358.71 with values between 9,768 and 21,474, both of which show limited dispersion and steady reporting across the observation period. Social performance indicators align with this trend, as female employee representation remained narrowly distributed, averaging 51.14% and varying between 49% and 52%, thereby reflecting a stable workforce gender composition.

In contrast to the relative stability observed across environmental and social dimensions, board independence exhibits substantially greater variation. Averaging 82.29% and spanning a wide range from 38% to 100%, this indicator demonstrates pronounced dispersion and distinguishes governance as the most variable sustainability dimension for Allianz SE over the study period.

Overall, Allianz SE displays relatively low variability across environmental and social indicators, suggesting stable sustainability performance and consistent disclosure practices between 2017 and 2023. Governance outcomes, particularly board independence, stand out as a clear outlier due to their substantially higher dispersion.

Santander

Across environmental, social, and governance dimensions, Banco Santander's descriptive statistics point to generally stable sustainability outcomes from 2017 to 2023, although variability is more pronounced in selected indicators.

Emission reduction averaged 407,855.57, with values ranging from 321,408 to 520,749, suggesting moderate dispersion while remaining within a relatively narrow band across years. A similar pattern is observed for energy consumption, which averaged 961,428.57 and ranged between 805,000 and 1,112,000, indicating stable operational energy use over time. Renewable energy utilisation averaged 65.71 and varied from 43 to 97, reflecting noticeable but contained variation across years rather than extreme fluctuation. Consequently, water consumption showed greater dispersion relative to other environmental indicators, averaging 2,194,007.14 and spanning a wide range from 956,817 to 2,956,420, indicating moderate to substantial year-to-year variation. In contrast, waste generation remained relatively stable, averaging 6,600 and ranging from 3,788 to 9,410, which suggests limited variability and consistent reporting across the study period.

Social performance indicators were notably stable, with female employee representation averaging 54.29% and varying narrowly between 53% and 55%, indicating a consistent workforce gender composition. Governance outcomes exhibited more pronounced variation, as board independence averaged 60.29% and ranged from 43% to 75%, highlighting governance as a comparatively more variable sustainability dimension for the firm.

Overall, Banco Santander demonstrates relatively low variability across most environmental and social indicators, alongside more observable dispersion within governance measures.

MetLife

n assessment of MetLife Inc.'s descriptive results indicates that sustainability performance remained largely consistent over the 2017–2023 period, although variability is more pronounced in certain environmental indicators.

Emission reduction averaged 102,181.43, with values ranging from 66,096 to 152,278, indicating moderate year-to-year variation. Energy consumption followed a similar pattern, averaging 225,189.29 and ranging between 162,112 and 288,457, which suggests relatively stable operational energy use over time. Renewable energy utilisation remained consistently high, averaging 91.43 and varying from 83 to 100, indicating limited dispersion across the observation period. Greater variability is observed in water consumption, which averaged 176,538.29 and ranged from 106,521 to 248,570, reflecting notable year-to-year fluctuation. Waste generation also shows moderate dispersion, averaging 1,987.57 with values between 1,156 and 2,937, indicating variability that is more pronounced than in energy-related indicators.

In contrast, social and governance measures display strong stability. Female employee representation averaged 53.29% and varied narrowly between 52% and 54%, suggesting a consistent workforce gender composition throughout the study period. Governance outcomes were similarly stable, as board independence averaged 92.14% and remained tightly clustered between 92% and 93%, indicating minimal variation in board structure.

Overall, MetLife Inc. demonstrates relatively stable social and governance performance alongside moderate variability in selected environmental indicators, particularly water consumption and emission reduction.

MS&AD Insurance

The descriptive statistics for MS&AD Insurance Group Holdings indicate a largely stable sustainability profile over the 2017–2023 period, with most indicators exhibiting low to moderate year-to-year variation and consistent reporting patterns.

Emission reduction averaged 355,344.29, with observed values ranging from 191,789 to 546,965, indicating noticeable dispersion across years. Energy consumption showed comparatively lower variability, averaging 258,882 and ranging between 217,863 and 305,002, suggesting stable operational energy use throughout the observation period. Renewable energy utilisation averaged 44.86 and varied from 33 to 73, reflecting moderate year-to-year variation without extreme fluctuation. Water consumption averaged 883,428.57, with values spanning from 683,000 to 1,074,000, indicating controlled variation over time. Waste generation displayed a narrower range relative to other environmental indicators, averaging 9,354.43 and ranging between 7,286 and 10,962, which suggests relatively stable waste management performance across years.

Social indicators were notably consistent, as female employee representation averaged 52.43% and varied narrowly between 50% and 54%, reflecting a stable workforce gender composition. Governance outcomes were similarly steady, with board independence averaging 41.71% and ranging from 36% to 45%, indicating limited variation in board structure during the study period.

Overall, MS&AD Insurance Group Holdings demonstrates low to moderate variability across environmental, social, and governance indicators, suggesting consistent sustainability performance and dependable disclosure practices from 2017 to 2023.

iv) IT

In this research, there are 6 companies that are under IT sector which namely NVIDIA Corp., Compal Electronics, Google, Intel, Samsung, and Taiwan Semiconductor. The descriptive statistics are measured through mean, median, min, max, SD, p95, Q1, and Q3 accordingly. In addition, the results are then compared across companies to explore which companies drive the sustainability effort and ESG practices effective and efficiently.

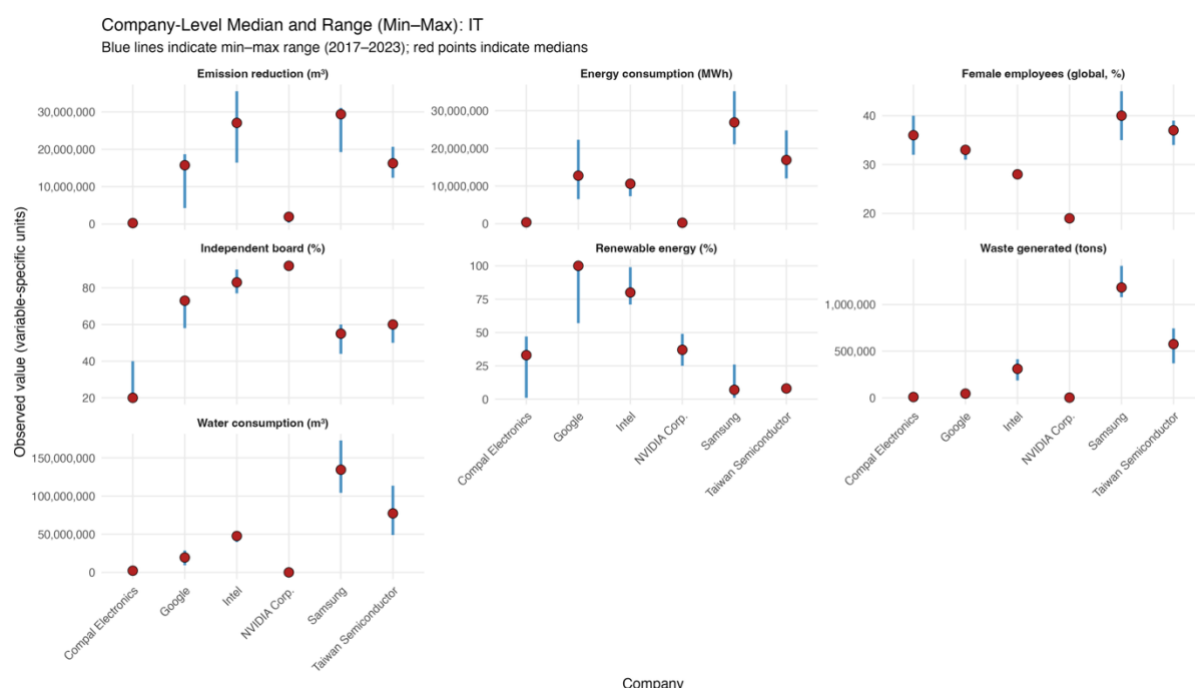


Figure 9 Minimum–Maximum Range Plot with Median Indicator for IT Sector

NVIDIA Corp.

The descriptive statistics for NVIDIA Corporation indicate a mixed sustainability profile over the 2017–2023 period, with relatively stable patterns observed in several indicators alongside substantial year-to-year variation in selected environmental measures.

Emission reduction averaged 1,606,427.43, with values ranging widely from 330,809 to 2,784,299, indicating substantial dispersion across years rather than a consistently clustered performance. Energy consumption exhibited more moderate variation, averaging 281,768.14 and ranging between 127,873 and 496,901, suggesting controlled but noticeable year-to-year fluctuation in energy use. Renewable energy utilisation remained comparatively stable, averaging 36.43 with values spanning from 25 to 49, indicating limited dispersion over the observation period. By contrast, water consumption displayed pronounced variability, averaging 176,105.57 and ranging from 39,506 to 471,777, which reflects substantial year-to-year fluctuation. Waste generation showed similarly high dispersion, with an average of 4,980.29 and values extending from 937 to 18,344, indicating uneven waste outcomes across the study period.

Social and governance indicators were markedly more stable. Female employee representation averaged 19% and varied narrowly between 18% and 20%, indicating minimal year-to-year change. Governance outcomes were also highly consistent, as board independence

averaged 91.71% and remained tightly clustered between 91% and 92%, reflecting a stable governance structure throughout the observation period.

Overall, NVIDIA Corporation's descriptive statistics reveal low variability across social and governance indicators alongside moderate to substantial variation in several environmental measures, particularly water consumption and waste generation.

Compal Electronics

An examination of Compal Electronics' descriptive statistics suggests that sustainability performance remained largely stable between 2017 and 2023, with most indicators exhibiting limited year-to-year variation, alongside wider dispersion in selected measures.

Emission reduction averaged 252,721, with observed values ranging from 214,618 to 300,306, indicating low variability across the study period. Energy consumption followed a similar pattern, averaging 360,582.14 and ranging between 295,651 and 400,016, which suggests relatively stable operational energy use over time. Renewable energy utilisation displayed greater dispersion, averaging 25 and spanning from 1 to 47, reflecting noticeable year-to-year variation compared to other environmental indicators. Water consumption remained comparatively consistent, with an average of 2,326,575.57 and values ranging from 2,019,285 to 2,683,948, indicating controlled variation over time. Waste generation also exhibited limited dispersion, averaging 12,366 and ranging between 7,529 and 21,075, suggesting generally stable waste outputs across years.

Social indicators showed moderate stability, as female employee representation averaged 36.71% and varied between 32% and 40%, indicating some fluctuation but no extreme shifts over the observation period. Governance outcomes exhibited more noticeable variation, with board independence averaging 24.29% and ranging from 20% to 40%, highlighting governance as a comparatively more variable sustainability dimension for the firm.

Overall, Compal Electronics demonstrates low variability across most environmental indicators, alongside moderate dispersion in renewable energy adoption and governance measures.

Google

Across the 2017–2023 period, Google’s sustainability indicators display a mixed pattern, with relatively stable outcomes observed for several measures alongside wider year-to-year dispersion in selected environmental indicators.

Emission reduction averaged 13,289,859.14, with values ranging from 4,261,039 to 18,687,674, indicating substantial variation across years rather than a tightly clustered trend. Energy consumption shows a comparable degree of dispersion, averaging 13,452,152.57 and spanning from 6,513,719 to 22,288,800, which reflects moderate to substantial variability over the observation period. By contrast, renewable energy utilisation remained consistently high, averaging 93.86% and ranging from 57% to 100%, indicating limited dispersion relative to other environmental indicators. Water consumption averaged 18,644,506.71 and ranged between 9,463,525 and 28,758,157, suggesting moderate variability across years. Waste generation, however, remained comparatively stable, averaging 43,746.71 with values between 28,153 and 57,113, indicating limited dispersion and consistent reporting over time.

Social and governance indicators show greater stability. Female employee representation averaged 32.71% and varied narrowly between 31% and 34%, reflecting minimal year-to-year change. Board independence averaged 68.43% and ranged from 58% to 73%, indicating modest variability in governance composition over the study period.

Overall, Google’s descriptive statistics indicate low variability across social indicators and renewable energy utilisation, alongside moderate to substantial dispersion in selected environmental measures, particularly emission reduction, energy consumption, and water use.

Intel

Across environmental, social, and governance dimensions, Intel Corporation exhibits largely stable sustainability outcomes over the 2017–2023 period, with most indicators showing limited year-to-year variation and consistent reporting patterns.

Emission reduction averaged 27,387,914.29, with observed values ranging from 16,425,000 to 35,539,000, indicating moderate dispersion across years while remaining within a controlled range. Energy consumption displayed comparatively lower variability, averaging 9,871,428.57 and ranging between 7,300,000 and 11,600,000, suggesting stable operational energy use throughout the observation period. Renewable energy utilisation remained consistently high, averaging 81.29 and varying from 71 to 99, reflecting limited dispersion over time. Water consumption averaged 46,356,362.86, with values spanning from 39,746,805 to 54,105,863, indicating moderate but controlled variation across years. Waste generation

showed a similar level of stability, averaging 308,385.71 and ranging from 186,800 to 414,000, which suggests generally consistent waste outputs over the study period.

Social indicators were notably stable, as female employee representation averaged 27.71% and varied narrowly between 27% and 28%, indicating minimal year-to-year change. Governance outcomes were similarly consistent, with board independence averaging 84.29% and ranging from 77% to 90%, reflecting limited variability in governance composition.

Overall, Intel Corporation demonstrates low variability across most environmental, social, and governance indicators, alongside moderate dispersion in emission reduction and water consumption.

Samsung

Over the 2017–2023 period, Samsung Electronics' sustainability indicators reflect broadly stable performance, with most measures showing limited year-to-year variation alongside more pronounced dispersion in selected environmental and governance indicators.

Emission reduction averaged 26,780,383.86, with values ranging from 19,249,000 to 31,081,000, indicating moderate dispersion within a controlled range. Energy consumption followed a similar pattern, averaging 27,706,000 and spanning from 21,073,000 to 35,177,000, which suggests generally stable energy use with some year-to-year fluctuation. Renewable energy utilisation exhibited greater variability relative to other energy indicators, averaging 12 and ranging from 1 to 26, reflecting noticeable variation across years. Water consumption remained comparatively consistent, averaging 138,906,571.4 and ranging between 104,253,000 and 172,811,000, indicating controlled variation over time. Waste generation also showed limited dispersion, with an average of 1,207,845.29 and values between 1,078,309 and 1,413,365, suggesting stable waste outputs and consistent reporting.

Social indicators were relatively stable, as female employee representation averaged 40% and varied between 35% and 45%, indicating moderate but contained variation across the study period. Governance outcomes displayed more noticeable dispersion, with board independence averaging 54.29% and ranging from 44% to 60%, highlighting governance as a comparatively more variable sustainability dimension for the firm.

Overall, Samsung Electronics demonstrates low to moderate variability across most environmental and social indicators, alongside greater dispersion in renewable energy utilisation and board independence.

Taiwan Semiconductor

While several sustainability indicators for TSMC exhibit limited year-to-year fluctuation, others display moderate dispersion, indicating a mixed variability profile over the 2017–2023 period.

Emission reduction averaged 16,457,193.14, with observed values ranging from 12,372,108 to 20,678,804, indicating moderate dispersion within a controlled range across years. Energy consumption followed a similar pattern, averaging 17,545,028.57 and spanning from 12,016,200 to 24,775,000, which suggests moderate variability in annual energy use over the study period. Renewable energy utilisation remained comparatively stable, averaging 8.43 and ranging narrowly between 7 and 11, indicating limited dispersion and consistent adoption levels. Water consumption averaged 78,400,000 and ranged from 49,000,000 to 113,600,000, reflecting moderate year-to-year variation relative to other indicators. Waste generation showed lower variability, averaging 547,363.86 with values between 369,745 and 744,019, suggesting generally consistent waste outcomes across the observation period.

Social indicators were notably stable, as female employee representation averaged 36.29% and varied between 34% and 39%, indicating limited fluctuation over time. Governance outcomes were similarly consistent, with board independence averaging 57.43% and ranging from 50% to 60%, reflecting modest variation in governance composition.

Overall, TSMC demonstrates low variability across most sustainability indicators, with moderate dispersion observed primarily in energy and water consumption.

v) Consumer Discretionary

In this research, there are 2 companies that are under consumer discretionary sector which namely Nike Inc. and Nissan Motor. The descriptive statistics are measured through mean, median, min, max, SD, p95, Q1, and Q3 accordingly. In addition, the results are then compared across companies to explore which companies drive the sustainability effort and ESG practices effective and efficiently.

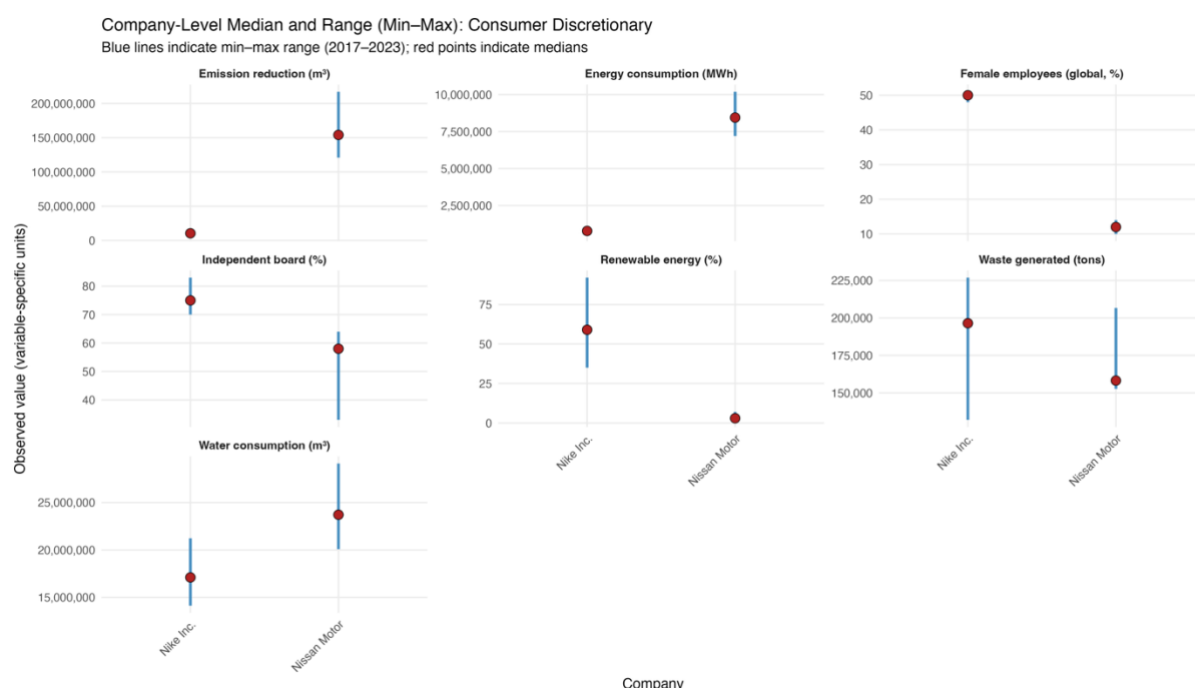


Figure 10 Minimum–maximum range plot with median indicator for Consumer Discretionary sector

Nike

An examination of Nike Inc.’s descriptive statistics suggests that sustainability performance remained broadly stable between 2017 and 2023, with most indicators exhibiting limited year-to-year variation and consistent reporting patterns.

Emission reduction averaged 10,581,729.57, with observed values ranging from 9,537,243 to 11,817,270, indicating low dispersion across the study period. Energy consumption followed a similarly stable pattern, averaging 722,400.86 and ranging between 575,213 and 876,263, which suggests controlled variation in annual energy use. Renewable energy utilisation displayed comparatively greater dispersion, averaging 59.86 and spanning from 35 to 92, reflecting noticeable but contained year-to-year variation. Water consumption remained relatively consistent, averaging 17,475,400 and ranging from 14,121,700 to 21,233,400, indicating moderate but regulated variation over time. Waste generation also exhibited limited dispersion, with an average of 181,069.86 and values between 132,007 and 226,886, suggesting stable waste management outcomes across years.

Social and governance indicators were notably stable. Female employee representation averaged 49.71% and varied narrowly between 48% and 51%, indicating minimal year-to-year change in workforce gender composition. Board independence averaged 76% and ranged from 70% to 83%, reflecting limited variation and a generally stable governance structure throughout the observation period.

Overall, Nike Inc. demonstrates low variability across most environmental, social, and governance indicators, with moderate dispersion observed primarily in renewable energy utilisation and water consumption.

Nissan Motor

Across environmental, social, and governance dimensions, Nissan Motor Co., Ltd. exhibits generally stable sustainability outcomes over the 2017–2023 period, with most indicators showing low to moderate year-to-year variation and consistent reporting patterns.

Emission reduction averaged 163,140,703.6, with observed values ranging from 120,924,692 to 217,021,585, indicating moderate dispersion across years rather than a tightly clustered trend. Energy consumption followed a similar pattern, averaging 8,537,791.14 and ranging between 7,195,408 and 10,189,082, which suggests relatively stable operational energy use with limited fluctuation over time. Renewable energy utilisation remained low in absolute terms but showed limited dispersion, averaging 4 and ranging from 2 to 7, indicating gradual variation across the observation period. Water consumption was comparatively stable, averaging 23,843,714.29 and ranging from 20,090,000 to 29,118,000, which reflects controlled variation in annual water use. Waste generation also exhibited limited dispersion, with an average of 168,022 and observed values between 152,674 and 206,645, suggesting generally consistent waste management outcomes across years.

Social indicators remained stable, as female employee representation averaged 12% and varied between 10% and 14%, indicating limited year-to-year change. Governance outcomes displayed greater dispersion relative to other dimensions, with board independence averaging 52.86% and ranging from 33% to 64%, highlighting governance as a comparatively more variable sustainability indicator for the firm.

Overall, Nissan Motor Co., Ltd. demonstrates low to moderate variability across most environmental and social indicators, alongside more noticeable dispersion in governance measures.

Cross-sector Observations and Summary

This subsection synthesises the descriptive statistical results across sectors to provide a sectoral context for the subsequent Spearman correlation analysis between ESG indicators and corporate sustainability performance (CSP). While the preceding sections focus on within-sector patterns, cross-sector observation enables a broader assessment of how ESG performance characteristics differ across industries with distinct operational and organisational structures.

Overall, environmental KPI exhibit greater dispersion and variability across sectors compared to social and governance KPIs. Variables such as emission reduction, renewable energy adoption, water consumption, and waste generation frequently display skewed distributions and wider ranges, indicating heterogeneous sustainability performance across industries. These patterns suggest that environmental outcomes are more sensitive to sector-specific operational characteristics, scale of activities, and resource intensity. In contrast, social and governance indicators generally demonstrate more stable distributions across sectors, reflecting relatively consistent reporting practices and organisational policies in these dimensions.

Industries characterised by higher operational intensity, including the Industrial and Information Technology sectors, tend to display greater variability in environmental indicators. Within these sectors, renewable energy adoption and resource-related measures often show uneven distributions, suggesting differences in the pace and scope of sustainability integration across firms. Such variation is consistent with the diverse production processes, infrastructure requirements, and investment cycles typically observed in these industries.

By comparison, the financial sector generally exhibits lower variability across several environmental indicators, reflecting a comparatively smaller direct environmental footprint relative to production-oriented industries. Nevertheless, variation remains observable in certain environmental measures, indicating that firm-level operational practices and reporting boundaries may still influence sustainability outcomes within this sector. The Healthcare sector demonstrates a mixed pattern, where some ESG indicators show stable distributions while others display noticeable dispersion, highlighting the heterogeneity of sustainability performance among firms operating under similar regulatory and operational environments. Interpretation of cross-sector patterns in the Consumer Discretionary sector should be approached with caution due to the smaller sample size relative to other sectors. Despite this limitation, descriptive results suggest that environmental indicators may exhibit greater variability than social and governance measures, reflecting differences in production processes, supply-chain exposure, and sustainability strategies.

Collectively, the cross-sector observations indicate that sectoral context plays an important role in shaping ESG performance patterns. Differences in distributional characteristics across sectors imply that observed ESG–CSP relationships may be influenced not only by sustainability initiatives but also by underlying sectoral attributes. Accordingly, the inclusion of cross-sector observation enhances the interpretation of descriptive results and provides an essential contextual foundation for the subsequent correlation analysis.

4.3 Outliers Detection

Outlier detection was conducted during the data pre-processing stage using the R statistical software environment. All ESG indicators were processed programmatically to ensure consistency and reproducibility across variables and firms. Following data import and variable standardisation, a custom outlier detection function was implemented to systematically evaluate all numeric ESG indicators. Within this procedure, numeric variables were first automatically identified, while non-numeric variables (such as company name, sector, and year) were excluded from outlier computation.

For each numeric variable, the first quartile (Q1) and third quartile (Q3) were computed using empirical quantiles, with missing values excluded from the calculation. The interquartile range (IQR) was then calculated as the difference between Q3 and Q1. Lower and upper outlier thresholds were defined as $Q1 - 1.5 \times IQR$ and $Q3 + 1.5 \times IQR$, respectively.

The dataset was subsequently filtered iteratively across all numeric ESG variables. During each iteration, observations falling outside the defined IQR thresholds for the current variable were removed, while observations containing missing values for that variable were retained. This iterative filtering ensured that any observation identified as an outlier in at least one ESG indicator was excluded from the final analytical sample.

The outlier removal process preserved the full multivariate structure of the dataset by filtering entire observations rather than individual variable values. This approach ensured internal consistency across ESG indicators for each firm-year observation and avoided distortions in downstream multivariate analyses. Finally, the resulting outlier-cleaned dataset was exported and used consistently for all subsequent analyses, including correlation analysis, heterogeneity testing, and predictive modelling.

None of the companies were completely excluded from the dataset at this stage. Rather, each KPI variable's extreme data points were removed, producing a cleaned dataset (final_ESG_no_outliers.csv). The dataset preserved its authentic variability, indicating true variations in company sustainability performance, by keeping valid observations and eliminating only those deemed statistically excessive. This approach strengthened the robustness of the subsequent analyses by ensuring that the data represented actual sustainability trends rather than distorted or erroneous figures. Based on final_ESG_no_outliers.csv file, Compal Electronics rows of 2017-2020 and Taiwan Semiconductor rows of 2017 -2022 were removed.

Following this phase, Taiwan Semiconductor and Compal Electronics continued to be included in the dataset along with their associated valid observations. However, because these companies showed fewer than two meaningful correlations across the ESG KPIs during the heterogeneity testing stage, they were subsequently removed from further analysis. This exclusion resulted from limited or no variance of ESG KPIs data, which restricted the ability to compute reliable meta-analytic estimates.

Additionally, after the outlier detection procedure, four companies which are **Hitachi Heavy Industries Ltd., Vinci, Nissan Motor Co. Ltd., and Samsung Electronics Co. Ltd.** were totally removed from the cleaned dataset. Due to scale deviation or inconsistent data relative to other companies in the sample, all these companies' observations were found to be outliers across several KPI variables. Therefore, to preserve the general validity and homogeneity of the dataset used for correlation, heterogeneity, and predictive modelling, their removal was required to avoid distortions in later analyses.

4.4 Spearman's Correlation Analysis

Following the completion of the outlier detection process, the cleaned dataset (final_ESG_no_outliers.csv) was used to examine the relationships between individual ESG KPIs and the overall ESG performance score. Given the existence of non-linear connections and the ordinal structure of several ESG indicators, the Spearman's rank-order correlation was chosen as the proper non-parametric method. This approach is appropriate for datasets with varied distributions between firms and years because it assesses the magnitude and direction of the monotonic connection between variables without assuming normality. The Spearman's correlation coefficient was computed using the following equation (4.3):

$$\rho = 1 - \frac{6\sum d_i^2}{n(n^2 - 1)} \quad (4.3)$$

Where d_i represents the difference between the ranks of two variables for each observation, and n denotes the number of paired observations. The value of ρ ranges between -1 and $+1$, where a value close to $+1$ indicates a strong positive monotonic relationship, -1 indicates a strong negative monotonic relationship, and 0 indicates no monotonic association. For better interpretability and dependability, Fisher's Z-transformation was used to create

confidence intervals (CI) for each correlation coefficient. This made it possible to find statistically significant correlations between ESG KPIs and the total ESG score for all companies. *Spearman_correlations_with_ci.csv*, a summary of the correlation data, served as a basis for later heterogeneity testing and predictive modelling.

Spearman's Correlation Analysis Results per Company and Sector

Following that, industrial, healthcare, financial, information technology (IT), and consumer discretionary sectors are presented and analysed below based on the findings of the Spearman's rank-order correlation analysis. The following table of Spearman's analysis results and forest plot highlight and compare the monotonic correlations across sectors and companies individually.

i) Industrials

3M Company, Caterpillar Inc. and Siemens

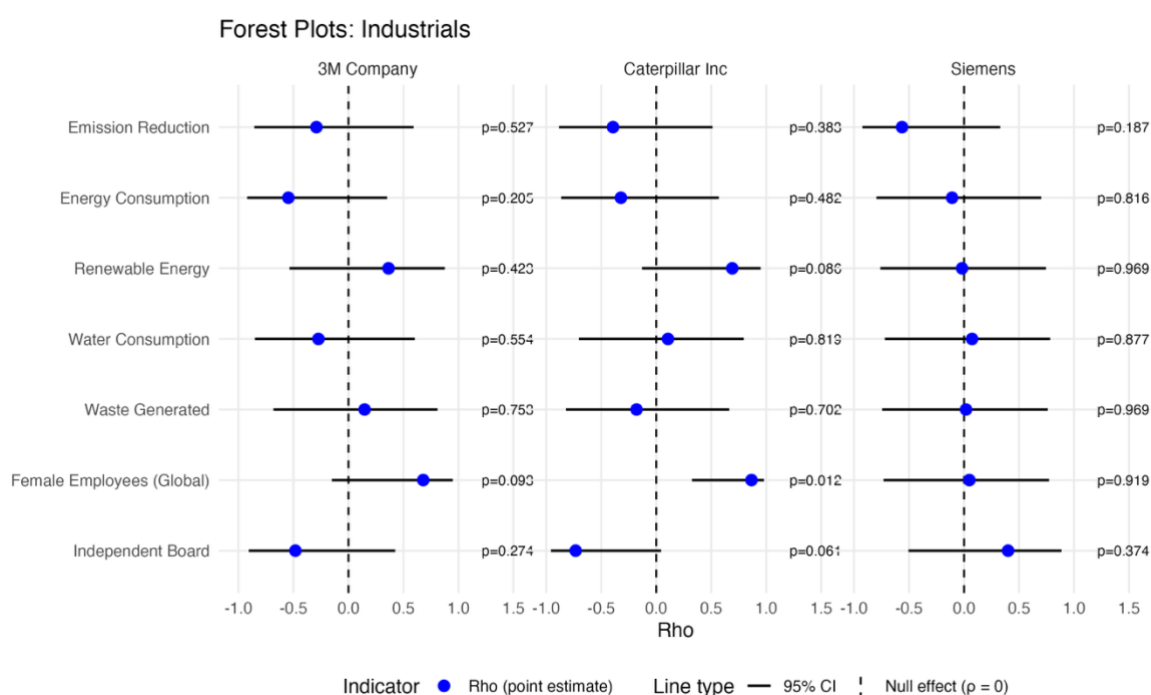


Figure 11 Forest plot for Industrial sector

3M Company

Individual ESG KPIs and the company's overall ESG score have different strengths and directions of association, according to the Spearman's rank-order

correlation values for 3M Company, as displayed in `spearman_correlations_with_ci.csv`. Most environmental indicators showed mild to moderate negative relationships that were not statistically significant at the 5% level, including energy consumption, water consumption, and emission reduction. Conversely, renewable energy and waste generated showed weak positive associations. Improvements in gender diversity may lead to better sustainability performance, as seen by the social indicator, that showed the largest positive correlation with the ESG score: the percentage of female employees. Nevertheless, considering the limited number of observations, this association remained statistically marginal. In the same manner, the governance indicator (independent board), showed a somewhat negative connection, indicating that board independence would not have a direct impact on ESG scores throughout the examined period.

Overall, the findings show that there was no statistically significant relationship between any KPI and 3M Company's ESG performance. However, in this instance, the direction and magnitude of the coefficients offer preliminary evidence that social indicators may be more strongly associated with sustainability performance than environmental or governance variables.

Caterpillar Inc.

The results of Caterpillar Inc.'s Spearman's rank-order correlation, which are displayed in `spearman_correlations_with_ci.csv`, showed that the company's ESG KPIs and its total ESG score had different strengths and directions of association. Most environmental variables, such as waste generated, energy consumption, and emission reduction, showed mild to moderate negative associations that were statistically insignificant at the 5% level. However, water consumption showed a slight and negligible positive connection.

Although this result remained statistically marginal, a reasonably strong positive association was found for renewable energy, suggesting that increased use of renewable energy sources may be associated with enhanced sustainability performance. Gender diversity may have had a major impact on Caterpillar's overall sustainability performance over the study period, as evidenced by the strong and statistically significant positive association between the ESG score and female employees globally. Greater board independence may not have correlated with higher ESG ratings

throughout the examined timeframe, according to the governance indicator Independent Board, which showed a strong negative connection that almost reached significance.

Overall, these findings imply that social dimensions, specifically workforce diversity were more closely linked to Caterpillar's ESG performance than environmental or governance metrics.

Siemens

The results of Siemens AG's Spearman's rank-order correlation, which are displayed in `spearman_correlations_with_ci.csv`, demonstrated a range of associations between the company's ESG KPIs and its overall ESG score, both in terms of strength and direction. Most environmental variables, such as energy consumption, renewable energy, and emission reduction, showed weak to moderate negative correlations that were not statistically significant at the 5% level. Water use and waste production, on the other hand, demonstrated extremely weak and negligible positive connections, suggesting a negligible contribution to the company's ESG score.

Moreover, gender diversity had little noticeable impact on overall ESG performance throughout the examined period, based on female employees globally KPI, which likewise showed a modest and statistically insignificant positive connection. In the same manner, the independent board governance indicator showed a weakly positive connection that was not statistically significant.

Overall, the findings show that neither one environmental, social, or governance element significantly influenced Siemens' ESG performance.

Sector-specific Observation

Among the three companies analysed, Caterpillar Inc. demonstrates the strongest overall associations, particularly in the social dimension, where gender diversity exhibits a statistically significant positive correlation with ESG performance. This implies that, in comparison to its industry counterparts, Caterpillar's gender diversity and inclusivity strategy and sustainability outcomes are more clearly aligned.

Social KPI exhibit more pronounced positive tendencies than environmental or governance variables, and 3M Company shows mild but generally statistically insignificant relationships. Siemens, on the other hand, has the weakest associations overall, with ESG ratings demonstrating weak and statistically insignificant correlations across governance, social, and environmental KPIs.

These patterns may be an indication of industrial sectors approach to sustainability, where higher performance gains also mean higher operational waste and consumption.

ii) Healthcare

Amgen, Merck & Co., UnitedHealth Group, AbbVie, and Novartis

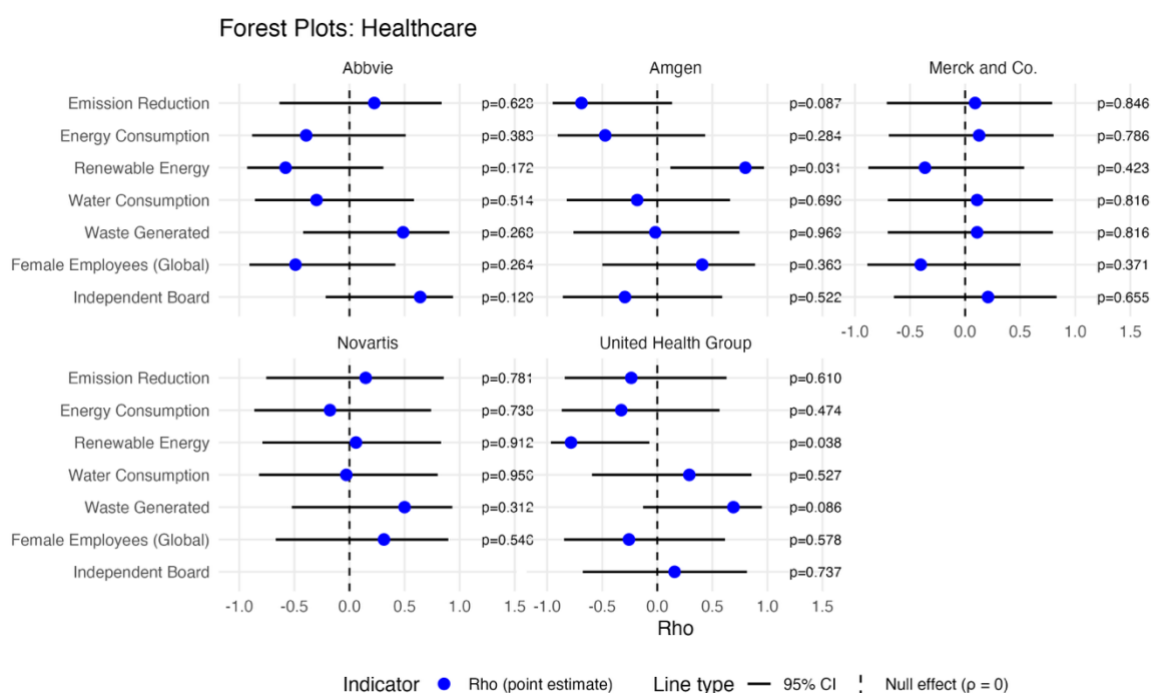


Figure 12 Forest plot for Healthcare sector

Amgen.

As seen in `spearman_correlations_with_ci.csv`, Amgen Inc.'s Spearman's rank-order correlation results showed conflicting relationships between the company's ESG KPIs and its total ESG score. Energy consumption and emission reduction showed moderately negative relationships among the environmental indicators, but these relationships did not reach statistical significance at the 5% level, indicating that lower ESG scores during the study period were not directly correlated with reductions in these indicators. There were very weak and statistically negligible negative correlations between waste generated and water consumption.

On the other hand, Amgen's ESG score showed a substantial and statistically significant positive correlation with renewable energy, suggesting that better sustainability performance was directly linked to increased use of renewable energy

sources. The social indicator, female employees worldwide, showed a moderate but statistically insignificant positive association, indicating that gender diversity may, albeit not definitively, improve sustainability outcomes. The independent board, a measure of governance, showed a weak and negligible negative correlation.

Overall, the results indicate that Amgen's renewable energy initiatives were the main driver of its ESG performance, underscoring the company's environmental dedication as a crucial factor in its sustainability trajectory.

Merck & Co.

As identified in `spearman_correlations_with_ci.csv`, Merck & Co., Inc.'s Spearman's rank-order correlation results revealed weak and statistically negligible connections between the company's ESG KPIs and its total ESG score. Emission reduction, energy usage, and water consumption showed extremely modest positive correlations among the environmental measures, suggesting little impact on the company's ESG performance. Renewable energy showed a slight negative correlation, indicating that variations in ESG scores were not directly linked to shifts in the use of renewable energy. In a similar vein, waste production showed a weakly positive correlation.

There was a moderate but statistically insignificant negative association between the social indicator, female employees globally, and overall ESG performance over the study period, suggesting that gender representation within the organisation had little discernible impact. In addition to being statistically insignificant, the independent board governance measure showed a weak positive connection.

Overall, Merck & Co.'s ESG performance seemed to be quite stable and balanced, with no one ESG factor having a significant impact.

UnitedHealth Group

Different associations between UnitedHealth Group's ESG KPIs and its total ESG score were found in the Spearman's rank-order correlation data, which are shown in `spearman_correlations_with_ci.csv`. Most environmental variables, such as energy consumption and emission reduction, displayed modest and statistically insignificant negative relationships, indicating that improvements in ESG performance were not highly correlated with reductions in energy use or emissions. While garbage generated exhibited a reasonably strong positive connection that almost reached significance,

water usage showed a mild but statistically insignificant positive association, suggesting that waste management techniques may have somewhat improved sustainability.

Increases in the use of renewable energy did not appear to be associated with higher ESG ratings during the study period, as seen by the substantial and statistically significant negative correlation between renewable energy and ESG performance. Rather than an actual negative association, this surprising discovery can point to data errors or reporting variations in the company's energy declarations.

Both the governance indicator, independent board, and the social indicator, female employees worldwide, showed weak and statistically negligible correlations.

Overall, the results indicate that UnitedHealth Group's ESG performance was not driven by consistent trends across environmental, social, or governance dimensions. The mixed directionality of associations, particularly the negative relationship with renewable energy, suggests that the company's ESG outcomes may have been influenced by broader operational or reporting factors rather than direct performance changes in individual KPIs.

AbbVie

As demonstrated in `spearman_correlations_with_ci.csv`, AbbVie Inc.'s Spearman's rank-order correlation results showed weak to moderate relationships between the company's ESG KPIs and its overall ESG score; none of these relationships approached statistical significance at the 5% level. Emission reduction was one of the environmental indicators with a weakly positive correlation, whereas energy consumption, water usage, and renewable energy all had negative correlations of varied degrees. These findings imply that during the research period, changes in AbbVie's environmental performance indicators did not correspond with its overall ESG score.

The amount of waste generated showed a moderately positive association, suggesting that better waste management practices might have had a small beneficial impact on ESG results. The social indicator, female employees globally, showed a somewhat negative correlation, indicating that differences in gender representation might not have had a substantial impact on ESG performance. On the other hand, although this relationship was not statistically significant, the governance measure, independent board, demonstrated a relatively high positive association, suggesting that board independence may have improved AbbVie's sustainable performance.

Overall, the environmental, social, and governance aspects of AbbVie's ESG performance showed conflicting links; the biggest, if not statistically significant, positive association was found in governance.

Novartis

According to spearman_correlations_with_ci.csv, Novartis AG's Spearman's rank-order correlation data showed usually weak and statistically negligible relationships between the company's ESG KPIs and its overall ESG score. Energy usage and water use revealed weak negative correlations among the environmental variables, but emission reduction and renewable energy showed modest positive associations. These minimal coefficients show that during the study period, changes in ESG outcomes were not significantly correlated with variations in Novartis's environmental performance.

Although there was no statistical support, trash generated showed a moderate but statistically insignificant positive association, indicating that waste management advancements may have been somewhat correlated with overall ESG performance. The social indicator, female employees globally, likewise showed a weakly positive correlation, suggesting that gender diversity had a little but not significant contribution to sustainability performance. There was insufficient or partial data disclosure for this KPI throughout the period, as evidenced by the governance indicator, independent board, being unavailable (NA).

Environmental and social variables did not appear to be the main drivers of Novartis's ESG performance, which was generally balanced but statistically non-significant across all dimensions.

Sector-specific Observation

Based on the companies analysed, Amgen exhibits the strongest and most clearly defined relationship, particularly within the environmental dimension. Amgen stands out due to the statistically significant positive correlation between renewable energy use and ESG performance, suggesting that certain environmental activities may have a more noticeable impact on sustainability results for some healthcare companies. Merck & Co. and Novartis, on the other hand, show rather consistent ESG performance that is not highly correlated with changes particularly KPIs, as evidenced by their generally weak and statistically insignificant relationships across all ESG dimensions.

UnitedHealth Group exhibits the most inconsistent pattern with mixed directionality across environmental parameters and a statistically significant negative correlation between Renewable Energy and ESG performance. This result highlights the difficulty of interpreting ESG–KPI correlations within diverse healthcare service providers, even though it can be the result of reporting methodology differences rather than a negative sustainability relationship.

Among the healthcare companies examined, AbbVie exhibits relatively stronger governance-related relationships, with board independence exhibiting the most positive, albeit statistically insignificant, relationship with ESG performance. This implies that for some pharmaceutical companies, governance systems might have a more significant, if indirect, impact on sustainability outcomes.

Overall, the results of the healthcare industry indicate that environmental, social, and governance variables have varying degrees of importance among organisations, indicating that ESG performance is not always driven by a single factor.

iii) IT

NVIDIA Corp., Compal Electronics, Intel, Google, and Taiwan Semiconductor

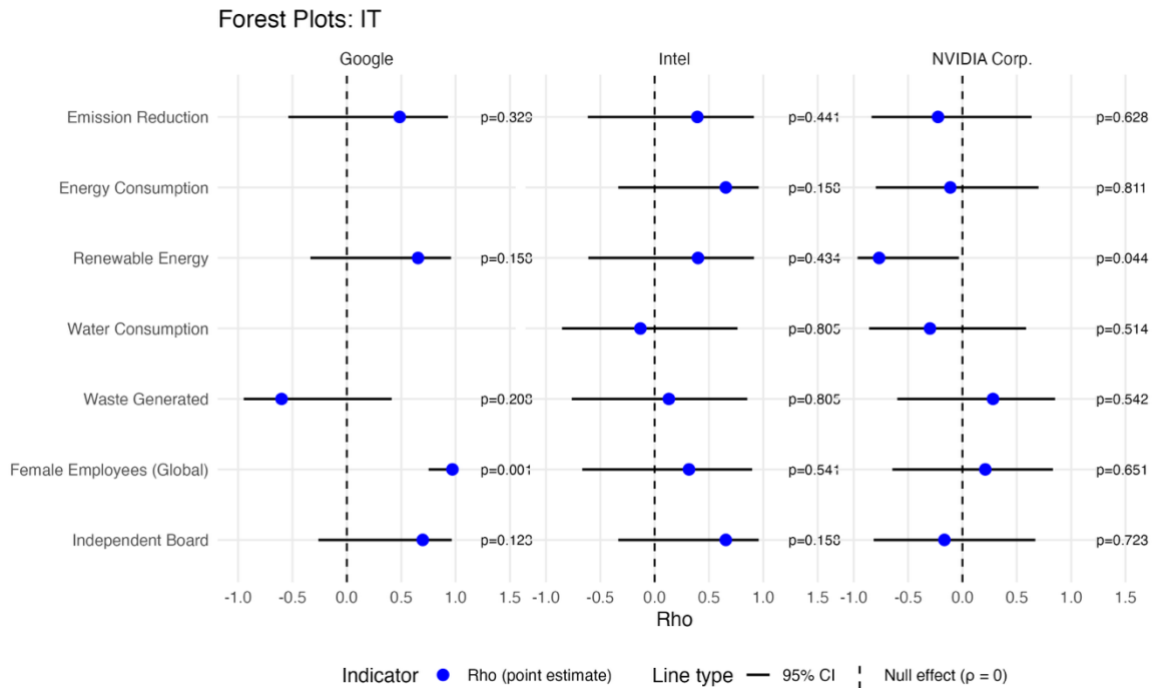


Figure 13 Forest plot for IT sector

NVIDIA Corp.

Mixed correlations were found between NVIDIA Corporation's ESG KPIs and its total ESG score, according to the Spearman's rank-order correlation statistics, which are displayed in `spearman_correlations_with_ci.csv`. Emission reduction, energy use, and water usage showed weak negative relationships among the environmental indicators, indicating that improvements in these areas were not directly correlated with increases in ESG scores. There was a slight positive correlation with waste generated, but it was not statistically significant.

Renewable energy demonstrated a strong and statistically significant negative correlation, indicating that increases in renewable energy usage were paradoxically associated with lower ESG scores during the observed period. Rather than a real negative sustainability impact, this inverse relationship can be the result of temporal reporting effects or gaps between operational improvements and their realisation in ESG ratings.

The governance indicator, independent board, showed a mild negative correlation, and the social indicator, female employees globally, showed a weak positive association and both correlations are statistically insignificant. Overall,

NVIDIA's ESG performance showed no consistent pattern across the three ESG dimensions.

Compal Electronics

Mostly due to absence of data, Compal Electronics' Spearman's rank-order correlation results, as shown in `spearman_correlations_with_ci.csv`, showed erratic and statistically insignificant associations between the company's ESG KPIs and its total ESG score. The environmental indicators: emissions reduction, energy consumption, renewable energy, and water consumption all displayed high p-values and inconsistent correlation orientations, indicating that there was not enough variation among observations to generate significant statistical relationships.

The amount of waste generated showed a perfect positive association, but this figure should be evaluated cautiously because it likely resulted from a small sample size or very few data points. Likewise, there were positive but statistically insignificant correlations between the governance indicator, independent board, and the social indicator, female employees globally.

Overall, rather than significant ESG dynamics, Compal Electronics' results were influenced by inadequate data variance. This company was not included in the subsequent heterogeneity analysis because of the limited number of observations, which limited the reliability of correlation estimates. This emphasises the significance of regular and thorough ESG reporting, especially in the technology manufacturing industry, where insufficient disclosure might compromise the validity of sustainability performance evaluations.

Google

With varied degrees of statistical significance, the Spearman's rank-order correlation values for Google, as displayed in `spearman_correlations_with_ci.csv`, showed typically strong positive associations between several ESG KPIs and the total ESG score. Although these relationships were not statistically significant at the 5% level, emission reduction and renewable energy showed moderate to strong positive associations among the environmental indicators, indicating that improvements in the company's ESG performance were accompanied by reductions in emissions and increased use of renewable energy sources.

Water consumption and energy consumption both showed perfect positive correlations, suggesting a clear monotonic relationship between these KPIs and the overall ESG score. However, rather than reflecting actual causal strength, such extreme coefficients probably reflect restricted variation in the available data. On the other hand, although the result was statistically insignificant, waste generated demonstrated a mildly negative connection, suggesting that larger waste levels would correspond with slightly lower ESG ratings.

Globally, the social indicator of female employees showed a very strong and statistically significant positive link with the ESG score, suggesting that improved sustainability performance was closely correlated with increases in the representation of women in the workforce. A positive but non-significant correlation was also found for the governance measure, independent board, indicating a possible but inconclusive relationship between ESG improvement and board independence.

All things considered, Google's ESG performance seems to have been largely influenced by social considerations, particularly gender diversity, and bolstered by strong environmental commitments, particularly in the usage of renewable energy. These findings align with a larger trend in the technology sector, where sustainability leadership is increasingly supported by social inclusion and transparent governance.

Intel

Intel Corporation's ESG KPIs and overall ESG score had modest and generally positive correlations, according to the Spearman's rank-order correlation statistics, which are displayed in `spearman_correlations_with_ci.csv`. However, none of these correlations approached statistical significance at the 5% level. Improvements in energy efficiency and adoption of renewable energy were linked to higher ESG scores, according to environmental metrics like emission reduction, renewable energy, and energy consumption that showed positive relationships. The somewhat large confidence intervals, which indicate moderate data variability, should be taken into consideration when interpreting these connections.

There was no impact on the company's ESG results, as seen by the extremely weak and statistically negligible connections between water consumption and waste generated. Similarly, there was a modest positive correlation between the ESG score and the social indicator of female employees worldwide, suggesting that gender diversity may have improved the company's sustainable status, albeit not significantly.

Although there was no statistical support, the governance indicator, independent board, showed a somewhat favourable association, indicating that board independence could promote ESG improvement.

In general, Intel's ESG performance seemed to be more in line with governance and environmental aspects, which is in line with its focus on manufacturing and technology.

Taiwan Semiconductor

The lack of sufficient valid observations across all ESG KPIs prevented the computation of Taiwan Semiconductor's (TSMC) Spearman's rank-order correlation values, as displayed in `spearman_correlations_with_ci.csv`. For correlation coefficients, p-values, and confidence intervals, all variables including emission reduction, energy consumption, renewable energy, water consumption, waste generated, female employees globally, and an independent board returned non-applicable (NA) results.

This result shows that there were insufficient variance or complete records throughout the study period in the available ESG data for TSMC, making it impossible to calculate significant monotonic connections between specific KPIs and the company's total ESG score. As a result of inadequate data reliability and comparability, TSMC was eliminated from the heterogeneity testing phase.

In essence, the lack of reliable correlations highlights a more general issue with ESG disclosure consistency in the semiconductor sector, as indicator definitions and reporting systems can differ greatly between years or reporting standards. This restriction emphasises how crucial standardised ESG disclosure procedures are for precise statistical evaluation and cross-company comparisons in subsequent studies.

Sector-specific Observation

Based on the analysed companies, Google exhibits the strongest and most consistent positive associations, particularly within the social dimension due to the statistically substantial positive association between social KPI and ESG performance, suggesting that workforce diversity has a greater influence on sustainability outcomes for platform-based technology organisations. Although certain extreme correlations seem to represent limited data variability rather than significant causal strength, environmental indicators for Google also exhibit comparatively strong positive connections.

On the other hand, NVIDIA shows mixed and directionally contradictory associations, such as a statistically significant negative correlation between ESG performance and the utilisation of renewable energy. Despite seeming counterintuitive, this pattern is probably not the result of an inverse sustainability effect, but rather of temporal reporting effects, grading technique lags, or structural discrepancies between operational improvements and ESG score realisation. As a result, NVIDIA's overall ESG performance seems to be influenced by a variety of factors rather than a single ESG driver. For Intel, social indicators are less closely aligned with ESG performance than environmental and governance measurements, which have weak but generally positive correlations that are not statistically significant. This pattern may indicate that governance structures and operational effectiveness are more strongly linked to sustainability performance.

Furthermore, insufficient variance and restricted data availability significantly limit statistical inference for Taiwan Semiconductor (TSMC) and Compal Electronics. TSMC's non-computable data and Compal's unpredictable correlations demonstrate ongoing issues with disclosure and comparability within some sectors of the semiconductor and technology production industries. Because of this, it is methodologically appropriate to exclude these enterprises from heterogeneity study since their ESG–KPI correlations cannot be properly evaluated.

Overall, the results from the IT sector indicate that ESG performance is quite firm-specific, with greater correlations found in businesses with more developed ESG disclosure procedures and a structured framework for sustainability reporting.

iv) Financials

Goldman Sachs, American Express, Allianz, Santander, MetLife, and MS&AD

Insurance

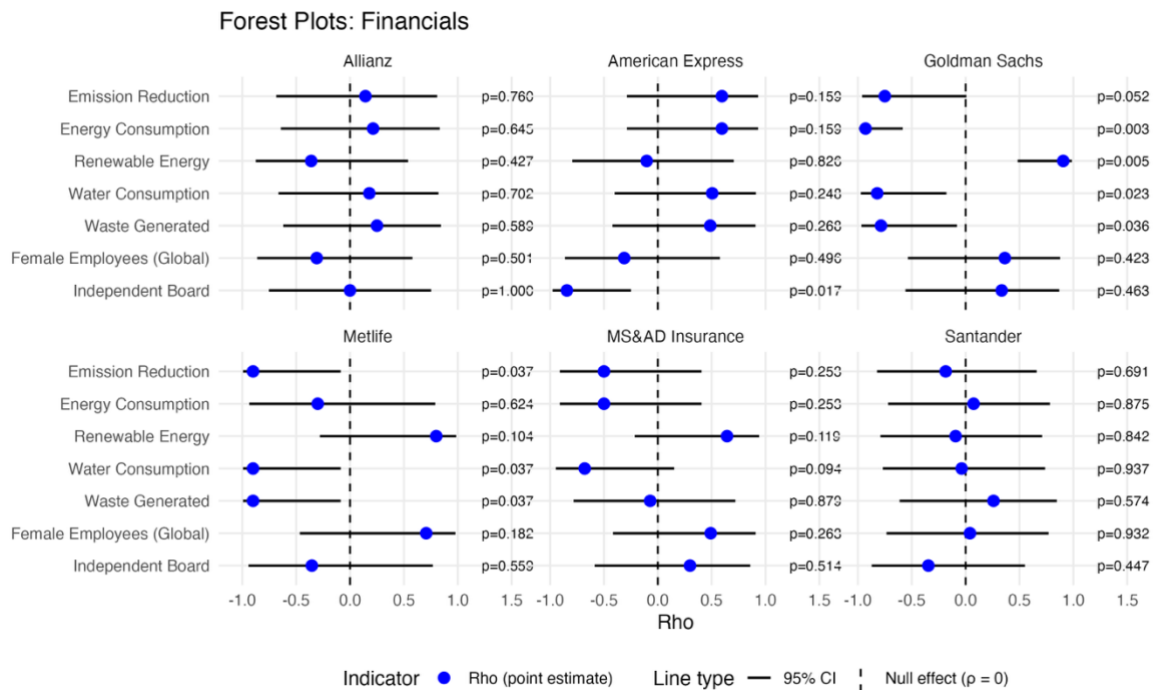


Figure 14 Forest plot for Financial sector

Goldman Sachs

As shown in `spearman_correlations_with_ci.csv`, the Spearman's rank-order correlation results for Goldman Sachs Group Inc. showed multiple strong and statistically significant relationships between ESG KPIs and the overall ESG score, demonstrating a definite directional influence of environmental performance on corporate sustainability outcomes.

Energy consumption was one of the environmental variables that had a very strong and statistically significant negative association with the ESG score, indicating that lower energy use was strongly associated with better sustainability performance. Strong negative relationships were also found between water consumption and waste generation, suggesting that higher ESG ratings were linked to reduced resource consumption and waste levels. The use of renewable energy is crucial for improving environmental sustainability, as evidenced by the strong and statistically significant positive link that renewable energy showed with the ESG score.

Although slightly above the 5% significance level, emission decrease also showed a strong negative correlation with ESG score, indicating that continuous emission management significantly improved overall ESG. However, there was little direct impact of workforce diversity and board independence on ESG performance during the study period, as evidenced by the weak and statistically insignificant positive correlations between the social indicator (female employees globally) and the governance metric (independent board).

Overall, of all the companies analysed, Goldman Sachs showed one of the most notable patterns of important environmental-ESG connections. The findings indicate that the company's sustainability performance was mostly influenced by its resource efficiency and shift to renewable energy, underscoring the environmental aspect as a crucial factor in determining corporate ESG strength in the banking industry.

American Express

American Express Company's ESG key performance indicators (KPIs) and its total ESG score showed typically moderate but mixed associations, according to the Spearman's rank-order correlation data shown in `spearman_correlations_with_ci.csv`. Although these relationships were not statistically significant at the 5% level, environmental variables like energy consumption and emission reduction showed moderately positive relationships, indicating that higher ESG scores were linked to greater reductions in energy use and emissions. The company's sustainability performance may have improved incrementally because of improvements in resource efficiency, as seen by the moderately favourable correlations found between water consumption and waste generation.

On the other hand, there were minor negative connections between the usage of renewable energy and the social indicator of female employees globally, indicating little to no relationship with overall ESG performance. Increases in board independence did not correlate with higher ESG ratings over the study period, according to the governance indicator, independent board, which demonstrated a strong and statistically significant negative connection. This suggests that the company's operational and reporting framework's sustainability performance may not have been directly impacted by governance enhancements alone.

Overall, the findings imply that environmental management metrics had a stronger correlation with American Express's ESG performance than did social or

governance aspects. The strong negative governance correlation indicates possible structural or temporal misalignments between governance reforms and their quantifiable impact on ESG performance within the financial sector context, even though the environmental metrics showed generally positive, albeit insignificant, relationships with ESG outcomes.

Allianz

The majority of ESG key performance indicators (KPIs) showed weak and statistically negligible relationships with the company's total ESG score, according to Allianz SE's Spearman's rank-order correlation data, which are shown in `spearman_correlations_with_ci.csv`. Emission reduction, energy consumption, and water consumption were among the environmental variables that had weak positive correlations, indicating that changes in the company's ESG performance were not significantly correlated with slight improvements in these areas. Renewable energy showed a slight negative association, suggesting that changes in the use of renewable energy had little impact on overall ESG outcomes throughout the period of the study.

In the same direction, waste generation showed a slight positive correlation with the ESG score, however the social indicator of female employees globally showed a weak negative correlation. Board independence, a measure of governance, did not exhibit any discernible link with the ESG score, suggesting that the company's sustainability performance indicators and governance composition are completely neutral.

Overall, the results indicate that there were no strong or statistically significant monotonic correlations between Allianz's environmental, social, or governance variables and its ESG performance.

Santander

Banco Santander S.A.'s Spearman's rank-order correlation data, displayed in `spearman_correlations_with_ci.csv`, revealed typically weak and statistically negligible associations between the company's total ESG score and its ESG key performance indicators (KPIs). Energy consumption and trash production showed modest positive relationships among the environmental metrics, whereas emission reduction and renewable energy showed weak negative correlations. These findings imply that the

company's overall ESG performance over the research period was not significantly impacted by changes in environmental performance criteria.

Similarly, there was no significant correlation between water consumption and ESG results. The percentage of female employees globally showed no discernible association from the social and governance aspects, whereas the governance variable, independent board, showed a modest negative relationship, indicating minimal or inconsistent governance effects on ESG performance.

Overall, Santander's findings imply that changes in any one environmental, social, or governance metric did not significantly influence the company's ESG performance trends.

MetLife

Several strong directional relationships between specific environmental indicators and the company's total ESG score were found in the Spearman's rank-order correlation data for MetLife, Inc., as shown in `spearman_correlations_with_ci.csv`. Strong and statistically significant negative connections were found between the ESG score and waste production, water consumption, and emission reduction. These findings demonstrate the company's efficacy in managing environmental efficiency as a driver of sustainability outcomes by indicating that fewer emissions, reduced water consumption, and enhanced waste management were highly associated with superior ESG performance during the research period.

While renewable energy use showed a strong but statistically marginal positive relationship, energy consumption showed a weak and insignificant negative association. This suggests that increased adoption of renewable energy may, though not definitively, improve ESG performance. Gender diversity may be favourably correlated with sustainable results inside the organisation, according to the social indicator, female employees globally, which showed a high positive but negligible relationship. The governance indicator, independent board, demonstrated a moderate negative correlation, suggesting that the composition of governance has little bearing on overall ESG performance.

Overall, MetLife's findings show that the company's environmental management strategies, specifically, decreases in emissions, water consumption, and waste production were the main drivers of its ESG score.

MS&AD Insurance

Despite the majority were not statistically significant at the 5% level, the Spearman's rank-order correlation results for MS&AD Insurance Group Holdings, as shown in `spearman_correlations_with_ci.csv`, showed generally moderate relationships between individual ESG KPIs and the company's overall ESG score. Emission reduction and energy consumption showed moderately negative relationships among the environmental indicators, indicating that, although not statistically supported, decreases in these indicators may have a positive impact on ESG performance.

An increased reliance on renewable energy sources may be advantageous to the company's sustainability outcomes, as seen by the reasonably high positive association between use of renewable energy and the ESG score. Additionally, water consumption showed a somewhat strong negative association that was on the verge of statistical significance, suggesting that efficient water management might significantly enhance ESG performance. On the other hand, there was very no correlation between waste generation and ESG results.

The percentage of female employees globally shown a somewhat favourable correlation with the social and governance dimensions, indicating that gender diversity may positively impact sustainability outcomes. Independent boards, on the other hand, displayed a weakly positive correlation, suggesting that governance had little impact on overall ESG performance over the study period.

Overall, the results indicate that while social and governance indicators showed lesser, non-significant effects, MS&AD Insurance's ESG performance was somewhat influenced by its environmental management practices, particularly the use of renewable energy and the reduction of water consumption.

Sector-specific Observation

Moving on to financial sector, Goldman Sachs and MetLife are notable for having the strongest and most consistent correlations, especially the environmental metrics. Additionally, strong and statistically significant negative connections with energy consumption, water use, waste generated, and emission reduction, along with positive correlations with renewable energy, are characteristics of ESG performance in both scenarios. This arrangement suggests that, compared to other industries, environmental KPIs are more strongly correlated with ESG outcomes for some financial institutions.

Renewable energy exhibits positive directional tendencies, while American Express and MS&AD Insurance show minor but generally statistically negligible environmental correlations. However, there are weak or sometimes negative correlations between governance-related indicators and ESG performance, suggesting that governance reforms might not instantly result in quantifiable increases in the sector's ESG scores. Allianz and Santander, on the other hand, consistently show weak and statistically insignificant correlations across environmental, social, and governance KPIs, indicating comparatively steady ESG performance that is not significantly impacted by transient changes in individual variables. The direction of sustainability, methodological variety, and the regulated character of huge financial institutions may have contributed to this tendency.

Overall, the results from the financial sector indicate that, especially for companies that reported measurable operational footprints, environmental KPI practices are more important in determining ESG performance as the number of KPI measured are higher than social or governance dimensions.

v) Consumer Discretionary

Nike

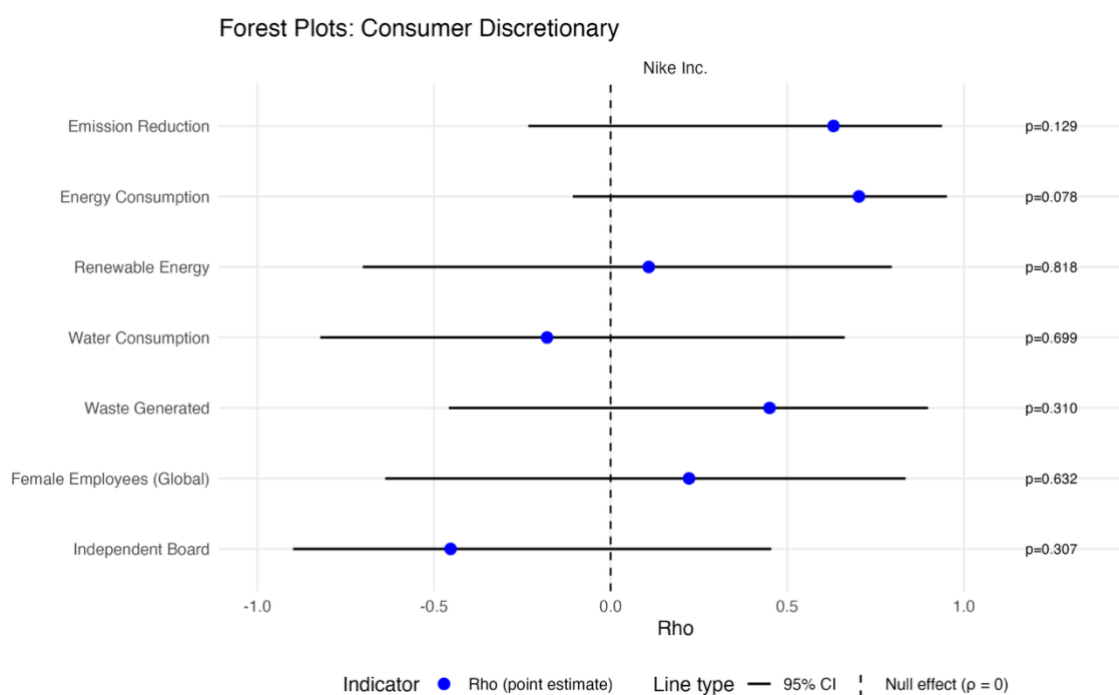


Figure 15 Forest plot for Consumer Discretionary sector

Nike

Nike Inc.'s Spearman's rank-order correlation data, shown in `spearman_correlations_with_ci.csv`, showed that the company's overall ESG score, and specific ESG key performance indicators (KPIs) had different strengths and directions of relationship. Improvements in these areas, especially through lower energy use and reduced emissions, may be associated to improved sustainability performance. Among the environmental indicators, emission reduction and energy consumption demonstrated strong positive correlations that were almost statistically significant. On the other hand, there was very no association between renewable energy and total ESG outcomes during the study period. Water management may not have had a significant impact on the company's ESG score, as evidenced by the weak negative correlation between water consumption and ESG performance. There was a moderately positive correlation between trash generation and ESG gains, suggesting that increased waste efficiency may have played a little role.

Globally, female employees showed a weak positive correlation in the social dimension, indicating that workforce diversity had little effect on overall sustainability outcomes. Changes in board independence or composition may not have directly improved ESG performance, according to the governance indicator, independent board, which shown a moderately negative correlation.

Overall, Nike's findings indicate that environmental initiatives, especially those pertaining to emissions and energy consumption, have a greater impact on the company's sustainability performance than social or governance considerations.

Cross-sector Observations (Industrials, Healthcare, IT, Financials, and Consumer Discretionary)

In this study, Spearman correlation analysis reveals substantial heterogeneity in the relationship between ESG key performance indicators and overall ESG performance, indicating that sustainability outcomes are highly context-dependent rather than uniform across industries. Additionally, the relative importance of ESG KPIs varies depending on sectoral nature, operational intensity, and reporting standards; hence, no single ESG dimension consistently dominates across all sectors.

In the industrial sector, most ESG KPIs exhibit weak and statistically insignificant associations with ESG performance. Workforce diversity represents a notable exception, demonstrating more consistent positive relationships across selected

organisations. Conversely, environmental indicators often show negative or marginal correlations, potentially reflecting the extent to which high operational intensity and resource consumption attenuate the measurable impact of environmental initiatives on overall ESG scores. However, the healthcare industry's environmental factors seem to be more important for some companies, especially when it comes to the adoption of renewable energy, while other companies show balanced but statistically weak links across ESG aspects.

Furthermore, the industry with the most company-specific variance is information technology. In contrast to hardware and semiconductor-focused companies, which demonstrate limited or non-computable correlations because of insufficient data variability and disclosure restrictions, platform-based technology companies show strong social-dimension relationships, most notably workforce diversity. These results demonstrate how the sector's observed statistical connections are shaped by the business nature and operational efficiency.

The financial sector on the other hand, demonstrates the most stable cross-firm trends, especially when it comes to the environmental aspect. For companies with measurable operational footprints, resource efficiency metrics such as energy use, water consumption, waste production, and emissions exhibit greater and more consistent correlations with ESG performance. However, the correlations between social and governance indicators are weaker and less consistent, indicating that environmental performance measurements are more important in determining ESG results in this sector.

Overall, the cross-sector research indicates that there isn't a single set of universal indicators that drives ESG performance. Rather, sector-specific operational features, disclosure policies, and sustainability priorities determine the degree, direction, and significance of ESG–CSP connections.

4.4.2 Effects of Multiple Hypothesis Testing and False Positives

This study adopts an exploratory approach to examine the associations between ESG key performance indicators and corporate sustainability performance across companies and sectors. Since many Spearman's' rank-order correlation tests were conducted, this introduces the potential for Type I error inflation due to multiple hypothesis testing.

Additionally, the company-level sample sizes are rather small, which reflects the limitations of data availability and the differences in ESG disclosure policies among

businesses. These restrictions raise the possibility that isolated statistically significant outcomes could occur by accident and have an impact on the accuracy of statistical inference.

As a result, precaution is applied while interpreting the results. The direction, strength, and consistency of observed associations across companies and sectors are given greater importance than individual p-values or exact confidence interval estimations. This pattern-based interpretation is consistent with best practices in exploratory sustainability and ESG research and lowers the possibility of overinterpreting spurious significance. Consequently, the reported correlations should be understood as indicative associations that highlight broader trends and comparative patterns, rather than as definitive evidence of causal relationships between individual ESG indicators and sustainability performance.

4.5 Heterogeneity Assessment and Testing

Furthermore, to ascertain if the correlations between ESG KPIs and total ESG scores were consistent across organisations, it was required to evaluate the degree of heterogeneity within the dataset, given the different directions and magnitudes of correlation coefficients observed among companies in Section 4.4. In meta-analytical and comparative research, heterogeneity testing is a crucial diagnostic step that assesses if the observed variability in correlation coefficients is more than would be predicted by chance alone. Instead of presuming consistency in ESG-KPI correlations, this guarantees that ensuing interpretations and predictive studies take firm-level or sectoral variations into account.

Standard meta-analytical metrics, such as Cochran's Q-statistic, I² index, and Tau-squared (τ^2), were used to assess heterogeneity. A statistically significant p-value ($p < 0.05$) denotes considerable heterogeneity, and the Q-statistic tests the null hypothesis that all correlation values have a common effect size and is computed. The heterogeneity of correlation coefficients was quantified using Cochran's Q-statistic, expressed as follows (Equation 4.4):

$$Q = \sum_{i=1}^k w_i (r_i - \bar{r})^2 \quad (4.4)$$

where w_i is the weight of each correlation (typically the inverse of its variance), r_i is the observed correlation for the i -th KPI, and $\bar{r}$ is the pooled correlation estimate. A statistically significant p-value ($p < 0.05$) indicates considerable heterogeneity across KPIs.

Next, the I^2 statistic (Equation 4.5) quantifies the percentage of total variation due to heterogeneity rather than chance, with benchmark values of 25%, 50%, and 75% denoting low, moderate, and high heterogeneity, respectively:

$$I^2 = \frac{Q - (k - 1)}{Q} \times 100\% \quad (4.5)$$

Lastly, Tau-squared (τ^2) estimates the between-group variance, providing insight into the magnitude of dispersion among correlation coefficients at the firm level (Equation 4.6):

$$\tau^2 = \frac{Q - (k - 1)}{C} \quad (4.6)$$

Essentially, using the cleaned correlation data (`final_ESG_no_outliers.csv`) and the appropriate confidence intervals produced by Fisher's Z-transformation, the heterogeneity statistics were calculated independently for each company and for all firms. A single summary assessment of each company's internal ESG consistency was obtained by calculating a pooled Spearman's correlation coefficient (ρ), which represents the overall strength and direction of association between the firm's ESG KPIs and its total ESG score. The degree of variability among the individual KPI correlations within each organisation was then evaluated using the heterogeneity diagnostics, which included Cochran's Q-statistic, I^2 index, and Tau-squared (τ^2). The following subsections provide an interpretation of the test results by industrials, healthcare, finance, information technology (IT), and consumer discretion. The results are compiled in `heterogeneity_results.csv`.

i. Industrials

The relationships between ESG KPIs and total ESG performance showed differing degrees of internal consistency, according to the heterogeneity results for the industrial sector, which included 3M Company, Caterpillar Inc., and Siemens AG (as shown in `heterogeneity_results.csv`). The heterogeneity measures for 3M Company showed minimal between-indicator variability ($Q = 6.612$, $p = 0.358$; $I^2 = 9.3\%$),

indicating that the ESG KPI relationships were comparatively homogeneous. As a result, the fixed-effects model was suitable, and the pooled Spearman's correlation ($\rho = -0.051$) indicated a weak and non-significant overall association between the total ESG score and ESG KPIs.

On the other hand, a random-effects model was justified because Caterpillar Inc.'s ESG indicators showed significant heterogeneity ($Q = 14.538$, $p = 0.024$; $I^2 = 58.7\%$). The pooled correlation ($\rho = 0.059$) indicates a weak but marginally positive relationship at the aggregate level, and this moderate degree of heterogeneity suggests variety in how specific KPIs relate to overall ESG performance.

The fixed-effects model was supported for Siemens AG because the heterogeneity test ($Q = 2.405$, $p = 0.879$; $I^2 = 0\%$) showed total homogeneity across ESG measures. Individual ESG KPIs and the company's overall ESG performance showed consistent but weak associations, as indicated by the pooled correlation ($\rho = -0.029$), which showed an insignificant overall association.

Finally, despite the exception of Caterpillar Inc., which displayed substantial internal variance, the industrial sector generally demonstrated uniform connections. This pattern implies that Caterpillar sustainability programs may have distinct effects across ESG dimensions, even though industrial enterprises maintain consistent ESG performance dynamics across dimensions.

ii. Healthcare

As shown in `heterogeneity_results.csv`, the healthcare sector's heterogeneity outcomes, which included Amgen Inc., Merck & Co., UnitedHealth Group, AbbVie Inc., and Novartis AG, showed differing levels of internal consistency in the relationships between ESG KPIs and overall ESG performance.

Amgen Inc. showed considerable heterogeneity ($Q = 9.931$, $p = 0.128$; $I^2 = 39.6\%$), indicating some variation in its ESG metrics. The pooled correlation ($\rho = -0.047$) showed a weak and statistically insignificant relationship between Amgen's ESG KPIs and total ESG score, indicating relatively consistent ESG reporting with limited directional divergence across indicators. As a result, a fixed-effects model was deemed appropriate.

The use of a fixed-effects model was supported by Merck & Co.'s perfect homogeneity ($Q = 1.668$, $p = 0.948$; $I^2 = 0\%$). There was a very weak and non-

significant correlation between ESG indicators and overall ESG performance, according to the pooled correlation coefficient ($\rho = -0.023$). This indicates that the company's sustainability reporting has a high degree of internal consistency and little fluctuation in its environmental, social, and governance aspects.

Similarly, the fixed-effects model was used for UnitedHealth Group, which showed moderate but statistically insignificant heterogeneity ($Q = 8.548$, $p = 0.201$; $I^2 = 29.8\%$). The company's ESG components progressed in very consistent but slightly distinct directions, according to the pooled correlation ($\rho = -0.084$), which showed a modest inverse association between the ESG KPIs and the entire ESG score.

Lastly, Novartis AG showed total homogeneity ($Q = 1.014$, $p = 0.961$; $I^2 = 0\%$), supporting the use of a fixed-effects model. The ESG KPIs and the overall ESG score showed a weak but positive link, according to the pooled correlation ($\rho = 0.144$), which suggests that its sustainability metrics are somewhat better aligned than those of other healthcare companies.

Overall, there was very little variability in the healthcare industry, and every business used the fixed-effects model. With only slight differences in the strength and direction of KPI connections, this suggests that ESG performance within healthcare companies tended to be consistent across environmental, social, and governance dimensions.

iii. Financials

As shown in `heterogeneity_results.csv`, the financial sector's heterogeneity results, which include Goldman Sachs Group Inc., American Express Company, Banco Santander S.A., MetLife Inc., and MS&AD Insurance Group Holdings, revealed significant differences in the internal consistency of ESG KPI relationships across firms.

Significant heterogeneity in the correlations between ESG KPIs and the overall ESG score was found for Goldman Sachs Group Inc. ($Q = 30.803$, $p < 0.001$; $I^2 = 80.5\%$). As a result, a random-effects model was used. The company's ESG dimensions varied significantly in their association with overall ESG performance, especially between environmental and governance metrics, according to the pooled Spearman's correlation ($\rho = -0.356$), which showed a moderately unfavourable overall relationship.

Additionally, American Express Company demonstrated moderate heterogeneity ($Q = 12.321$, $p = 0.055$; $I^2 = 51.3\%$), which supported the use of a

random-effects model. While several ESG KPIs may positively correlate with overall performance, the internal variability among indicators remained somewhat high, according to the pooled correlation coefficient ($\rho = 0.113$), which showed a weak and statistically non-significant positive association.

Banco Santander S.A., on the other hand, showed total homogeneity ($Q = 0.962$, $p = 0.987$; $I^2 = 0\%$), supporting the application of a fixed-effects model. ESG KPIs were internally consistent but had little effect on overall ESG outcomes during the study period, according to the pooled correlation ($\rho = -0.043$), which showed a weak and insignificant negative relationship.

The results for MetLife Inc. revealed statistically significant heterogeneity ($Q = 14.663$, $p = 0.023$; $I^2 = 59.1\%$), and a random-effects model was used. A moderately negative overall link was shown by the pooled correlation ($\rho = -0.418$), suggesting that there were significant variances in the ways that different ESG KPIs contributed to overall ESG performance. This outcome draws attention to possible discrepancies in the efficacy or weighting of the company's governance and environmental programs.

Finally, the use of a fixed-effects model was supported by MS&AD Insurance Group Holdings' moderate and statistically non-significant heterogeneity ($Q = 8.946$, $p = 0.177$; $I^2 = 32.9\%$). The ESG KPIs and the overall ESG score showed a weak and insignificant negative association, as evidenced by the pooled correlation coefficient ($\rho = -0.055$), which reflected comparatively constant internal performance dynamics across sustainability aspects.

In essence, the financial sector showed a mixed heterogeneity pattern; some companies, like Santander and MS&AD Insurance, maintained more consistent ESG linkages, while others, like Goldman Sachs and MetLife, demonstrated significant internal variability that necessitated random-effects analysis. These findings imply that ESG integration in the financial industry differs greatly between companies, which may be due to variations in business strategies, the extent of sustainability reporting, and the relative importance of environmental, social, and governance factors.

iv. IT

As observed in `heterogeneity_results.csv`, the information technology (IT) sector's heterogeneity assessment, which included NVIDIA Corporation, Google LLC, and Intel Corporation, revealed varying degrees of internal consistency in the relationships between ESG KPIs and overall ESG performance.

The selection of a fixed-effects model for NVIDIA Corporation was supported by the heterogeneity statistics ($Q = 4.367$, $p = 0.627$; $I^2 = 0\%$), which showed total homogeneity among ESG measures. The firm's ESG KPIs and overall ESG score had a weak and statistically insignificant negative link, as indicated by the pooled Spearman's correlation ($\rho = -0.188$). This implies that although NVIDIA's ESG dimensions moved in a generally similar trend, there may have been imbalances between environmental and governance concerns because of the somewhat reversed direction of the correlation across metrics.

Google LLC, on the other hand, showed significant and statistically significant heterogeneity ($Q = 52.658$, $p < 0.001$; $I^2 = 88.6\%$), which called for the use of a random-effects model. Despite significant diversity among indicators, the company's ESG KPIs were strongly aligned with its overall ESG performance, according to the pooled correlation ($\rho = 0.922$), which showed a very strong positive link. With varying degrees of impact across KPI aspects, this pattern might reflect Google's long-standing focus on integrated sustainability measures across social inclusion, environmental efficiency, and governance transparency.

The adoption of a fixed-effects model was justified by Intel Corporation's perfect homogeneity ($Q = 1.962$, $p = 0.923$; $I^2 = 0\%$). The company's sustainability performance was largely consistent across environmental, social, and governance indicators, according to the pooled correlation coefficient ($\rho = 0.372$), which showed a modest and positive link between ESG KPIs and the overall ESG score.

In general, there were both homogenous and heterogeneous ESG-KPI interactions in the IT sector. Google came out with high heterogeneity and a large positive pooled correlation, suggesting the existence of significant but complementary ESG trends, whilst NVIDIA and Intel showed consistent internal alignment with little variability. These results suggest that the degree of ESG integration in the IT industry might fluctuate greatly based on the operational complexity and focus on various sustainability pillars of individual companies.

v. Consumer Discretionary

Nike Inc. was the only company in the consumer discretionary category; the heterogeneity results are shown in `heterogeneity_results.csv`. The company's ESG indicators were completely homogeneous, according to the heterogeneity test ($Q = 5.754$, $p = 0.451$; $I^2 = 0\%$), indicating internal consistency in the correlations between

specific ESG KPIs and the overall ESG score. As a result, it was decided that a fixed-effects model was suitable for interpretation.

Subsequently, there is a small to moderately positive association between the company's ESG KPIs and its overall ESG performance that was shown by the pooled Spearman's correlation coefficient ($\rho = 0.247$). This suggests that Nike's environmental, social, and governance sustainability policies were generally in line with one another, with gains in one area typically translating into improvements overall ESG performance.

Overall, the findings show that Nike maintained consistent ESG performance patterns across metrics, demonstrating a well-balanced incorporation of sustainability activities into its corporate operations. The lack of notable heterogeneity implies that the company's ESG indicators changed uniformly and consistently during the study.

In summary, the heterogeneity assessment revealed that the degree of internal consistency among ESG KPIs varied both across and within sectors. Companies with high heterogeneity, such as Goldman Sachs, Caterpillar Inc., and Google LLC, demonstrated diverse relationships between ESG dimensions and overall sustainability performance, suggesting multidimensional ESG structures. Conversely, firms such as Siemens AG, Merck & Co., and Nike Inc. exhibited highly homogeneous patterns, reflecting stable ESG integration across indicators. These insights provide an essential foundation for the subsequent predictive modelling and hypothesis testing in Section 4.6, where the strength and direction of these relationships are examined more rigorously.

4.6 Predictive Modelling

Predictive modelling was used after the heterogeneity evaluation to assess how well ESG key performance indicators (KPIs) could predict overall ESG performance across enterprises. This step used the cleaned dataset (`final_ESG_no_outliers.csv`) to evaluate the predictive power, dependability, and generalisability of various machine learning techniques.

Five techniques were used to capture both linear and non-linear correlations between ESG dimensions: Extreme Gradient Boosting (XGBoost), Random Forest, Decision Tree, Support Vector Regression (SVR), and Least Absolute Shrinkage and Selection Operator (LASSO regression). These algorithms; SVR for kernel-based generalisation in non-linear domains, Random Forest and XGBoost for reliable ensemble-based prediction, Decision Tree

for hierarchical rule extraction, and LASSO regression for linear feature regularisation were chosen for their unique methodological benefits.

The dataset was split temporally, using observations from 2017-2021 to train the model and 2022-2023 for testing and validation of their predictive performance. By ensuring that forecasts were assessed on unobserved data, this temporal division tested each model's capacity to extrapolate future ESG performance given previous-year KPI patterns. In essence, the actual observed ESG scores for the testing year were compared to the predicted ESG ratings produced by each model. Each algorithm's performance was evaluated using common regression diagnostics, such as the Root Mean Squared Error (RMSE), Mean Absolute Error (MAE), and Coefficient of Determination (R^2), to determine predicted accuracy. Together, these measures measure the prediction accuracy, consistency, and explanatory power of the models.

Therefore, to identify the best predictive strategy for ESG performance forecasting, a comparison of model performance is conducted after the results for each model are presented and interpreted separately in the following subsections.

4.6.1 Individual Model Results

The results for each model are summarised and interpreted in the following subsections, starting with LASSO regression and moving on to Decision Tree, Random Forest, XGBoost, and Support Vector Regression (SVR) before a cross-model performance comparison. This structure allows a systematic interpretation of each algorithm's predictive behaviour, highlighting their relative strengths and limitations in forecasting sustainability trajectories across Multinational Companies.

Prior to the result, all predictive models were implemented and estimated using the R statistical software environment. Following data cleaning and outlier removal, all ESG predictor variables were standardised using z-score normalisation to ensure comparability across different measurement scales and to facilitate convergence of optimisation-based models. The dataset was then temporally partitioned into a training sample (observations up to 2021) and a testing sample (observations from 2022 onwards), enabling an out-of-sample evaluation of predictive performance. Predictor variables were structured as numeric matrices where required, while the dependent variable—corporate sustainability performance (CSP), proxied by the LSEG ESG score—was retained in its original scale for model estimation and evaluation.

Five predictive models were subsequently estimated in R. First, LASSO regression was implemented using cross-validated regularisation to identify the optimal penalty parameter and to perform simultaneous coefficient estimation and variable selection. Second, a decision tree model was estimated using recursive partitioning to capture non-linear relationships between ESG indicators and CSP. Third, a random forest model was trained by constructing an ensemble of decision trees based on bootstrap sampling and random feature selection at each split, improving predictive robustness and reducing variance. Fourth, XGBoost was implemented as a gradient boosting framework that iteratively minimises prediction error through sequential tree construction and learning-rate control. Finally, support vector regression (SVR) was applied using a margin-based optimisation approach to model potentially complex and non-linear associations between ESG indicators and CSP.

Lastly, each model predictions were generated for the test dataset and evaluated using multiple performance metrics, including the root mean squared error (RMSE), mean absolute error (MAE), and coefficient of determination (R^2), all computed in R. Subsequently, the results for each model are summarised and interpreted in the following subsections, beginning with LASSO regression and proceeding to decision tree, random forest, XGBoost, and support vector regression (SVR), before concluding with a cross-model performance comparison.

1. LASSO regression

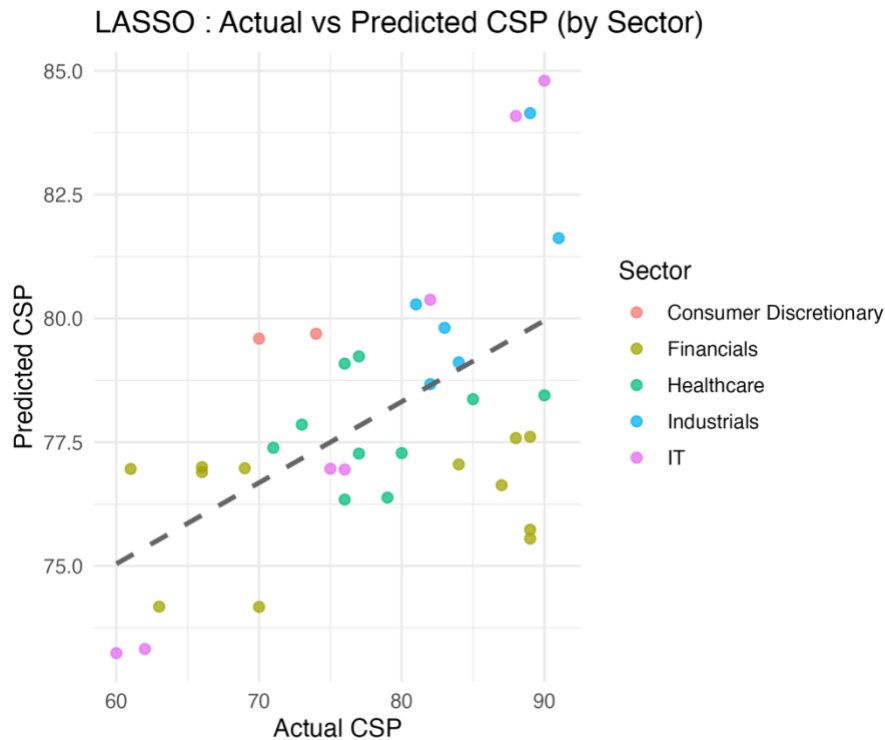


Figure 16 Actual vs Predicted for LASSO regression

Industrials: 3M Company, Caterpillar Inc., and Siemens

For all three companies, the model produced predicted ESG scores that closely approximated the actual reported values for 2022–2023, with deviations ranging between 3–10 points.

3M Company's sustainability performance was slightly underestimated by the model (Actual: 91 in 2022; Predicted: 81.65; Actual: 89 in 2023; Predicted: 84.51). Caterpillar Inc. exhibited comparable conduct, with actual ESG scores (83 and 81) slightly higher than expected values (79.93 and 80.43). With changes of roughly 3–5 points between the two testing years, Siemens AG showed the smallest prediction gap and relatively higher predictive precision.

Healthcare: Amgen, Merck & Co., UnitedHealth Group, AbbVie, Novartis

Amgen Inc. demonstrated sustained performance stability and a dependable model fit, as seen by the tight alignment between actual and anticipated ESG scores over both testing years (Actual: 77–80; anticipated: 77.27–77.28). While UnitedHealth

Group reported a minor underprediction (Actual: 79–76; Predicted: 76.28–76.25), Merck & Co. displayed a modest overestimation trend (Actual: 76–77; Predicted: 79.15–79.33), indicating balanced but firm-specific variances in ESG indicator influence.

Novartis AG and AbbVie Inc. showed larger prediction gaps. Compared to projections (77.36–77.89), AbbVie's actual ESG ratings were lower (71–73), suggesting possible model overfitting or a reduced sensitivity to company-specific ESG changes. In a similar vein, Novartis displayed a greater deviation (Actual: 90–85; Predicted: 78.46–78.54), which may indicate nonlinear dynamics between its ESG KPIs and overall ESG performance that were not well captured by the linear LASSO regression model.

Financials: American Express, Goldman Sachs, Allianz, MetLife, MS&AD Insurance, and Santander

With predicted scores (76.57–77.04) that were somewhat lower than the actual ESG ratings (87–84), Goldman Sachs showed the smallest divergence of the group. This suggests that although the model successfully captured directionality, it somewhat underestimated the firm's high ESG performance levels. Predictions (≈ 77) for both American Express and Allianz were regularly lower than actuals (66–69 for American Express and 88–89 for Allianz). The linear shrinkage effect of the LASSO regression model, which lowers variance at the price of exact magnitude accuracy, is shown in this alignment across firms.

Similar behaviour was displayed by MetLife and MS&AD Insurance, with actual scores (61–70) surpassing expected ones (73.83–76.95), but prediction gaps remained largely consistent between years. This consistency shows the model's dependability in preserving temporal stability, but it also shows that it is not very sensitive to sudden changes in ESG scores from year to year.

On the other hand, Santander demonstrated a comparable trend of underestimations, with projected ESG scores of around 75.56 and 75.36, while the actual scores were 89 for both 2022 and 2023. The significant and consistent discrepancy in predictions indicates that the LASSO model struggled to fully account for the elements influencing Santander's relatively impressive ESG performance, possibly due to the coefficient shrinkage effect of the model, which often biases predictions toward the overall average.

IT: NVIDIA, Compal Electronics, Google, and Intel

The LASSO regression model showed very constant predictive accuracy with consistent underestimate across enterprises in the information technology industry, which includes NVIDIA Corporation, Compal Electronics, Google LLC, and Intel Corporation. The actual and anticipated ESG ratings for NVIDIA Corporation were highly aligned (Actual: 76–75; anticipated: 76.93–76.95), suggesting that the model accurately and minimally represented the company's performance trend.

With predicted scores (≈ 72.8 –72.7) exceeding actual values (62–60), Compal Electronics showed mild overprediction, indicating that the company's lower ESG performance levels may have been oversmoothed by LASSO regression's linear regularisation. Predictions for Google LLC were only available for 2022 (Actual: 82; Predicted: 80.45), but large variances in ESG KPI reporting in 2023 caused the data to be omitted during outlier reduction. Despite this, the model showed a near approximation for the year that was provided, suggesting accurate performance within reasonable data bounds.

Similar consistent but moderate underestimate was seen in Intel Corporation's forecasts (Actual: 90–88; Predicted: 85.16–84.38), which reflects LASSO regression's propensity to compress variability and prioritise overall linear fit. The results for the IT sector indicate that although the LASSO regression model is good at identifying broad trends in ESG performance, its linear penalty structure may underestimate volatility among companies with quick cycles of innovation or shifting sustainability practices.

Consumer Discretionary: Nike Inc.

The LASSO regression model showed a moderate overestimation tendency in the consumer discretionary category, which was only represented by Nike Inc. The actual observed values (74 and 70, respectively) were consistently lower than the expected ESG scores (≈ 79.7 for both 2022 and 2023). This pattern suggests that while the model accurately depicted the overall trend of Nike's sustainability performance, it slightly overstated its scope.

The linear shrinkage effect of LASSO regression, which seeks to smooth temporal fluctuations in exchange for model stability, is reflected in the limited variation between the projected scores over years. This result implies that the regularisation requirement of the LASSO regression model may have less sensitivity to

short-term performance decreases, even though Nike's ESG performance trajectory was successfully approximated.

In conclusion, the LASSO regression model successfully captured the overall trend of company ESG performance and showed a generally high degree of predictive stability and consistency across sectors. The findings showed that, because to the intrinsic bias of LASSO regression's linear shrinkage mechanism, the model tended to somewhat underestimate higher ESG performance (like Siemens, Goldman Sachs, and Intel) and overestimate worse performers (like Compal Electronics and Nike Inc.). The model prioritised generalised linear trends by penalising less significant ESG indicators, improving stability at the expense of sensitivity to sudden changes in performance or firm-specific volatility.

Industrials and healthcare companies showed continuous year-over-year consistency and the highest predictive agreement between actual and anticipated ESG scores. The financial and IT industries, on the other hand, displayed larger prediction gaps, suggesting that their ESG dynamics might entail more intricate, non-linear interactions than LASSO regression's linear approximation. However, the model successfully preserved temporal coherence, generating consistent projections for 2022 and 2023 for most companies.

All things considered, these findings show that LASSO regression is a reliable baseline model for comprehending linear relationships between ESG KPIs and overall sustainability performance. Its propensity to smooth extreme changes, however, raises the possibility that later models with non-linear learning capabilities such as Decision Tree, Random Forest, and XGBoost, may be able to capture more complex and dynamic ESG–CSP relationships in later phases of research.

2. Decision Tree

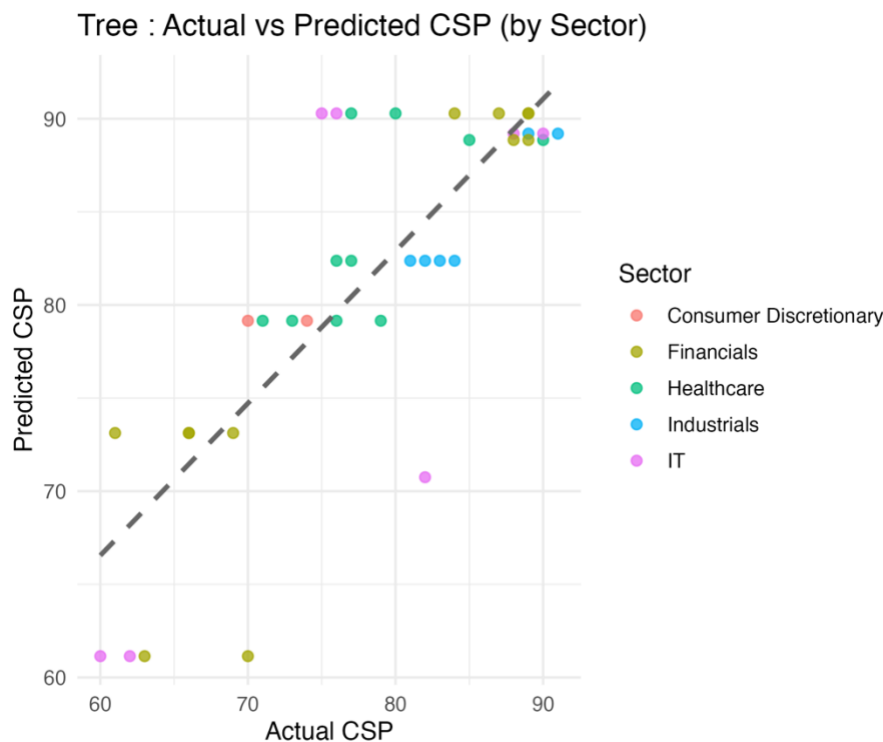


Figure 17 Actual vs Predicted for Decision Tree

Industrials: 3M Company, Caterpillar Inc., and Siemens

The Decision Tree model generated predicted ESG scores for all three industrial businesses that were extremely close to the actual reported values for 2022–2023, with variations typically lying within a small range of 0–3 points. This suggests that the model was successful in capturing the predominant ESG performance patterns for businesses in this industry.

The 3M Company showed the best match between actual and expected values. For both years, the model produced identical predictions (Predicted: 89.2), which nearly matched the actual scores of 89 in 2023 and 91 in 2022. This small underestimation implies that the model accurately and minimally depicted 3M's steady ESG trajectory.

Similarly, among the three companies, Siemens AG showed the least predicted discrepancy. With constant projected scores of 82.38 and actual scores of 82 and 84, the model's output demonstrated a high predictive precision and a great match. Siemens' ESG performance pattern appears to have been particularly well-suited to the rule-based structure of the Decision Tree, based on the close alignment.

Healthcare: Amgen, Merck & Co., UnitedHealth Group, AbbVie, Novartis

In the healthcare industry, the Decision Tree model yielded more inconsistent results, with companies exhibiting a combination of overestimation and minor underestimating. Healthcare organisations showed larger variances, indicating more complicated or less linear ESG performance behaviours, in contrast to the industrial sector where expectations stayed well matched.

In the industry, Amgen Inc. displayed the biggest prediction gap. For both 2022 and 2023, the model consistently projected an ESG score of 90.29, which was significantly higher than Amgen's stated actual values of 77 and 80. This trend raises the possibility that Amgen's sustainability performance was overestimated since the Decision Tree overgeneralised several ESG feature splits.

Merck & Co., on the other hand, showed a more moderate overprediction trend. The model somewhat overestimated the company's ESG performance, but it stayed within a reasonable range, with actual scores of 76–77 and predicted values fixed at 82.38. This suggests that the rule-based classifications in the model and Merck's ESG KPIs are more consistently aligned.

Among healthcare companies, UnitedHealth Group showed one of the best fits. With only slight differences of less than three points, the actual values (79 and 76) were extremely near to the model's predicted score of 79.15. This implies that the decision boundaries of the Decision Tree were in good alignment with the company's ESG trajectory.

Furthermore, AbbVie Inc. showed a similar pattern, albeit with a greater discrepancy between actual (71–73) and anticipated (79.15) scores. The model may have caught sector-level ESG trends but was less sensitive to AbbVie's firm-specific variances, according to the persistent overprediction.

Lastly, Novartis AG showed comparatively high predictive conformance. The model estimated the company's performance with slight variances (2-4 points), with actual values of 90 and 85 and a forecast value of 88.86 for both years. This implies that the hierarchical splits that the Decision Tree learnt accurately reflected Novartis' ESG profile.

Financials: American Express, Goldman Sachs, Allianz, MetLife, MS&AD Insurance, and Santander

For most companies in the financial sector, the Decision Tree model consistently overestimated, with only one company exhibiting a minor underprediction. The model's rule-based divides reflected sector-level ESG patterns but were less sensitive to firm-specific variations inside financial institutions, as evidenced by the variances, which ranged from mild (3–7 points) to more significant for specific companies (10–12 points). This is in accordance with the enormously diverse and frequently non-linear ESG systems found in the banking sector, where KPI practices and disclosure depth vary greatly between companies.

Among the group, Goldman Sachs and Santander had the most overestimations. In both years, Goldman Sachs' forecasted ESG scores of 90.29 exceeded the actual scores of 87 and 84 by three to six points. In a similar vein, Santander had consistent forecasts of 90.29 in 2022 and 2023, which were marginally higher than its actual readings of 89. Conversely, Allianz demonstrated one of the strongest predictive alignments in the industry, with small variances between the company's actual scores (88–89) and expected values (≈ 88.86).

MetLife and American Express showed more noticeable overestimations. Over the course of the two testing years, the model consistently predicted scores of 73.13 for both companies; however, actual values were significantly lower (69–66 for American Express and 66–61 for MetLife). These persistent gaps imply that the model was insensitive to year-to-year variations or firm-specific reductions in sustainability performance, generalising the ESG profile for mid-performing financial organisations. The only instance of continuous underprediction, on the other hand, was MS&AD Insurance, whose forecasted scores of 61.14 fell short of actual values of 63–70. This pattern suggests that the model's preset decision rules did not adequately account for the company's positive ESG movements.

Lastly, Santander demonstrated one of the most consistent predictive outcomes within the financial sector. Consequently, the model produced identical ESG score predictions of 90.29 for both 2022 and 2023, while the actual ESG ratings remained stable at 89 in both years. This resulted in only a marginal overestimation of approximately 1.29 points across the testing period. The close correspondence between the predicted and observed scores suggests that Santander's ESG performance closely aligned with the sector-level decision rules learned by the model. Furthermore, the company's stable ESG ratings over consecutive years indicate relatively consistent

sustainability performance, enabling the Decision Tree model to accurately capture its overall ESG trajectory despite the slight positive bias in the predictions.

Ultimately, the Decision Tree model showed moderate accuracy in magnitude for the financial sector, but it also showed clear temporal consistency among projections. The model tended to smooth variability, slightly underestimating abrupt improvements while overestimating mid- and lower-performing enterprises. This illustrates how Decision Trees are limited in their ability to provide generally consistent directional insights across time while capturing complex and diversified ESG practices among financial organisations.

IT: NVIDIA Corp., Compal Electronics, Google and Intel

Depending on the company, the Decision Tree model's predictive performance varied throughout the IT industry, showing a mix of significant overestimation, close alignment, and little underprediction. The sector's varied sustainability structures are reflected in this variety, with some businesses following steady ESG trajectories and others displaying more erratic or non-linear performance patterns.

The model predicted a constant score of 90.29 for both testing years, and NVIDIA Corporation had the biggest overestimation among the IT group. There were discrepancies of roughly 14–15 points because the actual ESG ratings were much lower (76 and 75). This significant discrepancy suggests that NVIDIA's ESG traits would not match the model's learnt decision bounds, indicating possible sector-level generalisation rather than firm-specific accuracy.

Compal Electronics, on the other hand, showed the best agreement between actual and anticipated scores. For both years, the model's projected value of 61.14 closely matched the actual values of 62 and 60. This small variation implies that Compal's comparatively constant and moderate ESG performance profile was correctly represented by the Decision Tree.

Due to data exclusions made during outlier filtering, Google LLC could only provide forecasts for 2022. The actual score for 2022 was 82, whereas the model anticipated a score of 70.75. Due to the company's more complicated or non-linear sustainability behaviour, Google's ESG performance appears to deviate from the more general patterns the model prioritised, as indicated by this underprediction of roughly 11 points.

One of the industry's most accurate forecast patterns was shown by Intel Corporation. With only slight differences of 1-2 points, the predicted scores (89.20 for both years) closely matched the actual ESG values (90 and 88). This robust alignment suggests that the Decision Tree model successfully captured a consistent and organised pattern in Intel's ESG performance.

Consumer Discretionary: Nike

Throughout both testing years, the Decision Tree model consistently produced an overestimation pattern for the consumer discretionary sector, which is only represented by Nike Inc. In 2022 and 2023, Nike's reported ESG values were 74 and 70, respectively, while the predicted ESG scores stayed at 79.15.

This led to variances of roughly 5 points in 2022 and 9 points in 2023, suggesting that the model overestimated Nike's performance level while capturing the general trend of the company's ESG trajectory. The forecasts' consistency over time indicates that the Decision Tree model identified a comparatively stable ESG structure for Nike but was insensitive to the company's annual variations or performance drops.

3. Random Forest

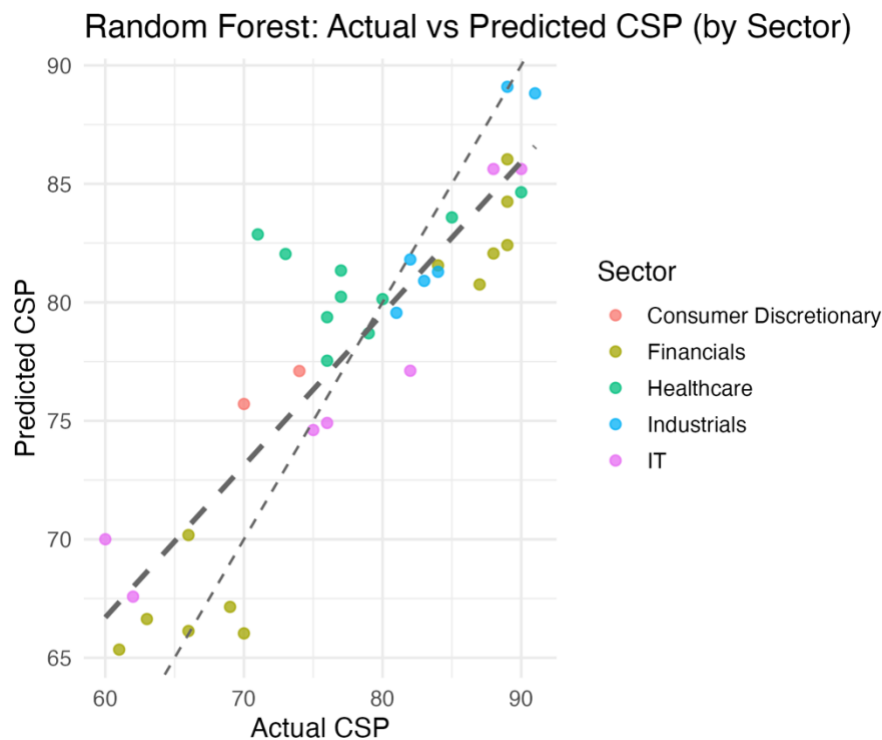


Figure 18 Actual vs Predicted for Random Forest

Industrials: 3M Company, Caterpillar Inc., and Siemens

Within the industrial sector, the Random Forest model showed high predictive alignment, with anticipated ESG scores for 2022–2023 nearly matching reported values. The ensemble model successfully captured the predominant ESG performance trends that define this industry, as evidenced by the moderate variations across all three companies, which were usually within 2–5 points.

In both years, the forecasts for 3M Company shown a high level of accuracy. While the model generated a virtually perfect approximation in 2023 (Actual: 89; Predicted: 89.80), the actual ESG score of 91 in 2022 was somewhat overestimated at 88.15. This close match indicates that Random Forest used its ability to capture non-linear connections across KPIs to effectively simulate 3M's comparatively steady and predictable ESG performance.

Although still within a reasonable range, Caterpillar Inc. showed a slightly wider prediction gap. Although the model captured the overall performance trend, it somewhat smoothed Caterpillar's year-to-year variance, as evidenced by the somewhat underestimated actual scores of 83 and 81 (predicted: 79.74 and 79.24). In a similar vein, Siemens AG underperformed in both years, with real values (82 and 84) above predicted ones (81.34 and 80.98). The approach may be a little conservative for companies whose ESG scores shift somewhat upward over time, according to the consistent direction of error. However, the strong fit shown by the close clustering of projected values supports Random Forest's applicability for simulating ESG dynamics in industrial companies.

Healthcare: Amgen, Merck & Co., UnitedHealth Group, AbbVie, Novartis

Companies in the healthcare industry showed a mix of near alignment, modest overestimation, and consistent directional trends in the Random Forest model's predictive accuracy. For companies like UnitedHealth Group and Merck & Co., the ensemble model successfully represented the overall ESG trajectory; however, AbbVie and Novartis showed more gaps, suggesting more intricate ESG dynamics inside specific healthcare organisations.

With predicted ESG ratings (≈ 81.13 – 81.35) higher than actual values of 77 and 80, Amgen Inc. demonstrated a moderate overprediction. The consistent upward bias implies that the model slightly overestimated Amgen's sustainability performance, even

though the deviations stayed within a reasonable range (about 1-4 points). This could be due to stable KPI patterns that the model interpreted as stronger than the final ESG ratings indicated. With predicted values (78.78–79.58) slightly higher than observed scores (76–77), Merck & Co. showed a similar but milder trend, suggesting that Random Forest accurately captured the general structure of Merck's ESG behaviour.

One of the closest fits in the sector was UnitedHealth Group. The actual scores of 79 and 76 closely matched the anticipated values of 79.20 and 77.56, indicating that the model successfully identified the company's ESG trajectory and underlying KPI correlations. AbbVie, on the other hand, showed a greater prediction gap, with actual scores (71–73) significantly lower than expected values (≈ 80.43 –80.60). AbbVie's ESG performance may have featured firm-specific changes or variable KPI behaviours that the model's aggregated decision structure was unable to completely capture, as suggested by this consistent overestimation.

Novartis AG showed the most pronounced deviation among healthcare firms, with actual ESG scores of 90 and 85 substantially exceeding predicted values (≈ 82.30 –83.09). These differences suggest that Novartis experienced strong positive ESG outcomes that were not fully reflected in KPI patterns from prior years, making them harder for the model to anticipate. Overall, healthcare results indicate that while Random Forest can model broad ESG performance trends, certain firms' more volatile or non-linear sustainability trajectories introduce prediction challenges that may require even more flexible or complex modelling approaches.

Financials: American Express, Goldman Sachs, Allianz, MetLife, MS&AD Insurance, and Santander

In the financial sector, the Random Forest model yielded reasonably accurate forecasts, with prediction errors generally ranging from less than one point to approximately nine points across the testing period. Nonetheless, there were still noticeable overestimations and underestimations, which reflected the various and occasionally nonlinear ESG systems seen in financial organisations.

With predicted scores of roughly 81.38 and 81.64 and actual values of 87 and 84, Goldman Sachs had one of the closest alignments in this group. Even though the model underestimated the company's ESG performance by three to six points, the forecasts stayed directionally consistent over time, indicating that the model was able to capture the firm's overall performance trajectory even while it dampened its higher

ESG scores. In 2022, American Express's ESG score was moderately underestimated (Actual: 69; Predicted: 68.69); while, in 2023, the model slightly overestimated the company's ESG score (Actual: 66; Predicted: 71.04).

Prediction differences were greater for Allianz and Santander, especially in 2023. While actual values for Allianz stayed high (88–89), forecasted values decreased from 85.07 in 2022 to 81.95 in 2023. This led to underpredictions of three to seven points, indicating that the model might not have adequately accounted for changes in the company's ESG baseline from year to year. Santander displayed a similar trend: actual scores stayed constant at 89 in both years, whereas predicted scores decreased from 85.88 to 80.27.

Consequently, among financial companies, MetLife and MS&AD Insurance showed the most alignment. For MetLife, the actual values of 66 and 61 nearly matched the anticipated scores, which were closely grouped around 65–65.8. With variations of three to four points between the two years, MS&AD Insurance demonstrated marginally better prediction stability. These findings imply that among mid-range performers with less erratic KPI trajectories, Random Forest successfully captured the ESG signal.

Lastly, Santander exhibited a consistent pattern of underprediction across both testing years. Although the company's actual ESG score remained stable at 89 in both 2022 and 2023, the Random Forest model predicted lower values of 85.88 and 80.27, resulting in underestimations of approximately three and nine points, respectively. The larger prediction error in 2023 suggests that the model was less responsive to Santander's sustained ESG performance over time, instead producing forecasts that regressed towards the sector average. Nevertheless, the model correctly reflected the absence of substantial year-to-year fluctuations in the company's ESG trajectory, indicating that it captured the overall stability of Santander's sustainability performance despite underestimating its magnitude.

IT: NVIDIA Corp., Compal Electronics, Google and Intel

The Random Forest model demonstrated a generally strong predictive alignment within the information technology sector, with most enterprises displaying minor and directionally consistent discrepancies between actual and anticipated ESG scores. For NVIDIA and Intel, the model successfully captured steady ESG trends; however, results for companies like Compal Electronics showed slightly bigger differences

because of more fluctuating KPI behaviours. Overall, the findings point to the ensemble approach's dependable performance in an industry with relatively structured yet innovation-driven sustainability trends.

One of the best fits in the industry was shown by NVIDIA Corporation. Predictions for both years (≈ 74.88 – 76.65) yielded extremely slight variations (1-2 points) from the company's actual scores of 76 and 75. This consistency shows that NVIDIA's ESG performance adhered to a stable KPI structure that matched the non-linear decision routes of the Random Forest model. There was also a close alignment for Google LLC, for which forecasts were only available in 2022: the model predicted a score of 78.05 compared to an actual result of 82. Given that Google's 2023 data was eliminated owing to outlier reduction, this slight underprediction represents an overall accurate trend capture.

Intel Corporation demonstrated comparable high prediction accuracy. With slight underestimations of 2-4 points, the anticipated ESG scores (≈ 86.24 – 86.40) roughly matched the actual values (90 and 88). This implies that Random Forest was able to successfully generalise from previous year's KPI behaviour because Intel's ESG indicators consistently contributed to its ultimate ESG grade. Compal Electronics, on the other hand, displayed a far greater deviation, with the model overestimating its performance by 4–10 points (Actual: 60–62 vs. Predicted: ≈ 66.61 – 69.66). This trend suggests that Compal's underlying ESG indicators might show anomalies or non-linear movements that the aggregated trees in the model only partially captured.

When analysed together, the IT sector results show that Random Forest works best when businesses have organised, rather steady ESG practices, like NVIDIA and Intel. Wider prediction gaps are introduced by companies with more unpredictable or variable year-to-year KPI dynamics, such as Compal Electronics. This suggests that sector-level accuracy could be improved by refining the model or adding more ESG features.

Consumer Discretionary: Nike

The Random Forest model showed good predictive stability with comparatively minor differences between actual and anticipated ESG scores for the consumer discretionary sector, which is only represented by Nike Inc. Nike's reported ESG performance (74 and 70) was consistently lower than the expected values (≈ 75.16 in 2022 and ≈ 75.08 in 2023), leading to slight overestimations of roughly 1 point in 2022 and 5 points in 2023.

This pattern suggests that while the model did a good job of capturing Nike's overall sustainability performance trend, it exaggerated the company's trajectory. Random Forest identified a rather stable underlying ESG structure for Nike, driven by moderate and persistent KPI patterns seen during the training phase, according to the consistent forecasted values across both years. Nevertheless, there was a greater forecast gap in the second testing year since the model seemed less sensitive to the drop in Nike's real ESG performance in 2023.

All things considered, Random Forest offered a dependable and directionally accurate estimate of Nike's ESG performance with a moderate size error.

4. XGBoost

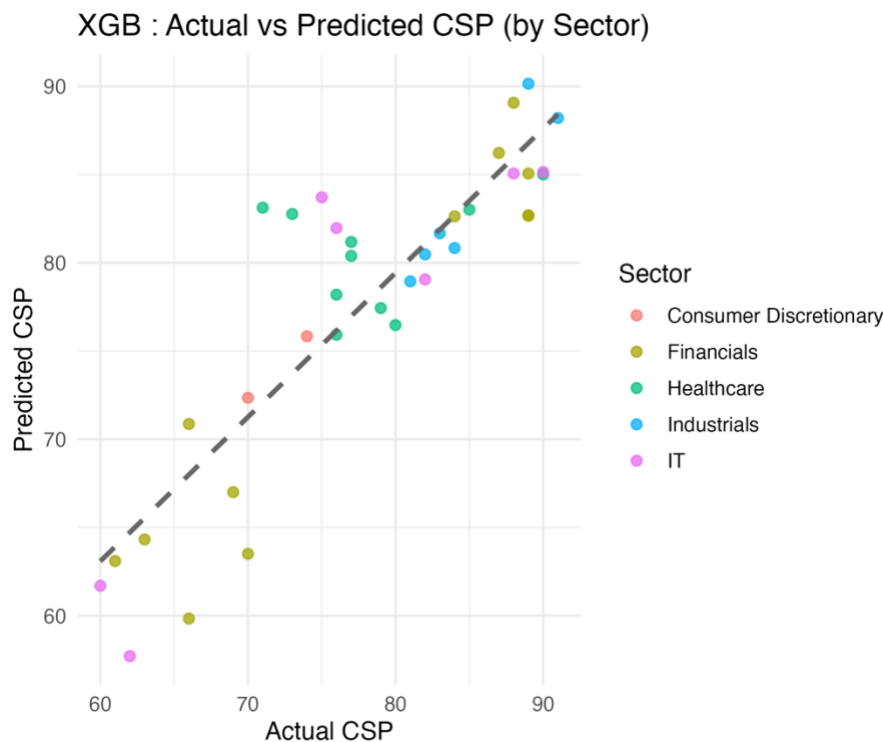


Figure 19 Actual vs Predicted for XGBoost

Industrials: 3M Company, Caterpillar Inc., and Siemens

The XGBoost model produced predictions for the industrial sector that were largely in line with the three companies' actual ESG scores, with variations often falling between one and four points. This illustrates how well the model captures the non-linear dynamics of ESG performance in this industry.

Among the algorithms examined, XGBoost generated some of the most accurate forecasts for 3M Company. The model somewhat overestimated performance in 2023 (Actual: 89; Predicted: 90.15) and underestimated the actual ESG score in 2022 (Actual: 91; Predicted: 88.20). These small variations show that XGBoost did a good job of capturing the company's steady sustainability trajectory and adapting to minor changes in direction over time.

Similar behaviour with minimal prediction gaps was shown by Caterpillar Inc. The algorithm once more maintained a close approximation in 2023 (Actual: 81; Predicted: 78.95). In 2022, the predicted score (81.68) was extremely close to the actual figure of 83. These findings imply that Caterpillar's ESG pattern was correctly

identified by XGBoost, but with a small underestimation, possibly because of the model's smoothing effect on firm-specific fluctuations.

Particularly for 2022, when the difference was small (Actual: 82; anticipated: 80.48), Siemens AG's anticipated values and actual scores demonstrated a high alignment. Siemens' actual performance increased somewhat to 84 in 2023 compared to the model's prediction of 80.84, which led to a little underestimation.

Healthcare: Amgen, Merck & Co., UnitedHealth Group, AbbVie, Novartis

The XGBoost model showed mixed predictive accuracy in the healthcare industry, resulting in a mix of substantial overestimations and mild underestimations among organisations. The healthcare industry's more complex and non-linear sustainability dynamics are reflected in the model's varying degrees of accuracy in capturing the greater variability in ESG performance patterns that the healthcare companies demonstrated when compared to the industrial sector.

The model produced forecasts for Amgen Inc. that deviated marginally from the actual values in both directions. While XGBoost underestimated Amgen's enhanced performance in 2023 (Actual: 80; Predicted: 76.47), it somewhat overestimated the company's ESG score in 2022 (Actual: 77; Predicted: 81.18). This reversal implies that the company's ESG adjustments did not entirely correspond with the learnt patterns of the model, maybe because of sudden or firm-specific swings in KPI focus.

The model continuously overestimated sustainability performance in both years for Merck & Co., exhibiting the reverse pattern. The model inferred greater ESG contributions from Merck's KPIs than was reflected in its overall ESG rating, as evidenced by the predicted values (78.19 in 2022 and 80.39 in 2023) above the actual scores (76 and 77).

With only 1–3-point variances, the model's forecasts for UnitedHealth Group were comparatively close to actual data. Predicted scores of 77.43 and 75.92 were close to actual scores of 79 and 76. UnitedHealth is one of the better-fitting healthcare instances because of its close alignment, which indicates that the company's ESG performance followed a steady trajectory that the model could accurately capture.

However, among the healthcare group, AbbVie Inc. showed the biggest predicted disparity. The model's projected values (82.77 and 83.12) were much higher than the actual ESG scores (73 and 71), indicating overestimations of more than 10 points in both years. This suggests that XGBoost's estimated non-linear patterns or

sector-level trends were significantly different from AbbVie's ESG performance, indicating either uncommon firm-specific behaviour or KPI-to-score correlations that the algorithm was unable to easily capture.

In a similar vein, Novartis AG likewise showed signs of moderate overprediction. The model anticipated ESG scores of 85.01 in 2022 and 83.01 in 2023, whereas the corresponding actual values were 90 and 85, showing a 5–7 point underestimation. The disparities indicate that the model's natural smoothing tendencies slowed Novartis' upward ESG momentum, while being less severe than AbbVie.

Financials: American Express, Goldman Sachs, Allianz, MetLife, MS&AD Insurance, and Santander

In the financial industry, the XGBoost model's forecast accuracy varied, resulting in a mix of slight overestimations and moderate underestimations. This variability reflects the sector's intricate ESG frameworks, where risk and governance-related KPIs usually have a greater impact than environmental or social indicators, making prediction more difficult for generalised non-linear models.

One of the closest alignments in the industry was shown by Goldman Sachs. The model's 2023 value (82.63) came within two points of the actual score of 84, and its 2022 prediction (86.23) nearly matched the actual score of 87. These comparatively tiny deviations show that Goldman Sachs' ESG trajectory was successfully captured by the model, most likely because of the company's performance showing steady and predictable patterns that complement XGBoost's feature-interaction learning.

With variances of about 6–7 points, the model consistently underestimated Banco Santander in both years (Actual: 89; Predicted: 82.66–85.06). This suggests that Santander's real ESG performance was higher than what XGBoost deduced from its KPI inputs, indicating unique sustainability practices unique to the company that are not adequately represented by the sector-wide trends.

With underpredictions of 6–7 points in both years (Actual: 66–61; Predicted: 59.84–63.09), MetLife displayed one of the worst discrepancies in the financial category. The ongoing undervaluation suggests that MetLife's ESG performance might have special risk-governance or social elements that the model does not give enough weight to. However, MS&AD Insurance showed substantial variations but comparatively close alignment. The projected values for 63 and 70 were 64.32 and 63.50, respectively. A comparatively constant but somewhat flattened trajectory is

indicated by the minor overestimation in 2022 and underestimating in 2023, which reflects XGBoost's propensity to prioritise overall patterns while narrowing extremes.

Consequently, American Express showed a relatively strong alignment in its predictions, although the model fluctuated between slight underestimations and overestimations. The predicted ESG score of 67.00 for 2022 was close to the actual score of 69, while the 2023 prediction of 70.86 was higher than the actual score of 66. These moderate discrepancies indicate that the model effectively captured the company's overall ESG trend, though some variations specific to individual years were not entirely reflected in the forecasts.

Lastly, Allianz displayed varied predictive accuracy over the two years. In 2022, the model fell short in estimating the company's ESG score (Actual: 89; Predicted: 82.69), but it produced a very precise prediction in 2023 (Actual: 88; Predicted: 89.07). This implies that while certain elements of Allianz's ESG performance were not fully accounted for in 2022, the model was able to accurately represent its performance in the following year.

IT: NVIDIA Corp., Compal Electronics, Google and Intel

Within the IT industry, the XGBoost model showed generally high predictive alignment; nevertheless, there were some noticeable firm-specific variations that are indicative of the industry's varied sustainability policies and quick technical advancement. Overall, the model did a good job of capturing the directionality of ESG performance, while different companies showed different degrees of magnitude accuracy.

In both testing years, XGBoost somewhat overestimated ESG scores for NVIDIA Corporation. The model predicted 81.97 in 2022 compared to an actual score of 76, and 83.71 in 2023 compared to an observed score of 75. These 6–9 point variances imply that non-linear KPI effects that beyond the model's learnt patterns may be involved in NVIDIA's quickly changing ESG commitments, particularly in areas like energy-intensive AI operations. The system read NVIDIA's KPI trends as indicators of better sustainability performance than what was shown in the final ESG ratings, as seen by the persistent upward bias.

Compal Electronics, on the other hand, had an inverted pattern but a closer alignment. In 2022 (predicted: 57.70 vs. actual: 62) and 2023 (predicted: 61.69 vs. actual: 60), the model's accuracy was slightly higher. These minor differences show

that Compal's comparatively steady and less erratic sustainability profile was effectively captured by XGBoost. The model's ability to adapt to slow changes in KPIs without overfitting is reflected in the little variations across years.

Due to the exclusion of outliers for 2023, estimates for Google LLC were only available for 2022. The model produced a forecast of 79.06, which is extremely near to the actual score of 82, suggesting a slight underestimating of about 3 points. This implies that XGBoost accurately caught the overall trend in the available year despite the complexity of Google's ESG framework, particularly its lofty ambitions for diversity and renewable energy.

Among the IT category, Intel Corporation showed one of the best predictive alignments. In 2022 and 2023, the model predicted scores of 85.15 and 85.06, respectively, compared to 90 and 88, respectively. For both years, deviations stayed between three and five points, indicating that the model successfully represented Intel's steady and well-researched ESG performance trend.

Consumer Discretionary: Nike

The XGBoost model showed high predictive alignment for the consumer discretionary sector, which is only represented by Nike Inc., with very slight differences between actual and anticipated ESG scores. In 2022, there was a little overestimation of less than two points, with the model estimating a score of 75.84 as opposed to the actual number of 74. In a similar vein, the model's prediction of 72.35 in 2023 was marginally lower than the actual score of 70, resulting in a divergence of just over two points.

These consistently narrow discrepancies across both years indicate that XGBoost captured Nike's sustainability trajectory with a relatively high level of precision. The model's boosted-tree architecture appears to have effectively learned Nike's ESG KPI patterns, particularly its environmental and governance indicators while still smoothing out year-to-year fluctuations. This is consistent with Nike's relatively stable reporting practices and progressive improvements across select ESG dimensions.

5. SVR (Support Vector Regression)

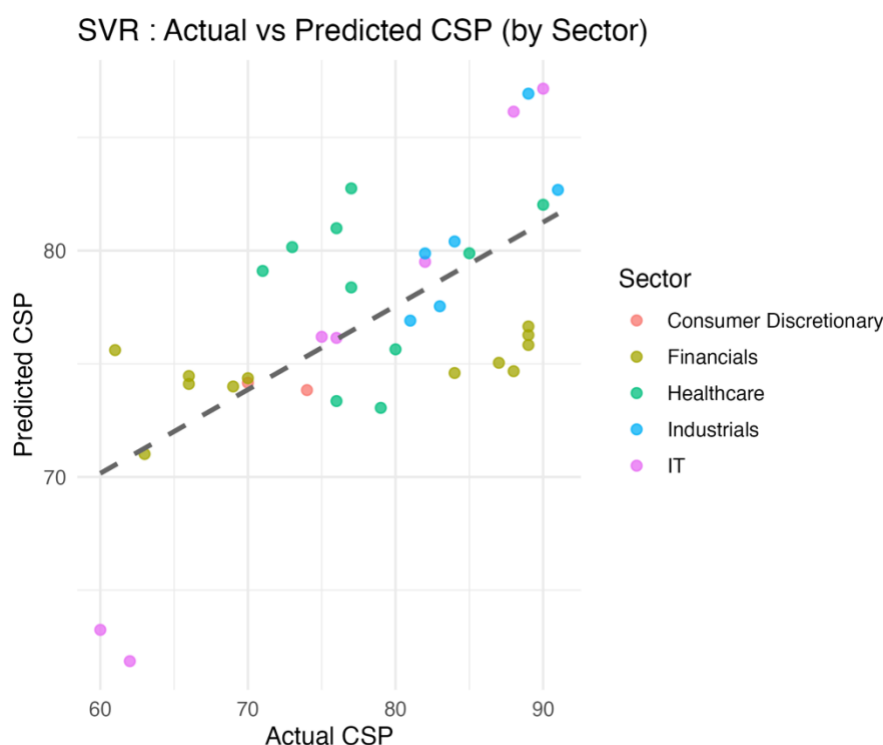


Figure 20 Actual vs Predicted for SVR

Industrials: 3M Company, Caterpillar Inc., and Siemens

The Support Vector Regression (SVR) model yielded directionally consistent forecasts for the industrial sector, although all three companies exhibited a moderate underestimate. Although the model caught the overall performance pattern, it tended to impose a smoothing effect typical of margin-based regression techniques, as evidenced by the differences between actual and anticipated ESG scores, which ranged from 4 to 7 points.

SVR produced predicted values for 3M Company of 82.68 (2022) and 86.93 (2023), which were marginally lower than the reported scores of 91 and 89. The model reduced the magnitude of both real values while accurately capturing the year-to-year decline, indicating a limited reaction to more extreme ESG inputs.

Caterpillar Inc. displayed a similar trend, with predicted values of 77.54 and 76.91 slightly overestimating actual ESG scores of 83 and 81. Even while these discrepancies are small, they suggest that SVR may have had trouble capturing firm-specific ESG changes, leading projections to a more centralised performance range.

Of the three companies, Siemens AG showed the strongest alignment. Siemens' ESG profile agreed well with the smooth nonlinear bounds learnt by the SVR model, as evidenced by the predicted scores of 79.88 (2022) and 80.40 (2023), which stayed within about 2-4 points of the actual values (82 and 84).

Healthcare: Amgen, Merck & Co., UnitedHealth Group, AbbVie, Novartis

The Support Vector Regression (SVR) model consistently underestimated the healthcare industry, with most predicted values falling short of the reported ESG scores for 2022–2023. The deviation's magnitude varied from 3 to 8 points, indicating a reasonable level of accuracy with discernible smoothing, which is an expected SVR behaviour that compresses extreme results in the direction of its learnt regression margin.

Amgen Inc. showed a pattern of mixed predictions. The model underestimated performance in 2023 (predicted: 75.64 vs. actual: 80) but somewhat overestimated it in 2022 (predicted: 78.37 vs. actual: 77). This reversal implies that SVR recorded the overall ESG level but was insensitive to upward trends from year to year.

SVR continuously overestimated Merck & Co.'s ESG position, with actual scores of 76 and 77 and forecasted values of 80.99 (2022) and 82.75 (2023). This suggests that Merck's ESG KPI profile might exaggerate projected performance by aligning with SVR's nonlinear decision bounds.

With anticipated scores of 73.05 and 73.35, which were 3–6 points lower than actual ESG values, UnitedHealth Group showed a persistent underprediction. The company's sharper sustainability performance shifts were flattened into a more stable midway by SVR, as evidenced by this persistent gap. Similar trends were seen at AbbVie Inc., where real scores (71–73) were lower than projected scores (≈ 79 –80). This implies that rather than representing firm-specific variability, the SVR model generalised AbbVie's ESG attributes towards the upper sector average.

Lastly, Novartis AG displayed one of the industry's biggest prediction gaps. The actual ratings of 90 and 85 were underestimated by the predicted values of 82.03 (2022) and 79.88 (2023), suggesting that SVR flattened Novartis' strong ESG performance into a more moderate trajectory.

Financials: American Express, Goldman Sachs, Allianz, MetLife, MS&AD Insurance, and Santander

The SVR model consistently overestimated the banking sector, with predicted ESG scores for both 2022 and 2023 typically above actual values. SVR's propensity to smooth firm-level oscillations and lean towards mid-range performance levels is reflected in the extent of prediction gaps, which ranged from 5 to 13 points.

With predicted values (≈ 74.6 – 75.0) far lower than its actual ESG scores of 87 and 84, Goldman Sachs clearly underpredicted. This significant discrepancy implies that SVR's nonlinear kernel structure, which might have flattened high-end variability, did not adequately capture Goldman's great sustainability performance.

The model continuously overstated ESG performance for American Express. SVR generalised the company's ESG trend higher, presumably as a result of broader sector-level trends encoded in the training data, since predicted scores of 74.00–74.11 exceeded actual values (69 and 66).

Allianz also showed persistent underprediction, with SVR predictions (≈ 74.7 – 75.8) falling short of the high ESG values of 89 and 88. Stronger-performing financial firms were drawn towards a mid-band prediction range, which is consistent with the compression effect seen for Goldman Sachs.

Santander has one of the industry's more consistent prediction tendencies. Predicted values (≈ 76.3 – 76.7) still under-represented performance but maintained a uniform variance, suggesting a well-defined but conservative model mapping, even though actual scores remained consistently high at 89 for both years.

SVR once more overestimated ESG performance for MetLife; estimates ranged from 74.46 to 75.61, while actual values were between 66 and 61. This implies that MetLife's relatively poor ESG performance was smoothed upward in the direction of the anticipated core trend for the industry.

Lastly, MS&AD Insurance displayed a similar overestimation pattern, with predicted values (≈ 71.01 – 74.37) being higher than actual scores (63 and 70). This consistent upward bias reinforces SVR's tendency to reduce performance dispersion and align companies toward a narrower prediction band.

IT: NVIDIA Corp., Compal Electronics, Google and Intel

The SVR model produced generally strong predictive alignment throughout the IT industry, with the majority of predicted ESG scores falling within a small range of the actual values. SVR was better at capturing the underlying ESG performance patterns

of technology businesses than other sectors, as evidenced by the relatively minor variances, which were typically between 1 and 4 points.

One of the closest model fits was shown by NVIDIA Corporation. Less than two points separated the actual ESG ratings of 76 and 75 from the projected scores of ≈ 76.14 for 2022 and ≈ 76.19 for 2023. This great degree of alignment implies that the ESG trajectory of NVIDIA followed smooth, steady patterns that were ideal for the nonlinear kernel behaviour of SVR.

With SVR projecting 61.86 and 63.25 against actual values of 62 and 60, Compal Electronics likewise displayed reasonably accurate forecasts. Although the modest overprediction in 2023 raises the possibility that the model misinterpreted Compal's performance as slightly more stable or improving than stated, the small variances show moderate precision.

Due to outlier-driven exclusion for 2023, the model only produced a prediction for Google in 2022. With an underestimating of roughly two to three points, the actual score (82) was rather close to the anticipated score (79.51). This implies that SVR was still able to estimate Google's overall performance direction even while the company's ESG performance shows some complexity.

Intel Corporation's actual and anticipated values were continuously highly aligned. With prediction gaps of about two to three points, SVR estimations (≈ 87.15 and ≈ 86.14) followed the actual scores of 90 and 88. This stability shows that SVR's ability to identify organised and somewhat nonlinear patterns in the data is in line with Intel's ESG behaviour.

Consumer Discretionary: Nike

The SVR model produced estimated ESG ratings that were extremely similar to the actual reported values for both testing years, demonstrating high predictive alignment for the consumer discretionary sector, which is represented only by Nike Inc. The slight discrepancies, which ranged from 0.2 to 4 points, show that SVR accurately depicted Nike's sustainable performance pattern.

In 2022, there was less than a one-point difference between the actual score (74) and the anticipated ESG score (73.84), indicating exceptional prediction accuracy. This implies that the nonlinear patterns identified by the SVR model were neatly aligned with Nike's ESG profile for that year.

Nike's ESG score (74.16) in 2023 was marginally higher than the reported value (70) according to SVR. The model predicted a more constant or gradual performance trajectory, but Nike's actual ESG rating indicated a faster fall that the model did not fully capture, as evidenced by the moderate discrepancy of about 4 points. This behaviour is in line with SVR's propensity to mitigate rapid changes in firm-specific performance.

Summary

When combined, the individual model findings demonstrate that all five algorithms were able to replicate the general trend of ESG performance across companies and years, albeit with significant variations in sensitivity to firm-specific variation and magnitude accuracy. As might be expected for regularised and margin-based models, LASSO regression and SVR tended to soften extreme ESG ratings, occasionally overstating lower or mid-range performers (like Compal Electronics, MetLife, and Nike) and slightly underestimating high performers (like Goldman Sachs, Intel, and Novartis). For businesses with steadier ESG trajectories (such as 3M, Siemens, and Intel), decision trees produced clear, rule-based forecasts and performed well; nevertheless, they often overstated performance when company-specific dynamics deviated from more general sector patterns.

In contrast, especially in the industrial, IT, and specific finance cases, the ensemble methods (Random Forest and XGBoost) generally produced the closest congruence between actual and forecast ESG scores. For companies with established, stable KPI profiles (such as 3M, UnitedHealth Group, NVIDIA, and Intel), Random Forest captured non-linear ESG–CSP correlations with comparatively minor and directionally consistent errors; nonetheless, it occasionally overstated inferior performance or underestimated upward movements. While XGBoost struggled with companies with highly idiosyncratic or volatile sustainability profiles (like AbbVie and, to a lesser extent, MetLife), it frequently produced the most accurate point forecasts, particularly when ESG patterns were rich but reasonably systematic, as seen for 3M, Goldman Sachs, Nike, and several IT companies.

In general, the cross-model evidence supports H_2 by indicating that ESG KPIs indeed include significant predictive information regarding business sustainability performance. However, the selected algorithm and the underlying stability of ESG dynamics at company and sector levels have a significant impact on the forecasting

capability's accuracy and resilience. While tree-based ensemble techniques like Random Forest and XGBoost seem more suited to capture the more intricate, non-linear ESG–CSP interactions typical of multinational corporations, linear regularised models offer a trustworthy baseline and show broad patterns. The following part formalises these comparative findings by evaluating each model's performance quantitatively.

4.6.2 Model Comparisons

Model	RMSE	MAE	R2
LASSO regression	7.98091329	6.6906735	0.32167786
Decision Tree	6.5166934	4.7952183	0.65813833
Random Forest	4.53852683	3.6179009	0.78099646
XGBoost	4.48126863	3.62542982	0.76573037
SVR	7.10587997	5.85940237	0.42804875

Table 5 Predictive Models results comparisons

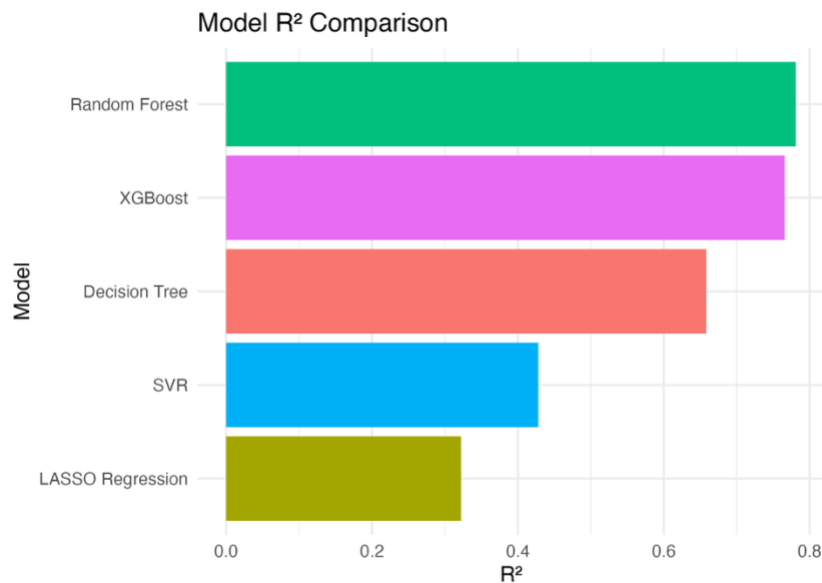


Figure 21 Predictive models comparison

Three common performance metrics were used in a cross-model comparison to assess the overall predictive efficacy of the five machine learning algorithms: Root Mean Square Error (RMSE), Mean Absolute Error (MAE), and the coefficient of

determination (R^2). Together, these criteria evaluate each model's precision, prediction error, and capacity to account for differences in sustainability performance among multinational corporations. This section illustrates performance differences between linear, tree-based, and kernel-based techniques and finds the most resilient and dependable algorithms for predicting ESG trajectories by comparing model outputs side by side. Additionally, the comparison provides a foundation for choosing the best prediction models for further theoretical and practical applications.

The performance indicators show distinct differences in how well each model captures the dynamics of ESG performance. With the RMSE of 7.98, MAE 6.69, and the lowest explanatory power ($R^2 = 0.322$), LASSO regression had the lowest predictive accuracy of the five models. These results indicate that the linear shrinkage limitations applied by LASSO regression were insufficient to describe the non-linear interactions inherent in ESG indicators, generating persistent underfitting and restricted variance capture.

The Decision Tree model shown a significant improvement, with R^2 rising significantly to 0.658 and RMSE and MAE falling to 6.52 and 4.80, respectively. This implies that more intricate ESG linkages were represented by the Decision Tree's hierarchical splitting structure than by the linear model. However, single-tree architectures' intrinsic instability and overfitting tendencies are reflected in the moderate error rates, which restrict generalisation performance.

Within the present dataset and modelling framework, Random Forest achieved the strongest predictive performance among the models evaluated, recording the highest R^2 (0.78) and among the lowest RMSE (4.53) and MAE values (3.62). These findings indicate superior performance relative to the other models evaluated in this study rather than implying universal superiority for ESG forecasting. Additionally, these measurements verify that the ensemble's combination of several decorrelated trees greatly enhanced prediction robustness, decreased variance, and successfully learnt non-linear ESG–CSP connections across businesses and time periods. The robust performance of Random Forest demonstrates its capacity to generalise effectively over a wide range of ESG behaviours.

With RMSE (4.48) and MAE (3.63) that closely matched Random Forest and an R^2 of 0.77 that indicated strong, though marginally less stable predictive power, XGBoost also demonstrated competitive performance. The model's sensitivity to noise, reliance on boosting sequential residuals, and increased vulnerability to overfitting

when dealing limited or heterogeneous ESG inputs could all be contributing factors to the somewhat higher error estimates compared to Random Forest.

Finally, with RMSE at 7.11, MAE at 5.86, and R^2 at 0.43, SVR fared poorly in comparison to the ensemble models but showed reasonable predictive capability. These findings suggest that the margin-based optimisation of SVR unduly smoothed firm-level variability, compressing the dispersion of ESG scores and decreasing the model's capacity to monitor abrupt or high-magnitude changes.

4.7 Hypothesis Testing

H₁: Sustainability initiatives in Multinational Companies (MNCs) positively influence corporate sustainability performance, as evidenced by key performance indicators (KPIs), industry information, and sustainability reports through meta-regression analysis.

The Spearman correlation analysis found inconsistent and generally poor relationships between ESG KPIs and overall ESG performance across all companies and industries. The adoption of renewable energy in Amgen, gender diversity in Caterpillar and Google, and environmental efficiency indicators in Goldman Sachs and MetLife were among the companies that showed statistically significant positive relationships, but these effects were not consistent across firms or ESG dimensions.

Environmental indicators often showed weak or non-significant correlations, with some companies (like Siemens, UnitedHealth Group, and AbbVie) showing negative relationships and others showing strong but opposing trends (like NVIDIA showing a significant negative correlation with renewable energy). Additionally, social indicators varied widely; just a few numbers of companies (like Google and Caterpillar) showed strong positive links, while many others showed minimal or negative associations.

This variation was confirmed by the heterogeneity tests. Consequently, several companies showed statistically significant heterogeneity ($I^2 > 50\%$, $p < 0.05$), demonstrating significant variation in the relationship between ESG KPIs and overall ESG performance within the same company. These companies included Caterpillar, Goldman Sachs, Google, and MetLife. Companies like Siemens, Merck, Novartis, Intel, and Nike, on the other hand, showed total homogeneity ($I^2 = 0\%$), but their pooled correlations were nevertheless modest and frequently close to zero. This implies that their ESG variables did not significantly predict overall ESG performance, despite their constant movement.

Additionally, sector-level patterns were inconsistent. The banking industry displayed the most noticeable effects, driven by substantial environmental correlations in companies like Goldman Sachs and MetLife, whereas the industrial and IT sectors largely displayed weak and non-significant pooling associations. High heterogeneity, however, showed that these effects could not be applied to the entire industry.

When combined, the correlation and heterogeneity data show that, within the entire sample of multinational corporations, CSR/ESG activities do not consistently show a positive or statistically significant relationship with CSP. Instead, there is significant variation in how sustainability indicators map onto overall ESG performance, and the strength and direction of correlations seem to be company-specific, KPI-specific, and highly context-dependent. The findings do not offer enough empirical evidence to support H1. Most companies show poor, inconsistent, or statistically insignificant correlations between certain ESG KPIs and sustainability performance, whereas isolated instances demonstrate strong positive links. Heterogeneity tests corroborate significant dispersion among KPIs and enterprises.

As a result, H₁ is not maintained as a generalisable effect, but it is partially supported. Certain companies and ESG aspects are impacted by CSR/sustainability initiatives, but the link is neither consistently positive nor stable enough throughout the international sample to support the hypothesis in the most general sense.

H₂: The developed predictive models will demonstrate accuracy and reliability in forecasting sustainability trajectories, supported by appropriate statistical methods and validation techniques.

The results from LASSO regression were the worst (RMSE = 7.92, MAE = 6.62, R^2 = 0.326), suggesting a low capacity for prediction. The low explanatory power and large error values imply that the nonlinear patterns present in ESG data were not well captured by LASSO regression's linear shrinkage penalty. Similarly, only a slight improvement was provided by the SVR model (RMSE = 7.11, MAE = 5.86, R^2 = 0.428). Its comparatively low explanatory power suggests that the model may have underfitted due to the smoothing impact of margin-based optimisation, missing sudden or significant changes in sustainability performance.

The Decision Tree model, on the other hand, performed noticeably better (RMSE = 6.52, MAE = 4.80, R^2 = 0.658), demonstrating its potential to discover nonlinear correlations between ESG indicators and overall sustainability results. However, the model's moderate error

size highlights single-tree structures' instability and overfitting tendencies, which usually restrict generalisation across diverse businesses and time periods.

The two ensemble learning models produced the most robust predictive performance within the present dataset and framework. With the lowest RMSE (4.53), MAE (3.62), and strongest explanatory power ($R^2 = 0.781$), Random Forest achieved the highest overall predictive accuracy in this study among the models evaluated. This performance reflects Random Forest's ability to aggregate several decorrelated decision trees, thereby reducing variance, improving robustness, and capturing complex ESG–CSP interactions. Additionally, XGBoost worked well (RMSE = 4.48, MAE = 3.63, $R^2 = 0.766$), demonstrating its ability to use sequential boosting to capture complex sustainability patterns. Its performance is nevertheless better than all non-ensemble models, while being marginally less stable than Random Forest, possibly because of its vulnerability to noise amplification during the boosting process.

Overall, the empirical evidence supports H₂. Within the present dataset and modelling framework, the ensemble-based models demonstrated stronger predictive performance than the linear and kernel-based benchmark models. While linear and kernel-based models show relatively low accuracy, ensemble approaches show significant prediction reliability and methodological resilience. An out-of-sample, time-based validation approach was utilised to assess model performance to address potential overfitting issues. Data from 2017–2021 were used for model training, whereas data from 2022–2023 were set aside for testing. Instead of focussing on in-sample fit, this method guarantees that predictive accuracy represents each model's capacity to generalise to unexpected future observations.

Additionally, internal cross-validation was applied in the LASSO regression to determine the optimal regularisation parameter, further reducing the risk of overfitting in the linear model. Specifically, when tested on out-of-sample data, Random Forest and XGBoost show how sophisticated ensemble-based techniques can accurately forecast sustainability trajectories across MNCs. Therefore, the results verify that predictive modelling offers a solid and dependable methodological tool for comprehending and predicting ESG performance patterns when paired with suitable validation techniques.

4.8 Contextual Justifications and Document Analysis

The sustainability reports and publicly available documentation of the multinational corporations in the collection are then used to provide contextual reasons. It is crucial to add descriptive, evidence-based insights from the original disclosures to the statistical results

because the quantitative analysis in this study is solely dependent on firm-reported ESG KPIs. By connecting the extracted KPI values to the particular sustainability initiatives each company has undertaken, this document analysis serves two purposes: (i) it validates the reliability of the extracted KPI values; and (ii) it explains variations, anomalies, or abrupt changes in the data that can be attributed to operational circumstances, external shocks, or company-specific strategies.

Next, to find initiatives, programs, or structural adjustments that align with the ESG performance metrics stated between 2017 and 2023, pertinent narrative portions of sustainability reports for each organisation were reviewed. The study ensures that the numerical values in the dataset are backed by verifiable disclosures rather than proxy estimates or secondary ratings by matching these documented efforts with the yearly KPI developments.

Additionally, the document analysis offers greater context for years where the data exhibits notable changes. For example, during the COVID-19 pandemic, several companies reported lower operational activity, which had an immediate impact on their ESG KPIs. When improvements in environmental KPIs may be partially attributable to short-term operational disruptions rather than long-term strategic implementation, these contextual factors are required to interpret the descriptive statistics, trendlines, and correlation results presented earlier in this chapter.

Below are the compilations of written ESG initiatives to justify the connection with ESG KPIs data that are presented based on each industry derived from the companies' sustainability report:

Industrials

3M Company

From 2017 to 2023, 3M Company's environmental KPIs display distinct time-series patterns that are consistent with the timing of reported sustainability initiatives. Emissions decline steadily across the period, with a more pronounced reduction after 2021. This shift aligns with the introduction of enhanced climate targets and increased investment in emissions-reduction measures, suggesting these initiatives likely contributed to the observed change in trend. Improvements in Scope 3 measurement from 2019 onward may also have affected reported values and should be considered when interpreting the emissions trajectory.

Energy consumption follows a downward trend over time, consistent with the implementation of corporate energy management strategies and facility-level efficiency

projects. The sharper decline observed in 2020 coincides with COVID-19-related operational adjustments, indicating that temporary external factors likely influenced energy use during this period. Renewable energy use increases consistently between 2017 and 2023. This upward trend corresponds with 3M Company's participation in RE100 and the progressive expansion of renewable electricity sourcing, suggesting these initiatives supported sustained growth in renewable energy adoption. Water consumption decreases overall across the study period. More pronounced reductions from 2022 to 2023 align with reported investments in advanced filtration and recirculation systems at high-use facilities, indicating that these targeted interventions likely contributed to the observed decline. While operational changes during the pandemic may have influenced water use, their specific impact cannot be isolated from the available disclosures. Waste generation fluctuates across the period, reflecting operational variability and external disruptions, particularly during the COVID-19 pandemic. The reduction observed by 2023 is consistent with the continued application of established waste-reduction programmes, including process optimisation and circularity initiatives, rather than a single discrete intervention.

Within the social dimension, the proportion of female employees globally increases modestly from 35% in 2017 to 37% in 2023. This gradual change aligns with the expansion of formal DE&I initiatives introduced from 2019 onward, suggesting these measures may have supported incremental progress in workforce gender representation.

Lastly, governance KPIs related to board independence vary over time but show an overall improvement by 2023. This pattern is consistent with ongoing board evaluation, refreshment, and independence policies disclosed throughout the period, indicating that governance outcomes reflect cumulative procedural changes rather than short-term interventions.

Caterpillar Inc.

Caterpillar Inc.'s emissions KPI shows an overall downward trend with modest variability from 2017-2023. The decline observed from 2017 to 2020 is consistent with reported investments in energy efficiency, lower-emission engine technologies, and site-level initiatives such as microgrids and solar-powered systems. Variations observed after 2021 align with reported shifts in product mix, particularly changes in the relative contribution of high-output machinery, engines, and turbines, suggesting that portfolio composition likely influenced emissions outcomes during this period. Energy consumption declines over time, a pattern consistent with ongoing investments in solar installations, renewable energy certificates, and

combined heat and power systems. The notable reduction in 2020 coincides with COVID-19-related production slowdowns, indicating that temporary operational constraints likely contributed to the observed decrease. Renewable energy use increases steadily across the period, aligning with expanded solar capacity at international facilities, microgrid deployment, and renewable energy procurement, which likely supported the upward KPI trend. Water consumption fluctuates across the study period. The decline observed in 2020 is consistent with reported operational disruptions, while subsequent increases align with facility expansion and enhanced water-risk monitoring disclosed from 2021 onward. These movements are consistent with the phased implementation of water management strategies, including micro-filtration, condensate recovery, and targeted interventions at high-risk sites, suggesting that both operational scale and conservation measures influenced the observed KPI pattern. Waste generation remains relatively stable but exhibits short-term variability. This pattern aligns with the continued operation of remanufacturing and recycling programmes alongside operational factors such as changes in packaging use, facility-level process improvements, and pandemic-related disruptions to recycling markets. The absence of a strong directional trend suggests that long-standing waste reduction initiatives may have offset increases associated with operational variability.

From a social perspective, the proportion of female employees remains stable at approximately 20% between 2017 and 2020 before increasing to 23% from 2021 onward. This shift coincides with the expansion of formal diversity and inclusion frameworks, moving beyond women-focused leadership initiatives to broader programmes encompassing inclusive leadership development, employee resource groups, and structured recruitment practices. While the numerical change is modest, the timing suggests these initiatives may have supported gradual improvements in workforce composition.

Finally, governance KPIs related to board independence remain stable across the period. This consistency aligns with Caterpillar Inc.'s disclosed governance practices, including annual independence determinations, strict director independence requirements, and regular governance reviews. The appointment of a Chief Sustainability & Strategy Officer in 2021 and the integration of ESG considerations into executive incentive structures are consistent with continued governance oversight, although these developments do not coincide with a discrete shift in the independence KPI.

Siemens

The emissions and energy consumption KPIs for Siemens between 2017 and 2023 exhibit a sustained downward trajectory with moderate year-to-year variation. This pattern aligns with the company's long-term decarbonisation pathway, which evolved from the multi-year CO₂-Neutral Program into Science Based Targets and the "Net Zero 2030" framework. The gradual reduction in emissions over the study period is consistent with expanded green electricity procurement, reductions in Scope 1 and Scope 2 emissions, and portfolio-level efficiency improvements. Observed fluctuations in the emissions data correspond with reported changes in energy use, business mix, and the introduction of internal carbon pricing mechanisms in selected markets, suggesting that both operational and policy-driven factors shaped the emissions profile. Renewable energy use increases steadily across the period. This upward trend is consistent with Siemens' expanded deployment of distributed energy systems, including on-site solar and wind installations, combined heat and power plants, and advanced energy-management technologies. The marked increase in the Renewable_Energy KPI corresponds with a rising share of renewable electricity in total consumption, supported by participation in RE100, long-term power purchase agreements, and site-level renewable integration. The alignment between these initiatives and the KPI trajectory suggests sustained progress rather than short-term fluctuations. Water consumption remains relatively stable in the early years before declining during and after 2020. The initial stability reflects steady operational demand, while the subsequent reductions coincide with pandemic-related operational adjustments and reduced reliance on chemically untreated cooling water. From 2021 onward, continued variability aligns with expanded water-risk assessments, supply-chain inclusion, and the introduction of local water targets, indicating that both operational changes and structured water management practices influenced the observed KPI movements. Waste generation varies moderately over time, with fluctuations closely associated with site-specific activities. Periods of elevated waste generation correspond with large-scale construction and demolition projects, most notably at the Erlangen Campus, while reductions follow project completion. The distinction between hazardous, non-hazardous, and construction waste in later disclosures, alongside increased emphasis on material recycling, is consistent with the moderate variability observed in the Waste_Generated KPI rather than a sustained directional shift.

Within the social dimension, the Female_Employees_Global KPI shows a gradual increase from 23% in 2017 to 27% from 2021 onward. This incremental change aligns with Siemens' long-term gender equity initiatives, including recruitment targets, leadership development programmes, and participation in global women's empowerment frameworks.

The absence of sharp inflection points in the KPI suggests that these initiatives supported steady progress rather than producing immediate structural change.

Social disclosures further indicate an expansion in the scope of inclusion-related initiatives over time. Earlier reporting focused primarily on gender representation, while later disclosures incorporate broader dimensions such as pay equity, inclusive culture initiatives, employee networks, and support for women in STEM and leadership roles. Although these developments extend beyond what is captured by the female representation KPI, they provide contextual depth for interpreting the gradual numerical changes observed.

From a governance perspective, Siemens maintains a stable Independent_Board KPI throughout the period. This consistency aligns with the company's established governance structure, including defined oversight roles across supervisory, managing, and sustainability boards, as well as regular independence and competency evaluations.

Healthcare

Amgen

From 2017 to 2023, Amgen's environmental KPIs display distinct time-series patterns that are consistent with the timing of reported sustainability initiatives.

Emissions decline steadily across the period, with more pronounced reductions observed from 2020 onward. This trajectory aligns with expanded renewable electricity procurement, energy-efficiency initiatives, and process optimisation measures implemented across manufacturing operations, suggesting these initiatives likely contributed to the observed emissions trend. Reported reductions associated with HVAC and air-exchange optimisation projects, alongside cumulative carbon reductions achieved through multi-year programmes, provide additional context for the sustained decline observed in the Emission_Reduction KPI. Energy consumption follows a downward trend over time, consistent with the implementation of facility monitoring systems, high-efficiency chiller installations, HVAC and freezer optimisation, and energy-efficient production technologies. The sharper reduction observed in 2020 coincides with COVID-19-related operational adjustments, indicating that temporary external factors likely influenced energy use during this period. Renewable energy use increases consistently between 2017 and 2023. This upward trend corresponds with Amgen's expanded procurement of renewable electricity, increased use of renewable energy certificates, and commitments to source renewable power across global facilities, suggesting these initiatives supported sustained growth in renewable energy adoption. Water consumption

decreases overall across the study period. Reported reductions align with ongoing water-efficiency assessments, reverse osmosis system installations, biomanufacturing innovations that reduce water intensity, and site-level water-reduction projects. Measured declines in water use associated with facility-level technology upgrades, operational controls, and reclamation programmes are consistent with the differences observed in the Water_Consumption KPI between 2017 and 2023. Waste generation fluctuates across the period, reflecting operational variability and evolving waste-management practices. The sharper reductions observed between 2022 and 2023 align with reported achievements in recycling manufacturing-related plastics, reusing shipping containers, expanding composting programmes, recycling personal protective equipment, and implementing process innovations, including sites achieving zero-waste-to-landfill status. These developments are consistent with the declines observed in the Waste_Generated KPI during the later years of the study.

Within the social dimension, the proportion of female employees globally remains relatively stable, ranging between 51% and 53% throughout the period. This stability aligns with sustained disclosures emphasising female workforce representation, leadership development initiatives, mentorship networks such as WE2, and inclusive recruitment strategies, suggesting that gender composition remained broadly consistent over time.

Lastly, governance KPIs related to board independence remain stable across the study period. This pattern is consistent with Amgen's disclosed governance practices, including the exclusive use of independent directors on key committees, annual board elections, board-level oversight mechanisms, and ongoing governance reviews. The maintained level of independence reflects continuity in governance structures rather than discrete structural changes.

Merck & Co.

From 2017 to 2023, Merck & Co.'s environmental KPIs exhibit clear time-series patterns that align with the timing and scale of reported sustainability initiatives. The Emission_Reduction KPI shows a sustained downward trend, with pronounced declines in 2020 and 2023. These reductions are consistent with the implementation of structured climate programmes, including the EDISON energy-efficiency framework, expanded renewable energy sourcing, continued Scope 1 and Scope 2 reductions, and increased Scope 3 transparency. The persistence of supply-chain decarbonisation and process-efficiency measures suggests cumulative, long-term effects rather than isolated interventions. Energy consumption declines gradually over the study period. This pattern aligns with disclosures on

global efficiency initiatives, internal Energy Centres of Excellence, and capital investment in energy-saving projects such as electrification, HVAC optimisation, and renewable energy installations. More pronounced reductions between 2020 and 2023 coincide with intensified efficiency programmes and expanded renewable procurement. Renewable energy use increases substantially across the period, with the Renewable_Energy KPI rising from approximately 1% in 2017 to over 50% by 2023. Early solar deployments in India and the United States progress into large-scale virtual power purchase agreements in later years, indicating a sustained expansion of renewable electricity sourcing consistent with the observed KPI trajectory. Water consumption shows year-to-year variability alongside targeted reductions. Declines in the Water_Consumption KPI align with wastewater treatment upgrades, water reuse initiatives, optimised cooling systems, and the application of water-risk assessment tools such as WRI Aqueduct and the WWF Water Risk Filter. More structured reductions observed from 2022 onward are consistent with increasingly formalised water targets and assessments. Waste generation fluctuates in response to operational activities, particularly construction, demolition, and soil-related waste. Elevated Waste_Generated KPI values coincide with years of major projects, while subsequent declines align with reductions in these non-avoidable categories and expanded circular economy practices. The implementation of the Merck Waste Scoring System supports an ongoing, process-oriented approach to waste management.

Within the social dimension, the Female_Employees_Global KPI remains stable at approximately 43–44% throughout the period. This stability aligns with Merck & Co.’s long-standing DE&I initiatives, which evolve over time from a primary focus on gender representation to broader inclusion dimensions, including ethnicity, disability, veteran status, and gender identity.

Lastly, governance KPIs related to board independence remain stable from 2017 to 2023. This consistency aligns with structured governance oversight, established compliance frameworks, and continued adherence to recognised standards such as ISO 14001. Minor year-to-year variations reflect contextual governance factors rather than structural change.

UnitedHealth Group

From 2017 to 2023, UnitedHealth Group's environmental KPIs exhibit time-series patterns that are consistent with the timing and scope of disclosed sustainability initiatives. The Emission_Reduction KPI shows gradual declines through 2019, followed by notable increases from 2021 to 2023. Early reductions align with reported low-cost energy conservation projects, LEED-aligned building practices, and an initial carbon-reduction trajectory. In contrast, the upward shift observed after 2021 coincides with disclosures of expanded reporting boundaries, portfolio growth, and the integration of additional global business units. These factors suggest that changes in carbon-accounting scope and operational expansion, rather than declining performance, likely contributed to the later-period KPI increases. Energy consumption displays a mildly increasing trend over the study period. Early-period stability aligns with efficiency gains from conservation projects, LEED-certified facilities, and HVAC and lighting upgrades. From 2020 onward, expanded facility portfolios, increased site occupancy, and continued real-estate development coincide with rising Energy_Consumption KPI values, despite the continued rollout of LED retrofits, building management systems, and efficiency project pipelines. This pattern suggests that portfolio expansion and boundary changes likely offset ongoing efficiency improvements. Renewable energy adoption increases progressively across the period. The absence of renewable procurement in early disclosures corresponds with Renewable_Energy KPI values of zero between 2017 and 2018. The initial increase in 2019 aligns with renewable electricity sourcing for a limited number of properties, while steady growth from 2020 to 2021 coincides with expanded assessments of on-site and off-site renewable options. The sharp rise observed in 2023 aligns with the company's first large-scale virtual power purchase agreement and formal global renewable energy commitments, indicating a clear structural shift in procurement strategy. Water consumption fluctuates year to year, reflecting operational and occupancy changes. Early disclosures emphasise fixture upgrades and water-efficient construction practices, while later initiatives include digital metering, landscape optimisation, and expanded water-management programmes across international facilities. Periods of reduced usage align with remote-work conditions, whereas increases correspond with higher site occupancy. The completion of a water-intensity assessment in 2023 aligns with more targeted water-management actions and provides context for recent KPI movements. Waste generation varies over time in line with evolving operational practices. Early reductions align with paper-reduction initiatives, composting pilots, and digital document transitions. Subsequent variability corresponds with changes in building activity, employee occupancy, and the phased introduction of waste-segregation improvements, zero-

landfill pilots, and circular-economy initiatives across multiple regions. These developments suggest that the Waste_Generated KPI reflects operational transitions rather than a single directional trend.

Within the social dimension, the Female_Employees_Global KPI remains relatively stable, fluctuating between approximately 66% and 71% from 2017 to 2023. This stability aligns with disclosures emphasising sustained diversity and inclusion efforts, leadership pipelines, employee resource groups, and targeted talent development programmes. The absence of sharp KPI shifts suggests continuity in workforce composition rather than discrete structural change.

Lastly, governance KPIs related to board independence remain stable across the study period. This pattern is consistent with UnitedHealth Group's long-standing governance framework, which emphasises board independence, ethical oversight, and formal nomination and evaluation processes. Minor year-to-year variations align with contextual governance factors rather than substantive changes in governance structure.

AbbVie

AbbVie's Emission_Reduction KPI exhibits gradual and sustained improvement, consistent with the timing of disclosed decarbonisation initiatives from 2017-2023. Early progress aligns with investments in energy-management systems, fleet electrification, and the adoption of 100% renewable electricity at European manufacturing sites. More pronounced KPI changes between 2020 and 2022 coincide with reported infrastructure upgrades, including boiler replacements, co-generation system installations, and expanded renewable electricity sourcing in North America. Structural measures outlined in 2023—such as supplier engagement under SBTi and capital investment in GHG-reduction projects—are consistent with the continued downward trajectory observed in the KPI. Renewable energy use increases steadily across the study period. The Renewable_Energy KPI rises from approximately 16% in 2017 to 56% by 2023, aligning with AbbVie's phased expansion of renewable electricity procurement. Early achievement of full renewable electricity use in European manufacturing is followed by broader global sourcing, on-site solar installations, and alignment with Science Based Targets. This progression is consistent with the sustained upward trend observed in the KPI. Water consumption shows a marked decline over time, with sharper reductions occurring in years associated with specific operational changes. Early decreases align with facility-level interventions such as rainwater harvesting and large-scale water savings at major sites. Subsequent reductions correspond with infrastructure upgrades, internal water recycling

systems, and the discontinuation of a highly water-intensive production process in 2022. Continued emphasis on water-risk assessment and treatment upgrades in 2023 is consistent with the ongoing improvements reflected in the Water_Consumption KPI. Waste generation declines following 2019, reflecting changes in waste-management practices. Reductions align with upgraded treatment systems, enhanced supplier oversight, improved packaging formats, and revised corporate waste evaluation standards introduced in 2022. The further decline observed in 2023 coincides with the adoption of new waste-management vendors and the achievement of zero-waste-to-landfill performance at a major facility, suggesting these operational changes likely contributed to the KPI movement.

Within the social dimension, the Female_Employees_Global KPI increases gradually from approximately 53% in 2017 to 56% by 2022–2023. This trend aligns with AbbVie’s long-standing focus on inclusive recruitment and leadership development initiatives for women. The absence of sharp inflection points suggests steady, incremental progress rather than short-term structural change.

Lastly, governance KPIs related to board independence remain consistently high across the period. This stability aligns with disclosures indicating a predominantly independent board structure, fully independent key committees, annual board evaluations, and the presence of a lead independent director. Minor variation observed in 2023 does not coincide with changes in governance practices and is consistent with broader board composition dynamics.

Novartis

Novartis’ Emission_Reduction KPI shows a gradual downward trend with moderate year-to-year variation. Early stability in 2017–2018 aligns with baseline environmental initiatives, while the slower decline from 2019 onward coincides with the introduction of more ambitious climate targets, including operational carbon neutrality by 2025 and value-chain neutrality by 2030. Emissions variability in 2020 is consistent with mixed operational effects during the COVID-19 period, combining reduced transport activity with higher energy demand for ventilation. Continued improvement from 2021 to 2023 aligns with expanded supplier engagement and technological upgrades at production facilities. Energy consumption declines steadily across the period, consistent with facility-level efficiency improvements. At the same time, renewable energy use increases substantially, with the Renewable_Energy KPI rising from approximately 14% in 2017 to over 90% by 2023. This progression aligns with early adoption of virtual power purchase agreements, expanded wind and solar procurement, and commitments to achieve 100% renewable electricity in operations by 2025. Water consumption

decreases progressively over the study period. This trend aligns with early water-reduction targets, wastewater reuse initiatives, and the adoption of less water-intensive production processes. More structured water-risk assessments introduced from 2022 onward are consistent with the continued decline observed through 2023. Waste generation declines following 2019, reflecting sustained waste-reduction and recycling initiatives. A temporary increase in 2020 aligns with increased use of disposable materials during the COVID-19 period, while subsequent declines correspond with expanded circularity measures and revised waste-management procedures.

Within the social dimension, the Female_Employees_Global KPI increases from approximately 41% in 2017 to around 51% by 2021 and remains stable thereafter. This pattern aligns with long-standing diversity and inclusion initiatives and the expansion of gender-balance and pay-equity measures over time.

Lastly, governance KPIs related to board independence remain constant at 100% throughout the period. This stability aligns with Novartis' established governance structure, including a fully independent, non-executive board and regular evaluation processes.

Financials

Goldman Sachs

From 2017 to 2023, Goldman Sachs' Emission_Reduction KPI exhibits a declining trend, with sharper reductions observed in 2020 and again in 2023. Early decreases between 2017 and 2019 align with disclosures on improved facility efficiency and increased renewable electricity procurement. The more pronounced reduction in 2020 coincides with both operational footprint reductions and broader COVID-19-related activity changes. While Goldman Sachs also reports extensive client-financed low-carbon initiatives, the KPI trend is most directly consistent with changes in its operational emissions profile rather than system-level financed emissions outcomes. Energy consumption declines steadily across the period, while renewable energy use reaches and remains at 100% from 2020 onward. These patterns align with disclosures on LEED-certified buildings, energy-efficient workplace design, building analytics, and continued sourcing of renewable electricity across global offices. The combination of declining Energy_Consumption and sustained Renewable_Energy KPIs suggests that operational energy management improvements were maintained even as the firm expanded its global footprint. Water consumption shows a substantial decline from 2017 to 2021, followed by continued reductions through 2023. This trend aligns with reported facility-level efficiency measures,

including low-flow fixtures, rainwater reuse, and water-recycling technologies such as zero-liquid-discharge systems at select locations. While the firm also supports water-related outcomes through client transactions, the KPI movements are consistent with internal operational efficiency improvements. Waste generation decreases notably over the study period, with a pronounced drop in 2020 and continued reductions thereafter. This pattern aligns with initiatives to reduce single-use plastics, expand recycling and composting, digitise internal materials, and improve waste-management practices across offices. The sustained downward trajectory suggests incremental operational improvements rather than isolated waste-reduction interventions.

Within the social dimension, the Female_Employees_Global KPI increases from approximately 38% in 2017 to 49% by 2023. This upward trend aligns with sustained disclosures on recruitment targets, leadership development initiatives, and gender pay-equity assessments. The absence of sharp inflection points suggests gradual progress driven by long-term workforce initiatives rather than short-term policy shifts.

Finally, governance KPIs related to board independence remain high throughout the period, increasing from approximately 82% in 2017 to over 90% by 2023. This stability aligns with Goldman Sachs' disclosures on board-independence criteria, leadership accountability, and ongoing governance oversight. Minor year-to-year variation reflects board composition dynamics rather than changes in governance structure.

American Express

From 2017 to 2023, American Express' Emission_Reduction KPI shows a sustained downward trend. This pattern aligns with the firm's long-standing carbon-neutral operations from 2018 onward, expanded renewable electricity sourcing, and facility-level efficiency improvements across offices and data centres. More pronounced reductions in later years are consistent with continued optimisation of building systems and sustained use of carbon offsets, suggesting incremental operational improvements rather than discrete one-off interventions. Energy consumption declines steadily over the study period, consistent with reported efficiency gains in offices and data centres. Investments in energy-efficient building design, improved building management systems, on-site solar installations, and energy audits across major locations align with the downward Energy_Consumption KPI trend. The sharper reductions observed during the pandemic years are consistent with increased remote working and reduced office occupancy, which likely amplified underlying efficiency gains. Renewable energy use increases rapidly and reaches full coverage from 2018 onward. This sustained plateau aligns

with the use of renewable electricity certificates, on-site solar generation at large data centres, and continued adherence to RE100-aligned procurement practices. The stability of the Renewable_Energy KPI after 2018 suggests that renewable sourcing became structurally embedded in operational energy management. Water consumption declines markedly between 2017 and 2023. This pattern aligns with facility-level water-efficiency measures, including low-flow fixtures, automated systems, and water-conscious building design, alongside reduced office occupancy during the pandemic period. The persistence of lower water use in later years suggests that structural efficiency measures remained effective beyond temporary operational changes. Waste generation decreases from 2017 to 2021 before showing a modest increase as office attendance resumes. This trajectory aligns with waste-reduction initiatives such as recycling, composting, digitalisation, and the removal of single-use plastics, while later increases are consistent with higher on-site activity. Overall, the Waste_Generated KPI reflects operational intensity rather than a reversal of waste-management practices.

Within the social dimension, the Female_Employees_Global KPI remains above 50% for most of the period, indicating relative stability in workforce gender composition. This pattern aligns with ongoing disclosures on leadership development, mentorship programmes, and pay-equity assessments, suggesting continuity in gender-balance efforts rather than structural shifts.

Lastly, governance KPIs related to board independence remain consistently high from 2017 to 2023. This stability aligns with established governance standards covering board composition, independence criteria, and risk oversight, alongside the integration of climate-related considerations into the enterprise risk management framework and support for TCFD-aligned disclosure practices.

Allianz

Allianz's Emission_Reduction KPI exhibits a declining trend that is consistent with its long-standing carbon-management approach between 2017 to 2023. Early stability and gradual reductions align with sustained carbon-neutral operations, structured mobility policies, and efficiency measures targeting business travel, energy use, and paper consumption. The sharper declines observed in 2020–2021 coincide with pandemic-related reductions in travel and office occupancy, while later disclosures highlight the formalisation of SBTi-aligned targets, expanded emissions boundaries, and strengthened governance under Group Sustainable Operations. Together, these developments suggest cumulative operational effects rather than isolated interventions. Energy consumption declines steadily across the period, aligning with

Allianz's multi-year efficiency programme. Reported initiatives such as data-centre consolidation, building retrofits, ISO 14001/50001 adoption, and tailored energy-management systems correspond with the downward Energy_Consumption KPI trajectory. Continued reductions after 2020 are consistent with portfolio optimisation, strategic energy procurement, and changes to office utilisation under the "New Work Model." Renewable energy use increases progressively and reaches full coverage by 2023. The Renewable_Energy KPI rises from approximately 45% in 2017 to 100% by the end of the study period, aligning with Allianz's RE100 commitment, expanded green-power procurement, and increased use of energy attribute certificates. The step-change observed after 2020 is consistent with integrated procurement strategies and broader deployment of renewable electricity across offices and data centres. Water consumption shows a marked decline, particularly from 2020 onward. This pattern aligns with facility-level efficiency measures such as water-saving fixtures and reuse systems combined with reduced building occupancy during the pandemic and the subsequent shift toward hybrid working. Although water is not a major operational input, targeted interventions in higher-stress locations are consistent with the sustained reductions observed through 2023. Waste generation declines over the study period, reflecting a gradual reduction in paper use and broader waste-management initiatives. The downward Waste_Generated KPI trend aligns with increased digitalisation, improved recycling practices, and corporate campaigns targeting single-use plastics. The introduction of group-wide waste standards from 2021 onward is consistent with the continued decline in reported waste volumes.

Within the social dimension, the Female_Employees_Global KPI remains broadly stable at approximately 51–52% across most years. This stability aligns with Allianz's long-standing diversity and gender-equity initiatives, including leadership development, mentoring programmes, flexible-working policies, and commitments under international DEI frameworks. Minor variation in later years reflects incremental workforce shifts rather than structural change.

Lastly, governance KPIs related to board independence remain consistently high from 2017 to 2023. This stability aligns with Allianz's two-tier governance structure, adherence to the German Corporate Governance Code, and established processes for board evaluation and sustainability oversight. The absence of material variation in the KPI reflects continuity in governance arrangements rather than episodic reform.

Santander

From 2017 to 2023, Santander's Emission_Reduction KPI shows a sustained downward trend, with more pronounced declines from 2020 onward. Early reductions between 2017 and 2019 align with the implementation of efficiency strategies targeting electricity use, paper consumption, and greenhouse gas emissions, alongside ISO 14001 certification and LEED-accredited buildings. The sharper reductions observed from 2020 to 2023 coincide with pandemic-related occupancy changes, the adoption of hybrid working models, the achievement of carbon-neutral operations, and the transition toward longer-term net-zero targets. While Santander reports extensive climate-aligned lending and renewable-energy financing, the KPI trend most directly reflects changes in the bank's operational emissions profile rather than system-level financed impacts. Energy consumption declines progressively across the study period. Moderate early reductions align with facility certifications and energy-efficiency programmes, while sustained declines after 2020 correspond with reduced on-site occupancy, enhanced building-management systems, and expanded efficiency measures under the Group's Energy Efficiency and Sustainability Plans. Continued improvements from 2022 onward align with investments in on-site solar capacity, smart technologies, EV-charging infrastructure, and performance monitoring, supporting the downward Energy_Consumption KPI trajectory. Renewable energy use increases substantially over time. The Renewable_Energy KPI rises from approximately 43% in 2017 to over 95% by 2023, reflecting early full renewable sourcing in key European markets and subsequent expansion through on-site generation and certified renewable procurement. The stepwise increases observed after 2020 align with integrated energy sourcing strategies and broader deployment across global operations, indicating that renewable electricity became structurally embedded in Santander's energy management. Water consumption shows a marked decline, particularly from 2020 onward. This pattern aligns with reduced building occupancy during the pandemic and facility-level efficiency upgrades. Subsequent reductions through 2023 are consistent with expanded water-saving measures, including motion-sensor fixtures, rainwater reuse systems, and targeted interventions in higher water-stress locations, as outlined in later sustainability plans. Waste generation declines steadily across the period, with sharper reductions observed from 2020 to 2021. This trajectory aligns with increased digitalisation, reduced office activity, and structured waste-reduction initiatives, including the elimination of single-use plastics in core markets by 2021. Continued declines through 2023 correspond with zero-waste certifications at major facilities and the expansion of circular-resource practices.

Within the social dimension, the Female_Employees_Global KPI remains relatively stable, declining modestly from approximately 55% in 2017–2019 to around 53% by 2023. This pattern aligns with long-standing initiatives focused on gender equality, leadership development, mentoring, and inclusive talent pipelines. The gradual change suggests workforce rebalancing across seniority levels rather than a departure from Santander's historically female-majority composition.

Lastly, governance KPIs related to board independence remain consistently high throughout the study period. This stability aligns with Santander's disclosures on formal independence criteria, annual board evaluations, and the establishment of dedicated oversight structures for sustainability and responsible banking. Minor year-to-year variation reflects board composition dynamics rather than changes in governance standards or practices.

MetLife

From 2017 to 2023, MetLife's Emission_Reduction KPI exhibits an overall downward trend with some year-to-year variation. Early reductions between 2017 and 2019 align with facility-level efficiency improvements and operational optimisation initiatives. The sharper declines observed in 2020 and 2021 are consistent with pandemic-related reductions in travel and building occupancy, alongside the continued use of renewable energy certificates to maintain carbon-neutral operations. Although emissions increase modestly from 2022 to 2023, the KPI remains below pre-pandemic levels, indicating a sustained improvement relative to the earlier baseline. Energy consumption follows a declining trajectory over the study period. Relative stability in 2017–2018 is followed by more pronounced reductions from 2019 onward, aligning with efficiency upgrades, space consolidation, and building performance improvements. The substantial decreases observed in 2020 and 2021 coincide with reduced facility utilisation under hybrid working arrangements, while continued reductions in 2022 and 2023 are consistent with MetLife's ongoing efforts to reduce the resource intensity of its real estate footprint. Renewable energy use increases steadily across the period, with the Renewable_Energy KPI rising from approximately 83% in 2017 to full coverage by 2021. This progression aligns with expanded procurement of certified renewable electricity across global operations. Minor variation observed after 2021 is consistent with sourcing adjustments rather than a reversal of the company's renewable electricity strategy. Water consumption declines gradually from 2017 to 2019, followed by a more pronounced reduction from 2020 onward. This pattern aligns with facility-level efficiency measures, behavioural awareness initiatives, and reduced building occupancy during the pandemic period. While a slight increase is

observed between 2022 and 2023, water use remains below pre-2020 levels, consistent with a longer-term downward trend. Waste generation decreases between 2017 and 2021, reflecting increased digitalisation, reduced paper use, and lower in-office activity during the pandemic. Subsequent increases from 2022 onward remain below pre-pandemic levels and align with a gradual return to office activity, indicating that the overall Waste_Generated KPI trend reflects changing operational intensity rather than a reversal of waste-reduction practices.

Within the social dimension, the Female_Employees_Global KPI remains stable at approximately 52–54% throughout the period. This consistency aligns with MetLife’s long-standing gender-equity initiatives, leadership development programmes, and pay-equity assessments, suggesting continuity in workforce composition rather than structural change.

Lastly, governance KPIs related to board independence remain consistently high from 2017 to 2023. This stability aligns with MetLife’s established governance standards, regular board evaluations, and ongoing renewal practices. The slight increase observed in 2023 is consistent with continued adherence to independence criteria rather than a substantive governance shift.

MS&AD Insurance

MS&AD Insurance’s Emission_Reduction KPI shows a sustained downward trend across 2017 to 2023. Gradual declines between 2017 and 2019 align with group-wide energy-saving initiatives, digitalisation of internal processes, reduced business travel, and office-efficiency improvements under long-running environmental programmes. The sharper reduction observed in 2020 coincides with pandemic-related declines in commuting, fuel use, and office occupancy, while continued improvement through 2023 aligns with the formalisation of Paris-aligned emissions targets, expanded renewable electricity use, and ongoing changes in work practices. While the Group also reports extensive underwriting and investment activity in renewable energy, the KPI trend most directly reflects changes in its operational emissions profile. Energy consumption declines steadily across the study period. This pattern aligns with disclosures on office and data-centre efficiency measures, including energy-saving equipment, smart lighting, building upgrades, and increased remote working during the pandemic. Continued reductions after 2020 are consistent with the sustained adoption of energy-management systems and operational efficiency technologies across the Group. Renewable energy use increases markedly over time, with the Renewable_Energy KPI rising from approximately 33% in 2017 to over 70% by 2023. This progression aligns with expanded procurement of renewable electricity, on-site solar installations, and participation in

national and industry renewable-energy initiatives. The steady upward trajectory suggests that renewable sourcing became increasingly embedded in operational energy management. Water consumption declines consistently from 2017 to 2023. This trend aligns with facility-level efficiency measures, internal resource-saving initiatives, and reduced office occupancy during the pandemic period. Additional declines observed in 2020–2021 are consistent with remote working arrangements, while continued reductions thereafter suggest the persistence of structural efficiency measures. Waste generation decreases notably between 2019 and 2021, reflecting increased digitalisation, waste-sorting initiatives, and reductions in single-use plastics. Continued declines through 2022 align with expanded circular-economy practices, including refill systems, recycled materials, and group-wide waste-awareness programmes, supporting the overall downward Waste_Generated KPI trend.

Within the social dimension, the Female_Employees_Global KPI increases gradually from approximately 50% in 2017 to around 54% from 2021 onward. This pattern aligns with disclosures on diversity and inclusion initiatives, including leadership development, mentoring programmes, flexible working arrangements, and gender-representation targets. The steady increase suggests incremental progress rather than abrupt structural change.

Lastly, governance KPIs related to board independence show modest improvement over time, with values ranging from approximately 36% to 45%. This trend aligns with disclosures emphasising the appointment of outside directors, the establishment of committees chaired by independent members, and strengthened governance oversight. The gradual increase reflects ongoing governance enhancement rather than episodic reform.

IT

NVIDIA Corp.

Over the course of the study period, NVIDIA's emissions trajectory displays year-to-year variation while remaining broadly consistent with efficiency-driven emissions management amid rapid business expansion.

Changes observed around 2019–2020 align with the implementation of server virtualisation, data-centre optimisation, and ISO-aligned environmental management systems, alongside continued growth in workforce and operations. Emissions patterns during 2021–2022 are consistent with reduced travel and commuting under pandemic-related remote working arrangements, while post-pandemic variation reflects operational normalisation rather than a departure from long-standing emissions-intensity objectives. Energy consumption

increases steadily across the period. This trajectory aligns with the expansion of energy-intensive data centres and online services, despite ongoing efficiency improvements such as advanced cooling systems, high-performance building design, smart controls, and the adoption of ISO 50001-aligned energy management practices. Reduced office occupancy during the pandemic moderated on-site energy demand, but continued growth in data-centre activity is consistent with the upward Energy_Consumption KPI trend. Renewable energy use increases gradually over time, with the Renewable_Energy KPI rising from approximately 29% in 2017 to around 44% by 2023. This progression aligns with expanded renewable electricity procurement across offices and data centres, on-site solar installations, and the adoption of progressively more ambitious renewable sourcing targets. The steady increase suggests incremental integration of renewable electricity rather than rapid structural change. Water consumption declines between 2017 and 2021, followed by increases in subsequent years. This pattern aligns with facility-level water-efficiency measures—including low-flow fixtures, recovered water systems, drought-resistant landscaping, and cooling-tower upgrades—alongside reduced site activity during the pandemic period. Post-2021 increases are consistent with the resumption of on-site operations and expanded facility use, indicating sensitivity of the KPI to operational intensity. Waste generation fluctuates over the study period. Variability observed between 2020 and 2023 aligns with disruptions to campus operations, reduced cafeteria activity, and changes in waste diversion rates during the pandemic. Ongoing initiatives such as composting, e-waste recycling, construction waste diversion, and enhanced segregation practices are consistent with longer-term efforts to manage waste streams rather than a sustained directional shift.

Within the social dimension, the Female_Employees_Global KPI remains relatively stable, fluctuating between approximately 18% and 20% throughout the period. This stability aligns with NVIDIA's sustained focus on inclusive recruitment, bias mitigation in hiring processes, leadership development programmes, and expanded outreach to under-represented groups. The absence of pronounced KPI shifts suggests continuity in workforce composition over time.

Lastly, governance KPIs related to board independence remain consistently high, with values of approximately 91–92% from 2017 to 2023. This stability aligns with NVIDIA's long-standing governance structure, including a predominantly independent board, lead-director arrangements, standing committees, and adherence to NASDAQ independence requirements. The lack of material variation reflects continuity in governance practices rather than episodic change.

Compal Electronics

The Emission_Reduction KPI for Compal shows a gradual improvement over the study period, consistent with the strengthening of group-wide emissions management and efficiency-focused operational changes. Early reductions align with equipment upgrades, plant-level energy efficiency measures, and systematic monitoring of emissions intensity. More pronounced changes around 2020–2021 coincide with COVID-19-related disruptions, including reduced inter-plant activity and travel, alongside temporary increases in generator use due to grid instability. Subsequent stabilisation aligns with the formalisation of longer-term climate commitments, including the adoption of a defined baseline year, annual reduction targets, and expanded Scope 3 assessment, indicating a transition from operational optimisation toward structured, target-driven decarbonisation. Energy consumption trends reflect Compal's sustained focus on plant efficiency and energy management. The Energy_Consumption KPI moves in line with automation, equipment modernisation, and facility-wide conservation programmes, supported by continuous KPI tracking. Pandemic-related effects are visible in 2020–2021, when reduced mobility lowered fuel intensity while reliance on backup generation temporarily increased diesel use at certain sites. Overall, the trend suggests efficiency gains offsetting operational variability rather than a structural increase in energy demand. Renewable energy use increases steadily over time. Growth in solar and hydropower procurement corresponds with notable increases in renewable electricity integration in 2018–2020 and again in 2023, supporting a gradual rise in the Renewable_Energy KPI. These developments align with Compal's longer-term commitments to RE100 and the integration of renewable sourcing into both operational planning and broader supply-chain decarbonisation strategies, helping to stabilise emissions intensity during periods of operational disruption. Water consumption remains relatively stable across the period, reflecting Compal's non-water-intensive production profile. Variations are primarily associated with workforce size and site expansion rather than manufacturing processes. Temporary increases during 2020–2021 align with heightened sanitation requirements, while subsequent stabilisation reflects facility-level efficiency upgrades and the use of water-risk assessments to guide management practices, particularly in higher-risk regions. Extension of water-risk considerations to suppliers from 2019 onward provides context for the limited long-term variability observed in the KPI. Waste generation is managed consistently through structured classification, centralised treatment, and high recycling and diversion rates. Year-to-year variation remains limited, with COVID-19-related sanitation measures affecting handling practices rather than overall waste volumes. Continued

progress toward zero-landfill certification at major sites and adherence to recognised diversion standards aligns with the generally stable Waste_Generated KPI and indicates mature waste-management practices rather than step-change reductions.

Within the social dimension, the Female_Employees_Global KPI remains broadly stable across the period. This pattern aligns with Compal's emphasis on equal pay, inclusive workplace policies, and gradual expansion of gender-focused initiatives, including leadership development, STEM programmes, and flexible working arrangements. The absence of sharp KPI shifts suggests continuity in workforce composition alongside incremental cultural and policy development.

Lastly, governance indicators reflect stable oversight structures throughout the period. A consistent board composition, the presence of independent directors and committees, and uninterrupted governance processes during the pandemic align with the steady Independent_Board KPI. Enhanced performance review procedures introduced after 2019 and expanded ESG disclosure practices indicate incremental strengthening of governance rather than structural change.

Google

Prior to interpreting Google's environmental performance, it is important to note that the company publishes disclosures primarily focused on environmental sustainability. As a result, governance indicators are derived from Alphabet Inc.'s proxy filings, while social indicators are sourced from publicly available workforce data. The Emission_Reduction KPI exhibits variation across the study period while remaining consistent with Google's long-standing carbon-neutral operating model. From 2017 to 2023, Google maintained net operational emissions of zero through a combination of efficiency improvements, renewable electricity procurement, and the use of carbon credits. Year-to-year variation in the KPI aligns with infrastructure expansion and methodological changes rather than a weakening of emissions controls. Emissions patterns in 2020–2021 are consistent with increased data-centre demand alongside reduced commuting and business travel during the COVID-19 period. Expanded Scope 3 coverage and the gradual transition toward life-cycle-based accounting further contextualise observed KPI fluctuations. Energy consumption increases steadily over the period, reflecting rapid growth in data-centre capacity and global cloud computing services. Despite consistently low power usage effectiveness values and ongoing investments in advanced cooling, hardware optimisation, and energy management systems, rising computational workloads outweighed efficiency gains. The upward Energy_Consumption KPI

trend is therefore consistent with scale-driven demand growth rather than declining operational efficiency. Renewable energy performance remains a defining feature of Google's environmental strategy. The company matched 100% of its annual global electricity consumption with renewable energy throughout the study period, supported by long-term power purchase agreements and continued expansion of solar and wind capacity. Variability observed in the Renewable_Energy KPI reflects regional and temporal mismatches between electricity demand and renewable supply rather than reductions in procurement effort. Ongoing commitments to round-the-clock carbon-free electricity provide context for the generally upward KPI trajectory. Water consumption increases markedly from 2017 to 2023, driven primarily by expanded data-centre operations. While Google reports ongoing investments in water-efficient cooling systems, non-potable water use, and site-specific stewardship initiatives, these measures did not offset the scale effects associated with hyperscale infrastructure growth. Temporary fluctuations during the pandemic are visible in office-related water use but are outweighed by sustained increases in data-centre demand. Expanded watershed replenishment programmes introduced after 2021 provide contextual mitigation rather than a reversal of the upward Water_Consumption KPI trend. Waste generation shows moderate variability over time, reflecting the balance between strong circular economy practices and rising material throughput. Google maintains high diversion rates and extensive refurbishment and remanufacturing programmes across its data-centre operations, with several sites achieving zero-waste-to-landfill status. Nevertheless, increased hardware deployment associated with infrastructure expansion contributes to fluctuations in the Waste_Generated KPI. Pandemic-related changes temporarily altered waste composition but did not materially shift long-term trends. Overall, KPI movements reflect operational scale effects alongside sustained circularity efforts.

Intel

The Emission_Reduction KPI for Intel shows a sustained downward trend over the study period, consistent with the company's long-standing, process-driven decarbonisation strategy. Reductions align with continued improvements in abatement technology, chemical substitution, and enhanced process controls, alongside formal climate governance and expanded Scope 3 methodologies. Emissions patterns during 2020–2021 show limited disruption despite the COVID-19 period, reflecting the uninterrupted operation of semiconductor manufacturing. Subsequent stabilisation aligns with the integration of absolute reduction targets and strengthened alignment with long-term net-zero commitments, indicating

cumulative progress rather than short-term adjustment. Energy consumption remains elevated across the period, reflecting the energy-intensive nature of semiconductor manufacturing, but the Energy_Consumption KPI indicates ongoing efficiency gains. Reported reductions in energy intensity align with ISO 50001-aligned energy management, systematic optimisation of chilled water and compressed air systems, automation, and facility-level design improvements. The persistence of industrial activity during the pandemic explains the absence of sharp demand reductions, while continued efficiency investments help moderate consumption growth relative to production scale. Renewable energy use increases steadily between 2017 and 2023. The Renewable_Energy KPI reflects expanded procurement of certified renewable electricity, increased on-site generation, and diversified regional power purchase agreements. The achievement of near-complete renewable electricity coverage across major operating regions by 2023 aligns with Intel's long-term target of full global renewable sourcing, indicating a structural shift in electricity procurement rather than episodic change. Water consumption patterns reflect the highly water-intensive nature of semiconductor manufacturing. The Water_Consumption KPI remains elevated but stable, consistent with Intel's emphasis on reuse, reclamation, and watershed restoration rather than absolute withdrawal reduction. Achieving return-and-restoration levels approaching or exceeding annual freshwater use aligns with reported investments in advanced reclamation systems, site-level efficiency technologies, and risk-based water planning. Limited disruption during the COVID-19 period reflects the continuity of manufacturing operations. Waste generation trends indicate increasing circularity despite ongoing expansion. The Waste_Generated KPI aligns with high recycling and diversion rates, extensive recovery of solvents and metals, and reduced landfill disposal, including the elimination of hazardous waste landfilling. Temporary increases associated with construction activity do not interrupt the longer-term pattern of material recovery and reuse, suggesting that waste outcomes reflect structural circular-economy practices rather than linear disposal growth.

Within the social dimension, the Female_Employees_Global KPI shows relative stability over the study period. This pattern aligns with Intel's sustained focus on diversity and inclusion initiatives, including leadership development, inclusive recruitment, and transparency in workforce metrics. Variations in representation reflect the scale and technical composition of the global workforce rather than a reversal of diversity commitments.

Lastly, governance indicators reflect consistent board independence throughout the period. The Independent_Board KPI aligns with disclosures emphasising formal oversight structures, committee-level supervision of sustainability and risk, and integration of ESG

considerations into governance processes. The absence of material variation in the KPI suggests continuity in governance architecture rather than episodic reform.

TSMC

TSMC's Emission_Reduction KPI increases between 2017 and 2021, followed by stabilisation with modest variation thereafter. The initial rise aligns with rapid fab expansion, advanced node deployment, and energy-intensive manufacturing processes that outweighed efficiency gains. From 2022 onward, moderation in emissions growth coincides with large-scale abatement deployment, carbon-neutral fuel use, expanded Scope 3 engagement, and the formal adoption of a Net Zero Roadmap covering Scopes 1, 2, and 3. Limited disruption during the COVID-19 period reflects the uninterrupted operation of semiconductor manufacturing. Energy consumption rises steadily across the period, consistent with increasing reliance on EUV lithography, cleanroom cooling, and advanced wafer processing. While extensive efficiency initiatives including AI-enabled cooling, ISO-aligned energy management, and supplier collaboration were implemented throughout the period, these measures moderated rather than reversed growth. The Energy_Consumption KPI therefore reflects scale-driven demand alongside continuous efficiency improvement. Renewable energy use increases gradually from a low base, with the Renewable_Energy KPI rising from approximately 7% in 2017 to around 11% by 2023. Modest growth reflects structural constraints in Taiwan's renewable electricity supply, while stronger increases after 2020 align with expanded power purchase agreements and full renewable sourcing at overseas offices. Acceleration in 2022–2023 corresponds with a sharp increase in contracted renewable capacity, supporting longer-term RE100 commitments. Water consumption increases substantially over time, consistent with the water-intensive nature of advanced semiconductor manufacturing. Rising withdrawals align with expanded production capacity, EUV deployment, and higher cleaning requirements. Although large-scale reclamation systems and recycling technologies improved efficiency from 2022 onward, these gains were offset by concurrent capacity expansion, explaining the sustained upward Water_Consumption KPI trend. Waste generation increases alongside production growth, reflecting higher material throughput and chemical use. Despite rising absolute volumes, TSMC maintains high recycling rates and minimal landfill disposal through chemical reuse, sludge valorisation, and zero-waste initiatives. The Waste_Generated KPI thus reflects scale effects moderated by mature circular-economy practices.

Within the social dimension, the Female_Employees_Global KPI declines modestly from approximately 39% to 34% across the period. This pattern aligns with the male-dominated

structure of engineering-intensive semiconductor roles. Disclosed initiatives focused on retention, work–life balance, and women’s development appear to have stabilised representation rather than producing rapid shifts.

Finally, governance indicators strengthen modestly over time. The Independent_Board KPI increases from around 50% to 60% from 2020 onward, aligning with revisions to Taiwan’s Corporate Governance Code and corresponding changes in board composition. Stability after 2020 reflects continuity in governance structure rather than episodic reform.

Consumer Discretionary

Nike

Nike’s Emission_Reduction KPI shows a period of relative stability between 2017 and 2019, followed by increased volatility in 2020 and a sustained decline thereafter. Early stabilisation aligns with gradual shifts toward lower-carbon logistics and supplier-level efficiency improvements. The increase observed in 2020 coincides with pandemic-driven growth in e-commerce fulfilment and reduced freight efficiency, while the subsequent decline aligns with reduced office operations and the expansion of supplier decarbonisation programmes. Continued reductions after 2021 are consistent with the elimination of coal boilers at supplier facilities, increased supplier participation in science-aligned targets, and broader adoption of alternative fuels and renewable electricity across Nike’s supply chain. Energy consumption follows a declining trend overall, despite a temporary increase in 2020. Reductions prior to 2020 align with facility retrofits, smart-building initiatives, and energy-management systems across headquarters and distribution centres. The pandemic-related increase reflects higher energy demand at logistics facilities, while sustained declines from 2021 to 2023 correspond with continued operational efficiency measures and the extension of energy-performance programmes to supplier facilities. Renewable energy use increases sharply across the period, with the Renewable_Energy KPI rising from approximately 35% in 2017 to over 90% by 2023. Early gains align with renewable sourcing at major logistics hubs, while acceleration after 2020 corresponds with expanded power purchase agreements, on-site generation, and the enabling of renewable procurement mechanisms for suppliers. The steep post-2020 increase reflects the integration of renewable energy into both Nike’s own operations and its manufacturing ecosystem. Water consumption declines steadily through 2020, followed by modest fluctuation thereafter. The early downward trend aligns with supplier-focused water-efficiency programmes, wastewater recycling systems, and process improvements. The persistence of lower consumption levels during and after the pandemic suggests that efficiency

gains were structurally embedded rather than activity dependent. Broader watershed initiatives provide contextual support for the sustained reduction observed over the full period. Waste generation increases slightly after 2020, reflecting higher production volumes, while remaining moderated by extensive diversion and recycling practices. Early reductions align with internal waste-minimisation initiatives, while subsequent increases correspond with growing material throughput rather than a weakening of circularity efforts. Continued expansion of reuse, recycling, and take-back programmes aligns with the stabilisation of the Waste_Generated KPI after 2021.

Within the social dimension, the Female_Employees_Global KPI increases gradually from approximately 48% to 51% between 2017 and 2023. This progression aligns with Nike's sustained focus on pay equity, leadership development, and inclusion initiatives. Stability during the pandemic period indicates continuity of social programmes rather than disruption.

Lastly, governance indicators show moderate year-to-year variation, with the Independent_Board KPI fluctuating between approximately 70% and 83%. These movements align with board refreshment and succession processes, while the absence of a sustained downward trend suggests continued adherence to independence standards and established governance practices throughout the period.

4.9 Chapter Summary

This chapter has presented the results of both explanatory and predictive analyses on the relationship between ESG KPIs and corporate sustainability performance among multinational corporations. The first hypothesis was partially supported, as statistically significant associations were identified for selected ESG KPIs, while the pooled meta-analytic evidence indicated that the relationships between ESG KPIs and corporate sustainability performance were company-, sector-, and KPI-specific rather than consistently positive across the sample. Meanwhile, the second hypothesis was supported by the predictive modelling results, in which the ensemble-based machine learning models achieved the strongest predictive performance within the study dataset and modelling framework when forecasting corporate sustainability performance using ESG indicators.

Overall, the results demonstrate that ESG KPIs provide a measurable basis for examining corporate sustainability performance and developing predictive models of sustainability outcomes. The integration of meta-analysis and predictive modelling offers complementary explanatory and predictive perspectives, enabling both an understanding of

observed ESG–CSP relationships and the evaluation of future sustainability performance within the scope of this study. The next chapter discusses these findings in relation to the theoretical frameworks, considers their implications for corporate management and sustainability policy, and presents recommendations for future research.

CHAPTER 5

Discussion, Recommendation, and Conclusion

5.1 Introduction

This chapter interprets the empirical results generated in Chapter 4, focusing on the observed relationships between sustainability initiatives, ESG KPIs, and CSP across MNCs. The results indicate that sustainability initiatives are associated with measurable variation in CSP by LSEG ESG ratings, although the strength and direction of these relationships differ across sectors and ESG dimensions. Predictive modelling outcomes further suggest that sustainability trajectories can be forecast with varying degrees of accuracy, depending on the stability, consistency, and disclosure quality of underlying ESG indicators. Together, the findings highlight both the explanatory value and the limitations of ESG-based metrics in capturing sustainability performance, underscoring the importance of sectoral context, methodological choice, and data structure in sustainability assessment.

Additionally, the chapter presents an organised discussion of (i) overall observations on the ESG–CSP relationship, (ii) important findings that arise across sectors and analytical approaches, and (iii) the alignment of ESG behaviour with the UNSDGs. The chapter concludes by summarising the study's key findings and implications, followed by recommendations for managerial, policy, and future research applications.

5.2 Discussion

This chapter incorporates results from the descriptive statistics, correlation analyses, heterogeneity evaluations, predictive modelling outcomes, and contextual justification through document analysis in line with the two objectives of the study.

Essentially, ESG ratings represent a widely used formal indicator for investors seeking to incorporate sustainability considerations into strategic investment decisions and are therefore employed in this study as a proxy for corporate sustainability performance (CSP) (Cini & Ferrari, 2024). The UNSDGs, business disclosures, and underlying ESG KPIs are all evaluated in relation to these ratings. This chapter illustrates the similarities and differences in sustainability performance across multinational corporations by placing the quantitative findings into sectoral, operational, and methodological frameworks.

5.2.1 Observation of the Relationship Between ESG KPIs, ESG Ratings (CSP Proxy), and Corporate Sustainability Disclosures

Collectively, the descriptive, predictive, and document-based data show that ESG KPIs offer a solid and meaningful overview of sustainability performance when used in conjunction with company disclosures. Emission Reduction (SDG 13), Energy Consumption (SDG 7), Renewable Energy (SDG 7 & SDG 13), Water Consumption (SDG 6), and Waste Generation (SDG 12) are examples of environmental KPIs that show strong alignment with reported sustainability strategies, decarbonisation pathways, resource-efficiency programs, and industry-specific operational realities.

Female Employees Globally (SDG 5), which measures social performance, exhibits very constant values across all companies, showing adherence to diversity, equality, and inclusion (DEI) pledges and consistent HR disclosure practices. As a reflection of long-standing board structures and corporate governance frameworks, governance indices, in particular Board Independence (SDG 16), continue to be steady.

The results indicate that while ESG KPIs capture operational execution, this finding suggests that policymakers and standard setters should avoid interpreting annual ESG ratings as immediate indicators of operational sustainability improvements. Instead, regulatory frameworks should encourage simultaneous disclosure of both underlying ESG KPIs and aggregated ESG ratings to improve transparency for investors and other stakeholders. Consequently, changes in ESG KPIs from year to year do not always translate into proportional movements in ESG ratings. For example, in manufacturing-intensive sectors such as semiconductors, firms like TSMC and Intel exhibited rising energy and water consumption KPIs driven by capacity expansion and advanced process deployment, while ESG ratings remained relatively stable due to strong governance frameworks and long-term decarbonisation commitments.

Conversely, consumer-facing firms such as Nike showed temporary increases in emissions and waste KPIs during 2020, which did not materially affect ESG ratings once document analysis clarified COVID-19-related logistics disruptions and subsequent supply-chain decarbonisation measures. Similarly, technology firms such as Google displayed rising energy and water consumption associated with digital scaling, while ratings remained resilient due to sustained renewable energy procurement and climate-governance continuity. These examples illustrate how corporate sustainability disclosures provide essential contextual interpretation such as pandemic-related operational disruptions, scope and boundary changes, and structural

transitions allowing observed KPI volatility to be reconciled with comparatively stable ESG ratings.

Taken together, the quantitative findings and document analysis demonstrate that corporate sustainability performance is best understood through the combined interpretation of ESG KPIs, ESG ratings, and corporate sustainability disclosures, all of which work together to contribute to several UNSDGs, including SDGs 5, 6, 7, 12, 13, and 16.

5.2.2 Key Findings of This Research

First, the analysis discovers that the strongest sectoral influence on CSP is found in environmental KPIs, namely emission reduction, energy use, and renewable energy. Companies in highly resource-intensive sectors (such as IT manufacturing and industrial) have greater KPI variability, whereas financial and healthcare companies have more consistent KPI behaviour. The prominence of environmental indicators suggests that sectors with high resource intensity should prioritise operational decarbonisation, renewable energy adoption and resource-efficiency investments, as these initiatives appear to differentiate sustainability performance more consistently than social or governance indicators. Additionally, policymakers may therefore consider strengthening sector-specific environmental reporting requirements rather than adopting uniform ESG disclosure expectations across all industries. This reflects varying operational complexity, legal frameworks, and sustainability strategy.

Second, the correlation results indicate no consistently substantial association between ESG KPIs and ESG ratings, with many relationships appearing weak or statistically insignificant. This suggests that ESG ratings capture a broader and more composite representation of sustainability performance than annual KPI movements alone, incorporating elements such as risk exposure, governance quality, strategic intent, and disclosure practices. While this supports the view that KPIs primarily reflect operational execution and ESG ratings reflect more systemic sustainability conditions, it also raises important implications for treating ratings as a proxy for CSP. Reliance on ESG ratings may obscure short-term operational improvements or deteriorations that are visible in KPI data but absorbed or diluted within broader rating methodologies. Consequently, ESG ratings should be interpreted as an aggregate and lagged indicator of sustainability performance rather than a direct or immediate reflection of operational outcomes, reinforcing the value of combining ratings with KPI-level analysis when assessing CSP.

Third, the results of heterogeneity show significant differences amongst companies. Companies like Goldman Sachs, MetLife, and Google, have substantial internal variability, but many others have homogenous ESG KPIs–CSP connections. These examples demonstrate how non-linear indicator interactions, variations in indicator weighting, and changing disclosure boundaries all contribute to the complexity of sustainability performance.

Fourth, since ESG indicators gathered from corporate sustainability reports are heterogeneous and non-linear, predictive modelling shows that within the analytical framework of this study, the ensemble-based techniques, particularly Random Forest and XGBoost, achieved lower prediction errors than the linear and kernel-based models evaluated. Persistent underfitting arises from the ESG–CSP relationship's firm-level variability, interaction effects across ESG dimensions, and non-linear response patterns that linear models like LASSO regression are unable to capture. Among the ensemble approaches, Random Forest exhibited the most stable performance by aggregating predictions from multiple decorrelated trees, thereby reducing sensitivity to noise, reporting inconsistencies, and year-to-year volatility in ESG disclosures. Although XGBoost also captures complex ESG interactions, its reliance on sequential error correction makes it slightly more sensitive to residual noise and data heterogeneity, resulting in marginally higher prediction error in comparison. On the other hand, firm-level variation is smoothed by kernel-based models like SVR, which restricts their capacity to monitor sudden or significant changes in CSP. These results show that ensemble approaches that strike a balance between robustness and flexibility are more appropriate for modelling sustainability trajectories in the context of ESG-based CSP prediction.

Among ensemble approaches, Random Forest exhibited the most stable performance based on the present datasets and framework. By aggregating predictions from multiple decorrelated trees, it reduced sensitivity to noise, reporting inconsistencies, and year-to-year volatility in ESG disclosures. However, the performance advantages of ensemble models should be interpreted with caution. The relatively short time series available for most firms constrains achievable predictive accuracy and increases the risk of overfitting as model complexity rises. While cross-validation mitigates this risk to some extent, forecasts remain sensitive to structural breaks such as COVID-19-related disruptions and disclosure boundary changes that are difficult to model with limited historical depth. Within the present analytical framework and datasets, the lower prediction errors achieved by the ensemble-based models suggest that flexible analytical approaches may provide additional value when modelling ESG datasets characterised by heterogeneous disclosures and non-linear relationships. This finding should not be interpreted as evidence that such models are universally superior to conventional

statistical techniques. Rather, it indicates that under analytical conditions similar to those examined in this study, ensemble approaches may complement traditional methods by providing additional predictive insights into corporate sustainability performance. Consequently, organisations may benefit from integrating ensemble machine learning into internal ESG monitoring systems to improve forecasting of sustainability trajectories, while regulators and ESG data providers should consider exploring advanced predictive analytics as complementary tools for analysing complex ESG datasets and supporting sustainability assessment.

Lastly, the validity of KPI patterns reflecting real organisational actions is confirmed by contextual analysis. The correspondence between disclosures and quantitative outcomes validates the dependability of the dataset and emphasises the significance of combining operational data with qualitative sustainability narratives. Together, these results highlight the importance of employing a hybrid strategy that combines document review, machine learning, and meta-regression analysis to comprehend how corporate sustainability performance inside multinational corporations is impacted by sustainability initiatives.

5.2.3 Limitations and Gaps of This Research

Despite the valuable insights produced by this hybrid analytical technique, several limitations should be recognised to contextualise the findings and guide future research. The accessibility and uniformity of ESG KPI data among the selected MNCs is one of the main constraints. Many companies did not have complete KPI disclosures for the 2017–2023 timeframe since sustainability reporting practices are still mostly voluntary and differ greatly between sectors and geographical areas. Because of this, the final sample size was limited to companies who had completely reported datasets, which would limit how broadly the findings can be applied. Subsequently, inconsistencies in reporting borders, indicator definitions, and disclosure depth introduce intrinsic heterogeneity even within the chosen companies, making it impossible to fully standardise even thorough data cleaning.

Furthermore, sectoral differences within the dataset further limit the scope of cross-industry comparisons. Some industries were better represented in the final sample, especially those with more developed sustainability policies or stricter regulations, while others were left out because of inadequate disclosures. This unequal representation makes it more difficult to investigate sector-specific sustainability practices in-depth and lessens the findings' applicability to the entire range of multinational corporations.

Conversely, due to the study's focus on a seven-year period (2017–2023) which was characterised by notable disruptions like the COVID-19 pandemic that affected company operations, reporting cycles, and sustainability agendas, temporal restrictions also pose a drawback. In addition to improving the robustness of meta-regression and predictive modelling results, a longer time horizon would probably provide a clearer picture of structural sustainability trends.

Lastly, the analytical methods used in the study assess correlations and prediction patterns but do not prove causation. The results cannot definitively establish whether changes in sustainability initiatives directly result in improvements in ESG ratings or anticipated sustainability trajectories without addressing endogeneity or using causal inference techniques. Therefore, this is still a promising area for additional methodological improvement.

Overall, the limitations do not diminish the study's outcomes but highlight how future research might improve modelling strategies, increase dataset coverage, widen KPI selection, and incorporate causal inference methodologies. Additionally, addressing these gaps would improve our knowledge of how company performance is impacted by sustainability initiatives and expedite the completion of global sustainability objectives.

5.3 Recommendations

Initially, companies should strengthen internal coordination between ESG disclosure practices, KPI boundary definitions, and long-term sustainability strategies to reduce misalignment between operational performance and ESG ratings. The empirical results show that year-to-year improvements in ESG KPIs frequently did not translate into corresponding changes in ESG ratings, particularly where scope changes, pandemic-related disruptions, or delayed disclosure updates occurred. Establishing clearer internal processes that align KPI measurement, reporting timing, and strategic targets would improve the interpretability of ESG performance for external stakeholders and reduce the risk that genuine operational progress is diluted within broader rating methodologies.

Following that, companies should prioritise sustainability initiatives that demonstrate persistent, cumulative effects rather than short-term KPI optimisation. The findings indicate that firms with sustained investments in decarbonisation pathways, renewable energy procurement, water stewardship, and circular economy practices exhibited more stable ESG ratings over time, even when individual KPIs fluctuated due to external shocks or capacity expansion. This suggests that long-term, system-level sustainability strategies rather than

isolated initiatives, as they are more likely to support consistent CSP outcomes as reflected in ESG ratings, particularly in environmentally intensive sectors.

Third, organisations should reassess how social and governance indicators, particularly board independence and gender diversity, are incorporated into strategic decision making rather than treated solely as compliance or reporting metrics. The empirical results show that these indicators remained largely stable across firms and over time, and that improvements in environmental performance were more frequently associated with changes in ESG ratings than shifts in social or governance measures. This suggests that while social and governance structures provide an important baseline for corporate sustainability performance, their strategic contribution may be under leveraged in current corporate practice. Strengthening the integration of these indicators into leadership evaluation, succession planning, and risk oversight could enhance their relevance to long term sustainability outcomes rather than reinforcing their role as static background conditions.

Moreover, ESG rating providers and regulators should improve transparency around rating construction to address the observed disconnect between operational KPI changes and rating movements. The findings indicate that substantial improvements or deteriorations in firm level ESG KPIs, particularly during periods of disruption such as the COVID-19 pandemic or reporting scope expansion, were not always reflected in corresponding rating adjustments. Clearer disclosure of weighting schemes, sector specific criteria, and update frequencies would help reduce this misalignment and improve the interpretability of ESG ratings for firms and investors that rely on them as proxies for corporate sustainability performance.

Next, policymakers ought to promote a higher degree of standardisation for ESG KPI definitions, reporting boundaries, and disclosure frequencies across various sectors. Unified reporting standards would enhance the comparability between firms while minimising discrepancies caused by differences in methodologies among ESG rating agencies. Additionally, regulatory bodies could urge ESG rating agencies to make their weighting methodologies, sector adjustments, and update frequencies publicly available to foster transparency and bolster confidence in ESG ratings among institutional investors. Finally, governments seeking to promote sustainable finance may consider supporting the responsible adoption of advanced analytical approaches in ESG assessment by encouraging high-quality ESG data, methodological transparency, and research into predictive sustainability analytics.

On the other hand, investors should complement ESG ratings with underlying KPI trend analysis when evaluating sustainability performance, particularly in sectors characterised by rapid technological change or significant operational expansion. This dual-layer assessment

would reduce the risk of overlooking operational improvements that are not immediately reflected in ESG ratings.

Moving on to the application of machine learning in ESG assessment, the findings of this study suggest that machine learning approaches may serve as complementary analytical tools alongside conventional statistical techniques when analysing ESG datasets exhibiting heterogeneous disclosures and non-linear relationships. Rather than replacing traditional methods, these approaches may support sustainability monitoring, scenario analysis, and evidence-based decision-making when supported by high-quality and consistent ESG data. The application of these approaches, however, remains dependent on data quality, reporting consistency, sample characteristics, and the analytical context. Consequently, investors, analysts, ESG rating providers, and policymakers may consider machine learning as a complementary decision-support tool alongside established analytical approaches when evaluating corporate sustainability performance. However, this should not be interpreted as suggesting that these techniques are universally superior to conventional statistical methods. Rather, the findings indicate that they may provide additional predictive insights under comparable analytical conditions.

Finally, future research should build on the demonstrated advantages of ensemble-based predictive models while addressing their current limitations. Although Random Forest and XGBoost models showed consistently lower prediction errors than linear alternatives in this study, their performance was constrained by short time series and sensitivity to structural breaks. Extending the temporal scope of analysis, incorporating alternative ESG datasets, and expanding the range of indicators would improve forecasting robustness and help clarify the conditions under which machine learning approaches can reliably model sustainability trajectories across sectors. Furthermore, future research should look more deeply at the underlying causes of the weak or statistically insignificant connections seen between ESG KPIs and ESG ratings. This might include investigating if the mismatch stems from the selection and implementation of ESG KPIs, the weighting and aggregation procedures used by ESG rating providers, or temporal lag effects between operational performance and rating revisions. Finally, additional research might investigate how qualitative assessments, risk-based evaluations, and proprietary scoring methods influence ESG ratings beyond disclosed KPI performance as such examination might increase transparency and understanding of how ESG scores are created, evaluated, and used in sustainability assessments.

5.4 Conclusion

This chapter synthesises the study's primary findings and highlights their substantive, methodological, and practical implications with respect to the stated research objectives, research questions, and hypotheses. Overall, the findings show that corporate sustainability performance in multinational corporations is influenced by a complex interaction of operational sustainability initiatives, governance structures, and long-term strategic orientation, rather than short-term changes in individual ESG indicators.

Firstly, Research Question 1 (RQ1) examined the relationship between sustainability initiatives (operationalised through ESG KPIs) and corporate sustainability performance (CSP) in multinational corporations, thereby addressing Research Objective 1 (RO1). The findings demonstrate that ESG KPIs are associated with variation in CSP as measured by LSEG ESG ratings; however, this relationship is neither uniform nor immediate across organisations or industries. Environmental KPIs, particularly emission reduction, energy consumption, and renewable energy, exhibited greater influence on sustainability outcomes than social and governance indicators, although the strength and direction of these relationships varied according to sectoral characteristics, operational complexity, and corporate disclosure practices. These findings indicate that ESG KPIs contribute to explaining variation in CSP, but sustainability performance is shaped by a broader interaction of operational, organisational, and strategic factors rather than annual ESG KPI movements alone. Therefore, Research Question 1 is addressed, while Hypothesis 1 is partially supported, as the findings confirm a generally positive relationship between ESG KPIs and CSP.

Consequently, Research Question 2 (RQ2) investigated the extent to which predictive modelling can forecast corporate sustainability performance using ESG KPIs, thereby addressing Research Objective 2 (RO2). Within the analytical framework of this study, the ensemble-based machine learning models, particularly Random Forest and XGBoost, achieved lower prediction errors than the linear and kernel-based models evaluated, suggesting that flexible modelling approaches are better suited to capturing the heterogeneous and non-linear characteristics of ESG datasets. Nevertheless, predictive performance remained constrained by short time series, firm-level heterogeneity, structural disruptions such as the COVID-19 pandemic, and changes in reporting boundaries. These findings demonstrate that machine learning can provide additional predictive capability under comparable analytical conditions, while also highlighting the importance of data quality and contextual interpretation when forecasting sustainability trajectories. Therefore, Research Question 2 is addressed, and Hypothesis 2 is partially supported, as ESG KPIs exhibit predictive value for forecasting

sustainability performance, although prediction reliability remains dependent on the analytical context and available data.

Subsequently, Research Question 3 (RQ3) examined which ESG KPIs contribute most strongly to corporate sustainability performance across multinational corporations, further supporting Research Objective 1 (RO1). The findings indicate that environmental indicators, particularly emission reduction, renewable energy, and energy consumption, contributed more substantially to differentiating sustainability performance than social and governance indicators. Conversely, Female Employees Globally and Board Independence KPIs remained comparatively stable across firms and over time, suggesting that these indicators primarily function as foundational conditions that support long-term sustainability rather than immediate drivers of variation in ESG ratings. Therefore, Research Question 3 is addressed by identifying the ESG dimensions that exert the greatest influence on corporate sustainability performance within the present study.

Lastly, Research Question 4 (RQ4) evaluated the robustness and generalisability of predictive modelling approaches for forecasting corporate sustainability performance across different multinational corporations, further addressing Research Objective 2 (RO2). The findings demonstrate that although ensemble-based models consistently achieved superior predictive performance within the present datasets and analytical framework, their effectiveness remained influenced by firm-level heterogeneity, sector-specific disclosure practices, limited historical observations, and structural changes affecting ESG reporting. These results indicate that while machine learning approaches can provide valuable predictive insights under comparable analytical conditions, their application should be interpreted with appropriate consideration of data quality, reporting consistency, and organisational context. Therefore, Research Question 4 is addressed by demonstrating that the robustness and generalisability of predictive models remain context-dependent rather than universally applicable across all sustainability settings.

Collectively, the findings addressing the four research questions demonstrate both the theoretical and practical contributions of this study. For companies, the findings indicate that long-term, system-level sustainability strategies are more likely to promote consistent corporate sustainability performance than short-term optimisation of individual ESG indicators. For investors, the observed divergence between ESG KPIs and ESG ratings highlights the importance of complementing ESG ratings with underlying KPI analysis when assessing sustainability performance. For ESG rating providers and regulators, the findings reinforce the need for greater transparency in rating methodologies, weighting schemes, and

update frequencies to improve the interpretability and credibility of ESG assessments. Together, these implications support more informed sustainability decision-making while encouraging greater consistency and transparency in ESG reporting and evaluation practices.

Overall, this study adds to the sustainability literature by empirically addressing the stated research questions using an integrated assessment of ESG indicators, predictive modelling, and contextual analysis. By demonstrating the conditional nature of the ESG-CSP relationship, improving methodological understanding of sustainability forecasting, and clarifying the implications of ESG measurement choices, the study provides a more nuanced understanding of corporate sustainability performance in multinational contexts, allowing for more informed assessment and strategy development.

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Appendices

1. Appendix 1 Literature Review articles via SharePoint:
https://strath.sharepoint.com/:f:/r/sites/MS_STU_NursMPhilProgress/Shared%20Documents/General/Literature%20review/Articles%20and%20Journals?csf=1&web=1&e=hI3jBs (access upon request)
2. Appendix 2 Sustainability reports of the 30 companies:
https://strath.sharepoint.com/:f:/r/sites/MS_STU_NursMPhilProgress/SharedDocuments/General/DataCollection/SustainabilityReports?csf=1&web=1&e=LoQwI1 (access upon request)
3. Appendix 3 GRI & SASB standard:
https://strath.sharepoint.com/:f:/r/sites/MS_STU_NursMPhilProgress/SharedDocuments/General/DataCollection/GRI%26SASBIndex?csf=1&web=1&e=WQWYgc (access upon request)
4. Appendix 4 Raw data and findings:
https://strath.sharepoint.com/:f:/r/sites/MS_STU_NursMPhilProgress/SharedDocuments/General/DataCollection/MethodologyProcess%26Results?csf=1&web=1&e=udl5Nj (access upon request)
5. Appendix 5 Sustainable initiatives from selected companies (2017-2023):
[https://strath.sharepoint.com/:x:/r/sites/MS_STU_NursMPhilProgress/SharedDocuments/General/DataCollection/Sustainable initiatives 2017-2023.xlsx?d=w37698909ec594c7a8a14e066004cf8a1&csf=1&web=1&e=elZ7Ac](https://strath.sharepoint.com/:x:/r/sites/MS_STU_NursMPhilProgress/SharedDocuments/General/DataCollection/Sustainable%20initiatives%202017-2023.xlsx?d=w37698909ec594c7a8a14e066004cf8a1&csf=1&web=1&e=elZ7Ac) (access upon request)
6. Appendix 6 Methodology workflow in R:
[https://strath.sharepoint.com/:u:/r/sites/MS_STU_NursMPhilProgress/SharedDocuments/General/DataCollection/MethodologyProcess%26Results/Methodology Workflow.R?csf=1&web=1&e=cXSZDH](https://strath.sharepoint.com/:u:/r/sites/MS_STU_NursMPhilProgress/SharedDocuments/General/DataCollection/MethodologyProcess%26Results/MethodologyWorkflow.R?csf=1&web=1&e=cXSZDH) (access upon request)
7. Appendix 7 Descriptive statistics results of Industrial companies:

Company	Variable	Mean	Median	Min	Max	SD	P95	Q1	Q3
3M Company	Emission Reduction	15070000	15120000	13226000	16180000	1028210.1	16168000	14654000	15828000
3M Company	Energy Consumption	8300000	8370000	7510000	8750000	426419.2	8726000	8130000	8605000
3M Company	Renewable Energy	38.43	35	18	56	13.99	54.8	30	50
3M Company	Water Consumption	41700000	41900000	34800000	4.60E+07	4308905.51	45940000	39350000	45250000

3M Company	Waste Generated	158000	152000	147000	177000	10954.45	174300	151000	164000
3M Company	Female Employees Global	36.29	37	35	37	0.95	37	35.5	37
3M Company	Independent Board	86.14	92	50	100	16.52	97.6	88.5	92
3M Company	LSEG ESG Score	90	90	88	93	1.63	92.4	89	90.5
Caterpillar Inc	Emission Reduction	1773428.57	1590000	1500000	2260000	318374.44	2228200	1535000	1997000
Caterpillar Inc	Energy Consumption	6066944.57	5733333	5380556	6988889	657165.41	6888055.7	5566250	6616667
Caterpillar Inc	Renewable Energy	22.14	21	17	28	4.41	27.7	19	25.5
Caterpillar Inc	Water Consumption	14946968.7	14573835	12870400	17791435	1541740.87	17155486	14214221	15482334.5
Caterpillar Inc	Waste Generated	654173.14	647513	610377	702273	35554.23	701357.1	629772.5	679752
Caterpillar Inc	Female Employees Global	21.29	20	20	23	1.6	23	20	23
Caterpillar Inc	Independent Board	91.29	91	90	92	0.76	92	91	92
Caterpillar Inc	LSEG ESG Score	76	76	65	84	7.21	83.7	71.5	82
Hitachi	Emission Reduction	129530000	121830000	67340000	269240000	67386412.1	230915000	91465000	132685000
Hitachi	Energy Consumption	5185400	5899900	2924000	6028100	1167965.5	6026570	4706400	6016500
Hitachi	Renewable Energy	6.29	2	0	23	8.6	20	1	8.5
Hitachi	Water Consumption	31417142.9	36410000	14230000	41340000	9623010.12	40500000	26190000	37780000
Hitachi	Waste Generated	1129428.57	1302000	356000	1384000	363273.94	1375600	1086000	1346000
Hitachi	Female Employees Global	19.29	19	18	22	1.38	21.4	18.5	19.5
Hitachi	Independent Board	71.43	75	54	83	9.31	81.2	68	76
Hitachi	LSEG ESG Score	87.71	88	84	91	3.04	91	85	90.5
Siemens	Emission Reduction	13663714.3	12578000	11459000	18177000	2731314.68	17807100	11817500	14898500
Siemens	Energy Consumption	3488170	3228888	2532499	5111666	1049340.61	5026241	2732360.5	4039708
Siemens	Renewable Energy	55.57	54	38	79	16.6	78.4	43	66
Siemens	Water Consumption	16627142.9	15300000	12930000	25520000	4142546.38	22964000	14630000	16690000
Siemens	Waste Generated	363985.71	304000	256200	580000	124810.48	548200	268350	435500
Siemens	Female Employees Global	25.43	26	23	27	1.72	27	24	27
Siemens	Independent Board	72	77	38	86	16.19	85.1	70	81.5

Siemens	LSEG ESG Score	83.57	83	82	86	1.51	85.7	82.5	84.5
Vinci	Emission Reduction	17702807.3	17147144	16129011	21382281	1916982.51	20715311.4	16403134	18227473.5
Vinci	Energy Consumption	9043582.29	8842062	8082242	10686843	872458.1	10309842.3	8491945.5	9355019
Vinci	Renewable Energy	20.43	17	6	38	13.23	37.7	10	31
Vinci	Water Consumption	11304272.1	11413666	8914846	13140699	1631590.69	13106940.6	10174971	12655376
Vinci	Waste Generated	2461766.14	2434213	1021735	4205464	1123516.49	4015997.2	1691081.5	3094394
Vinci	Female Employees Global	16	16	15	17	0.82	17	15.5	16.5
Vinci	Independent Board	74.43	69	67	91	9.29	88.6	68	79
Vinci	LSEG ESG Score	85.14	85	84	87	1.35	87	84	86

Table 6 Descriptive statistics results of Industrial companies

8. Appendix 8 Descriptive Statistics results of Healthcare companies:

Company	Variable	Mean	Median	Min	Max	SD	P95	Q1	Q3
Amgen	Emission Reduction	233285.71	263000	165000	296000	57255.9	290600	178000	276500
Amgen	Energy Consumption	898499.43	886952	833618	1030286	65310.51	995035.7	856812.5	912507.5
Amgen	Renewable Energy	40.29	36	11	90	32.64	86.7	12.5	60
Amgen	Water Consumption	2183285.71	2146000	2042000	2355000	122177.08	2344500	2091000	2279000
Amgen	Waste Generated	7709.14	9818	1982	10289	3731.72	10159.1	6089	9848.5
Amgen	Female Employees Global	52	52	51	53	0.58	52.7	52	52
Amgen	Independent Board	91.86	92	91	93	0.69	92.7	91.5	92
Amgen	LSEG ESG Score	76.57	76	73	80	2.7	80	75	78.5
Merck and Co.	Emission Reduction	7519128.57	7623000	6211000	8418000	747952.1	8332950	7201200	7989750
Merck and Co.	Energy Consumption	3643396.14	2463000	2337000	5385149	1548476.96	5373082.4	2407000	5252312
Merck and Co.	Renewable Energy	15.14	12	1	51	17.1	41.7	4.5	16.5
Merck and Co.	Water Consumption	16171428.6	14000000	12100000	20500000	3759305.91	20440000	13350000	19950000
Merck and Co.	Waste Generated	264142.86	245000	214000	371000	52828.11	347000	236500	273000
Merck and Co.	Female Employees Global	43.29	43	43	44	0.49	44	43	43.5
Merck and Co.	Independent Board	91.14	92	86	92	2.27	92	92	92

Merck and Co.	LSEG ESG Score	77.57	77	75	82	2.57	81.1	75.5	79
United Health Group	Emission Reduction	6845947.71	600525	300960	18855106	8184732.95	17497184.8	430550	13651971.5
United Health Group	Energy Consumption	927369.29	381692	365005	1782846	695342.85	1744977.9	371074	1609947
United Health Group	Renewable Energy	2	0	0	7	2.89	6.4	0	3.5
United Health Group	Water Consumption	974285.71	820000	560000	1810000	434006.8	1642000	695000	1120000
United Health Group	Waste Generated	30939.57	15521	7398	87452	33844.4	82868	9068	44035
United Health Group	Female Employees Global	69.29	70	66	71	1.6	70.7	69	70
United Health Group	Independent Board	80.57	80	78	82	1.51	82	80	82
United Health Group	LSEG ESG Score	76.14	76	70	80	3.76	80	74	79.5
AbbVie	Emission Reduction	607835.57	585000	572287	698900	44347.3	676130	581000	618331
AbbVie	Energy Consumption	2252028.86	2146000	1978000	2709962	258018.39	2631903.8	2081500	2383620
AbbVie	Renewable Energy	31.43	28	16	56	13.9	52.1	22.5	37.5
AbbVie	Water Consumption	4597142.86	4400000	4060000	5220000	427617.99	5166000	4330000	4920000
AbbVie	Waste Generated	43757.14	36900	30200	60900	12767.91	60210	34300	54850
AbbVie	Female Employees Global	54.29	54	53	56	1.38	56	53	55.5
AbbVie	Independent Board	91	92	85	92	2.65	92	92	92
AbbVie	LSEG ESG Score	77	76	71	81	4.12	81	74.5	81
Novartis	Emission Reduction	2696268.43	1147670	519400	5395300	2280728.13	5347900	932930	4972824.5
Novartis	Energy Consumption	3028010	3093587	1722222	4577766	1212824.77	4536100.8	1916668	3984579.5
Novartis	Renewable Energy	40	26	14	92	33.35	89.6	17	57
Novartis	Water Consumption	17171428.6	8500000	5200000	72300000	24465057.7	54180000	5550000	11550000
Novartis	Waste Generated	268682.86	349000	55400	474000	196416.72	463800	66190	435000
Novartis	Female Employees Global	46.43	45	41	51	4.47	51	43	51
Novartis	Independent Board	100	100	100	100	0	100	100	100

Novartis	LSEG ESG Score	86.43	86	85	90	1.72	89.1	85.5	86.5
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Table 7 Descriptive statistics results of Healthcare companies

9. Appendix 9 Descriptive Statistics results of Financial companies:

Company	Variable	Mean	Median	Min	Max	SD	P95	Q1	Q3
Goldman Sachs	Emission Reduction	259188	248862	179157	338876	66514.94	333462.5	206097.5	317613
Goldman Sachs	Energy Consumption	507881.43	506427	445881	549940	36947.13	547042.9	488725	537736
Goldman Sachs	Renewable Energy	98.14	100	94	100	2.61	100	96.5	100
Goldman Sachs	Water Consumption	945688	930682	810529	1093979	105788.23	1076964.5	872333	1019980
Goldman Sachs	Waste Generated	7655.14	5010	3638	13743	4144.8	13064.7	4549.5	11048
Goldman Sachs	Female Employees Global	40.71	39	38	49	3.9	46.9	38.5	41
Goldman Sachs	Independent Board	84	82	82	92	3.7	89.9	82	84
Goldman Sachs	LSEG ESG Score	81.29	84	67	89	8.73	88.7	77	87.5
American Express	Emission Reduction	147909.86	141510	98879	191725	36751.04	189410.8	120463	181164.5
American Express	Energy Consumption	331847.86	327439	269898	376988	41517.05	376614.8	304950.5	369354.5
American Express	Renewable Energy	94.57	100	62	100	14.36	100	100	100
American Express	Water Consumption	387782.29	334754	166171	609310	185981.19	603883	240591.5	561529
American Express	Waste Generated	2276.71	2432	806	3472	1103.38	3427.6	1386.5	3227
American Express	Female Employees Global	53.57	53	52	56	1.51	55.7	52.5	54.5
American Express	Independent Board	92.43	93	91	93	0.79	93	92	93
American Express	LSEG ESG Score	71.86	73	66	79	4.49	77.8	68.5	74
Allianz	Emission Reduction	343307.71	283456	233657	514351	115038.58	496065.4	251253	434592
Allianz	Energy Consumption	625857.43	588969	437321	831085	135512.85	801459.7	543381	718432.5
Allianz	Renewable Energy	66	57	45	100	22.58	96.7	47	83
Allianz	Water Consumption	1567300.57	1592564	1178788	1940030	325516.06	1923026.6	1272794	1857067
Allianz	Waste Generated	15358.71	14395	9768	21474	4742.38	20904.3	11451.5	19485.5
Allianz	Female Employees Global	51.14	51	49	52	1.07	52	51	52
Allianz	Independent Board	82.29	100	38	100	30.25	100	69	100

Allianz	LSEG ESG Score	90.86	91	86	95	3.34	94.7	88.5	93.5
Santander	Emission Reduction	407855.57	356488	321408	520749	88180.84	518183.4	339224.5	488947.5
Santander	Energy Consumption	961428.57	920000	805000	1112000	123451.55	1101500	873000	1073500
Santander	Renewable Energy	65.71	57	43	97	21.01	94.3	50	81.5
Santander	Water Consumption	2194007.14	2064113	956817	2956420	731768.27	2931349.9	1848262.5	2842087.5
Santander	Waste Generated	6600	6324	3788	9410	2206.28	9278.6	5025	8314
Santander	Female Employees Global	54.29	54	53	55	0.76	55	54	55
Santander	Independent Board	60.29	67	43	75	12.01	72.6	51.5	67
Santander	LSEG ESG Score	90.43	90	89	93	1.62	92.7	89	91.5
MetLife	Emission Reduction	102181.43	88935	66096	152278	37050.4	148253.8	69622.5	134358
MetLife	Energy Consumption	225189.29	220898	162112	288457	53839.71	288431.2	179076	273353
MetLife	Renewable Energy	91.43	91	83	100	7	99.7	85.5	97.5
MetLife	Water Consumption	176538.29	153387	106521	248570	56386.47	243938.9	136550	227095
MetLife	Waste Generated	1987.57	1662	1156	2937	691.79	2855.7	1505.5	2573.5
MetLife	Female Employees Global	53.29	54	52	54	0.95	54	52.5	54
MetLife	Independent Board	92.14	92	92	93	0.38	92.7	92	92
MetLife	LSEG ESG Score	59.86	61	51	69	6.74	68.1	54.5	64.5
MS&AD Insurance	Emission Reduction	355344.29	254635	191789	546965	173662.46	545271.8	210939.5	536071
MS&AD Insurance	Energy Consumption	258882	261969	217863	305002	31215.12	298322.5	235155.5	278514.5
MS&AD Insurance	Renewable Energy	44.86	40	33	73	13.75	66.7	37.5	46.5
MS&AD Insurance	Water Consumption	883428.57	961000	683000	1074000	159686	1051200	736500	996500
MS&AD Insurance	Waste Generated	9354.43	9947	7286	10962	1414.43	10838.7	8289	10354
MS&AD Insurance	Female Employees Global	52.43	53	50	54	1.51	54	51.5	53.5
MS&AD Insurance	Independent Board	41.71	42	36	45	3.09	45	41	43.5
MS&AD Insurance	LSEG ESG Score	61.57	60	56	70	4.79	68.5	58.5	64

Table 8 Descriptive statistics results of Financial companies

10. Appendix 10 Descriptive Statistics results of IT companies:

Company	Variable	Mean	Median	Min	Max	SD	P95	Q1	Q3
NVIDIA Corp.	Emission Reduction	1606427.43	1930139	330809	2784299	952348.07	2628041.9	876770	2223102.5
NVIDIA Corp.	Energy Consumption	281768.14	244760	127873	496901	139729.55	475329.8	175973.5	375448
NVIDIA Corp.	Renewable Energy	36.43	37	25	49	8.32	47.5	31	41
NVIDIA Corp.	Water Consumption	176105.57	96169	39506	471777	178111.83	448587	66773.5	245870
NVIDIA Corp.	Waste Generated	4980.29	2778	937	18344	6040.9	14427.8	2263	4138.5
NVIDIA Corp.	Female Employees Global	19	19	18	20	0.58	19.7	19	19
NVIDIA Corp.	Independent Board	91.71	92	91	92	0.49	92	91.5	92
NVIDIA Corp.	LSEG ESG Score	76.43	76	75	80	1.81	79.1	75	77
Compal Electronics	Emission Reduction	252721	253505	214618	300306	32043.57	295053	229179	271130
Compal Electronics	Energy Consumption	360582.14	365147	295651	400016	37533.9	397595.9	341004.5	390626
Compal Electronics	Renewable Energy	25	33	1	47	18.98	45.5	8	39
Compal Electronics	Water Consumption	2326575.57	2286986	2019285	2683948	254169.08	2641746.7	2126382	2521523
Compal Electronics	Waste Generated	12366	9324	7529	21075	5709.42	20463	7874.5	16442.5
Compal Electronics	Female Employees Global	36.71	36	32	40	3.04	40	35	39.5
Compal Electronics	Independent Board	24.29	20	20	40	7.32	35.5	20	25
Compal Electronics	LSEG ESG Score	53.29	50	47	62	6.02	61.4	49	58
Google	Emission Reduction	13289859.1	15736600	4261039	18687674	5674673.84	18137162.3	10683377	16488473.5
Google	Energy Consumption	13452152.6	12749458	6513719	22288800	5694729.4	21173657.7	9300947	17005598.5
Google	Renewable Energy	93.86	100	57	100	16.25	100	100	100
Google	Water Consumption	18644506.7	19537746	9463525	28758157	6831200.9	27277937.5	13703123	22672936.5
Google	Waste Generated	43746.71	45705	28153	57113	12277.51	56951.6	33532	54096
Google	Female Employees Global	32.71	33	31	34	1.38	34	31.5	34
Google	Independent Board	68.43	73	58	73	6.27	73	64.5	73

Google	LSEG ESG Score	74.14	78	63	82	7.69	81.7	68	80
Intel	Emission Reduction	273879 14.3	270700 00	164250 00	355390 00	647621 6.18	353365 00	252662 50	310744 50
Intel	Energy Consumption	987142 8.57	106000 00	730000 0	116000 00	155960 9.23	113900 00	895000 0	108500 00
Intel	Renewable Energy	81.29	80	71	99	11.06	97.2	72	87.5
Intel	Water Consumption	463563 62.9	476951 66	397468 05	541058 63	576011 6.26	535450 71.5	411326 10	503407 43
Intel	Waste Generated	308385 .71	311000	186800	414000	82362. 54	405810	258100	365350
Intel	Female Employees Global	27.71	28	27	28	0.49	28	27.5	28
Intel	Independent Board	84.29	83	77	90	5.09	89.7	81	89
Intel	LSEG ESG Score	87.86	88	85	90	1.46	89.4	88	88
Samsung	Emission Reduction	267803 83.9	293940 00	192490 00	310810 00	499051 5.64	308788 00	238998 43.5	299695 00
Samsung	Energy Consumption	277060 00	268990 00	210730 00	351770 00	491091 3.22	343205 00	247235 00	306730 00
Samsung	Renewable Energy	12	7	1	26	10.36	25.7	4.5	20.5
Samsung	Water Consumption	138906 571	134479 000	104253 000	172811 000	236308 27.9	170065 700	127424 500	152977 000
Samsung	Waste Generated	120784 5.29	118174 1	107830 9	141336 5	121761 .22	138684 7.1	112300 4.5	126774 6.5
Samsung	Female Employees Global	40	40	35	45	4.08	44.7	36.5	43.5
Samsung	Independent Board	54.29	55	44	60	4.89	58.8	55	55.5
Samsung	LSEG ESG Score	82.14	83	77	89	4.49	88.1	78.5	84.5
Taiwan Semiconductor	Emission Reduction	164571 93.1	162443 49	123721 08	206788 04	322881 8.43	205756 90.4	140859 21	188666 24.5
Taiwan Semiconductor	Energy Consumption	175450 28.6	169190 00	120162 00	247750 00	481816 1.24	240694 00	137450 00	208075 00
Taiwan Semiconductor	Renewable Energy	8.43	8	7	11	1.62	10.7	7	9.5
Taiwan Semiconductor	Water Consumption	784000 00	773000 00	4.90E+ 07	113600 000	241415 96.2	111020 000	605500 00	939000 00
Taiwan Semiconductor	Waste Generated	547363 .86	575740	369745	744019	152688 .85	723224 .2	405249 .5	665772
Taiwan Semiconductor	Female Employees Global	36.29	37	34	39	1.98	38.7	34.5	37.5
Taiwan Semiconductor	Independent Board	57.43	60	50	60	3.78	60	56	60

Taiwan Semicond uctor	LSEG ESG Score	84.71	83	81	90	3.5	89.7	82.5	87
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Table 9 Descriptive statistics results of IT companies

11. Appendix 11 Descriptive Statistics results of Consumer Discretionary companies:

Company	Variable	Mean	Median	Min	Max	SD	P95	Q1	Q3
Nike Inc.	Emission Reduction	10581729.6	10522073	9537243	11817270	747796.65	11569927.2	10126305.5	10971455
Nike Inc.	Energy Consumption	722400.86	779386	575213	876263	122602.4	857980.1	605936	807036
Nike Inc.	Renewable Energy	59.86	59	35	92	23.77	88.4	37.5	79
Nike Inc.	Water Consumption	17475400	17103600	14121700	21233400	2423180.92	20664780	15981050	18953500
Nike Inc.	Waste Generated	181069.86	196463	132007	226886	41477.35	225562.7	141329.5	214737
Nike Inc.	Female Employees Global	49.71	50	48	51	1.11	51	49	50.5
Nike Inc.	Independent Board	76	75	70	83	3.87	81.2	75	77
Nike Inc.	LSEG ESG Score	72.57	73	70	75	1.72	74.7	71.5	73.5
3 Motor	Emission Reduction	163140704	154039689	120924692	217021585	37756079.7	213815978	133792763	191206717
Nissan Motor	Energy Consumption	8537791.14	8443465	7195408	10189082	1147731.22	9992209.4	7575503	9392788.5
Nissan Motor	Renewable Energy	4	3	2	7	2	6.7	2.5	5.5
Nissan Motor	Water Consumption	23843714.3	23714000	20090000	29118000	3524358.04	28308600	20683500	26308500
Nissan Motor	Waste Generated	168022	158199	152674	206645	21014.18	201218	155571	173747
Nissan Motor	Female Employees Global	12	12	10	14	1.53	14	11	13
Nissan Motor	Independent Board	52.86	58	33	64	13.79	64	45.5	62
Nissan Motor	LSEG ESG Score	78.57	79	73	83	4.08	83	75.5	82

Table 10 Descriptive statistics results of Consumer Discretionary companies

12. Appendix 12 Spearman's Analysis Results for 3M Company

Company	KPI	Rho	P_Value	CI_Lower	CI_Upper
3M Company	Emission_Reduction	-0.291	0.527	-0.856	0.592

3M Company	Energy_Consumption	-0.546	0.205	-0.92	0.352
3M Company	Renewable_Energy	0.364	0.423	-0.536	0.877
3M Company	Water_Consumption	-0.273	0.554	-0.851	0.604
3M Company	Waste_Generated	0.147	0.753	-0.682	0.81
3M Company	Female_Employees_Global	0.68	0.093	-0.151	0.948
3M Company	Independent_Board	-0.482	0.274	-0.906	0.426

Table 11 Spearman analysis result for 3M Company

13. Appendix 13 Spearman's Analysis Results for Caterpillar Inc.

Company	KPI	Rho	P_Value	CI_Lower	CI_Upper
Caterpillar Inc	Emission_Reduction	-0.393	0.383	-0.884	0.512
Caterpillar Inc	Energy_Consumption	-0.321	0.482	-0.865	0.569
Caterpillar Inc	Renewable_Energy	0.691	0.086	-0.129	0.95
Caterpillar Inc	Water_Consumption	0.107	0.819	-0.703	0.796
Caterpillar Inc	Waste_Generated	-0.179	0.702	-0.821	0.664
Caterpillar Inc	Female_Employees_Global	0.866	0.012	0.325	0.98
Caterpillar Inc	Independent_Board	-0.733	0.061	-0.958	0.045

Table 12 Spearman analysis result for Caterpillar Inc.

14. Appendix 14 Spearman's Analysis Results for Siemens

Company	KPI	Rho	P_Value	CI_Lower	CI_Upper
Siemens	Emission_Reduction	-0.564	0.187	-0.924	0.329
Siemens	Energy_Consumption	-0.109	0.816	-0.797	0.702
Siemens	Renewable_Energy	-0.018	0.969	-0.761	0.745
Siemens	Water_Consumption	0.073	0.877	-0.72	0.783
Siemens	Waste_Generated	0.018	0.969	-0.745	0.761
Siemens	Female_Employees_Global	0.048	0.919	-0.732	0.773
Siemens	Independent_Board	0.4	0.374	-0.505	0.886

Table 13 Spearman analysis result for Siemens

15. Appendix 15 Spearman's Analysis Results for Amgen

Company	KPI	Rho	P_Value	CI_Lower	CI_Upper
Amgen	Emission_Reduction	-0.688	0.087	-0.949	0.135

Amgen	Energy_Consumption	-0.473	0.284	-0.904	0.435
Amgen	Renewable_Energy	0.8	0.031	0.118	0.969
Amgen	Water_Consumption	-0.182	0.696	-0.822	0.662
Amgen	Waste_Generated	-0.018	0.969	-0.761	0.745
Amgen	Female_Employees_Global	0.408	0.363	-0.498	0.888
Amgen	Independent_Board	-0.294	0.522	-0.857	0.59

Table 14 Spearman analysis result for Amgen

16. Appendix 16 Spearman's Analysis Results for Merck & Co.

Company	KPI	Rho	P Value	CI Lower	CI Upper
Merck and Co.	Emission_Reduction	0.091	0.846	-0.711	0.79
Merck and Co.	Energy_Consumption	0.127	0.786	-0.692	0.803
Merck and Co.	Renewable_Energy	-0.364	0.423	-0.877	0.536
Merck and Co.	Water_Consumption	0.109	0.816	-0.702	0.797
Merck and Co.	Waste_Generated	0.109	0.816	-0.702	0.797
Merck and Co.	Female_Employees_Global	-0.403	0.371	-0.887	0.503
Merck and Co.	Independent_Board	0.208	0.655	-0.646	0.831

Table 15 Spearman analysis result for Merck & Co.

17. Appendix 17 Spearman's Analysis Results for United Health Group

Company	KPI	Rho	P Value	CI Lower	CI Upper
United Health Group	Emission_Reduction	-0.236	0.61	-0.84	0.629
United Health Group	Energy_Consumption	-0.327	0.474	-0.867	0.565
United Health Group	Renewable_Energy	-0.783	0.038	-0.966	-0.072
United Health Group	Water_Consumption	0.291	0.527	-0.592	0.856
United Health Group	Waste_Generated	0.691	0.086	-0.129	0.95
United Health Group	Female_Employees_Global	-0.257	0.578	-0.846	0.615
United Health Group	Independent_Board	0.157	0.737	-0.676	0.814

Table 16 Spearman analysis result for United Health Group

18. Appendix 18 Spearman's Analysis Results for AbbVie

Company	KPI	Rho	P_Value	CI_Lower	CI_Upper
AbbVie	Emission_Reduction	0.225	0.628	-0.636	0.836
AbbVie	Energy_Consumption	-0.393	0.383	-0.884	0.511
AbbVie	Renewable_Energy	-0.58	0.172	-0.928	0.307
AbbVie	Water_Consumption	-0.299	0.514	-0.859	0.586
AbbVie	Waste_Generated	0.487	0.268	-0.421	0.907
AbbVie	Female_Employees_Global	-0.49	0.264	-0.908	0.417
AbbVie	Independent_Board	0.642	0.12	-0.216	0.94

Table 17 Spearman analysis result for AbbVie

19. Appendix 19 Spearman's Analysis Results for Novartis

Company	KPI	Rho	P_Value	CI_Lower	CI_Upper
Novartis	Emission_Reduction	0.147	0.781	-0.755	0.856
Novartis	Energy_Consumption	-0.177	0.738	-0.864	0.741
Novartis	Renewable_Energy	0.059	0.912	-0.79	0.831
Novartis	Water_Consumption	-0.029	0.956	-0.821	0.801
Novartis	Waste_Generated	0.5	0.312	-0.524	0.933
Novartis	Female_Employees_Global	0.313	0.546	-0.669	0.897
Novartis	Independent_Board	NA	NA	NA	NA

Table 18 Spearman analysis result for Novartis

20. Appendix 20 Spearman's Analysis Results for NVIDIA Corp.

Company	KPI	Rho	P_Value	CI_Lower	CI_Upper
NVIDIA Corp.	Emission_Reduction	-0.225	0.628	-0.836	0.636
NVIDIA Corp.	Energy_Consumption	-0.112	0.811	-0.798	0.7
NVIDIA Corp.	Renewable_Energy	-0.767	0.044	-0.964	-0.033
NVIDIA Corp.	Water_Consumption	-0.299	0.514	-0.859	0.586
NVIDIA Corp.	Waste_Generated	0.281	0.542	-0.599	0.853
NVIDIA Corp.	Female_Employees_Global	0.21	0.651	-0.645	0.832
NVIDIA Corp.	Independent Board	-0.166	0.723	-0.817	0.671

Table 19 Spearman analysis result for NVIDIA Corp.

21. Appendix 21 Spearman's Analysis Results for Compal Electronics

Company	KPI	Rho	P_Value	CI_Lower	CI_Upper
Compal Electronics	Emission_Reduction	0.5	0.667	-1	NA
Compal Electronics	Energy_Consumption	-0.5	0.667	-1	NA
Compal Electronics	Renewable_Energy	-0.5	0.667	-1	NA
Compal Electronics	Water_Consumption	-0.5	0.667	-1	NA
Compal Electronics	Waste_Generated	1	0	NA	NA
Compal Electronics	Female_Employees_Global	0.5	0.667	-1	NA
Compal Electronics	Independent_Board	0.866	0.333	-1	NA

Table 20 Spearman analysis result for Compal Electronics

22. Appendix 22 Spearman's Analysis Results for Google

Company	KPI	Rho	P_Value	CI_Lower	CI_Upper
Google	Emission_Reduction	0.486	0.329	-0.538	0.93
Google	Energy_Consumption	1	0	NA	NA
Google	Renewable_Energy	0.655	0.158	-0.335	0.958
Google	Water_Consumption	1	0	NA	NA
Google	Waste_Generated	-0.6	0.208	-0.949	0.412
Google	Female_Employees_Global	0.971	0.001	0.752	0.997
Google	Independent_Board	0.698	0.123	-0.262	0.964

Table 21 Spearman analysis result for Google

23. Appendix 23 Spearman's Analysis Results for Intel

Company	KPI	Rho	P_Value	CI_Lower	CI_Upper
Intel	Emission_Reduction	0.393	0.441	-0.615	0.913
Intel	Energy_Consumption	0.655	0.158	-0.335	0.958
Intel	Renewable_Energy	0.399	0.434	-0.61	0.914
Intel	Water_Consumption	-0.131	0.805	-0.852	0.762
Intel	Waste_Generated	0.131	0.805	-0.762	0.852
Intel	Female_Employees_Global	0.316	0.541	-0.666	0.897
Intel	Independent_Board	0.655	0.158	-0.335	0.958

Table 22 Spearman analysis result for Intel

24. Appendix 24 Spearman's Analysis Results for Taiwan Semiconductor

Company	KPI	Rho	P Value	CI Lower	CI Upper
Taiwan Semiconductor	Emission Reduction	NA	NA	NA	NA
Taiwan Semiconductor	Energy Consumption	NA	NA	NA	NA
Taiwan Semiconductor	Renewable Energy	NA	NA	NA	NA
Taiwan Semiconductor	Water Consumption	NA	NA	NA	NA
Taiwan Semiconductor	Waste Generated	NA	NA	NA	NA
Taiwan Semiconductor	Female Employees Global	NA	NA	NA	NA
Taiwan Semiconductor	Independent Board	NA	NA	NA	NA

Table 23 Spearman analysis result for Taiwan Semiconductor

25. Appendix 25 Spearman's Analysis Results for Taiwan Semiconductor

Company	KPI	Rho	P Value	CI Lower	CI Upper
Goldman Sachs	Emission Reduction	-0.75	0.052	-0.961	0.007
Goldman Sachs	Energy Consumption	-0.929	0.003	-0.99	-0.584
Goldman Sachs	Renewable Energy	0.906	0.005	0.483	0.986
Goldman Sachs	Water Consumption	-0.821	0.023	-0.973	-0.179
Goldman Sachs	Waste Generated	-0.786	0.036	-0.967	-0.08
Goldman Sachs	Female Employees Global	0.364	0.423	-0.536	0.877
Goldman Sachs	Independent Board	0.335	0.463	-0.559	0.869

Table 24 Spearman analysis result for Goldman Sachs

26. Appendix 26 Spearman's Analysis Results for American Express

Company	KPI	Rho	P Value	CI Lower	CI Upper
American Express	Emission Reduction	0.595	0.159	-0.287	0.931
American Express	Energy Consumption	0.595	0.159	-0.287	0.931
American Express	Renewable Energy	-0.103	0.826	-0.794	0.705

American Express	Water Consumption	0.505	0.248	-0.401	0.911
American Express	Waste Generated	0.487	0.268	-0.421	0.907
American Express	Female Employees Global	-0.312	0.496	-0.862	0.577
American Express	Independent Board	-0.844	0.017	-0.976	-0.25

Table 25 Spearman analysis result for American Express

27. Appendix 27 Spearman's Analysis Results for Allianz

Company	KPI	Rho	P_Value	CI_Lower	CI_Upper
Allianz	Emission_Reduction	0.143	0.76	-0.684	0.809
Allianz	Energy_Consumption	0.214	0.645	-0.642	0.833
Allianz	Renewable_Energy	-0.36	0.427	-0.876	0.539
Allianz	Water_Consumption	0.179	0.702	-0.664	0.821
Allianz	Waste_Generated	0.25	0.589	-0.62	0.844
Allianz	Female_Employees_Global	-0.309	0.501	-0.861	0.579
Allianz	Independent_Board	0	1	-0.753	0.753

Table 26 Spearman analysis result for Allianz

28. Appendix 28 Spearman's Analysis Results for Santander

Company	KPI	Rho	P_Value	CI_Lower	CI_Upper
Santander	Emission_Reduction	-0.185	0.691	-0.823	0.66
Santander	Energy_Consumption	0.074	0.875	-0.719	0.783
Santander	Renewable_Energy	-0.093	0.842	-0.791	0.71
Santander	Water_Consumption	-0.037	0.937	-0.769	0.737
Santander	Waste_Generated	0.259	0.574	-0.613	0.847
Santander	Female_Employees_Global	0.04	0.932	-0.735	0.77
Santander	Independent_Board	-0.346	0.447	-0.872	0.55

Table 27 Spearman analysis result for Santander

29. Appendix 29 Spearman's Analysis Results for MetLife

Company	KPI	Rho	P_Value	CI_Lower	CI_Upper
MetLife	Emission_Reduction	-0.9	0.037	-0.993	-0.086
MetLife	Energy_Consumption	-0.3	0.624	-0.935	0.792

MetLife	Renewable_Energy	0.8	0.104	-0.28	0.986
MetLife	Water_Consumption	-0.9	0.037	-0.993	-0.086
MetLife	Waste_Generated	-0.9	0.037	-0.993	-0.086
MetLife	Female_Employees_Global	0.707	0.182	-0.466	0.979
MetLife	Independent_Board	-0.354	0.559	-0.942	0.768

Table 28 Spearman analysis result for MetLife

30. Appendix 30 Spearman's Analysis Results for MS & AD Insurance

Company	KPI	Rho	P_Value	CI_Lower	CI_Upper
MS&AD Insurance	Emission_Reduction	-0.5	0.253	-0.91	0.406
MS&AD Insurance	Energy_Consumption	-0.5	0.253	-0.91	0.406
MS&AD Insurance	Renewable_Energy	0.643	0.119	-0.214	0.941
MS&AD Insurance	Water_Consumption	-0.679	0.094	-0.947	0.152
MS&AD Insurance	Waste_Generated	-0.071	0.879	-0.782	0.72
MS&AD Insurance	Female_Employees_Global	0.491	0.263	-0.416	0.908
MS&AD Insurance	Independent_Board	0.299	0.514	-0.586	0.859

Table 29 Spearman analysis result for MS&AD Insurance

31. Appendix 31 Spearman's Analysis Results for Nike Inc.

Company	KPI	Rho	P_Value	CI_Lower	CI_Upper
Nike Inc.	Emission_Reduction	0.631	0.129	-0.233	0.938
Nike Inc.	Energy_Consumption	0.703	0.078	-0.107	0.952
Nike Inc.	Renewable_Energy	0.108	0.818	-0.702	0.796
Nike Inc.	Water_Consumption	-0.18	0.699	-0.822	0.663
Nike Inc.	Waste_Generated	0.45	0.31	-0.458	0.899
Nike Inc.	Female_Employees_Global	0.222	0.632	-0.638	0.835
Nike Inc.	Independent_Board	-0.453	0.307	-0.899	0.455

Table 30 Spearman analysis result for Nike Inc.

32. Appendix 32 Actual vs Predicted results for LASSO regression

Company	Sector	Year	Actual	Predicted
3M Company	Industrials	2022	91	81.9106471
3M Company	Industrials	2023	89	85.7912957
Nike Inc.	Consumer Discretionary	2022	74	80.2695523

Nike Inc.	Consumer Discretionary	2023	70	80.2339589
Amgen	Healthcare	2022	77	77.5171838
Amgen	Healthcare	2023	80	77.5696047
Caterpillar Inc	Industrials	2022	83	79.5137392
Caterpillar Inc	Industrials	2023	81	80.1279147
Goldman Sachs	Financials	2022	87	76.0401764
Goldman Sachs	Financials	2023	84	77.114755
American Express	Financials	2022	69	77.2333247
American Express	Financials	2023	66	77.2218829
Merck and Co.	Healthcare	2022	76	79.3687982
Merck and Co.	Healthcare	2023	77	79.6810361
United Health Group	Healthcare	2022	79	76.9648448
United Health Group	Healthcare	2023	76	76.9007799
NVIDIA Corp.	IT	2022	76	75.7646364
NVIDIA Corp.	IT	2023	75	75.7838593
AbbVie	Healthcare	2022	73	78.4256434
AbbVie	Healthcare	2023	71	77.7356452
Novartis	Healthcare	2022	90	79.0533606
Novartis	Healthcare	2023	85	78.9600873
Compal Electronics	IT	2022	62	71.0688364
Compal Electronics	IT	2023	60	71.0018929
Google	IT	2022	82	80.50793
Intel	IT	2022	90	86.1222389
Intel	IT	2023	88	85.1188373
Siemens	Industrials	2022	82	78.1189039
Siemens	Industrials	2023	84	78.7205853
Allianz	Financials	2022	89	78.0538567
Allianz	Financials	2023	88	77.8997343
Santander	Financials	2022	89	75.308569
Santander	Financials	2023	89	75.0356144
MetLife	Financials	2022	66	77.1216531
MetLife	Financials	2023	61	77.2145811
MS&AD Insurance	Financials	2022	63	73.0324966
MS&AD Insurance	Financials	2023	70	73.0264019

Table 31 Actual vs Predicted results for LASSO regression

33. Appendix 33 Actual vs Predicted results for Decision Trees

Company	Sector	Year	Actual	Predicted
3M Company	Industrials	2022	91	89.2
3M Company	Industrials	2023	89	89.2
Nike Inc.	Consumer Discretionary	2022	74	79.1538462
Nike Inc.	Consumer Discretionary	2023	70	79.1538462

Amgen	Healthcare	2022	77	90.2857143
Amgen	Healthcare	2023	80	90.2857143
Caterpillar Inc	Industrials	2022	83	82.375
Caterpillar Inc	Industrials	2023	81	82.375
Goldman Sachs	Financials	2022	87	90.2857143
Goldman Sachs	Financials	2023	84	90.2857143
American Express	Financials	2022	69	73.125
American Express	Financials	2023	66	73.125
Merck and Co.	Healthcare	2022	76	82.375
Merck and Co.	Healthcare	2023	77	82.375
United Health Group	Healthcare	2022	79	79.1538462
United Health Group	Healthcare	2023	76	79.1538462
NVIDIA Corp.	IT	2022	76	90.2857143
NVIDIA Corp.	IT	2023	75	90.2857143
AbbVie	Healthcare	2022	73	79.1538462
AbbVie	Healthcare	2023	71	79.1538462
Novartis	Healthcare	2022	90	88.8571429
Novartis	Healthcare	2023	85	88.8571429
Compal Electronics	IT	2022	62	61.1428571
Compal Electronics	IT	2023	60	61.1428571
Google	IT	2022	82	70.75
Intel	IT	2022	90	89.2
Intel	IT	2023	88	89.2
Siemens	Industrials	2022	82	82.375
Siemens	Industrials	2023	84	82.375
Allianz	Financials	2022	89	88.8571429
Allianz	Financials	2023	88	88.8571429
Santander	Financials	2022	89	90.2857143
Santander	Financials	2023	89	90.2857143
MetLife	Financials	2022	66	73.125
MetLife	Financials	2023	61	73.125
MS&AD Insurance	Financials	2022	63	61.1428571
MS&AD Insurance	Financials	2023	70	61.1428571

Table 32 Actual vs Predicted results for Decision Trees

34. Appendix 34 Actual vs Predicted results for Random Forest

Company	Sector	Year	Actual	Predicted
3M Company	Industrials	2022	91	88.1336667
3M Company	Industrials	2023	89	88.9418333
Nike Inc.	Consumer Discretionary	2022	74	75.4236667
Nike Inc.	Consumer Discretionary	2023	70	75.0048333
Amgen	Healthcare	2022	77	80.587

Amgen	Healthcare	2023	80	80.4718333
Caterpillar Inc	Industrials	2022	83	80.1273333
Caterpillar Inc	Industrials	2023	81	78.8643333
Goldman Sachs	Financials	2022	87	81.7785
Goldman Sachs	Financials	2023	84	81.3395
American Express	Financials	2022	69	68.2655
American Express	Financials	2023	66	71.5028333
Merck and Co.	Healthcare	2022	76	79.5396667
Merck and Co.	Healthcare	2023	77	80.267
United Health Group	Healthcare	2022	79	79.9971667
United Health Group	Healthcare	2023	76	77.277
NVIDIA Corp.	IT	2022	76	75.8601667
NVIDIA Corp.	IT	2023	75	77.0371667
AbbVie	Healthcare	2022	73	80.613
AbbVie	Healthcare	2023	71	81.9513333
Novartis	Healthcare	2022	90	83.2665
Novartis	Healthcare	2023	85	82.6548333
Compal Electronics	IT	2022	62	66.6378333
Compal Electronics	IT	2023	60	69.7378333
Google	IT	2022	82	77.8125
Intel	IT	2022	90	85.6533333
Intel	IT	2023	88	85.6533333
Siemens	Industrials	2022	82	81.2948333
Siemens	Industrials	2023	84	80.579
Allianz	Financials	2022	89	85.0223333
Allianz	Financials	2023	88	83.1711667
Santander	Financials	2022	89	86.0341667
Santander	Financials	2023	89	80.613
MetLife	Financials	2022	66	66.0536667
MetLife	Financials	2023	61	65.3475
MS&AD Insurance	Financials	2022	63	64.7853333
MS&AD Insurance	Financials	2023	70	64.0286667

Table 33 Actual vs Predicted results for Random Forest

35. Appendix 35 Actual vs Predicted for XGBoost

Company	Sector	Year	Actual	Predicted
3M Company	Industrials	2022	91	88.2034531
3M Company	Industrials	2023	89	90.1513824
Nike Inc.	Consumer Discretionary	2022	74	75.8367691
Nike Inc.	Consumer Discretionary	2023	70	72.3456421
Amgen	Healthcare	2022	77	81.1798477
Amgen	Healthcare	2023	80	76.4699783

Caterpillar Inc	Industrials	2022	83	81.675499
Caterpillar Inc	Industrials	2023	81	78.9477921
Goldman Sachs	Financials	2022	87	86.2273331
Goldman Sachs	Financials	2023	84	82.6328278
American Express	Financials	2022	69	66.9983444
American Express	Financials	2023	66	70.8626862
Merck and Co.	Healthcare	2022	76	78.1927338
Merck and Co.	Healthcare	2023	77	80.3901672
United Health Group	Healthcare	2022	79	77.4337769
United Health Group	Healthcare	2023	76	75.9222031
NVIDIA Corp.	IT	2022	76	81.9657745
NVIDIA Corp.	IT	2023	75	83.7119293
AbbVie	Healthcare	2022	73	82.7650299
AbbVie	Healthcare	2023	71	83.1241302
Novartis	Healthcare	2022	90	85.0063477
Novartis	Healthcare	2023	85	83.0110092
Compal Electronics	IT	2022	62	57.7039452
Compal Electronics	IT	2023	60	61.6935959
Google	IT	2022	82	79.0569992
Intel	IT	2022	90	85.1453857
Intel	IT	2023	88	85.0619659
Siemens	Industrials	2022	82	80.478508
Siemens	Industrials	2023	84	80.8358917
Allianz	Financials	2022	89	82.6921997
Allianz	Financials	2023	88	89.0701065
Santander	Financials	2022	89	82.6607666
Santander	Financials	2023	89	85.0579224
MetLife	Financials	2022	66	59.8351974
MetLife	Financials	2023	61	63.0942459
MS&AD Insurance	Financials	2022	63	64.3183975
MS&AD Insurance	Financials	2023	70	63.5041885

Table 34 Actual vs Predicted results for XGBoost

36. Appendix 36 Actual vs Predicted for SVR

Company	Sector	Year	Actual	Predicted
3M Company	Industrials	2022	91	82.6833087
3M Company	Industrials	2023	89	86.9341532
Nike Inc.	Consumer Discretionary	2022	74	73.8393051
Nike Inc.	Consumer Discretionary	2023	70	74.1600187
Amgen	Healthcare	2022	77	78.3747774
Amgen	Healthcare	2023	80	75.64007
Caterpillar Inc	Industrials	2022	83	77.5427087

Caterpillar Inc	Industrials	2023	81	76.908151
Goldman Sachs	Financials	2022	87	75.0452838
Goldman Sachs	Financials	2023	84	74.5947885
American Express	Financials	2022	69	73.9989308
American Express	Financials	2023	66	74.110134
Merck and Co.	Healthcare	2022	76	80.989963
Merck and Co.	Healthcare	2023	77	82.7496328
United Health Group	Healthcare	2022	79	73.0533648
United Health Group	Healthcare	2023	76	73.3542892
NVIDIA Corp.	IT	2022	76	76.144176
NVIDIA Corp.	IT	2023	75	76.1936597
AbbVie	Healthcare	2022	73	80.1558272
AbbVie	Healthcare	2023	71	79.1040611
Novartis	Healthcare	2022	90	82.0260423
Novartis	Healthcare	2023	85	79.8848767
Compal Electronics	IT	2022	62	61.8640795
Compal Electronics	IT	2023	60	63.2472791
Google	IT	2022	82	79.505191
Intel	IT	2022	90	87.1543859
Intel	IT	2023	88	86.1389368
Siemens	Industrials	2022	82	79.8777104
Siemens	Industrials	2023	84	80.4046118
Allianz	Financials	2022	89	75.8306011
Allianz	Financials	2023	88	74.6737975
Santander	Financials	2022	89	76.6519316
Santander	Financials	2023	89	76.2698988
MetLife	Financials	2022	66	74.4609034
MetLife	Financials	2023	61	75.6057852
MS&AD Insurance	Financials	2022	63	71.0143411
MS&AD Insurance	Financials	2023	70	74.3658847

Table 35 Actual vs Predicted results for SVR