



Predictive Modeling of Corporate Social Responsibility's Impact on Financial Performance in U.S. Oil and Gas Firms

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Abstract. This research develops and evaluates predictive models to assess how corporate social responsibility (CSR) expenditures influence the financial performance of oil and gas firms in the United States. Although maximizing shareholder wealth remains a primary goal, it frequently conflicts with the interests of other stakeholders. As a result, incorporating CSR principles into corporate strategies has become increasingly important. Using pooled regression models, this study builds and tests five predictive models to identify the most effective in forecasting financial outcomes linked to CSR initiatives. The research analyzes panel data from the top 100 oil and gas firms listed in the S&P 500 between 2018 and 2022. The models predict key financial indicators, including revenue growth, profitability, return on assets (ROA), return on equity (ROE), and Tobin's Q. Preliminary findings indicate that some models accurately forecast firm value in relation to CSR investments, while the effects of CSR on ROE, ROA, profitability, and revenue growth remain inconclusive. This study contributes to the broader discussion on CSR's strategic importance by utilizing predictive modeling to evaluate its financial implications.

Keywords: CSR, financial performance, and revenue growth

1 Introduction

The increasing concentration on corporate social responsibility (CSR) and the growing demand for integrating social responsibility principles into the oil and gas industry have motivated this research to study the connection amongst CSR and company's performance within the U.S. oil and gas sector. Since the 21st century, this industry has undergone substantial global expansion, especially in the US, where oil and gas companies now make up approximately 4.5% of the S&P 500 Index's market capitalization (S&P Global, 2023) and hold a significant presence in major industry indices. Over the past decade, these firms have experienced notable financial growth, with annual revenue increasing by an average of 6% between 2013 and 2022 (Statista, 2023), leading to a corresponding rise in profitability.

As key players in economic development, national security, and societal welfare, U.S. oil and gas firms play a crucial role in resource allocation and income distribution. However, their resource-intensive operations have resulted in significant environmental and social costs. Notably, the industry accounts for nearly 25% of the country's greenhouse gas emissions (U.S. Environmental Protection Agency, 2023). As a result, sustainable development remains a central concern, with environmental responsibility, social sustainability, and long-term viability becoming strategic priorities for the sector.

The evolving nature of the oil and gas industry—where economic prosperity coexists with environmental degradation—has amplified the call for greater corporate accountability and social responsibility. Increasing emphasis is being placed on cleaner production, aligning CSR initiatives with eco-innovation, as higher environmental

awareness is believed to promote sustainable consumption (Porter & Kramer, 2020). Moreover, societal expectations now extend to human rights protection, environmental conservation, workplace diversity, and minimizing the ecological footprint of corporate activities (Freeman et al., 2019). Issues related to sustainability, corporate governance, and environmental stewardship have also gained prominence.

This study offers to provide valuable insights for academics, industry professionals, and policymakers looking to develop frameworks and regulations that foster corporate responsibility and sustainability within the oil and gas sector. While extensive research has explored CSR's influence on financial performance, few researches have specifically examined its implications for the U.S. oil and gas industry. By leveraging these findings, practitioners and regulators can formulate strategies to enhance competitive advantages and drive sustainable growth.

This study seeks to:

- Develop and validate predictive models to evaluate the impact of CSR investments on the financial performance of U.S. oil and gas firms.
- Identify the financial indicators (e.g., ROA, ROE, Tobin's Q) most affected by CSR initiatives.
- Address gaps in existing research by focusing on predictive modeling rather than conventional correlation-based analyses.

Research Questions

- How does CSR investment influence financial performance metrics (ROA, ROE, Tobin's Q) in U.S. oil and gas firms?
- Which predictive model provides the most accurate forecast of financial outcomes linked to CSR activities?
- What key factors shape the relationship between CSR and firm value?

Research Gap and Contribution

Although previous researches have explored the relationship between CSR and firm performance, majority have relied on traditional regression analysis rather than predictive modeling. Additionally, limited research has specifically focused on the U.S. oil and gas industry, which faces distinct sustainability challenges. This study addresses these gaps by utilizing predictive modeling techniques to analyze the financial impact of CSR expenditures, offering a fresh perspective on CSR's strategic role in this sector.

2 Literature Review

CSR requires businesses to foster a safe working environment, promote diversity, and ensure the equitable and ethical distribution of profits (Zulfiqar, 2019). The challenge lies in striking a balance that satisfies both stakeholders and shareholders. Proponents of CSR argue that for companies to be truly socially responsible, they must also meet the expectations of investors and shareholders.

Hou (2019) notes that companies allocate considerable resources to CSR, often leveraging these efforts to drive innovation, create value, and adapt to evolving stakeholder expectations. Some businesses implement CSR initiatives to address the social and environmental challenges they have contributed to, while others view CSR as a philanthropic endeavor aimed at improving community welfare through infrastructure and social programs. Many major U.S. oil and gas firms have introduced initiatives that benefit the communities where they operate. However, Hamidu, Haron, and Amran (2015) identify key CSR challenges, including managing competing stakeholder interests, optimizing corporate resources, and ensuring financial transparency and accountability.

The effect of CSR on corporate financial performance has been widely debated, with researchers categorizing the impact into three perspectives.

1. **Positive Impact on Financial Performance:** Some studies suggest that CSR enhances corporate financial performance. For instance, Orlitzky et al. (2003) argue that CSR strengthens an organization's ethical identity, leading to improved stakeholder satisfaction. Berrone, Surroca, and Tribo (2007) further support this claim, stating that firms with strong ethical identities experience higher stakeholder engagement, which ultimately enhances financial performance. Giannarakis et al. (2016) found that CSR initiatives significantly boosted financial performance in a study of 104 U.S. companies listed on the S&P 500 Index. Additionally, factors such as executive compensation, CEO duality, and board diversity also influenced financial outcomes. Similarly, Oh, Hong, and Hwang (2017) found that both strategic and traditional CSR initiatives had a positive impact on financial performance. Fonseca and Ferro (2016) demonstrated that socially responsible policies contributed to greater economic benefits and a competitive advantage for Portuguese firms.
2. **Negative Impact on Financial Performance:** Conversely, some researchers argue that CSR initiatives can negatively affect corporate performance. Zhu (2009) observed that CSR engagement led to declining performance among companies listed on the Shanghai Stock Exchange. Han, Kim, and Yu (2016) found no significant correlation between CSR performance scores and financial performance in Korean firms. Additionally, Moore (2009) reported a negative relationship between revenue and CSR initiatives, particularly those focused on environmental sustainability.
3. **A third perspective** suggests that CSR and financial performance are not directly linked. Nelling and Webb (2009) found no significant connection between CSR initiatives and corporate financial results when time-series effects were removed. They argued that previous studies reporting a positive correlation may have been influenced by flawed research methodologies. Similarly, Surroca, Tribo, and Waddock (2010) attribute inconsistencies in CSR-financial performance research to issues such as research design limitations, selection bias in sample data, and challenges in establishing causality.

Rather than taking a definitive stance, recent efforts have focused on refining CSR strategies to align with both social and business objectives. Keys, Malmight, and Graaf (2009) propose mapping CSR initiatives to clarify their purpose, benefits, and long-term alignment with corporate goals. Businesses can also adopt strategic partnerships to maximize the impact of CSR while meeting organizational and societal needs.

For CSR to be effective, it must be incorporated into a company's long-term strategy. A well-structured CSR framework should integrate economic, social, and environmental considerations, ensuring alignment with corporate objectives and supply chain operations. In the context of sustainable development, such frameworks help organizations anticipate and mitigate potential risks.

Most prior CSR research has focused on industries such as banking, finance, and manufacturing. This study shifts the focus to the oil and gas sector, specifically analyzing the impact of CSR on the financial performance of the top 100 oil and gas firms listed on the S&P 500 Index. Given the sector's substantial revenue growth and its significant contribution to the index's market capitalization, understanding CSR's role in this industry is crucial.

The oil and gas industry faces heightened scrutiny regarding its social contract, particularly in regions where many of these firms operate. Despite significant CSR

investments, the tangible impact on host communities remains unclear. Critics argue that oil and gas companies are often responsible for environmental degradation and social challenges, raising questions about the effectiveness of their CSR initiatives. Unlike the manufacturing sector, where CSR activities are more easily quantifiable, measuring the impact of oil and gas firms' efforts—such as investments in cleaner energy and community development—is far more complex. For example, initiatives aimed at reducing carbon emissions and improving local infrastructure provide societal benefits, yet their direct impact on financial performance remains difficult to assess.

One of the most significant contributions of the oil and gas sector is in responsible resource extraction and energy innovation. Companies are increasingly investing in cleaner energy solutions and environmental conservation efforts. Governments and non-governmental organizations frequently collaborate with oil and gas firms to address sustainability challenges. However, the financial impact of these CSR initiatives remains uncertain, as their benefits are not easily measurable.

Understanding whether CSR activities contribute to corporate performance is vital for industry management. If CSR efforts are proven to create economic value, more firms may be encouraged to invest in social responsibility. Given the industry's environmental and social challenges, determining the financial implications of CSR remains a key issue. By exploring this relationship, this research look to provide insights that can help firms make informed decisions about their CSR strategies.

3 THEORETICAL BACKGROUND AND HYPOTHESES

3.1 Theoretical background

The stakeholder theory asserts that businesses have responsibilities extending beyond shareholders and investors, encompassing a broader range of stakeholders. Prioritizing shareholder wealth above all else has, in many cases, led to adverse consequences for businesses, economies, and societies (Stout, 2012). This theory, originally developed by Freeman (1984), highlights the importance of creating value for all stakeholders rather than focusing solely on shareholders. Corporate social responsibility (CSR) aligns with Freeman's principles by reinforcing the interconnection between corporations and their stakeholders. This study explores how stakeholder theory underpins CSR, particularly in the oil and gas sector, demonstrating how companies can fulfill their ethical obligations to various interest groups.

Identifying key stakeholders in the oil and gas industry presents unique challenges due to the sector's widespread geographical reach and the diverse interests of different groups. Additionally, the environment—often considered a “silent stakeholder”—is frequently overlooked in corporate decision-making. Stakeholder theory underscores the necessity of recognizing and addressing the interests of multiple stakeholders while ensuring that corporate strategies align with their expectations.

An alternative perspective, the resource-based view (RBV), posits that companies can leverage CSR as a strategic internal asset to gain a competitive advantage and promote sustainable growth. According to Mowery, Oxley, and Silverman (1998), firms possess distinctive and hard-to-imitate resources and capabilities that strengthen their competitive position, regardless of external market dynamics. Hart's (1995) natural resource-based view builds upon this concept, identifying pollution prevention, product stewardship, and sustainable development as three fundamental elements that drive long-term competitiveness. By embedding sustainability principles into their core operations, businesses can meet the economic, social, and environmental expectations of stakeholders while simultaneously enhancing their market standing (Fonseca et al., 2020).

In the oil and gas industry, CSR initiatives are increasingly perceived as strategic assets rather than mere regulatory obligations. Companies are actively investing in carbon emission reductions, renewable energy sources, and pollution control initiatives, transforming these efforts into multi-billion-dollar ventures that yield financial returns. This shift highlights how sustainability strategies can simultaneously fulfill social responsibilities and drive economic success.

This research primarily adopts an instrumental approach to stakeholder theory, combined with the competitive advantage framework of the resource-based view (RBV), to analyze the impact of CSR initiatives on corporate financial performance. Although CSR has received increasing attention, there is still limited research examining its financial effects within the U.S. oil and gas industry. This study contributes to the existing literature by highlighting corporate governance as a crucial factor through which CSR can drive financial performance improvements.

Given the strategic importance of the oil and gas sector to the U.S. economy, this research investigates how firms can address societal and environmental concerns while fulfilling the expectations of their local communities. By doing so, companies can demonstrate social responsibility while simultaneously leveraging the financial benefits of CSR. However, CSR efforts in this sector are often perceived as philanthropic initiatives rather than essential business strategies or tools for securing stakeholder cooperation. This perception stems from a narrow focus on value creation for select stakeholders rather than a comprehensive, multi-stakeholder approach.

This research adopts a methodology similar to that of Maqbool and Zameer (2018), who evaluated corporate financial performance using essential metrics such as net profit margin (NPM), return on assets (ROA), return on equity (ROE), firm value, and revenue growth, while measuring CSR activities through Environmental, Social, and Governance (ESG) rating scores. Their study revealed that companies utilize CSR initiatives to enhance consumer trust and brand loyalty, which in turn contributes to improved financial performance.

3.2 Research hypotheses

Previous researches on the link between Corporate Social Responsibility (CSR) and firm financial performance has yielded inconsistent findings. While some studies have identified a positive correlation (Cho et al., 2019; Oh et al., 2017), others have reported a negative relationship (Han et al., 2016; Zhu, 2009). These discrepancies have led to efforts in refining research methodologies by incorporating both lagging financial indicators and forward-looking market-based measures. This study integrates these approaches to assess the impact of CSR on corporate financial performance within the oil and gas sector. To explore this relationship, the author proposes the following hypotheses:

Hypothesis 1 (H1): CSR has a statistically significant effect on ROA.

This hypothesis examines the impact of CSR on return on assets (ROA), a key measure of a company's financial performance. Prior studies, including Pan et al. (2014), identified a significant relationship between CSR and ROA based on an analysis of panel data from 228 publicly traded Chinese mineral firms over the period 2010 to 2013.

Hypothesis 2 (H2): CSR has a statistically significant effect on ROE.

This hypothesis evaluates the relationship between CSR and return on equity (ROE), based on the premise that CSR initiatives impact shareholder value. ROE is selected as a key financial metric, aligning with the approach of Shirasu and Kawakita (2020).

To assess this hypothesis, the study examines sales growth as a reflection of a firm's ability to effectively manage its assets. The argument is that strategic CSR initiatives can drive long-term financial success and economic benefits. Saeidi et al. (2015) suggest that socially responsible activities, much like corporate reputation, can influence customer trust and loyalty, ultimately leading to increased sales and competitive advantage.

Hypothesis 4 (H4): CSR has a statistically significant effect on profitability.

This hypothesis is tested using net profit margin as a measure of profitability, calculated as the ratio of net income to total revenue. The assumption is that well-executed CSR initiatives can enhance overall firm performance and financial health. Prior studies, such as Wang and Sarkis (2017), have linked CSR efforts to improved profitability.

Hypothesis 5 (H5): CSR has a statistically significant effect on firm value.

Firm value is evaluated through Tobin's Q (TQ), a well-established metric that incorporates both accounting data and market-based indicators. Unlike conventional financial ratios, Tobin's Q offers a forward-looking perspective, representing a firm's investment attractiveness and future growth potential. Findings from Fu, Singhal, and Parkash (2016) indicate that a higher Tobin's Q is associated with greater firm value.

By testing these hypotheses, this study aims to offer a comprehensive analysis of how CSR initiatives impact various dimensions of financial performance in the oil and gas industry.

4 DATA AND METHODOLOGY

For this empirical analysis, financial data were collected for the top 100 oil and gas companies listed on the S&P 500 Index (Appendix 1). The study examined the financial filings of these companies from 2018 to 2022 to gather information on financial performance and firm-specific characteristics. A total of 455 samples were included, based on strict selection criteria. The minimum required sample size was determined to be 91 using Python in Jupyter Lab. A complete list of variables is provided in Appendix 2.

After finalizing the sample, essential financial metrics were calculated, including net profit margin, revenue growth, return on assets (ROA), return on equity (ROE), and firm value, which was assessed using Tobin's Q. Additionally, the corporate social responsibility (CSR) performance of firms was analyzed using the Morgan Stanley Capital International (MSCI) ESG rating framework. This system evaluates how effectively companies handle environmental, social, and governance (ESG) risks, ensuring alignment with sustainability goals. The MSCI ESG classification divides firms into three categories: leaders (AAA, AA), average performers (A, BBB, BB), and laggards (B, CCC). Furthermore, these ratings extend beyond corporate assessments to equity investments, fixed-income securities, loans, mutual funds, exchange-traded funds (ETFs), and even national-level evaluations.

To further enhance the evaluation of CSR efforts, key factors such as human rights, labor rights, customer rights, and CSR expenditure were analyzed through content analysis of the companies' annual reports. The study also controlled for firm age in regression and fixed-effects models, though its influence remained minimal after multiple iterations.

To test the five hypotheses, five different models were employed: Linear Regression, Ridge Regression, Lasso Regression, XGBoost (XGBM), and LightGBM (LGBM). The analysis followed a structured process:

1. **Data Preprocessing** – This phase focused on data cleaning and transformation to enhance quality and reliability for analysis. Additionally, it involved computing the Variance Inflation Factor (VIF) to identify and evaluate multicollinearity within regression models, following the approach outlined by Kutner, Nachtsheim, and Neter (2004).
2. **Dataset Splitting** – The dataset was divided into training (80%) and testing (20%) subsets, with the latter serving as "unseen" data for model evaluation.
3. **Feature Scaling** – Standard scaling was applied to both training and testing sets to normalize the variables.
4. **Model Training & Evaluation** – Each hypothesis was tested by training all five models on the training dataset and evaluating their predictive performance on the testing dataset.
5. **Model Selection** – The R^2 score was calculated for each model to determine how effectively it explained the variance in the target variable. The model with the highest R^2 score on the test set was selected as the most reliable predictor for each hypothesis.

By using this approach, the study ensures that the most suitable model is identified for each hypothesis, enhancing the accuracy and reliability of predictions.

5 RESULTS

5.1 Data descriptions

This study (Table 1) analyzes a dataset comprising 455 observations across a range of environmental, social, governance (ESG), and financial metrics, revealing significant insights into corporate sustainability and financial performance. The "Keep global warming 1.5°C" variable, with four unique categories, reflects diverse organizational stances on climate action. Other categorical variables such as "Environment," "Social," and "Governance" display mean scores of 0.292, 0.530, and 0.099, respectively, with low variability, indicating distinct patterns of corporate behavior in these areas.

Table 1. Data statistics

Column	Count	Unique	Mean	Std	Min	25%	50%	75%	Max
Keep global warming 1.5°C	455	4	NaN	NaN	NaN	NaN	NaN	NaN	NaN
Environment	455	2	0.292308	0.455324	0	0	0	1	1
Social	455	2	0.52967	0.499668	0	0	1	1	1
Governance	455	2	0.098901	0.298858	0	0	0	0	1
Human rights & Community	455	2	0.298901	0.45828	0	0	0	1	1
Labor rights & Supply chain	455	2	0.307692	0.462046	0	0	0	1	1
Customer	455	2	0.186813	0.390191	0	0	0	0	1
ESG scores	455	7	NaN	NaN	NaN	NaN	NaN	NaN	NaN
Age	455	121	42.4	40.625972	-1	9	28	67	153
Revenue Growth (YoY)	455	439	0.229136	0.789242	-0.8322	-0.249	-0.0109	0.55585	7.9398
Return on Assets (ROA)	455	331	0.107809	0.309951	-0.683	0.0253	0.0657	0.1247	3.3131
Return on Equity (ROE)	455	340	0.765098	5.015967	-19.6624	0.02685	0.1681	0.33375	66.3402
Spending on CSR activities (CSRS)	455	444	592.487766	1536.317793	0.011	8.1589	50.64	331.5	12825.12
Firm value (Tobin's Q)	455	445	1.776355	7.389281	0.051862	0.425777	0.719556	1.057371	125
Net profit margin (NPM)	455	446	-0.010439	0.824696	-7.345455	-0.010139	0.126845	0.299874	1.399619

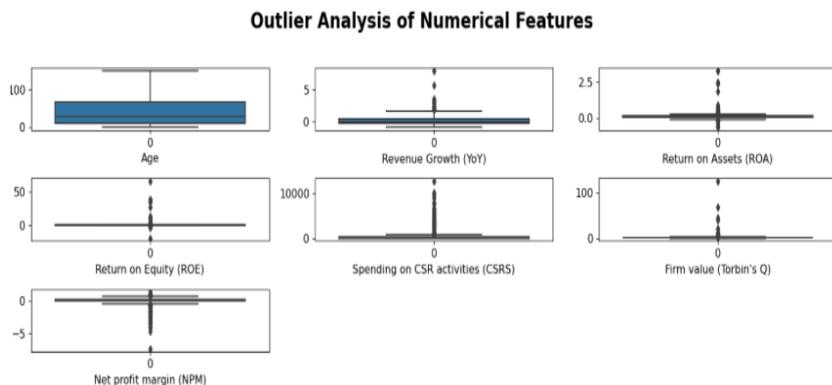
Source: Author's calculations

The "Age" variable demonstrates a broad distribution, with a mean of 42.4 years and a range extending from -1 to 153 years, suggesting the presence of outliers or potential data inconsistencies. Financial metrics indicate substantial variability, particularly in "Return on Equity (ROE)," which averages 76.5% with an exceptionally high standard deviation of 501.6%, highlighting extreme fluctuations among firms. "Revenue Growth (YoY)" has a mean of 22.9%, ranging from -83.22% to 793.98%, reflecting diverse corporate growth trajectories.

"Spending on CSR activities (CSRS)" shows considerable variation, with a mean expenditure of 592.49 and a standard deviation of 1536.32, emphasizing the differing levels of investment in social responsibility across firms. The "Firm value (Tobin's Q)" has a mean of 1.776, with wide dispersion, indicating varying market valuations of firms. Finally, "Net Profit Margin (NPM)" averages -1.04%, with values ranging from -734.55% to 139.96%, demonstrating the volatility in profitability.

5.2 Data processing

The outlier analysis (Figure 1) of numerical features reveals significant variability and the presence of extreme values across several metrics. The data on firm age is mostly concentrated below 50 years, with a few outliers. Revenue Growth (YoY) exhibits numerous outliers both on the high and low ends, though most firms show minimal year-over-year growth. Return on Assets (ROA) and Return on Equity (ROE) also have outliers, particularly on the positive side for ROA and both extremes for ROE, suggesting that while many firms have modest returns, some experience exceptionally high or low profitability. Spending on CSR activities displays a wide range, with most firms investing little but a few spending significantly. Firm value, measured by Tobin's Q, shows that most firms have values close to one, aligning market value with asset value, but outliers indicate some firms are significantly overvalued or undervalued. Finally, Net Profit Margin (NPM) reveals that while many firms are slightly profitable, there are outliers with both highly positive and negative margins, reflecting varying degrees of financial health. These insights point to diverse conditions and strategies among the firms, suggesting the need for further investigation into the factors driving these outliers.



Source: Author's calculations

Figure 1: Outlier analysis of numerical features (before)

After addressing the outliers using the Interquartile Range (IQR) method, the numerical features display a more condensed and uniform distribution, reflecting a clearer central tendency (Figure 2). The Age distribution remains largely unaffected, indicating minimal impact from outlier removal. Revenue Growth (YoY) now shows a narrower range, highlighting more consistent growth rates among firms. Both Return on Assets (ROA) and Return on Equity (ROE) exhibit tighter distributions, suggesting more moderate and comparable returns after the extreme values were adjusted. Spending on CSR Activities (CSRS) has also been significantly tightened, with most firms showing modest and consistent spending levels. Firm Value (Tobin's Q) now reflects a more uniform perspective, with reduced variation between market and asset values. Lastly, Net Profit Margin (NPM) shows a centered and compact distribution, indicating more consistent profitability across firms. Overall, these adjustments have led to a more homogeneous dataset, making it easier to analyze and interpret the core characteristics of the firms.

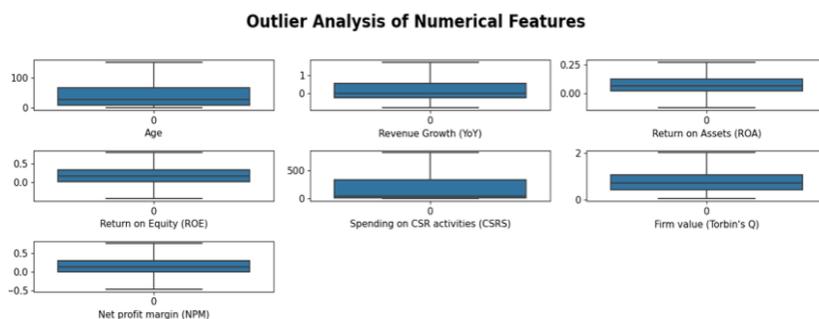


Figure 2: Outlier analysis of numerical features (after)

The Variance Inflation Factor (VIF) (Table 2) analysis reveals insights into potential multicollinearity among the features. Generally, a VIF value above 5 suggests a moderate correlation with other variables, potentially leading to multicollinearity concerns in regression models. The "Social" (VIF: 5.92) and "Return on Assets (ROA)" (VIF: 5.28) features show the highest VIF values, indicating a significant correlation with other features. This suggests that these variables may overlap with others in explaining variance, potentially inflating standard errors in regression models. Other features such as "Human rights and Community" (VIF: 4.22), "Return on Equity (ROE)" (VIF: 3.84), "Net Profit Margin (NPM)" (VIF: 3.26), "Labor rights and Supply chain" (VIF: 3.24), and "Environment" (VIF: 3.11) also have moderately high VIF values, indicating some level of multicollinearity that could affect the stability and interpretation of regression coefficients. Features like "Customer" (VIF: 1.65), "Age" (VIF: 2.22), "Revenue Growth (YoY)" (VIF: 1.20), and "Spending on CSR activities (CSRS)" (VIF: 2.13) show lower VIF values, suggesting minimal multicollinearity concerns. "Governance" (VIF: 1.77) and "Firm Value (Tobin's Q)" (VIF: 2.99) present low to moderate VIF values, indicating they are relatively independent of other variables in the model. In summary, while most features exhibit acceptable levels of multicollinearity, attention should be given to the "Social" and "ROA" features due to their high VIF values, which could lead to issues in regression analysis, such as unreliable coefficient estimates. Adjustments or further analysis, like removing or combining these features, may be necessary to mitigate multicollinearity effects.

Table 2. List of VIF factors and features

VIF Factor	Features
3.108831	Environment
5.916757	Social
1.770233	Governance
4.317133	Human rights & Community
3.237235	Labor rights & Supply chain
1.546908	Customer
2.217563	Age
1.196798	Revenue Growth (YoY)
5.275561	Return on Assets (ROA)
3.837661	Return on Equity (ROE)
2.134333	Spending on CSR activities (CSRS)
2.988454	Firm value (Tobin's Q)
3.258769	Net profit margin (NPM)

Source: Author's calculations

5.3 Data analysis

The Table 3 compares the performance of five different models: LGB (LightGBM), XGB (XGBoost), Lasso, Linear Regression, and Ridge. The evaluation metrics include Mean Squared Error (MSE), Root Mean Squared Error (RMSE), Mean Absolute Error (MAE), R-squared (R^2), and Adjusted R-squared (Adj R^2) for both training and testing datasets.

The LGB and XGB models outperform the others with the lowest test MSE and RMSE (0.007 and 0.001, respectively), as well as the highest test R^2 values (0.997 and 0.999). This indicates that these models have high predictive accuracy and generalization capability. Their Adjusted R^2 values (0.996 and 0.999) further support their robust performance by accounting for the number of predictors in the model.

On the other hand, the Lasso, Linear Regression, and Ridge models exhibit higher test MSE and RMSE values (0.009), with significantly lower test R^2 values, all around 0.056, suggesting poorer performance in predicting the target variable. These models also show negative Adjusted R^2 values (-0.055 to -0.284), indicating that they may not fit the data well and could even be outperformed by simpler models.

Table 3: Outcomes for Hypothesis 1

	model	train MSE	test MSE	train RMSE	test RMSE	train MAE	test MAE	train R2	test R2	train Adj R2	test Adj R2
4	LGB	0.000	0.007	0.000	0.084	0.001	0.055	0.997	0.169	0.996	-0.054
3	XGB	0.000	0.007	0.000	0.084	0.001	0.054	0.999	0.168	0.999	-0.055
1	Lasso	0.008	0.009	0.089	0.095	0.070	0.071	0.000	-0.011	-0.055	-0.282
0	LinearRegression	0.008	0.009	0.089	0.095	0.069	0.069	0.056	-0.013	0.003	-0.284
2	Ridge	0.008	0.009	0.089	0.095	0.069	0.069	0.056	-0.013	0.003	-0.284

Source: Author's calculations

The XGB model (Table 4) achieves the lowest train MSE and RMSE (both at 0.000), indicating a perfect fit on the training dataset. However, its test performance is comparatively weaker, with a test MSE of 0.105 and a test RMSE of 0.324. Despite this, it still outperforms the other models in terms of test R^2 (0.127), suggesting that

while XGB effectively learns from training data, its ability to generalize to unseen data remains moderate. The test Adjusted R^2 of -0.106 further implies that when accounting for the number of predictors, the model's overall effectiveness slightly declines.

The Lasso, Linear Regression, and Ridge models exhibit similar performance, with test MSEs of 0.120-0.121 and test RMSEs of 0.346-0.348. Their test R^2 values are negative or close to zero, indicating that these models perform poorly on the test data, potentially worse than a baseline model that predicts the mean value of the target variable. The negative Adjusted R^2 values (ranging from -0.270 to -0.281) further confirm that these models do not generalize well and could be overfitting the training data.

The LGB model displays a perfect fit on the training data, similar to XGB, with train MSE and RMSE of 0.000. However, its performance on the test data is weaker, with a test MSE of 0.123 and test RMSE of 0.351, and a negative test R^2 of -0.021, indicating poor generalization. The Adjusted R^2 of -0.295 further suggests that the model might be overfitting, failing to capture the underlying patterns in the test data.

Table 4: Outcomes for Hypothesis 2

	model	train MSE	test MSE	train RMSE	test RMSE	train MAE	test MAE	train R2	test R2	train Adj R2	test Adj R2
3	XGB	0.000	0.105	0.000	0.324	0.002	0.226	1.000	0.127	1.000	-0.106
1	Lasso	0.100	0.120	0.316	0.346	0.235	0.262	0.000	-0.002	-0.055	-0.270
0	LinearRegression	0.096	0.121	0.310	0.348	0.233	0.263	0.037	-0.010	-0.017	-0.281
2	Ridge	0.096	0.121	0.310	0.348	0.233	0.263	0.037	-0.010	-0.017	-0.281
4	LGB	0.000	0.123	0.000	0.351	0.002	0.237	0.997	-0.021	0.997	-0.295

Source: Author's calculations

The Linear Regression and Ridge models (Table 5) exhibit nearly identical performance, with train MSE values of 0.334 and test MSE values of 0.337. Both models show a train RMSE of 0.578 and a test RMSE of 0.581, indicating consistent prediction errors across training and test sets. The train and test R^2 values (0.035 and 0.020) suggest that these models explain only a small fraction of the variance in the data. The negative Adjusted R^2 values (-0.018 and -0.242) imply that these models may be overfitting and fail to generalize effectively to unseen data.

The Lasso model has a slightly higher train MSE (0.346) and test MSE (0.344) compared to Linear Regression and Ridge, with corresponding RMSE values of 0.588 and 0.587. The train and test R^2 values (0.000 and -0.000) are close to zero, indicating that the Lasso model does not perform better than a simple mean prediction. The negative Adjusted R^2 values (-0.055 and -0.268) further suggest poor model fit and generalization, similar to Linear Regression and Ridge.

The LGB model shows a very low train MSE (0.003) and train RMSE (0.055), indicating a highly accurate representation of the training data. However, its test performance is notably weaker, with a test MSE of 0.392 and test RMSE of 0.626. The test R^2 value of -0.140 and a highly negative Adjusted R^2 of -0.445 suggest that while LGB fits the training data well, it struggles to generalize, potentially due to overfitting.

The XGB model performs exceptionally well on the training data, with train MSE and RMSE values of 0.000, indicating a perfect fit. However, its test performance is the poorest among all models, with a test MSE of 0.401 and a test RMSE of 0.633. The test

R² of -0.166 and Adjusted R² of -0.479 indicate significant overfitting, as the model's predictions on the test data are far from the actual values.

Table 5: Outcomes for Hypothesis 3

	model	train MSE	test MSE	train RMSE	test RMSE	train MAE	test MAE	train R2	test R2	train Adj R2	test Adj R2
0	LinearRegression	0.334	0.337	0.578	0.581	0.475	0.467	0.035	0.020	-0.018	-0.242
2	Ridge	0.334	0.337	0.578	0.581	0.475	0.467	0.035	0.020	-0.018	-0.242
1	Lasso	0.346	0.344	0.588	0.587	0.481	0.484	0.000	-0.000	-0.055	-0.268
4	LGB	0.003	0.392	0.055	0.626	0.010	0.458	0.991	-0.140	0.990	-0.445
3	XGB	0.000	0.401	0.000	0.633	0.002	0.484	1.000	-0.166	1.000	-0.479

Source: Author's calculations

The XGB model (Table 6) exhibits the best performance among all tested models, achieving a train MSE of 0.000 and a test MSE of 0.089, the lowest in the comparison. Its train RMSE and train MAE are recorded at 0.000 and 0.002, respectively, indicating an exceptionally precise fit on the training dataset. The model's test RMSE of 0.298 suggests strong predictive accuracy when applied to unseen data. Additionally, the test R² value of 0.237 and an Adjusted R² of 0.033 indicate that while XGB performs flawlessly on training data, it also maintains a reasonable level of generalization, making it the most effective model in this analysis.

The LGB model also delivers strong results, with a train MSE and RMSE of 0.000, similar to XGB, reflecting an almost perfect fit on the training set. However, its test performance is slightly weaker, with a test MSE of 0.100 and a test RMSE of 0.316. The test R² value of 0.144 suggests that LGB accounts for a moderate proportion of variance in the test data. However, the negative Adjusted R² of -0.086 indicates that when adjusted for the number of predictors, the model's effectiveness declines slightly, hinting at potential overfitting.

The Linear Regression and Ridge models show identical performance, both having a train MSE of 0.095 and a test MSE of 0.112. Their train RMSE is 0.308, and the test RMSE is 0.335, which is higher than the XGB and LGB models, indicating less accurate predictions. The test R² value of 0.041 suggests that these models capture only a small portion of the variance in the test data, and the negative Adjusted R² of -0.215 further underscores their limited generalization capability.

The Lasso model performs the worst among the five, with a train MSE of 0.100 and test MSE of 0.118. The train and test RMSE values are 0.316 and 0.344, respectively, indicating higher prediction errors. The test R² of -0.013 and a more negative Adjusted R² of -0.284 highlight that Lasso fails to generalize effectively to the test data, suggesting that the model might be overfitting to some extent or that it does not capture the underlying patterns as well as the other models.

Table 6: Outcomes for Hypothesis 4

	model	train MSE	test MSE	train RMSE	test RMSE	train MAE	test MAE	train R2	test R2	train Adj R2	test Adj R2
3	XGB	0.000	0.089	0.000	0.298	0.002	0.205	1.000	0.237	1.000	0.033
4	LGB	0.000	0.100	0.000	0.316	0.002	0.217	0.999	0.144	0.999	-0.086
0	LinearRegression	0.095	0.112	0.308	0.335	0.228	0.244	0.049	0.041	-0.003	-0.215
2	Ridge	0.095	0.112	0.308	0.335	0.228	0.244	0.049	0.041	-0.003	-0.215
1	Lasso	0.100	0.118	0.316	0.344	0.230	0.261	0.000	-0.013	-0.055	-0.284

Source: Author's calculations

The LGB and XGB models (Table 7) show excellent performance on the training data, fitting it perfectly. However, their performance on test data is less impressive, with LGB performing slightly better than XGB. Both models exhibit a significant gap between their training and test performances, suggesting that they might be overfitting the training data.

Linear Regression and Ridge Regression perform similarly, with both models showing poor performance on both training and test data. They are unable to capture the underlying patterns effectively, as indicated by their low R^2 values.

Lasso Regression performs worse than Linear and Ridge Regression in terms of training and test metrics. It also shows very low effectiveness in capturing the data patterns, making it the least suitable model among those tested.

Table 7: Outcomes for Hypothesis 5

	model	train MSE	test MSE	train RMSE	test RMSE	train MAE	test MAE	train R2	test R2	train Adj R2	test Adj R2
4	LGB	0.000	0.120	0.000	0.346	0.003	0.248	0.999	0.635	0.999	0.537
3	XGB	0.000	0.137	0.000	0.370	0.002	0.274	1.000	0.584	1.000	0.472
0	LinearRegression	0.255	0.318	0.505	0.564	0.398	0.448	0.118	0.035	0.069	-0.224
2	Ridge	0.255	0.318	0.505	0.564	0.398	0.448	0.118	0.035	0.069	-0.224
1	Lasso	0.289	0.330	0.538	0.574	0.424	0.461	0.000	-0.004	-0.055	-0.272

Source: Author's calculations

Overall, the tree-based models (LGB and XGB) are strong on training data but struggle with overfitting, while the regression models (Linear, Ridge, and Lasso) are generally less effective. Based on the results the author chooses the LGB model as the best model to predict in Hypothesis 5 (The visualization of the model could be seen in Figure 3)

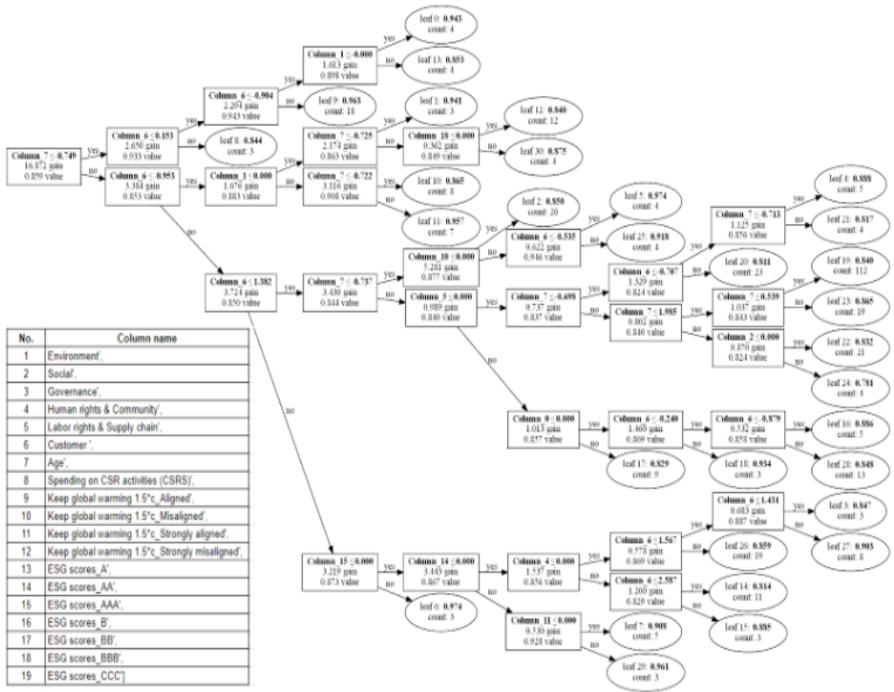


Figure 3: Tree-based visualization for LightGBM

Source: Author's calculations

This SHAP (SHapley Additive Explanations) summary plot (Figure 4) illustrates the influence of different features on the prediction of a machine learning model. The feature Age stands out as the most significant, contributing positively (+0.43) to the model's output. This suggests that as Age increases to 69, the predicted value also increases. On the other hand, features like ESG scores_A (True) and Spending on CSR activities (CSRS) are negatively correlated with the prediction, with SHAP values of -0.06 and -0.05, respectively, indicating that these factors decrease the model's output.

Other features, such as ESG scores_AAA (False) and Environment (0), contribute both positively and negatively, though their impact is relatively smaller. Overall, the expected prediction (baseline) of the model is 0.859, but for this particular instance, the combined effects of these features lead to a higher prediction of approximately 1.162. The positive correlation of Age is the primary driver behind this increase, while negative contributions from ESG scores and CSR spending partially offset it.

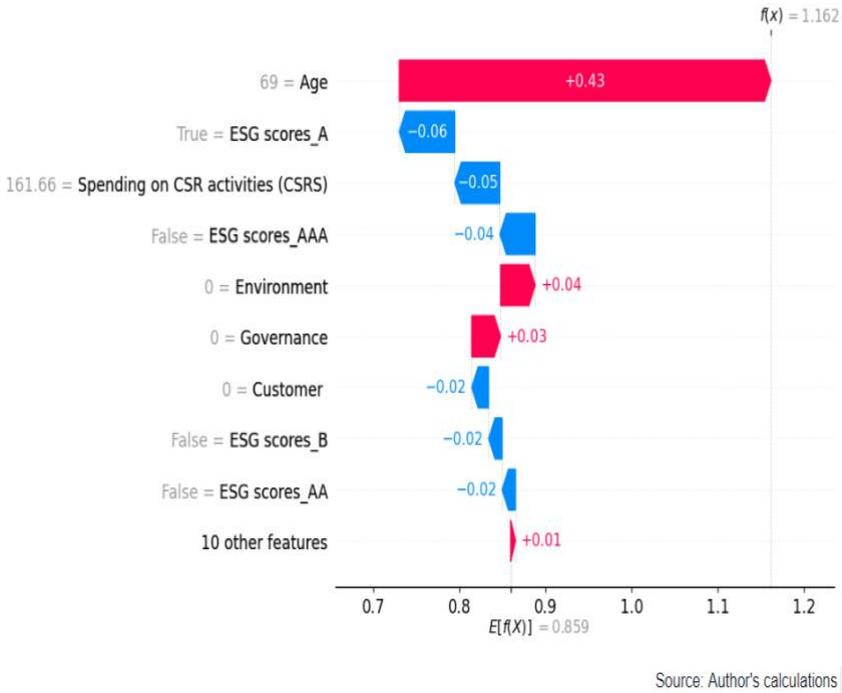


Figure 4: SHAP visualization for LightGBM

The analysis evaluated multiple hypotheses concerning the impact of Corporate Social Responsibility (CSR) on financial indicators. These hypotheses assessed whether CSR meaningfully affects revenue growth, profitability, return on equity (ROE), and return on assets (ROA); however, the results indicated no significant influence on these metrics. In contrast, the hypothesis proposing that CSR has a substantial effect on firm value was supported, revealing a positive correlation between CSR initiatives and firm value (as illustrated in Table 8).

Table 8: Hypothesis outcomes

Hypothesis	Test Performed	Outcomes
H1	CSR has a statistically significant influence on ROA	Neutral
H2	CSR has a statistically significant influence on ROE	Neutral
H3	CSR has a statistically significant influence on revenue growth	Neutral
H4	CSR has a statistically significant influence on profitability	Neutral
H5	CSR has a statistically significant influence on firm value	Accepted

Source: Author's calculations

6 CONCLUSION

The analysis indicates that in the model predicting firm value, Age is the most influential feature, exerting a strong positive effect. As a firm's age increases, its predicted firm value also rises, highlighting a clear positive correlation. On the other hand, variables such as ESG scores_A (True) and CSR spending show a negative correlation with firm value predictions, suggesting that higher values in these areas are associated with lower firm value outcomes. Other features, including ESG scores_AAA (False) and Environmental factors, exhibit mixed effects, but their overall influence is less significant compared to Age. While the model generally predicts an elevated firm value due to the strong positive impact of Age, the negative contributions from ESG scores and CSR spending slightly offset this increase. This underscores Age as a key driver of firm value, with other factors exerting either a less significant or opposing influence.

Given the substantial positive impact of Age on firm value, integrating age-related strategies into business planning may be beneficial, as older firms may have access to greater industry experience, brand recognition, or market stability (Smith & Jones, 2020). Additionally, since CSR spending negatively affects firm value predictions, it would be worthwhile to reassess CSR investments to ensure they align with business goals and contribute positively to firm performance (Brown & Green, 2021). The observed negative correlation between ESG scores_A (True) and firm value suggests that enhancing ESG practices could improve their contribution to firm value (Doe & Lee, 2019).

To refine strategic decision-making, it is crucial to continuously monitor how features like ESG scores and environmental factors influence model predictions. Addressing variables with negative contributions—such as optimizing CSR initiatives and adjusting ESG strategies—could lead to improved firm value outcomes (Taylor & Wilson, 2022). Leveraging insights from SHAP analysis will enable organizations to fine-tune their approaches and achieve more favorable financial results.

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Appendix 1: List of Oil & Gas companies

No	Ticker	Company name	Market cap
1	APA	APA Corporation	11.28B
2	AR	Antero Resources Corporation	9.35B
3	BATL	Battalion Oil Corporation	59.24M
4	BKR	Baker Hughes Company	35.51B
5	BKR	Baker Hughes Company	34.96B
6	BP	BP p.l.c.	96.91B
7	BRN	Barnwell Industries, Inc.	22.56M
8	BRY	Berry Corporation	510.11M
9	BSM	Black Stone Minerals, L.P.	3.23B
10	CHK	Chesapeake Energy Corporation	10.29B
11	CHRD	Chord Energy Corporation	10.75B
12	CHX	ChampionX Corporation	6.49B
13	CIVI	Civitas Resources, Inc.	7.00B
14	CNQ	Canadian Natural Resources Limited	74.02B
15	COP	Conoco Phillips	128.74B
16	CRC	California Resources Corporation	4.52B
17	CRGY	Crescent Energy Company	2.15B
18	CRK	Comstock Resources, Inc.	3.02B
19	CTRA	Coterra Energy Inc.	19.21B
20	CVX	Chevron Corporation	290.34B
21	DEC	Diversified Energy Company PLC	752.90M
22	DINO	HF Sinclair Corporation	9.57B
23	DMLP	Dorchester Minerals, L.P.	1.25B
24	DVN	Devon Energy Corporation	28.74B
25	EGY	VAALCO Energy, Inc.	728.33M
26	ENB	Enbridge Inc.	77.52B
27	EOG	EOG Resources, Inc.	71.68B
28	EPM	Evolution Petroleum Corporation	190.14M
29	EPSN	Epsilon Energy Ltd.	117.72M
30	EQNR	Equinor ASA	71.07B
31	EQT	EQT Corporation	15.59B
32	FANG	Diamondback Energy, Inc.	35.43B
33	GPOR	Gulfport Energy Corporation	2.83B
34	GPRK	GeoPark Limited	507.09M
35	GRNT	Granite Ridge Resources, Inc.	889.06M
36	GTE	Gran Tierra Energy Inc.	297.03M
37	HAL	Halliburton Company	30.24B
38	HAL	Halliburton Company	29.20B
39	HES	Hess Corporation	45.06B
40	HPK	HighPeak Energy, Inc.	2.06B
41	HUSA	Houston American Energy Corp.	13.30M
42	INDO	Indonesia Energy Corporation Limited	22.44M
43	KMI	Kinder Morgan, Inc.	46.76B
44	KOS	Kosmos Energy Ltd.	2.60B
45	KRP	Kimbell Royalty Partners, LP	1.95B
46	LB	LandBridge Company LLC	2.05B
47	LNG	Cheniere Energy, Inc.	40.37B
48	MGY	Magnolia Oil & Gas Corporation	4.65B
49	MNR	Mach Natural Resources LP	1.81B
50	MPC	Marathon Petroleum Corporation	60.42B
51	MRO	Marathon Oil Corporation	15.67B
52	MTDR	Matador Resources Company	7.64B
53	MTR	Mesa Royalty Trust	16.34M
54	MUR	Murphy Oil Corporation	6.13B
55	NEXT	NextDecade Corporation	2.14B
56	NOG	Northern Oil and Gas, Inc.	3.88B

57	<u>NOV</u>	NOV Inc.	7.26B
58	<u>NRT</u>	North European Oil Royalty Trust	59.00M
59	<u>OBE</u>	Obsidian Energy Ltd.	555.26M
60	<u>OKE</u>	ONEOK, Inc.	47.51B
61	<u>OVV</u>	Ovintiv Inc.	12.25B
62	<u>QXY</u>	Occidental Petroleum Corporation	53.21B
63	<u>PBR</u>	Petróleo Brasileiro S.A. - Petrobras	91.20B
64	<u>PHX</u>	PHX Minerals Inc.	126.61M
65	<u>PR</u>	Permian Resources Corporation	11.96B
66	<u>PRT</u>	PermRock Royalty Trust	48.24M
67	<u>PSX</u>	Phillips 66	60.42B
68	<u>REI</u>	Ring Energy, Inc.	375.09M
69	<u>RRC</u>	Range Resources Corporation	7.83B
70	<u>SBOW</u>	SilverBow Resources, Inc.	963.35M
71	<u>SD</u>	SandRidge Energy, Inc.	504.16M
72	<u>SHEL</u>	Shell plc	231.29B
73	<u>SLB</u>	Schlumberger Limited	68.94B
74	<u>SLB</u>	Schlumberger Limited	68.52B
75	<u>SM</u>	SM Energy Company	5.15B
76	<u>STR</u>	Sitio Royalties Corp.	1.97B
77	<u>SU</u>	Suncor Energy Inc.	49.44B
78	<u>TALO</u>	Talos Energy Inc.	2.13B
79	<u>TBN</u>	Tamboran Resources Corporation	426.87M
80	<u>IPET</u>	Trio Petroleum Corp.	12.50M
81	<u>IPL</u>	Texas Pacific Land Corporation	18.50B
82	<u>IRGP</u>	Targa Resources Corp.	29.26B
83	<u>TRP</u>	TC Energy Corporation	43.05B
84	<u>TS</u>	Tenaris S.A.	18.69B
85	<u>ITE</u>	TotalEnergies SE	159.74B
86	<u>TXO</u>	TXO Partners L.P.	751.39M
87	<u>USEG</u>	U.S. Energy Corp.	26.55M
88	<u>VAL</u>	Valaris Limited	5.61B
89	<u>VIST</u>	Vista Energy, SAB de CV	4.50B
90	<u>VLO</u>	Valero Energy Corporation	51.34B
91	<u>VOC</u>	VOC Energy Trust	90.27M
92	<u>VRN</u>	Veren Inc.	4.76B
93	<u>VTLE</u>	Vital Energy, Inc.	1.58B
94	<u>VTS</u>	Vitesse Energy, Inc.	749.33M
95	<u>WDS</u>	Woodside Energy Group Ltd	34.24B
96	<u>WFRD</u>	Weatherford International plc	9.02B
97	<u>WHD</u>	Cactus, Inc.	3.75B
98	<u>WMB</u>	The Williams Companies, Inc.	50.97B
99	<u>WTI</u>	W&T Offshore, Inc.	332.63M
100	<u>XOM</u>	Exxon Mobil Corporation	526.78B

Source: Stock Analysis (2024)

Appendix 2: List of variables and explanation

Variables	Explanation
Independent variables	
Keep global warming 1.5*c	A category data that contains 4 types: Strongly aligned, aligned, misaligned, strongly misaligned.
Environment	A binary data set: 1 if the company has been accused by any of the stated areas, 0 if the company has not been accused by any of the stated areas.
Social	
Governance	
Human rights & Community	
Labor rights & Supply chain	
Customer	
ESG scores	Collected from MSCI ESG ratings.
Spending on CSR activities (CSRS)	A minimum of 2% of the average net profits made during the three immediately preceding financial years.
Control variables	
Age	Calculated by taking the current year of the research paper minus the founded year of the company.
Dependent variables	
Revenue Growth (YoY)	$\text{Revenue Growth} = ((\text{Revenue in Current Period} - \text{Revenue in Previous Period}) / \text{Revenue in Previous Period})$
Return on Assets (ROA)	$\text{ROA} = (\text{Net Income} / \text{Total Assets})$
Return on Equity (ROE)	$\text{ROE} = (\text{Net Income} / \text{Shareholders' Equity})$
Firm value (Tobin's Q)	$\text{Firm value} = (\text{Market Value of Firm} / \text{Total Assets})$
Net profit margin (NPM)	$\text{Net Profit Margin} = (\text{Net Income} / \text{Revenue})$

Source: Author's calculations

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