4 ESG PERFORMANCE AND LONG-TERM VALUE IN ENERGY ENTERPRISES: AN ESG-CENTRIC ECONOMIC ANALYSIS AND FORECASTING

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Abstract

Against the backdrop of China's dual carbon goals and the energy sector's critical role in economic sustainability, this study explores the relationship between ESG performance and long-term value creation in energy enterprises. Leveraging the machine learning method, namely the random forest model, we test the predictive effects of representative financial indicators on ESG performance. Empirical results reveal a significant positive link between ESG performance and energy enterprises' long-term value. Notably, among ESG dimensions, governance (G) acts as the most influential driver, differing from prior literature emphasizing environmental (E) factors. This divergence stems from state-owned enterprises' governance advantages, facilitating effective risk management and strategic alignment. Financial indicators, especially total enterprise assets, current ratio, and earnings per share growth rate, highlight the necessity of financial health in supporting sustainable practices. Heterogeneity analysis further shows that energy enterprises with lower media attention and innovation capability gain more from ESG initiatives in enhancing long-term value. This study challenges the conventional focus on environmental factors in state-dominated sectors. By proposing governance-oriented policies and enterprise strategies, this study establishes governance as a critical lever. We offer a novel forecast pathway for sustainable growth under China's dual carbon agenda. Additionally, the research findings hold implications for emerging economies aiming to integrate ESG criteria into long-term economic stability frameworks.

Keywords: *ESG, Long-Term Value, Energy Enterprise, Financial Status, Forecast*

JEL Classification: *G30, G32, Q56, M14, L11*

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1. Introduction

With the advancement of the global sustainable development agenda, many economic entities and organizations have put much effort into achieving this goal. The United Nations proposed the Sustainable Development Goals (SDGs) in 2015, which aim to encourage enterprises worldwide to consider the coordinated development of the economy, society, and environment. Since then, many countries and regions have integrated the SDGs into their development strategies and policy frameworks. From the perspective of environmental issues, there are lots of countries that have introduced strict carbon emission policies, prompting domestic enterprises to adjust their business strategies to meet environmental protection requirements. This is also a global commitment to cope with climate change risks (Su et al., 2025). Since enterprises are one of the vital forces to drive the development of the economy, they are also striving to make changes to reduce emissions and achieve long-term growth. It can also be seen as an important reason for practicing enterprises' environmental, social, and governance (ESG) framework. In the energy sector, ESG performance is not only a matter of enterprises social responsibility but also directly affects long-term competitiveness and market valuation. As a pillar industry of the global economy, energy enterprises face significant environmental and social pressures, such as carbon emissions, resource consumption, and community relations. Figure 1 illustrates the carbon dioxide emissions of the retail, chemical, transportation, and energy industries, as well as the total emissions across all industries. The total carbon emissions across all industries in China exhibited an increasing trend from 2015 to 2021. Notably, compared to other industries, the energy sector's share of carbon emissions has been increasing, approaching nearly half of the total emissions. This highlights the critical role of the energy industry in China's overall carbon footprint. This economic transformation has affected the capital market and investors as well. With the rise of socially responsible investment (SRI) and green finance, investors no longer simply focus on enterprises financial performance but incorporate ESG factors into investment decision-making.

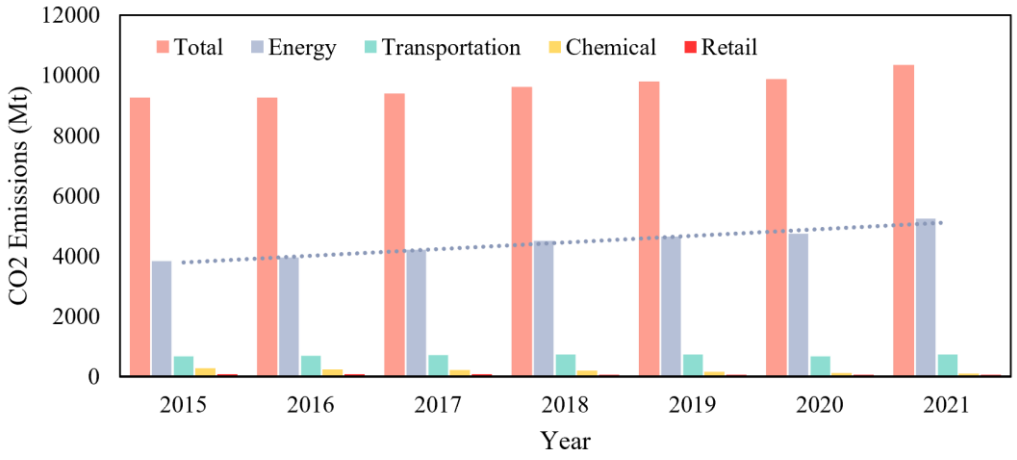

Figure. 1. Carbon Emissions by Sector in China

Data Source: Carbon Emission Accounts and Datasets (CEADs)

Traditional enterprise value evaluation mainly focuses on financial indicators. However, its limitations gradually emerge in facing the diverse demands of stakeholders. As an indicator

measuring the ratio of an enterprise's market value to its replacement cost, Tobin's Q is utilized in this study to explore its connection with enterprises' ESG performance in sustainable-oriented development. There are controversial discussions about the relationship between the two in the theoretical field. Some theories believe that good ESG scores will increase enterprises' costs and negatively impact the related financial indicators of Tobin's Q. Other investigations emphasize that ESG can enhance long-term value by enhancing enterprises' reputation and reducing risks. These viewpoints inspire us to conduct further research on analyzing the relationship between Tobin's Q and the ESG performance of enterprises, especially those in China's energy sector. It can be confusing for enterprises to invest in ESG practices since it is uncertain whether these investments can be converted into actual economic benefits. Therefore, this study aims to deeply analyze the relationship between enterprise ESG performance and Tobin's Q. Through empirical analysis, we attempt to reveal how ESG practices affect the long-term market value of energy enterprises and explore effective ESG paths to enhance their long-term value. By doing so, this study enriches the theoretical investigation of enterprise value assessment in the energy sector, integrating ESG factors into the financial evaluation framework. Also, more decision-making insights are provided for energy enterprise managers, which could be helpful for reasonably planning ESG strategies, reducing carbon emissions in the energy sector and ultimately achieving long-term economic growth and stability.

To sum up, this study contributes to the existing literature in several ways. **First**, unlike most prior studies that emphasize the environmental dimension, we find that governance plays a dominant role in enhancing the long-term value of energy enterprises, especially in the context of state-owned firms. **Second**, we introduce machine learning techniques—specifically the random forest model—to forecast ESG scores using traditional financial indicators, providing a novel methodological approach to ESG analysis. **Third**, by incorporating heterogeneity analysis, we identify that energy enterprises with low media attention and innovation capabilities benefit more significantly from ESG practices. This nuanced insight provides a new perspective for targeted policy and managerial recommendations. **Lastly**, our study offers empirical evidence based on China's energy sector and dual-carbon goals, which can serve as valuable references for other emerging economies pursuing sustainable development.

The structure of this paper is as follows: Theoretical analysis based on the existing literature and the corresponding research hypotheses are discussed in Section 2. We further explain our research design and conduct the empirical research in Section 3 and Section 4, respectively. Section 5 mainly studies the prediction of ESG by financial indicators using the random forest model. Section 6 provides further discussion according to the research findings. Lastly, the overall research outcomes are summarized in Section 7.

2. Theoretical analysis and hypotheses

The sustainable framework of Environmental, Social, and Governance (ESG) has become an important research topic in finance and management. Many studies have explored the theoretical foundations of ESG and the development of its rating systems (Liang & Renneboog, 2017; Jiang & Kim, 2020; Avramov et al., 2022). Moreover, advances in digital technologies such as artificial intelligence have shown mixed impacts on firms' energy use efficiency, which may in turn influence their ESG performance and sustainability potential (Zhang & Zeng, 2024; Qin et al., 2024; Zhou et al., 2024). Berg et al. (2022) researched the "aggregation chaos" in the ESG rating system, referring to the differences in assessments by various rating agencies. The study analyzed how these discrepancies impact investor decisions and proposed suggestions for promoting rating standardization and increasing transparency. Additionally, the role of ESG in risk prevention is another important topic. Relevant research indicates that enterprises with high ESG performance tend to effectively reduce financial, market, and legal risks, especially showing more stability during periods of economic turbulence (Koh et al., 2014). Enterprises can enhance their recognition and

trust within local communities by demonstrating social responsibility and supporting post-disaster recovery, as Mithani (2017) analyzed, thereby improving their performance and image during disasters. Zhou and Wang (2020) emphasized that CSR not only enhances the image of subsidiaries in local communities but also effectively mitigates the negative impact on the parent enterprise during reputation crises, making it an important strategy for multinational enterprises' reputation management.

The long-term value of an enterprise is a key indicator of its potential growth ability, governance level, and risk management capabilities, all of which play a crucial role in ensuring its long-term sustainable development (Chen et al., 2018; Pekovic et al., 2018; Duque & Aguilera, 2021; Su et al., 2024a). Wong et al. (2021) concluded that ESG certification can enhance an enterprise's market value, with its impact being particularly significant in specific industries. On the contrary, some studies suggest that excessive focus on an enterprise's ESG performance and related investments may reduce resource allocation efficiency and investment imbalances, potentially hurting the enterprise's performance and value (Zhou et al., 2025). Additionally, in the pursuit of improving ESG performance, enterprises may face increased production costs and pressure to make related investments, which could result in a decline in enterprise performance and value (Barnea & Rubin, 2010; Masulis & Reza, 2015). At the same time, several investigations argue that there is no significant correlation between ESG performance and enterprise value, revealing the complex relationship between the two (Orlitzky, 2013; Humphrey et al., 2012). Therefore, Hypothesis 1 of the following empirical study is proposed as follows:

> *Hypothesis 1:* The ESG performance positively impacts on energy enterprises' long-term value.

Numerous studies focus on the economic consequences of ESG, examining its impact on enterprise financial performance, capital costs, and market valuation, while highlighting the potential long-term benefits and challenges of ESG investments (Eichholtz et al., 2010; Albertini, 2013; Chen & Xie, 2022). The stock price response to the release of ESG-related news, as investigated by Serafeim and Yoon (2023), is influenced by the ESG rating and the level of disagreement in the market. Although implementing the ESG framework has brought numerous benefits in reflecting enterprise value, some studies have also demonstrated controversies, and its impact varies across different industries (Chen & Zhang, 2024). Meanwhile, the financial performance of an enterprise also influences the evaluation of its ESG performance. Eccles et al. (2014) explored the impact of enterprise sustainable development on organizational processes and performance, providing a theoretical foundation for the relationship between ESG performance and enterprise financial performance. Garcia and Orsato (2020) tested the institutional differences hypothesis and explored the relationship between ESG performance and financial performance. As a result, the second hypothesis of this study is presented below:

> *Hypothesis 2:* The financial performance of energy enterprises can predict their ESG outcomes.

For enterprises in different industries, the impact of each dimension of E, S, and G on long-term value may vary. Barnett et al. (2012) investigated the nonlinear effects of ESG dimensions on financial performance and found significant differences in the impact of environmental, social, and governance performance on the long-term value of enterprises. Boiral and Henri (2017) examined the environmental performance of mining enterprises and found that environmental performance has a significant impact on the long-term value of enterprises, particularly in resource-intensive industries. Edmans (2011) explored the impact of employee satisfaction on the long-term value of enterprises, finding that improvements in social performance can enhance enterprise value by increasing employee productivity and reducing turnover rates. Busch and Hoffmann (2011) investigated the impact of carbon emissions of energy enterprises on financial performance and found that improvements in environmental performance have a significant positive effect on the long-term value of energy enterprises. In the context of China's energy sector, where state-owned

enterprises (SOEs) dominate, governance mechanisms often play a more decisive role in shaping long-term value than environmental or social efforts. SOEs are typically more tightly integrated with government policies, and their governance structures—such as board composition, internal supervision, and performance evaluation—are directly linked to policy compliance and implementation efficiency (Yu, 2013; Li & Su, 2024). A sound governance framework facilitates alignment with national strategic objectives, including carbon reduction targets, environmental accountability, and financial stability. Moreover, governance efficiency affects how quickly and accurately enterprises respond to external pressures, including ESG policy reforms, green financing mechanisms, and investor expectations. Studies have shown that well-governed SOEs are more likely to achieve sustainability transitions with lower agency costs and better strategic coordination (Chen et al., 2018; Jiang & Kim, 2020; Zhou et al., 2024; Su et al., 2024). This explains why the governance dimension (G) may exert a stronger influence on the long-term value of energy enterprises in China, compared to environmental or social dimensions. As a result, we propose the third hypothesis:

Hypothesis 3: The performance of each ESG dimension has varying impacts on the long-term value of energy enterprises.

Based on the above existing research, we further put forward some sub-hypotheses as below:

Hypothesis 3a: The environmental dimension positively impacts their long-term value.

Hypothesis 3b: The social dimension positively impacts their long-term value.

Hypothesis 3c: The governance dimension positively impacts their long-term value.

Concerning the above hypotheses, we conduct the following empirical investigation to explore the relationship between energy enterprises' ESG performance and their long-term value. More factors are also involved to provide deep insights regarding ESG-centric economic analysis and forecasting.

3. Research design

3.1. Model construction

To achieve the research objectives of this study, two models were employed. The two-way fixed effects model was used for baseline regression to determine the impact of ESG performance on the long-term value of energy enterprises, while the random forest prediction model was utilized to predict ESG scores based on financial indicators. Random forest is selected over other machine learning methods, such as gradient boosting trees (GBT), for several reasons. First, it is more robust to overfitting and noise, especially when dealing with high-dimensional and nonlinear data, which are typical characteristics of financial indicators and ESG scores. Second, random forest provides straightforward feature importance metrics, which aligns with our research goal of identifying which financial indicators are most predictive of ESG performance. Third, random forest performs well even when tuning is limited, whereas GBT models require more extensive parameter optimization and are more sensitive to hyperparameter settings. Given the exploratory nature of our prediction task, random forest offers an effective and interpretable solution.

First, the two-way fixed effects odel is employed to examine the impact of ESG ratings on the long-term value of energy enterprises. The two-way fixed effects panel data model is constructed as follows:

$$TQ_{it} = \alpha + \beta ESG_{it} + \gamma Control_{it} + \mu_i + \sigma_t + \varepsilon_{it} \quad (1)$$

where, i represents enterprises, t denotes years, and TQ is Tobin's Q ratio, which represents enterprises' long-term value. ESG refers to the ESG score of enterprises, while $Control$ includes relevant control variables mainly reflecting aspects of an energy enterprise's financial status.

Specifically, these variables include return on assets (ROA), asset levels ($ASSET$), earnings per share growth rate ($EPSGR$), net profit margin (NPM), the ratio of EBIT to total revenue ($EBITTR$), and current ratio (CR). μ_i represents individual fixed effects, σ_t denotes time-fixed effects, and ε_{it} is the random error term.

Furthermore, this study applies the random forest algorithm and utilizes Equation (2) to measure the explanatory power of each predictor variable on the target variable Y . The data from 2015 to 2022 is divided into two parts: 80% is used as the training set for model training, while the remaining 20% serves as the test set to evaluate the generated random forest. Predictions of ESG scores that fluctuate within points are considered accurate. In this method, the abovementioned financial indicators are involved to test whether they can predict the ESG performance of the energy enterprises being analyzed.

$$Y \sim ASSET + CR + EPSGR + EBITTR + ROA + NPM \tag{2}$$

3.2. Variable measures

The explained variable selected in the empirical investigation is Tobin's Q ratio. Enterprise value is a comprehensive concept that reflects not only an enterprise's health and growth potential but also the quality of management decisions and governance. Tobin's Q ratio is defined as the ratio of market value to replacement cost, representing the enterprise's future growth potential and profitability, while the denominator reflects the enterprise's cost structure. Following Fang et al. (2015), Tobin's Q represents investors' attitudes toward the enterprise's future prospects. Therefore, this study adopts this metric to measure the long-term value of enterprises.

As for the explanatory variable, ESG has become an important indicator for evaluating an enterprise's sustainable development capabilities and fulfilling social responsibilities. Given that the ESG scores in the CNRDS database include both overall scores and sub-scores for E, S, and G, which facilitate further research, this study selects the ESG scores from the CNRDS database as the performance metric for enterprise ESG (Xiang et al., 2025).

Table 1. The definitions of the core and control variables

Variable	Capability	Symbol	Description
Explained		TQ	Tobin's Q value (market value/total assets)
Explanatory		ESG	ESG score
Control	Scale	ASSET	Total enterprise assets
	Profitability	ROA	Return on assets
		NPM	Net profit margin
		EBITTR	The ratio of EBIT to total revenue
	development capacity	EPSGR	Earnings per share growth rate
	Solvency	CR	Current ratio
Other	Media attention	WSI	Web search index
	Ability to innovate	IP	Invention patents

Regarding control variables, traditional financial indicators impact enterprise value (Zhang et al., 2021). Therefore, this study selects return on assets (ROA), asset levels ($ASSET$), earnings per share growth rate ($EPSGR$), net profit margin (NPM), the ratio of EBIT to total revenue ($EBITTR$), and current ratio (CR) as control variables to more accurately analyze the impact of ESG performance on the long-term value of energy enterprises. Among these, asset levels reflect

the size of the enterprise, return on assets, net profit margin, and the ratio of $EBIT$ to total revenue reflect the enterprise's profitability, earnings per share growth rate reflects the enterprise's development capacity, and the current ratio reflects the enterprise's solvency. By effectively coordinating these key capabilities in enterprise development, an enterprise can promote growth and maximize its potential value.

In addition to the core and control variables, we introduce two supplementary variables for the heterogeneity analysis in Section 6. The Web Search Index (WSI) is used to measure the level of media or public attention received by an enterprise, reflecting its visibility and exposure in online platforms. The Invention Patents (IP) variable captures the innovation capability of an enterprise, indicating its technological development level. These variables are not included in the baseline regression but are employed in sub-sample analysis to explore differentiated effects of ESG on firm value under varying attention and innovation levels.

Considering other variables, to ensure the scientific and rational nature of the research results, this study introduces two additional variables-network search index (WSI) and invention patents (IP) in the subsequent heterogeneity analysis. Introducing these variables could provide a more comprehensive perspective in analyzing the heterogeneity in the relationship between energy enterprises' long-term value and ESG performance, helping to further explore the stability and consistency of the research findings.

The variables, symbols, and specific definitions used in this study are shown in Table 1.

3.3. Data sources

This study selects panel data of energy-related enterprises from 2015 to 2022 for empirical analysis. Specifically, energy enterprises are identified based on the industry classification provided by the China Securities Market and Accounting Research (CSMAR) database, which follows the China Securities Regulatory Commission (CSRC) industry classification system. We select firms classified under the "Energy" sector, which includes traditional fossil energy industries (e.g., coal, oil, and gas) as well as new energy enterprises (e.g., solar and wind energy). Firms in adjacent sectors such as chemicals and utilities are excluded unless their primary business operations fall under the energy category. All data are sourced from the CSMAR and CNRDS databases. The descriptive statistics of the variables used in the study are presented in Table 2. It can be observed that, although all are energy-related enterprises, the differences in financial indicators are significant, whereas the differences in ESG scores are relatively smaller.

Table 2. Descriptive statistics

VarName	Obs	Mean	SD	Min	Max
TQ	863	1.536	1.5463	0.765	13.328
ESG	876	3.240	0.3545	1.758	4.039
ROA	876	2.342	8.3365	-175.080	13.590
ASSET	876	23.292	1.5382	18.370	26.723
EPSGR	856	-0.546	4.4567	-64.500	5.489
NPM	876	0.070	0.4327	-6.522	1.207
EBITTR	876	0.173	0.4299	-6.246	1.381
CR	876	1.237	1.5885	0.028	11.357

4. Empirical investigation

4.1. Benchmark estimates

Based on the two-way fixed effects model, this study examines the impact of ESG scores on the long-term value of energy enterprises, with the results presented in Column (1) of Table 3. The results indicate a positive coefficient, which is significant at the 5% level, suggesting that ESG performance positively impacts the long-term value of energy enterprises.

In addition, some scholars have reached similar conclusions, further validating the reliability of the findings in this study. Both Khan et al. (2016) have research evidence showing that enterprises with outstanding ESG performance have higher financial performance and stock price returns in the long run. Eccles et al. (2014) believe that improvements in ESG performance in the energy sector may have a more significant impact on financial performance. Thus, Hypothesis 1 is validated. Meanwhile, it can be observed that among the control variables, ROA, ASSET, and EPSGR have significant impacts, indicating that the long-term value of energy enterprises is notably influenced by enterprise size, profitability, and development capacity, particularly the scale effect.

Beyond statistical significance, the economic implications of our results are noteworthy. A 1-point increase in ESG score is associated with approximately a 0.169 increase in Tobin's Q, indicating that ESG performance has a material impact on firms' long-term market valuation. This reinforces the view that ESG investments can be economically justified rather than mere reputational tools. In the energy sector, particularly in China, where carbon intensity is high, this result suggests that improved ESG can signal lower regulatory risks, better operational transparency, and alignment with national sustainability goals, thus enhancing investor confidence and valuation.

Our study highlights a more prominent role of the governance dimension (G), diverging from studies that stress environmental factors (Busch & Hoffmann, 2011; Flammer, 2015). This nuance is likely driven by the state-owned nature of many Chinese energy enterprises, where governance reforms have stronger signaling and efficiency effects than marginal environmental investments.

Table 3. Benchmark regression and robustness test results

	(1) TQ	(2) Eliminate 2019	(3) Replace TQ	(4) Winsor	(5) TQ
ESG	0.1689**	0.1606**	0.2096**	0.1571*	
	(2.2918)	(2.0363)	(2.5077)	(1.9593)	
L.ESG					0.1031*
					(1.6594)
ROA	-0.0306**	-0.0307**	-0.0326**	-0.0373	-0.0409
	(-2.1327)	(-2.3282)	(-2.2665)	(-1.0618)	(-1.5974)
ASSET	-0.9805***	-1.0466***	-1.0064***	-1.0198***	-0.7426***
	(-3.1030)	(-3.1272)	(-3.1067)	(-3.4921)	(-3.7291)
EPSGR	0.0139**	0.0198**	0.0146***	0.0227**	0.0122
	(2.4378)	(2.5185)	(2.6463)	(2.3047)	(1.5413)
NPM	0.6182	-0.2179	0.4822	-0.8601	-0.1685
	(0.6658)	(-0.1595)	(0.4677)	(-0.4779)	(-0.1731)
EBITTR	-0.8774	-0.0859	-0.7239	0.3215	0.4091

		(-1.1686)	(-0.0812)	(-0.8706)	(0.2571)	(0.4655)
CR		0.0944	0.0916	0.1026	0.0947	0.1330*
		(0.9444)	(0.9294)	(0.9602)	(0.7917)	(1.6815)
_cons		23.9407***	25.4630***	24.5315***	24.8261***	18.5245***
		(3.2162)	(3.2321)	(3.2091)	(3.5877)	(4.0738)
Two-way effects	fixed	√	√	√	√	√
N		840	731	840	840	715
r2_a		0.8219	0.8159	0.8190	0.8173	0.8396

Notes: ***, **, and * refer to statistical significance at the 1%, 5%, and 10% levels, respectively

4.2. Analysis of ESG dimensions by two-way fixed effects model

ESG performance has increasingly become an important indicator, as it comprehensively evaluates an enterprise's environmental, social, and governance aspects, and has attracted more attention from market investors and governments in recent years. This section will further explore which aspect of Environmental, Social or Governance dimension has a more significant impact on the long-term value of energy enterprises. The regression results are shown in Table 4.

From the results, it can be seen that governance (G) has a more significant impact on the long-term value of energy enterprises. This is an interesting finding, as environmental factors are typically considered to have a more significant impact (Flammer, 2015). Upon exploring the reasons behind this, it was found that a sound governance structure has a more significant impact on corporate social responsibility (including ESG performance). Especially in the energy sector, governance factors can enhance the decision-making capacity and transparency of the board, helping enterprises better address challenges related to the ESG issues.

Table 4. Environmental, Social and Governance factor analysis

	(1)	**(2)**	**(3)**
	TQ	**TQ**	**TQ**
E	0.0036		
	(0.0549)		
S		0.0311	
		(0.4906)	
G			0.1781**
			(2.5224)
ROA	-0.0306**	-0.0305**	-0.0305**
	(-2.1320)	(-2.1095)	(-2.1226)
ASSET	-0.9822***	-0.9819***	-0.9777***
	(-3.1072)	(-3.0946)	(-3.1104)
EPSGR	0.0138**	0.0138**	0.0136**
	(2.3939)	(2.3964)	(2.3774)
NPM	0.5979	0.6055	0.6173
	(0.6517)	(0.6465)	(0.6745)

EBITTR	-0.8519	-0.8637	-0.8719
	(-1.1424)	(-1.1476)	(-1.1905)
CR	0.0884	0.0882	0.0956
	(0.8937)	(0.8897)	(0.9495)
_cons	24.5237***	24.4244***	23.8131***
	(3.2975)	(3.2609)	(3.2504)
Two-way fixed effects	√	√	√
N	840	840	840
r2_a	0.8211	0.8211	0.8226

Notes: ***, **, and * refer to statistical significance at the 1%, 5%, and 10% levels, respectively.

Additionally, most energy enterprises in China are state-owned enterprises. A strong, reasonable and mature governance structure can improve decision-making efficiency, risk management, and compliance. Governance is especially crucial in state-owned enterprises because it directly affects the effective implementation of national policies and the long-term strategic direction of the enterprise (Yu, 2013). State-owned energy enterprises face higher social responsibility expectations, and good governance helps them better respond to societal and governmental expectations, ensuring long-term stability and development. Therefore, governance plays a more significant role in the long-term value of energy enterprises, particularly in state-owned enterprises. Optimizing governance can facilitate the sustainable development of the enterprise and the realization of national strategic goals. While previous literature, such as Flammer (2015), often highlights the critical role of environmental (E) factors in enhancing firm value, especially in private-sector or Western contexts, our study identifies governance (G) as the dominant driver in China's energy industry. This divergence stems from the SOE-dominated structure of China's energy sector, where governance mechanisms play a more pivotal role in shaping long-term strategy, enforcing accountability, and aligning firm behavior with national policy goals. In such firms, environmental and social practices are often embedded within governance frameworks, and their effectiveness depends heavily on board oversight and internal decision-making structures. Therefore, the governance dimension functions not only as an ESG component but also as an institutional foundation for ESG execution in the state-owned context.

4.3. Robustness test

To further verify the robustness of the results, the following methods were adopted for robustness checks, with the results presented in Columns (2)-(5) of Table 3.

First, considering the outbreak of the COVID-19 pandemic in 2019, which impacted multiple aspects of energy enterprises and potentially affected their ESG scores and long-term value performance, the 2019 data was excluded for testing. Secondly, the core dependent variable representing the enterprise's long-term value was replaced. A new Tobin's Q value was calculated by excluding intangible assets and goodwill from total assets. Moreover, the data were winsorized by removing the top and bottom 1% of extreme values for robustness checks. The results show that, after these robustness tests, the regression results remain significantly positive, further confirming the positive impact of ESG scores on enterprises' long-term value. Finally, in this study, we conduct regression tests using ESG scores lagged by one period. The results remain statistically significant, indicating that the baseline regression findings are robust and reliable. The above robustness tests further ensure the reliability of the results, laying a solid foundation for further analysis in the following sections.

4.4. Heterogeneity analysis

4.4.1. Media attention heterogeneity analysis

With the development of the internet, people are increasingly inclined to obtain information online. Social media has increasingly influenced customers' decision-making processes and behaviors. At the same time, the use of social media and customers' engagement with social networks can impact their opinions, interests, and behaviors (Tang, 2015; Su et al., 2024).

For energy enterprises, different levels of online attention can also impact the representation of their value. Therefore, this study divides energy enterprises into two groups based on high and low levels of online attention for analysis, with the results presented in columns (1)-(2) of Table 5. It can be inferred that the long-term value of energy enterprises with lower online attention is more likely to be influenced by ESG scores. One possible reason is that such enterprises often face information asymmetry and lower market pricing efficiency, with ESG scores serving as an important basis for investors to assess the enterprise's potential and risks. Moreover, Eccles et al. (2014) mentioned that enterprises with low attention are more susceptible to the impact of negative news. Kim et al. (2018), in their study on the impact of corporate social responsibility performance on enterprise value in South Korean enterprises, specifically emphasized the sensitivity of low-attention enterprises, particularly when there are changes in social responsibility or ESG performance. The findings of these scholars are consistent with the conclusions of this study.

Furthermore, with the rise of green finance and responsible investment, outstanding ESG scores can enhance an enterprise's market competitiveness, attract more investments, and further influence its long-term value (Eccles et al., 2014). This finding could be of a great help for the enterprises with lower online attention to improve their ESG performance and achieve greater long-term growth.

The underlying mechanism may lie in the informational asymmetry and signaling role of ESG practices. Enterprises with low media attention often suffer from weak visibility, limited stakeholder engagement, and fewer reputational resources. As a result, ESG disclosure becomes a valuable tool to signal trustworthiness and strategic alignment to investors, regulators, and the public. Moreover, lacking the publicity advantage enjoyed by high-attention firms, these enterprises may face greater barriers to accessing capital or policy support, making ESG a viable pathway to build credibility and legitimacy. Therefore, the stronger dependence on ESG among low-attention firms may reflect compensatory behavior in response to their disadvantaged external exposure.

4.4.2. Innovation capability heterogeneity analysis

Obviously, the differences in the innovation capabilities of energy enterprises can have varying impacts on their long-term value. This study uses the number of innovation patents to represent an enterprise's innovation capacity and divides energy enterprises into two groups: high and low innovation capability.

The results are presented in Columns (3)-(4) of Table 5. The results show that regardless of whether energy enterprises have high or low innovation capabilities, their long-term value is affected by ESG scores. However, enterprises with weaker innovation capabilities are more likely to be influenced. This may be because enterprises with weaker innovation capabilities typically cannot gain a competitive advantage through technological innovation, so their long-term value relies more on other factors, especially ESG scores (Huang et al., 2020). Strong ESG performance can compensate for the lack of innovation, helping enterprises enhance their brand image, improve market competitiveness, attract investment, and effectively respond to external environmental and policy changes, thereby impacting their long-term value (Huang, 2010; Flammer, 2015). Therefore, for enterprises with weaker innovation capabilities, improving ESG scores may significantly improve their long-term development potential and market evaluation.

Table 5. Heterogeneity test results

	WSI		IP	
	(1)	(2)	(3)	(4)
	Low	High	Low	High
ESG	0.2476*	0.0006	0.2526***	0.1271**
	(1.9695)	(0.0075)	(3.0561)	(2.6752)
ROA	-0.0643	-0.0139	-0.0312**	-0.0075
	(-1.1298)	(-1.5398)	(-2.2099)	(-1.0678)
ASSET	-0.5099**	-0.5349**	-1.0747***	-0.1330**
	(-2.3844)	(-2.3063)	(-3.1004)	(-2.6224)
EPSGR	0.0007	0.0161**	0.0156**	-0.0001
	(0.0529)	(2.1978)	(2.2016)	(-0.1329)
NPM	-0.2018	0.9098	0.3909	0.5648
	(-0.3349)	(0.6751)	(0.3796)	(1.4018)
EBITTR	0.6471	-1.8160	-0.6175	-0.0922
	(1.0120)	(-1.5438)	(-0.7211)	(-0.2676)
CR	0.2641***	0.0036	0.1316	0.0288
	(3.7513)	(0.0441)	(1.3918)	(0.5004)
_cons	12.0262**	14.5443***	25.4293***	3.9699***
	(2.4675)	(2.6724)	(3.1653)	(3.3195)
Two-way fixed effects	√	√	√	√
N	315	502	656	166
r2_a	0.9186	0.8547	0.8258	0.9546

Notes: ***, **, and * refer to statistical significance at the 1%, 5%, and 10% levels, respectively.

5. Random forest prediction of ESG scores

5.1. The correlation between financial indicators and ESG score

The accuracy of the model predictions from 2015 to 2022 is shown in Figure 2. The experimental results indicate that the vast majority of predictions using financial characteristics to estimate ESG scores achieve an accuracy of over 80%, with half of them exceeding 95%. This demonstrates a significant intrinsic relationship between ESG scores and the financial condition of energy enterprises. ESG aims to assess the impact of financial performance on enterprise value. Although the accuracy rate fluctuates, in most years it is above 80%, indicating that the random forest method for predicting the ESG performance of energy enterprises based on financial indicators has certain feasibility and effectiveness.

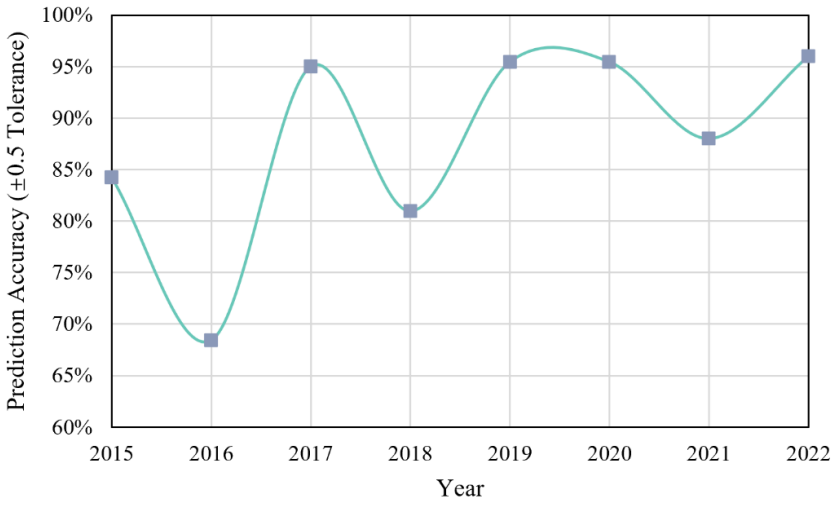

Figure 2. ESG score prediction accuracy

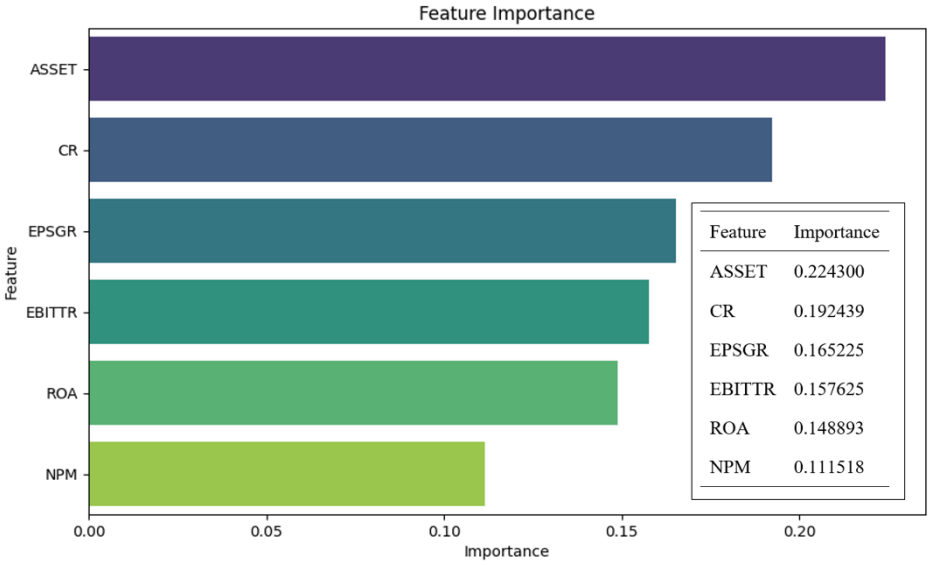

Figure 3. Visualization of Factor Importance

In analyzing the relative importance of variables, this study calculates the MDG values assigned to predictors by the random forest model, with the results shown in Figure 3. The *ASSET* actor is the most important, accounting for approximately 22%. *CR*, *EPSGR*, and *EBITTR* are also critical factors, each accounting for more than 15%. *ROA* and *NPM* follow, with proportions of 14% and 11%, respectively.

The highest proportion of asset size indicates that, for energy enterprises, firm size has a significant impact on ESG ratings. Additionally, the strong correlation between mid- to long-term profitability indicators and ESG ratings aligns with the sustainability principles upheld by ESG. The current ratio (CR) ranks second in importance, reflecting the short-term solvency of enterprises. The short-term debt repayment ability has an important position in ESG performance prediction.

5.2. Prediction patterns of key financial features for enterprise ESG scores

To further explore the relationship between financial characteristics and enterprise ESG scores, this study employs partial dependence plots to examine the predictive patterns of industry and key financial indicators on ESG scores. By visualizing the marginal effects of target features on prediction outcomes, we analyze their direct impact, aiming to enhance the predictive performance. Figure 4 presents the partial dependence plots of key financial characteristics.

$ASSET$ is the most important variable in predicting and explaining ESG scores. The size of energy enterprises has a significant positive impact on ESG scores, primarily within the 21-24 range. However, when the size exceeds 24, this effect becomes more moderate. CR is the second most important factor in explaining and predicting ESG scores. Overall, it shows a negative effect, especially when CR is in the 1-1.5 range, where the effect becomes more pronounced. CR reflects short-term solvency, whereas ESG scores are more of an evaluation of an enterprise's long-term value. Therefore, as CR increases, the ESG score tends to decrease. $EBITTR$ follows a similar trend to CR, exhibiting a negative effect on the explanation and prediction of ESG scores. When the indicator is negative, it has an adverse effect on the prediction of ESG scores. However, once it turns positive, the higher the value, the higher the ESG score. ROA and NPM exhibit a consistent trend in explaining and predicting ESG scores, both initially increasing and then decreasing. The turning point for ROA is 3.5, while for NPM, it is approximately 0.1. From the analysis of overall and individual financial characteristics above, it is evident that when an enterprise's financial indicators fall within a relatively normal range, they exhibit a stable correlation with ESG scores.

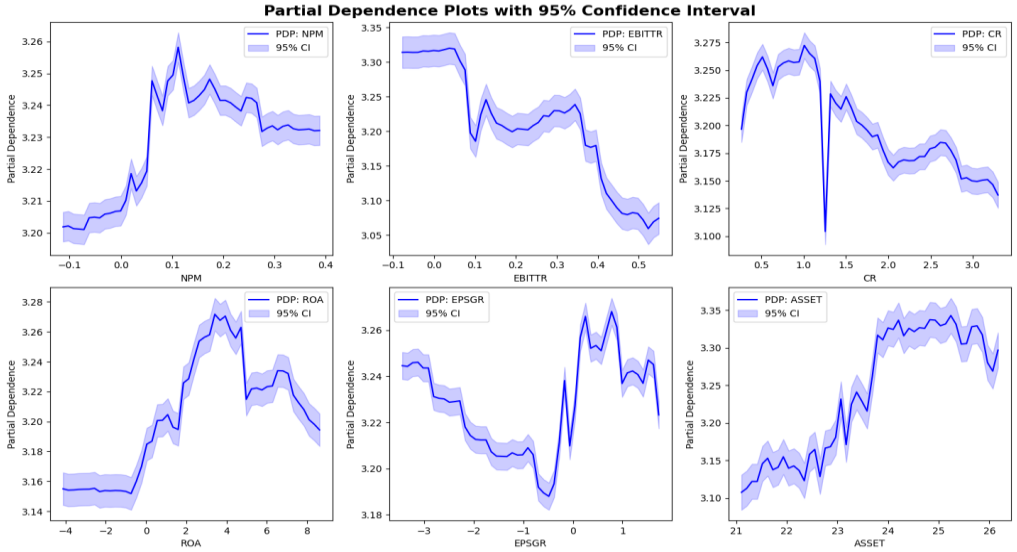

Figure 4. Partial Dependence Plots of Various Factors

NPM, *ROA* and *EPSGR* are long-term financial indicators related to enterprise profitability. It can be observed that these indicators generally have a positive predictive effect on ESG performance. *CR* is a short-term financial indicator, while *EBITTR*, although classified as an intermediate to long-term indicator of enterprise operational capability, can be considered a short-term indicator in annual comparisons. Both of these short-term financial indicators generally have a negative predictive effect on ESG performance. However, these financial indicators can comprehensively reflect the financial performance of an energy enterprise. Both the short- or long-term indicators could significantly determine the ESG outcomes and it validates Hypothesis 2 proposed in this study.

Based on Tobin's Q theory and signaling theory, it can be demonstrated that enterprises can use financial indicators to convey signals to the outside world, thereby influencing expectations of their future value. Indicators such as *ROA*, *NPM*, and *EBITTR* reflect an enterprise's profitability-the stronger the profitability, the higher the market value, and the more outstanding Tobin's Q may be. *ASSET*, representing asset scale, affects asset replacement costs, thereby influencing the denominator of Tobin's Q. This illustrates that enterprise financial indicators can also determine an energy enterprise's ESG performance, which could indirectly impact its long-term value. Combined with the previous analysis, it is evident that long-term financial indicators are more likely to influence an enterprise's long-term value.

5.3 Analysis of prediction differences across the ESG dimensions

To further analyze the relationship between financial indicators and the environmental, social, and governance (ESG) dimensions, this study employs financial data to predict the environmental, social, and governance scores from the ESG ratings in the CNRDS database for the period 2015-2022.

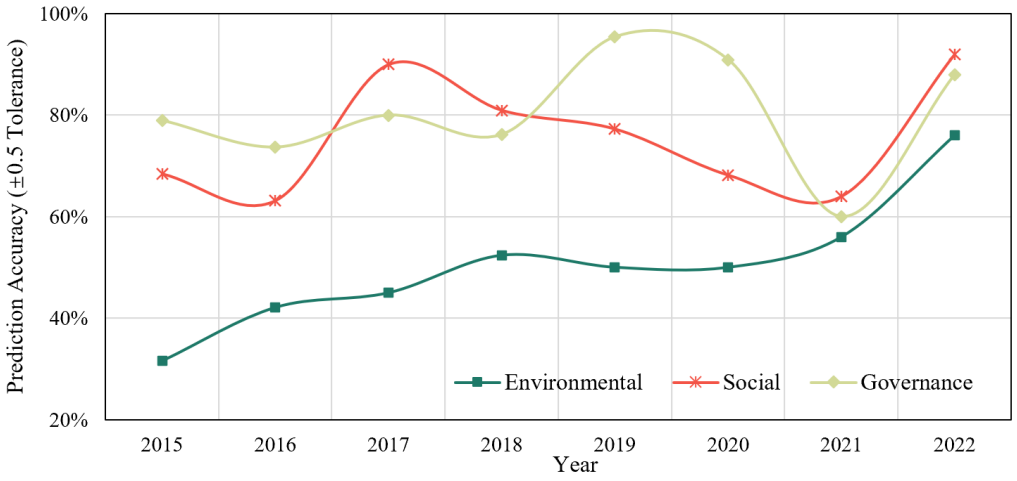

Figure 5. Prediction Accuracy of the E, S and G dimensions

Through training and prediction of various sub-dimension scores in the CNRDS ESG system using the random forest model, this study has identified the following characteristics:

First, in the environmental and social dimensions, financial data's predictive ability for scores is notably lower than for the overall score (see Figure 5). Specifically, the environmental dimension's prediction accuracy is 40%–60%, while the social dimension ranges from 60% to 80%, indicating

that financial characteristics are less considered in evaluating environmental and social responsibility scores. This partly reflects that an enterprise's environmental and social performance may diverge from traditional financial values. In the short term, environmental and social performance may not significantly impact financial outcomes, and financial differences may not directly affect strategic decisions in these areas, reducing motivation for enterprises to actively fulfill social responsibility. Moreover, environmental accounting metrics (such as carbon accounting) are not integrated into the financial statement framework, and disclosure standards for environmental and social financial information remain unclear. As a result, enterprises' environmental and social disclosures may be incomplete, opaque, or inaccurate, making it difficult for investors and evaluators to obtain comprehensive, comparable data, which weakens the connection between these factors and an enterprise's financial performance.

However, in the governance dimension, as shown in Figure 5, the prediction accuracy of the random forest model reaches 70%-90%, demonstrating a close relationship between an enterprise's financial condition and its governance level. This indicates that the current ESG rating system's intersection with financial performance is reflected in the governance dimension. This finding is consistent with the earlier regression results discussed regarding the environmental (E), social (S), and governance (G) sub-dimensions.

The prediction accuracy for the environmental dimension shows a year-on-year increase, indicating that the weight of the environmental dimension in ESG ratings is growing. This aligns with real-world developments. As environmental conditions worsen and the dual carbon goals are set, there are increasingly stringent carbon emission requirements for energy enterprises, which has indeed led to a heightened focus on environmental development. Besides, the prediction accuracy for the social dimension shows significant fluctuations. One possible reason is that the relationship between the social dimension and financial data may be more indirect, making it difficult for the model to predict consistently. Compared to the environmental or governance dimensions, changes in the social dimension may be more influenced by external factors, such as corporate culture and social responsibility initiatives, which may not be accurately captured by traditional financial indicators, leading to instability in the model. The above analysis further validates the results of the regression models presented earlier, ensuring the robustness of the findings in this study. Additionally, Hypothesis 3 and Hypothesis 3c are confirmed.

6. Further discussion

Based on the above empirical investigation, prediction research and heterogeneity, many interesting findings are uncovered and they could be helpful for further policy implementations to improve the long-term growth of energy enterprises and even the economy. The key findings of this study is summarized as follows:

The ESG performance positively impacts on energy enterprises' long-term value.

- The financial performance of energy enterprises can predict their ESG outcomes. Specifically, the long-term resources, short-term repayment ability, profitability and growth potential are relatively crucial to determine the ESG performance of energy enterprises.
- The performance of each ESG dimension has varying impact on the long-term value of energy enterprises. Among the three dimensions, the governance plays the most important role in achieving the long-term growth.
- Regarding the heterogeneity, the ESG performance is more likely impact on the long-term value of the energy enterprises with less media attention and innovation capability.

The development of energy enterprises is one of the significant strategies for China to achieve the dual carbon goals. Compared with other sectors, energy sector also occupies a large proportion of the total carbon emission. Therefore, achieving the long-term value of energy enterprises is

important for China to realize long-term economic growth and sustainable development. From the above analytic results, it is found that the governance dimension is more important than the environmental dimension for the energy enterprises to improve their long-term value. This result can be different with our expectation before conducting the empirical investigation as environmental factors are verified as a more significant impact in existing related studies (Flammer, 2015). The reason to explain this phenomenon is that most of the energy enterprises in Chian are state-owned. Their governance structures are comparatively more reasonable, solid and mature. In the energy sector, stronger governance capability could be helpful for providing optimal financial decision-makings and reinforcing the resilience to against external risks and uncertainties (Su et al., 2024b; Li & Su, 2024). During the critical period of energy transition, we may pay more attention to the energy enterprises internal governance structure, operation transparency, risk management and commercial ethics, rather than environmental performance to flexibly adapt social dynamics. This could be a more efficient pathway for energy enterprises to obtain a higher long-term value. In addition, financial status is verified to be the vital impact factor to determine the ESG performance. The asset, current ratio and earnings per share growth rate are the main financial indicators to predict the ESG outcomes. As abovementioned, the asset, current ratio and earnings per share growth rate reflect an energy enterprise's long-term resources, short-term repayment ability, profitability and growth potential, respectively. Therefore, these perspectives could be the key for energy enterprises to improve their ESG performance and achieve long-term growth ultimately. Concerning the heterogeneity, the energy enterprises with less media attention and innovation capability can more effectively achieve their long-term value by improving the ESG performance, especially from the governance perspective. The above findings present different point of view compared with the existing studies. For instance, He et al. (2023) and Chai et al. (2023) suggested that media coverage is one of an important factors to supervise and improve corporate ESG performance. The different result may mainly due to the sector of the enterprises. Many energy enterprises in this study are state-owned and media attention may not the crucial driven force for them to improve the long-term value. As above mentioned, the governance dimension is proved to be the most important for these enterprises to achieve better ESG outcomes. Hence, focusing on the inner structure and operational strategy can be more helpful than the public attention. Besides, the positive relationship between enterprise ESG performance and innovation capability has also been verified by some related investigations (Zhou et al., 2024b; Long et al., 2023). These findings partially support our heterogeneity research outcome. Here are some reasons for the energy enterprises that has lower innovation capacity to more efficiently improve their long-term growth based on ESG. It could be difficult for the enterprises with low innovation capabilities to rapidly reduce carbon emissions through technological breakthroughs. Alternatively, they can achieve significant improvement in ESG by optimizing existing equipment upgrades, financial and energy efficiency management. Moreover, to achieve the dual carbon goals, the government provides tax incentives and subsidies to enterprises with excellent ESG performance. The enterprises with weak innovation capabilities are more dependent on such policy resources. For example, they can alleviate the financial pressure of insufficient technology investment by financing through green bonds or participating in the carbon emission trading market.

Based on the key findings, some recommendations are proposed for the energy enterprises to improve their long-term value and for the government to achieve long-term economic growth. First, the energy enterprises can establish a long-term sustainable development vision and fully integrate the ESG concept into their strategic planning and daily operations. At the same time, the government also need to consider further improve and refine the policies and regulations related to ESG performance by clarifying the specific responsibilities and goals of energy enterprises in the environmental, social, and governance aspects. Meanwhile, for those enterprises with good financial conditions and active participation in ESG practices, financial support priority should be given to providing low-cost financing channels, thereby promoting the enterprises to utilize their financial advantages to enhance their ESG performance. Energy enterprises should pay more attention to

their financial management through optimizing the capital structure, improving the allocation efficiency of long-term resources and enhancing short-term solvency and profitability. Furthermore, it is necessary for the energy enterprises with low media attention to take the initiative to strengthen communication and interaction with stakeholder community and actively disclose ESG information. As for the energy enterprises with weak innovation capabilities, seeking external and diverse collaborations with other technology industries and research organizations can be of great help to integrate ESG development framework with advanced technology and management experience.

7. Conclusions

The long-term value of energy enterprises is pivotal for national economic stability and sustainable development. This study explores the relationship between ESG performance and long-term value in energy enterprises. Specifically, in the empirical investigation, we introduce the two-way fixed effects model to confirm a positive relationship between energy enterprises' ESG performance and long-term value, underscoring the strategic significance of ESG integration in the energy sector. By utilizing random forest model, we find that representative financial indicators exhibit predictive power for ESG outcomes. Furthermore, we focus on ESG criterion and reveal that governance (G) emerges as the most influential driver of long-term value among the three dimensions. Lastly, we present a heterogeneity analysis, suggesting that enterprises with lower media attention and weaker innovation capabilities are more likely to enhance long-term value through improved ESG performance. These findings position governance not only as a critical ESG dimension but also as a practical lever for enterprise-level strategy and policy design. By establishing a novel forecasting pathway aligned with China's dual-carbon goals, this study contributes to both academic inquiry and real-world application. The implications further extend to emerging economies seeking to integrate ESG principles into frameworks for long-term economic stability and sustainable development. Based on these findings, practical recommendations for energy enterprises and the government are proposed to foster long-term growth and stability. In this paper, we attempt to conduct the empirical investigation combining with the two-way fixed effects model and machine learning approach to test the relationship of energy enterprises' ESG performance and their long-term value. The predictive result also tells the important role of financial status in achieving the long-term growth. Practically, we further discuss actionable insights for policymakers and energy enterprises to navigate energy transition risks. By highlighting governance as a critical lever, this study provides a novel pathway to achieve long-term, sustainable growth under China's dual-carbon agenda. However, we also believe that this study has some limitations, such as the disadvantage of using random forest model in the prediction part. In the future research, it can be try to use better machine learning methods such as gradient boosting trees for research.

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