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The Effects of Carbon Emission Intensity, Green Process Innovation and Top Management Team Characteristics on Firm Performance

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Abstract: Climate change and environmental degradation driven by excessive fossil fuel consumption in the energy sector have intensified concerns regarding carbon emissions and their implications on firm performance. In response to these challenges, firms are increasingly required to manage environmental impacts, adopt green process innovation, and strengthen managerial effectiveness. This study aims to analyze the effects of carbon emission intensity, green process innovation, and top management team characteristics on firm performance by examining companies in the Indonesian energy sector during the 2022–2024 period. A total of 101 observations were selected using a purposive sampling method. Using regression analysis, the results show that carbon emission intensity has a negative effect on firm performance, green process innovation does not have a significant effect, and top management team characteristics simultaneously influence firm performance, with the age of the Chief Executive Officer having a negative partial effect. These findings indicate that environmental performance and managerial characteristics play an important role in shaping firm performance in the energy sector.

Keywords: Carbon Emission Intensity, Green Process Innovation, Top Management Team Characteristics, Firm Performance

INTRODUCTION

The impacts of climate and environmental issues are increasingly being felt. One of the main factors is the excessive use of fossil fuels, which increases emissions into the atmosphere (Bilgili et al., 2024). Emissions from fossil fuels, which mostly come from the energy sector, have contributed significantly to global warming. Based on data released by Global Carbon Project (2023), total global carbon emissions reached 37,792 $MtCO_2$ in 2023, with Indonesia ranking 8th as the largest emitter in the world. This fact shows that Indonesia has a significant contribution to global emissions, so clear policies and strategies are needed to reduce emissions (Massagony et al., 2025).

Carbon emission intensity is an indicator used to assess a company's environmental impact by measuring the amount of carbon emissions produced relative to the company's

economic output, for example per unit of revenue (Perera et al., 2023). In contrast to absolute emissions data, which often does not reflect differences in the scale of operations between companies, carbon emissions intensity provides a more proportional relative measure, resulting in fairer and more accurate comparisons. (Vaicondam et al., 2024). Managing carbon emissions intensity not only provides an overview of environmental efficiency, but also has important implications for companies. Companies with high emissions tend to experience declining performance due to negative market responses (Houqe et al., 2022).

In addition to controlling carbon emission intensity, companies can also improve performance through the implementation of green process innovations. This innovation is an effort to improve the production process by utilizing environmentally friendly technology to minimize negative impacts on the environment (Tjahjadi et al., 2023).As a form of sustainability-oriented innovation, green process innovation not only focuses on emphasizing compliance with environmental regulations, but also encourages increased efficiency in operational activities.

Furthermore, company performance is also influenced by internal management aspects. The top management team (TMT) plays a role in a company's strategic decisions because this group is the primary actor with authority in determining the organization's direction and policies (Hambrick, 2007). This crucial role is believed to influence the quality of strategic decisions taken by the TMT, which in turn impacts company performance. Important attributes such as the proportion of female TMT members, the Chief Executive Officer (CEO)'s educational background, the TMT's size, the CEO's nationality, and the CEO's age are factors that stakeholders concerned with corporate governance and performance should consider (Tjahjadi et al., 2023).

This research is grounded in Legitimacy Theory and Stakeholder Theory to explain the relationship between environmental practices and firm performance. Legitimacy Theory argues that firms seek alignment with socially constructed norms and values to maintain public acceptance (Suchman, 1995). Accordingly, carbon emission intensity reflects firms' efforts to meet environmental expectations, where effective emission management can enhance corporate legitimacy and firm performance. From a Stakeholder Theory perspective, managers are responsible for balancing the interests of various stakeholder groups, whose pressures encourage firms to adopt green process innovations as part of their strategic and operational practices which can strengthen trust, reputation, and long-term performance (Freeman, 2015).

Upper Echelons Theory is also adopted in this research, positing that organizational outcomes are shaped by the characteristics, values, and cognitive bases of TMT. The theory is employed to explain how TMT characteristics influence firm performance. TMT attributes is expected to enhance decision-making quality by incorporating diverse perspectives, expanding strategic insight, and improving adaptability to dynamic business environments. These characteristics reflect the firm's strategic capacity and are ultimately manifested in its performance outcomes (Bekos & Chari, 2025; Wagdi & Fathi, 2024).

Although prior studies have widely examined environmental practices and managerial characteristics, empirical evidence regarding the impact of carbon emission intensity, green process innovation, and TMT characteristics on firm performance in Indonesia is still scarce. Therefore, this study aims to examine the effect of carbon emission intensity, green process innovation, and top management team (TMT) characteristics on firm performance. Specifically, this research investigates the influence of female TMT proportion, TMT size, CEO educational background, CEO nationality, and CEO age on firm performance.

METHOD

This study employs a quantitative panel data regression approach, analyzed using EViews software. The dataset consists of panel observations covering the period from 2022 to

2024 and comprises energy sector companies listed on the Indonesia Stock Exchange (IDX), which has been identified by the Financial Services Authority (OJK) as a major contributor to national carbon emissions. The sample was selected using a purposive sampling method and includes firms consistently listed on the IDX during the study period that published both annual and sustainability reports. An additional criterion was applied to the carbon emission intensity variable, requiring firms to disclose quantitative emission data, while no further restrictions were imposed on green process innovation and top management team (TMT) characteristics due to data availability. The final sample consists of 101 observations.

The measurement and operationalization of the study variables are described as follows:

Carbon Emission Intensity

Carbon emission intensity comparing total greenhouse gas emissions to its economic output (Perera et al., 2023). Following Saikia & Maji (2024), this study measures carbon emission intensity as the ratio of total Scope 1 and Scope 2 emissions to total revenue. Higher carbon emission intensity indicates lower emission efficiency, while lower values reflect more effective energy and emission management (Vaicondam et al., 2024).

Green Process Innovation

Green process innovation refers to the development of environmentally friendly operational processes. It is measured using content analysis, a systematic technique for classifying textual information (Gunawan & Abadi, 2017), applied to corporate sustainability reports based on five indicators adapted from Xie et al. (2019). A score of 0 is assigned when the indicator is not disclosed in the report. A score of 1 is given when the disclosure is purely qualitative. A score of 2 indicates qualitative disclosure supported by numerical information, while a score of 3 reflects comprehensive disclosure that includes qualitative statements, numerical data, and additional quantitative evidence such as tables or figures. The green process innovation score for each observation is obtained by summing the scores across all indicators and then normalizing the total by dividing it by the maximum possible score.

Table 1. Indicators of Green Process Innovation

Indicator	Description
PROC1	Targeting reductions in resource or energy consumption and improving resource or energy efficiency
PROC2	Use of recycled materials, recycling techniques, or environmentally friendly technologies
PROC3	Implementation of environmental campaigns
PROC4	Use of pollution control equipment
PROC5	Adoption of pollution control projects or technologies

Source: Xie et al. (2019)

Top Management Team Characteristics

TMT characteristics reflect managerial diversity, experience, and strategic orientation, which shape decision-making quality and firm performance. Accordingly, female TMT proportion, TMT size, CEO educational background, CEO nationality, and CEO age are expected to positively influence firm performance through enhanced leadership effectiveness, knowledge diversity, and strategic capability.

Table 2. Measurements of TMT Characteristics

Indicator	Description	Source
Female TMT	Ratio of female TMT members to total TMT members	Ren & Wang (2011)
TMT Size	Total number of TMT members	Tjahjadi et al. (2023)
CEO Education	Weighted score: 1 = Bachelor + 2 = Master + 3 = Doctorate	Papadimitri et al. (2020)

CEO Nationality	Dummy variable: 1 = foreign CEO, 0 = Indonesian CEO	Badru & Raji (2016)
CEO Age	CEO age in years	Naseem et al. (2020)

Source: Xie et al. (2019)

Firm Size

Firm size reflects the scale of a firm's operations and is measured as the natural logarithm of total assets, following Assenga et al. (2018), this measure is used to control for differences in firm scale that may influence performance.

Leverage

Leverage represents the extent to which a firm relies on debt financing. Following Achyarsyah (2016), leverage is measured as the ratio of total liabilities to total assets. Higher leverage indicates greater financial risk due to increased dependence on debt.

Firm Performance

Firm performance is measured using Tobin's Q, defined as the ratio of market capitalization plus the book value of liabilities to the book value of total assets (Pucheta-Martínez & Gallego-Álvarez, 2020). A Tobin's Q greater than 1 indicates that the firm is expected to generate value above its invested capital, whereas a value below 1 suggests the firm is undervalued or inefficient in utilizing its assets.

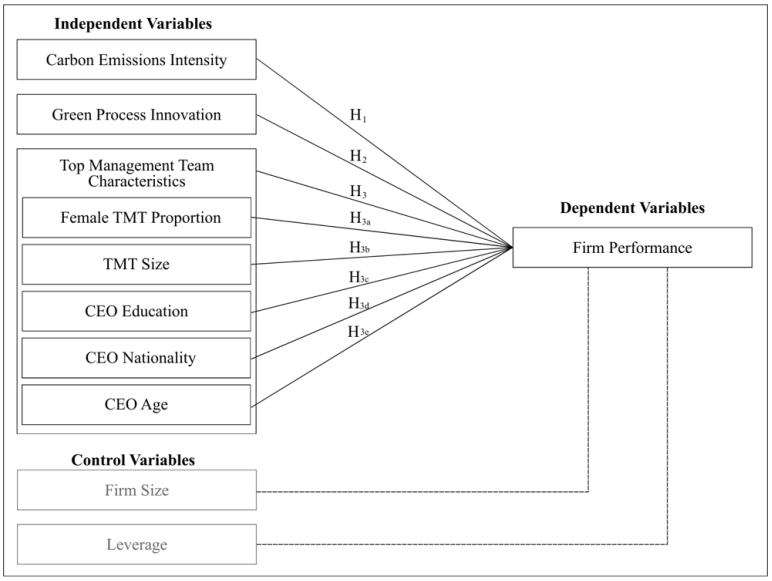

Figure 1. Conceptual Framework

Based on the theoretical foundations and the conceptual framework presented above, this study proposes several hypotheses to examine the relationships among the variables.

These hypotheses are formulated to empirically test the expected direction and significance of each relationship, as follows:

H_1 Carbon emission intensity has a negative effect on firm performance.

H_2 Green process innovation has a positive effect on firm performance.

H_3 Top management team (TMT) characteristics affect firm performance, as reflected in:

- H_{3a} Female TMT proportion has a positive effect on firm performance.
- H_{3b} TMT size has a positive effect on firm performance.
- H_{3c} CEO educational background has a positive effect on firm performance.
- H_{3d} CEO nationality has a positive effect on firm performance.

- H_{3e} CEO age has a positive effect on firm performance.

RESULTS AND DISCUSSION

Results

Descriptive Statistics

Table 3. Descriptive Statistics Result

Variable	Mean	Median	Max	Min	Std. Dev.
FP	1.029	0.960	2.128	0.559	0.305
CEI	6.7×10^{-7}	2.7×10^{-8}	2.0×10^{-5}	2.9×10^{-11}	2.9×10^{-6}
GPI	0.701	0.733	1.000	0.267	0.174
TMT_FEM	0.142	0.000	0.667	0.000	0.193
TMT_SIZE	4.366	4.000	15.000	2.000	2.226
CEO_ED	2.218	2.000	5.000	0.000	1.285
CEO_NAT	0.069	0.000	1.000	0.000	0.255
CEO_AGE	54.030	56.000	69.000	33.000	7.834
FSIZE	29.635	29.414	32.758	25.634	1.766
LVR	0.436	0.489	0.878	0.055	0.207

Source: EViews

Referring to Table 3, Firm performance (FP) shows a mean value of 1.029, indicating moderate performance variation among energy sector firms. Carbon emission intensity (CEI) records a very small average value (6.7×10^{-7}), suggesting that most firms report low emission intensity, although substantial variation exists across companies. Green process innovation (GPI) has a relatively high mean of 0.701, indicating that most firms have moderately to well-developed green process innovation practices. Figure 2 presents the average scores of the five GPI indicators across all observations during the 2022–2024 period.

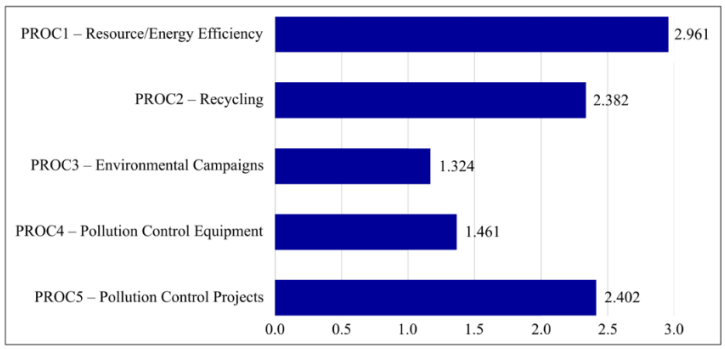

Figure 2. Average Scores of Each GPI Indicator 2022-2024

The results show that Energy and Resource Efficiency (PROC1) records the highest average score (2.961), approaching the maximum value. This indicates that improvements in energy and resource efficiency represent a primary focus for most firms, as such initiatives directly affect operational efficiency, cost reduction, and profitability. In addition, data related to energy and resource consumption are generally supported by standardized operational records, making them easier to measure and disclose. In contrast, Environmental Campaigns (PROC3) exhibit the lowest average score (1.324). These activities are often perceived as part of corporate social responsibility initiatives with limited direct impact on core operational performance, reducing their strategic priority. Moreover, the outcomes of environmental campaigns are difficult to quantify and are typically reported in a narrative manner. This disparity suggests that energy sector firms place greater emphasis on green process innovations that generate direct operational and financial benefits, while initiatives with more indirect impacts receive less disclosure.

Regarding TMT characteristics, the Female TMT proportion (TMT_FEM) is relatively low, with a mean of 0.142, indicating limited gender diversity at the top management level. The average TMT size is 4.366 members, reflecting moderate variation in managerial structures across firms. CEO educational background (CEO_ED) shows an average score of 2.218, suggesting that most CEOs possess at least undergraduate or postgraduate qualifications.

Furthermore, the mean value of CEO nationality (CEO_NAT) is 0.069, indicating that the majority of firms are led by domestic CEOs. CEO age averages 54.03 years, reflecting a predominance of mature and experienced executives. Firm size (FSIZE) and leverage (LVR) exhibit moderate dispersion, indicating relatively similar firm scales but varying capital structures among the sampled companies.

Panel Data Model Selection

Before conducting the panel data regression analysis, it is essential to determine the most appropriate model to ensure accurate and reliable results. The choice of model depends on the characteristics of the data. To identify the best-fitting model, several statistical tests are performed, including the Chow test, Hausman test, and Lagrange Multiplier (LM) test which help to determine whether the fixed effects or random effects approach is more suitable.

Table 4. Panel Regression Model Selection

Test Type	Probability	Selected Model
Chow Test	0.000	Fixed Effect Model
Hausman Test	0.0001	Fixed Effect Model

Source: EViews

The Chow test results indicate that FEM is more appropriate than the CEM, as evidenced by a p-value below 0.05. Furthermore, the Hausman test also suggests that FEM is preferable to the Random Effects Model (REM), with a p-value below 0.05. The LM test was not conducted because it is only applied to select between CEM and REM, while the previous tests identified FEM as the selected model. Therefore, the model selection results confirm that the FEM is the most suitable regression model for this study.

Table 5. Classical Assumption Tests

Test Type	Test Statistic	Probabilty
Normality	Jarque Bera	0.252
Multicolinearity	Centered VIF	< 10
Heteroskedasticity	Prob. Obs*R-square	0.188
Autocorrelation	Durbin-Watson stat	1.386

Source: EViews

Table 5 presents the results of classical assumption tests for the regression model. The normality test, using the Jarque–Bera statistic, yielded a value of 0.252 (>0.05), indicating that the residuals are normally distributed. Multicollinearity was examined with the centered VIF, and all variables had VIF values below 10, suggesting no multicollinearity issues. The heteroskedasticity test based on Prob. Obs*R^2 produced a value of 0.188 (>0.05), showing no evidence of heteroskedasticity. The Durbin–Watson statistic was 1.3863, which falls between –2 and 2, indicating no autocorrelation in the residuals. Overall, these results confirm that the regression model satisfies the classical assumptions.

Hyphothesis Test

The results of the coefficient of determination test in Table 6 show an adjusted R^2 of 0.759, indicating that 75.9% of the variation in the dependent variable FP is jointly explained

by the independent and control variables (CEI, GPI, TMT_FEM, TMT_SIZE, CEO_ED, CEO_NAT, CEO_AGE, FSIZE, and LVR). The remaining 24.1% is explained by other factors not included in the regression model.

Table 6. Coefficient Determination Result

Description	Value
R^2	0.867
Adj. R^2	0.759

Source: EViews

The F-test was conducted to determine whether all independent variables in the research model jointly affect the dependent variable. As shown in Table 7, the F-statistic is 8.004 with a p-value of 0.000, which is less than 0.05. This indicates that collectively, all independent and control variables (CEI, GPI, TMT_FEM, TMT_SIZE, CEO_ED, CEO_NAT, CEO_AGE, FSIZE, and LVR) have a significant effect on FP. Therefore, the regression model used in this study is considered suitable for explaining variations in firm performance.

Table 7. F-test Result

Description	Value
F-statistic	8.004
Prob (F statistic)	0.000

Source: EViews

To test hypothesis H3, F-test was also conducted on the subset of TMT characteristics, including the TMT_FEM, TMT_SIZE, CEO_ED, CEO_NAT, and CEO_AGE, along with firm FSIZE and LVR. The F-test results for this subset are presented in Table 8. Since the p-value is less than 0.05, it can be concluded that TMT characteristics collectively have a significant effect on firm performance. These results support hypothesis H3, which posits that TMT characteristics influence firm performance.

Table 8. Partial F-test Result

Description	Value
F-statistic	7.029
Prob (F statistic)	0.000

Source: EViews

The t-test, or partial test, was conducted to examine the individual effect of each independent variable on the dependent variable in the regression model. The test results are presented in Table 9.

Table 9. T-test Results

Variable	Coefficient	t-Stat	p-Value
CEI	-0.047	-3.114	0.003
GPI	0.005	0.017	0.987
TMT_FEM	0.059	0.218	0.828
TMT_SIZE	-0.010	-0.449	0.655
CEO_ED	0.044	1.537	0.130
CEO_NAT	-0.156	-0.675	0.503
CEO_AGE	-0.010	-2.010	0.049
FSIZE	-0.765	-5.502	0.000
LVR	1.282	3.379	0.001

Source: EViews

The t-test results indicate that the CEI has a p-value of 0.003 ($p < 0.05$) with a negative coefficient of -0.047, suggesting that carbon emission intensity has a significant negative effect on firm performance, thus supporting hypothesis H_1. Meanwhile, the other independent variables GPI, TMT_FEM, TMT_SIZE, CEO_ED, and CEO_NAT have p-values above 0.05, indicating that these variables do not significantly affect firm performance.

Additionally, CEO_AGE has a p-value of 0.049 ($p < 0.05$) with a negative coefficient of -2.010, which contradicts the hypothesized positive effect. Therefore, CEO_AGE also does not support the proposed hypothesis. Overall, hypotheses H_2, H_{3a}, H_{3b}, H_{3c}, H_{3d}, and H_{3e} are rejected because the respective variables do not show a significant impact on firm performance in the expected direction. On the other hand, the control variable FSIZE has a p-value of 0.000 ($p < 0.05$) with a coefficient of -0.765, indicating that firm size has a significant negative effect on firm performance. Similarly, the control variable LVR has a p-value of 0.001 ($p < 0.05$) with a coefficient of 1.282, showing a significant positive effect of leverage on firm performance.

Discussion

The Effect of Carbon Emission Intensity on Firm Performance

The carbon emission intensity (CEI) variable has a coefficient of -0.047 with a p-value of 0.003 ($p < 0.05$), indicating a significant negative effect on firm performance. This finding is consistent with previous studies showing that higher carbon emission intensity adversely affects firm performance (Houqe et al., 2022; Saikia & Maji, 2024). Theoretically, these results support legitimacy theory, which posits that firms are expected to align their operations with environmental norms to maintain social license to operate. Nyahuna et al. (2023) explain that legitimacy is eroded when carbon emissions exceed socially acceptable levels, prompting market penalties as investors respond negatively to high emissions as an environmental externality risk.

From the investor perspective, high carbon intensity signals vulnerability to regulatory sanctions and low sustainability commitment. The negative market reaction to carbon intensity observed during the study period reflects investor sensitivity to climate risk, consistent with empirical evidence from global markets (Zhang, 2022). This trend may also be influenced by the strengthening of environmental regulations in Indonesia, such as the launch of IDXCarbon in 2023, which formally converts carbon emissions into corporate risk. Carbon risk arises from the transition to a low-carbon economy due to regulatory pressure, changing consumer preferences, and potential reputational damage (Wang et al., 2022). Through the newly implemented carbon trading mechanism, firms with high emissions face potential direct economic costs and regulatory interventions that can reduce cash flows (Duong et al., 2025). This explains why higher carbon emission intensity is negatively reflected in Tobin's Q, the measure of firm performance used in this study.

The Effect of Green Process Innovation on Firm Performance

The green process innovation (GPI) has a coefficient of 0.005 with a p-value of 0.987 ($p > 0.05$), indicating that GPI does not have a significant effect on firm performance. From a stakeholder theory perspective, pressure from stakeholders can encourage firms to develop green capabilities and implement green process innovations in response to their expectations (Husnaini & Tjahjadi, 2021). However, Jayaraman et al. (2023) note that in developing countries, stakeholder attention and concern for green innovation are still relatively low. Similarly, as Akib et al. (2025) explain, investors in the Indonesian capital market may not yet consider green innovation an important factor in investment decisions. As a result, green process innovation does not receive adequate market recognition, and its impact on firm performance is not reflected in the short term.

These findings are consistent with Ma et al. (2017) that show green process innovation does not significantly affect firm performance in the short term because its benefits tend to materialize over the long term. also report that some firms are even reluctant to adopt green process innovation due to the delayed realization of its benefits (Zhang & Jiang, 2025). Nevertheless, the results suggest that while GPI may not significantly influence short-term firm performance, it remains strategically valuable in the long run, as it represents a long-term investment whose benefits accrue over time. Successful implementation of green innovation requires commitment and consistency, enabling firms to enhance reputation, efficiency, and stakeholder satisfaction (Gultom & Khomsiyah, 2025).

The Effect of Top management team characteristics on Firm Performance

The F-test results for all TMT characteristics show a p-value of 0.000 ($p < 0.05$), indicating a significant joint effect on firm performance. These findings support hypothesis H3, suggesting that variations in TMT composition collectively explain significant differences in firm performance. The individual effects of each TMT characteristic are discussed next.

The Female TMT Proportion on Firm Performance

Female TMT proportion has a positive coefficient of 0.059 with a p-value of 0.828 ($p > 0.05$), indicating that the proportion of female TMT members does not significantly affect firm performance. According to Upper Echelons theory, gender can influence managers' cognitive frameworks, but in energy companies, over half of the sampled firms have no female TMT members, as reflected by the median value of 0.000. Gender diversity does not automatically enhance market-based performance measures such as Tobin's Q, and positive effects generally occur only when women hold active strategic influence rather than symbolic roles (Lu, 2024).

The TMT Size on Firm Performance

TMT size has a negative coefficient of -0.010 with a p-value of 0.655 ($p > 0.05$), indicating that TMT size does not significantly affect firm performance. Theoretically, larger TMTs are often seen as proxies for greater cognitive capacity and collective resources, as suggested by Upper Echelons theory. However, studies show that TMT demographic characteristics and heterogeneity do not necessarily have a direct effect on performance (Hui, 2020). Oversized teams can create coordination and communication challenges (Jiang & Kim, 2022), slow decision-making processes (Leviany & Soviani, 2020), and increase leader dominance and internal conflicts (Le et al., 2023). Overall, TMT size alone does not significantly influence firm performance; rather, the effectiveness and quality of the team are more critical determinants than size.

The CEO Education

CEO education has a positive coefficient of 0.044 with a p-value of 0.130 ($p > 0.05$), indicating that CEO education does not significantly affect firm performance. Studies suggest that formal education level does not always translate into better firm performance, as sector-specific competencies may not be reflected solely by formal qualifications (Emestine & Setyaningrum, 2019). Upper Echelons theory posits that executive decisions in complex corporate environments are shaped by bounded rationality when managers process diverse and uncertain information. In the highly standardized and regulated energy sector, strategic decisions are primarily guided by regulatory knowledge, technology, and industry infrastructure (Söderholm, 2020). Therefore, formal education is not a differentiating factor, and CEO educational background does not significantly influence firm performance in this context.

The CEO Nationality on Firm Performance

CEO nationality has a negative coefficient of -0.156 with a p-value of 0.503 ($p > 0.05$), indicating that CEO nationality does not significantly affect firm performance. According to Upper Echelons theory, CEO nationality could theoretically enhance firm performance through added expertise, global experience, and broader networks (Nguyen, 2023). However, in the Indonesian context, the relationship between executive characteristics and firm outcomes is strongly shaped by local institutional dynamics, limiting the expected effect (Parquinda & Wibowo, 2022). The non-significant result in this study may also be due to sample limitations, as foreign CEOs are represented in only seven observations (6.93% of the sample), reducing statistical power. Therefore, the lack of significance likely reflects extreme sample homogeneity rather than conclusive evidence that CEO nationality is irrelevant.

The CEO Age on Firm Performance

CEO age has a negative coefficient of -0.010 with a p-value of 0.049 ($p < 0.05$), indicating that CEO age has a significant negative effect on firm performance. According to Upper Echelons theory, personal characteristics such as age influence executives' preferences and strategic decisions. Older CEOs tend to maintain the status *quo*, focus on short-term performance, allocate less to R&D, engage more in diversification, and maintain lower operational leverage (Han & Jo, 2024). As retirement approaches, older CEOs often have shorter career horizons and are less willing to pursue high-risk strategies, especially if the benefits materialize after their tenure (McClelland et al., 2012). While measured risk-taking can enhance firm performance if supported by managerial capability, older CEOs' risk aversion may limit value creation. In contrast, younger CEOs are generally more energetic, motivated, and responsive to market opportunities, which explains the observed negative effect of CEO age on firm performance (Bhabra & Zhang, 2016).

CONCLUSION

This study demonstrates that firm performance in Indonesia's energy sector during 2022–2024 is largely driven by internal strategic factors, particularly the management of carbon emissions and the collective capacity of top management teams, rather than by individual executive characteristics or green process innovation. High carbon emission intensity negatively affects firm performance because investors perceive it as an environmental and regulatory risk, which can reduce market valuation and constrain financial performance. In contrast, green process innovation does not significantly influence firm performance, likely because its benefits are long-term and not yet recognized by the market.

While the composition and characteristics of the top management team collectively influence performance, individual factors such as the proportion of female TMT, TMT size, CEO education, CEO nationality do not have a significant effect, except for CEO age, which negatively impacts performance due to a tendency to prioritize short-term stability and avoid strategic risks.

This study advances industrial management and corporate governance research by providing empirical evidence on the impact of carbon emission management and top management team dynamics on firm performance in the energy sector. It demonstrates that strategic internal management, particularly managing carbon risks and aligning TMT capabilities, is more critical than individual executive characteristics or short-term green innovations, offering a framework for improving operational efficiency, sustainability integration, and strategic decision-making in industrial organizations.

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