

## HOW RENEWABLE ENERGY DRIVES FIRM VALUE IN INDONESIA'S ENERGY SECTOR: CARBON EMISSION MEDIATION AND GREEN INVESTMENT MODERATION

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### Abstract

This study examines the effect of renewable energy on firm value with carbon emission as a mediating variable and green investment as a moderating variable among energy sector companies listed on the Indonesia Stock Exchange. Using a quantitative panel data approach, the study applies fixed-effects regression analysis to a sample of 38 companies over the 2022–2024 period, yielding 114 firm-year observations. Data were collected from annual reports and sustainability reports, with firm value proxied by Tobin's Q and robustness confirmed using Price-to-Book Value. The findings reveal that renewable energy negatively and significantly affects carbon emission, carbon emission negatively and significantly affects firm value, and renewable energy positively and significantly affects firm value directly. Carbon emission is confirmed as a partial mediator in the renewable energy–firm value relationship, as evidenced by significant Sobel-Goodman test results. Green investment positively moderates the effect of renewable energy on firm value, indicating that firms combining renewable energy adoption with greater environmental capital expenditure achieve stronger market valuation outcomes. All findings remain consistent under alternative firm value measurement. Grounded in stakeholder theory and signaling theory, this study contributes an integrated moderated mediation framework to the environmental finance literature and provides empirical evidence that renewable energy and green investment function as complementary strategic assets in creating firm value within Indonesia's energy transition context.

**Keywords:** renewable energy, carbon emission, firm value, green investment, energy transition

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### INTRODUCTION

Growing imperatives to curb greenhouse gas emissions and reduce reliance on conventional fossil-based energy have set in motion a far-reaching reconfiguration of the world's energy system. The global renewable energy market reached USD 1,078.7 billion in 2025 and is forecast to expand to USD 1,838.57 billion by 2034, equivalent to a CAGR of 6.17% (Fortune Business Insights, 2026). This rapid expansion is propelled by mounting environmental concerns, as energy-related CO<sub>2</sub> emissions worldwide climbed by 1.1% in 2023 to a record 37.4 billion tons, with greenhouse gases accounting for more than 65% of the increase. In response, governments and institutional investors have intensified commitments to renewable energy deployment; the European Union, for instance, has set a target of raising renewables to account for 42.5% of total final energy consumption by 2030, supported by EUR 75 billion in clean energy financing from the European Investment Bank (Kimathi, 2026). This momentum is further reflected in large-scale infrastructure investments, such as Allianz Global Investors' entry into Germany's Amprion power grid with a planned investment exceeding EUR 36 billion by 2029 to support the country's renewable electricity transition (Reuters, 2026). These developments underscore that renewable energy is no longer a peripheral

consideration but a central driver of corporate strategy and investment decision-making worldwide.

Indonesia, as one of the largest energy-consuming economies in Southeast Asia, has positioned renewable energy development as a strategic national priority in pursuit of its Net Zero Emission target by 2060. The Asia Pacific region, in which Indonesia plays a significant role as one of the world's leading biofuel producers, accounted for USD 730.08 billion of the global renewable energy market in 2025, representing 67.68% of global industry share (Fortune Business Insights, 2026). At the national level, Indonesia's Ministry of Energy and Mineral Resources recorded renewable energy investment realization of USD 1.3 billion in the first semester of 2025, approaching the annual target of USD 1.5 billion, driven primarily by solar and geothermal projects (Setiawan, 2025). This investment momentum is further supported by institutional financing initiatives, as PT Indonesia Infrastructure Finance actively channels funding toward renewable energy projects aligned with the national Net Zero Emission 2060 agenda through public-private collaboration (Antara, 2025). At the corporate level, Pertamina New and Renewable Energy reinforced its regional commitment by acquiring a 20% stake in Citicore Renewable Energy Corporation of the Philippines for USD 120 million, signaling Indonesia's expanding role in ASEAN's clean energy transition (Kencana, 2026). These developments indicate that renewable energy investment in Indonesia is no longer driven solely by regulatory mandates but increasingly by corporate value creation considerations, raising the empirical question of how such investments affect firm value in the Indonesian energy sector.

The relationship between renewable energy, carbon emission, and firm value has been theoretically grounded in stakeholder theory, which posits that firms creating value for a broad range of stakeholders—including environmental stakeholders—are more likely to sustain long-term financial performance. Stakeholder theory argues that corporate environmental responsiveness, such as renewable energy adoption, strengthens firm legitimacy and reduces stakeholder-related risks (Freeman et al., 2020; Kivits & Sawang, 2021; Mahajan et al., 2023). Empirically, renewable energy adoption has been consistently linked to carbon emission reduction, as evidenced across developing economies including Indonesia, where the dynamic impact of renewable energy on CO<sub>2</sub> emissions has been documented (Akram et al., 2020; Idroes et al., 2024; Saidi & Omri, 2020). The reduction in carbon emissions, in turn, carries value relevance for investors, as firms with lower carbon intensity are perceived as bearing reduced regulatory, reputational, and transition risks, thereby commanding higher market valuations (Benkraiem et al., 2022; Choi & Luo, 2021; Han et al., 2023). In the Indonesian context specifically, renewable energy utilization has been shown to positively influence firm performance in the energy sector, both through systematic review and empirical examination (Hutahayan et al., 2025; Sitompul et al., 2024), while comparable evidence from European non-financial companies further confirms that renewable energy adoption enhances financial performance (Issa & Hanaysha, 2023). These theoretical and empirical foundations collectively suggest that carbon emission serves as a mediating mechanism through which renewable energy translates into improved firm value, a pathway that warrants formal empirical investigation within the Indonesian energy sector.

Beyond the direct pathway from renewable energy to firm value, green investment has emerged as a critical boundary condition that amplifies how renewable energy adoption is perceived and rewarded by capital markets. Signaling theory posits that firms use observable actions to communicate unobservable quality to information-asymmetric markets, and green investment serves as one such credible signal of genuine environmental commitment (Connelly et al., 2025; Friske et al., 2023). Empirically, green investment has been shown to improve firm performance and stock returns, particularly among energy sector companies where environmental credibility is closely scrutinized by investors (Chen & Ma, 2021; Putrika & Ardianto, 2025). In the Indonesian context, green investment has been found to positively influence firm value, with corporate governance serving as a complementary mechanism that reinforces this relationship

(Widarwati et al., 2024). When green investment is combined with renewable energy adoption, the signaling effect is strengthened, as investors interpret the simultaneous commitment to clean energy use and environmental capital allocation as a more credible indicator of long-term sustainability performance (Friske et al., 2023; Uyar et al., 2020). However, firms that fail to align green investment with genuine renewable energy transition risk being perceived as engaging in greenwashing, which can undermine rather than enhance market valuation (Uyar et al., 2020). This suggests that green investment moderates the relationship between renewable energy and firm value, a proposition that has yet to be formally examined within an integrated moderated mediation framework in the Indonesian energy sector.

Despite the growing body of literature on renewable energy, carbon emission, and firm value, existing studies have predominantly examined these relationships in isolation, leaving a significant gap in the understanding of their integrated dynamics. Studies focusing on the Indonesian energy sector have examined the effect of renewable energy on firm performance independently, without incorporating carbon emission as a mediating mechanism or green investment as a moderating variable (Hutahayan et al., 2025; Sitompul et al., 2024). Similarly, research on carbon emission and firm value has largely treated carbon performance as a direct antecedent of market valuation, without situating it within a broader causal chain originating from renewable energy adoption (Benkraiem et al., 2022; Han et al., 2023). On the moderating side, while green investment has been shown to influence firm value in Indonesia, its boundary-conditioning role in the renewable energy–firm value relationship has not been empirically tested (Putrika & Ardianto, 2025; Widarwati et al., 2024). Crucially, no prior study has simultaneously examined carbon emission as a mediator and green investment as a moderator within a unified moderated mediation framework, particularly in the Indonesian energy sector during the 2022–2024 period, which represents a critical window of accelerating energy transition policy implementation. This study therefore addresses these gaps by proposing and testing an integrated model that captures the conditional indirect effect of renewable energy on firm value through carbon emission, moderated by green investment.

This study investigates how renewable energy shapes firm value through both a direct pathway and an indirect channel via carbon emission, with green investment conditioning the strength of this relationship, among energy sector companies listed on the Indonesia Stock Exchange during the 2022–2024 period. The novelty of this study lies in its integration of a moderated mediation framework that simultaneously captures the direct valuation effect of renewable energy, the transmission pathway operating through emission reduction, and the amplifying role of green investment as a moderating condition — an approach that has not been previously applied in the Indonesian energy sector context. From a theoretical standpoint, this study enriches stakeholder theory and signaling theory by generating empirical evidence of how renewable energy adoption translates into market value through both direct and conditional indirect mechanisms. Practically, this study offers guidance for corporate managers in formulating renewable energy and green investment strategies that maximize firm value, as well as for regulators and policymakers in designing incentive structures that align energy transition goals with capital market performance. Empirical results reveal that renewable energy exerts a significant positive direct influence on firm value, renewable energy negatively affects carbon emission, carbon emission negatively affects firm value, and green investment amplifies the positive valuation impact of renewable energy, collectively confirming all proposed hypotheses. These results imply that energy companies in Indonesia should not only accelerate renewable energy adoption but also strategically allocate green investment to send credible sustainability signals to the market, thereby enhancing long-term market valuation within Indonesia's accelerating energy transition landscape.

## LITERATURE REVIEW AND HYPOTHESIS FORMULATION

### *Theoretical Framework*

Stakeholder theory provides the foundational theoretical lens through which the relationship between corporate environmental actions and firm value is understood in this study. Stakeholder theory argues that firms do not operate solely for the benefit of shareholders but are accountable to a broader set of stakeholders, including employees, customers, communities, regulators, and environmental constituencies, whose support is essential for long-term organizational survival (Freeman et al., 2020; Mahajan et al., 2023). Firms that proactively address stakeholder environmental expectations—such as through renewable energy adoption and carbon emission reduction—are more likely to secure stakeholder legitimacy, reduce operational risks, and strengthen their competitive position in the market (Kivits & Sawang, 2021). In the context of the energy sector, where environmental scrutiny from regulators, investors, and communities is particularly intense, alignment with stakeholder environmental expectations through sustainable energy practices is increasingly translated into superior market valuation (Mahajan et al., 2023). Stakeholder theory therefore predicts that renewable energy adoption, by reducing carbon emissions and satisfying the environmental expectations of multiple stakeholder groups, positively influences firm value through enhanced legitimacy and reduced environmental risk exposure.

Signaling theory complements stakeholder theory by explaining the mechanism through which corporate environmental actions are communicated to and interpreted by capital markets. Signaling theory posits that in markets characterized by information asymmetry, firms use observable and costly signals to credibly convey their unobservable quality and strategic intentions to external parties, particularly investors (Connelly et al., 2025). In the context of environmental performance, both renewable energy adoption and green investment serve as credible signals of a firm's long-term sustainability commitment, as these actions require substantial capital allocation that opportunistic firms would find difficult to imitate (Friske et al., 2023). Investors and market participants interpret these signals as indicators of reduced regulatory risk, enhanced operational efficiency, and superior environmental governance, thereby rewarding signaling firms with higher market valuations (Connelly et al., 2025; Friske et al., 2023). However, the credibility of environmental signals is contingent on their consistency; firms that claim environmental commitment through green investment without achieving genuine carbon emission reductions risk being perceived as engaging in greenwashing, which undermines signaling effectiveness and erodes firm value (Uyar et al., 2020). Signaling theory therefore predicts that green investment strengthens the positive effect of renewable energy on firm value by reinforcing the credibility and market visibility of a firm's environmental transition.

### ***Hypothesis Development***

Renewable energy adoption represents one of the most direct corporate strategies for reducing carbon emission intensity in the energy sector. When firms substitute fossil fuel-based energy with renewable sources, greenhouse gases generated per unit of economic output necessarily decline, as renewable technologies produce negligible direct emissions compared to coal or natural gas combustion. Stakeholder theory posits that such substitution fulfills environmental stakeholder expectations, thereby reducing regulatory exposure and strengthening firm legitimacy (Freeman et al., 2020; Mahajan et al., 2023). Prior studies consistently document the emission-reducing effect of renewable energy across multiple country contexts, with evidence demonstrating that increasing the share of renewable energy in the total energy mix displaces fossil fuel consumption and leads to significant CO<sub>2</sub> reductions (Saidi & Omri, 2020). In developing economies, this effect is heterogeneous but generally negative, particularly when renewable adoption is accompanied by complementary technological improvements (Akram et al., 2020; Edziah et al., 2022). Studies further confirm that renewable energy combined with green technology accelerates emission reduction and contributes to carbon neutrality targets in emerging economy contexts (Behera et al., 2023; Justice et al., 2024). Critically, within the Indonesian context, the dynamic impact of renewable energy on reducing CO<sub>2</sub> emissions and ecological footprint has

been empirically established, confirming its relevance at the firm level in Indonesia's energy sector (Idroes et al., 2024). Based on this evidence, the following hypothesis is proposed:

***H1: Renewable energy has a negative effect on carbon emission.***

Carbon emission performance has increasingly become a value-relevant indicator in capital markets, reflecting growing integration of environmental risk into financial valuation frameworks. High-emission firms face elevated regulatory penalties, reputational damage, and transition risks that reduce expected future cash flows and raise investor discount rates, mechanically suppressing market valuation. Stakeholder theory reinforces this by suggesting that firms with high carbon emissions experience reduced stakeholder confidence, greater exposure to regulatory and reputational risks, and ultimately lower market valuations (Mahajan et al., 2023). International evidence consistently shows that capital markets price carbon emission information negatively, with higher emission levels associated with lower firm valuations across diverse institutional contexts, particularly where carbon trading schemes and environmental regulations are stringent (Choi & Luo, 2021). Studies focusing on the world's most sustainable firms further confirm that superior carbon performance translates into higher market valuations by reducing investor perceptions of future environmental cost exposure (Benkraiem et al., 2022). Country-specific evidence from Taiwan and Korea similarly establishes that lower-emission firms are rewarded with higher market-to-book ratios, with the effect amplified in carbon-intensive industries under intensive regulatory monitoring (Han et al., 2023; Lee & Cho, 2021). Voluntary carbon disclosure has additionally been shown to amplify the negative market impact of high carbon emissions (Z.-Y. Sun et al., 2022). Based on this evidence, the following hypothesis is proposed:

***H2: Carbon emission has a negative effect on firm value.***

Beyond its indirect effect through carbon emission reduction, renewable energy directly enhances firm value through multiple mechanisms. Renewable energy insulates firms from fossil fuel price volatility, stabilizing operating margins and improving earnings predictability. It also improves environmental reputation among investors and regulators, generating legitimacy value that translates into competitive advantage. Signaling theory further suggests that renewable energy adoption constitutes a credible, capital-intensive signal of long-term sustainability commitment that reduces perceived investment risk and attracts sustainability-oriented institutional investors (Connelly et al., 2025; Friske et al., 2023). Prior studies confirm that firms with higher renewable energy usage record superior financial and market performance, attributing this to cost efficiency gains from stable energy pricing, improved access to green financing instruments, and reputational premiums in capital markets (Issa & Hanaysha, 2023). A systematic review of existing literature identifies innovation, governance, and regulation as key conditions under which renewable energy positively influences multiple dimensions of firm performance, confirming that its financial benefits are multi-dimensional and extend beyond simple cost savings (Sitompul et al., 2024). Empirical evidence from Indonesian energy sector companies specifically confirms a positive relationship between renewable energy use and firm performance within Indonesia's institutional context (Hutahayan et al., 2025). At the policy level, green energy transition strategies have been shown to enhance the long-term financial standing of energy firms by improving asset quality and reducing regulatory exposure (Zhang & Kong, 2022). Based on this evidence, the following hypothesis is proposed:

***H3: Renewable energy has a positive effect on firm value.***

The mediating role of carbon emission reflects a sequential pathway through which environmental actions generate market-recognized financial outcomes: renewable energy adoption reduces carbon emission intensity, which in turn reduces regulatory risk, reputational damage, and transition cost burdens, thereby improving investor perceptions of future cash flows and enhancing market valuation. This means the financial benefits of renewable energy are partly generated through real environmental improvement that capital markets recognize and reward, rather than through signaling alone. Stakeholder theory supports this pathway by positing that

carbon emission reduction strengthens firm legitimacy and reduces stakeholder-related risks that ultimately manifest in higher market valuations (Freeman et al., 2020; Mahajan et al., 2023). Prior literature in corporate finance identifies carbon emission intensity as the primary transmission channel through which environmental strategies affect financial performance, with transition risk exposure operating as the key mechanism linking emission levels to market valuation outcomes (Wang et al., 2022). Evidence further shows that corporate environmental strategy influences financial performance through its effect on carbon performance metrics, with financial benefits only partially channeled through emission outcomes — implying partial rather than full mediation in the renewable energy–firm value relationship (Luo & Tang, 2021). Additional evidence confirms that carbon emission reduction functions as an intermediate mechanism in the environmental strategy–financial performance chain, rather than a merely parallel environmental outcome (Busch et al., 2022). Based on this evidence, the following hypothesis is proposed:

**H4: Carbon emission mediates the effect of renewable energy on firm value.**

Green investment serves as a boundary condition that amplifies the positive effect of renewable energy on firm value by reinforcing the credibility of a firm's environmental commitment. Signaling theory explains this mechanism: when green investment accompanies renewable energy adoption, the combined signal is stronger and more credible, as simultaneous capital allocation to environmental initiatives and clean energy use reduces information asymmetry regarding a firm's genuine sustainability orientation, making greenwashing perceptions far less likely (Connelly et al., 2025; Friske et al., 2023). Prior studies demonstrate that green investment improves firm performance in capital-intensive industries through reduced regulatory exposure and enhanced environmental reputation, mechanisms that naturally amplify the valuation benefits of accompanying renewable energy adoption (Chen & Ma, 2021). Evidence from capital-intensive sectors further shows that firms combining green investment with cleaner production practices achieve stronger market performance outcomes than firms pursuing either strategy independently (Y. Sun & Yang, 2022). In the Indonesian context, green investment has been found to positively influence firm value, with the strength of its effect conditioned by governance mechanisms that ensure accountability in environmental capital allocation (Widarwati et al., 2024). Additional Indonesian evidence confirms that green investment influences stock returns through financial performance channels, establishing that market rewards for environmental expenditure operate through measurable financial intermediaries rather than sentiment alone (Putrika & Ardianto, 2025). Based on this evidence, the following hypothesis is proposed:

**H5: Green investment strengthens the positive effect of renewable energy on firm value.**

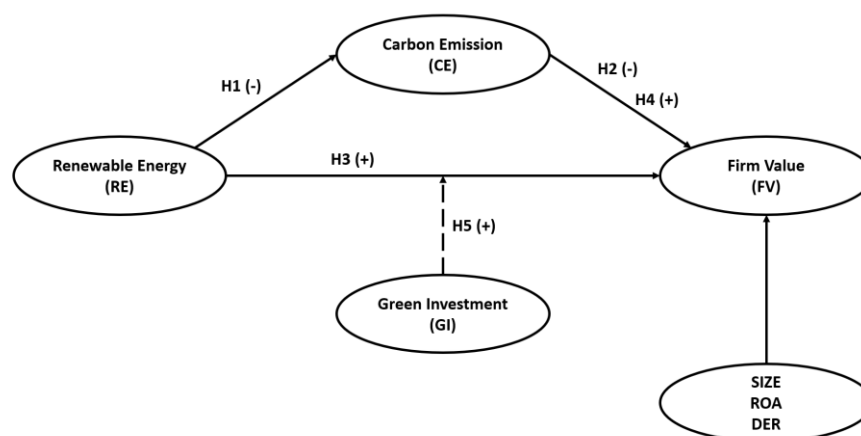


Figure 1. Research Framework

Figure 1 illustrates the moderated mediation model proposed in this study. Renewable energy (RE) is hypothesized to directly and positively affect firm value (FV) (H3) and to indirectly affect firm value through carbon emission (CE) as a mediating variable, whereby RE negatively

affects CE (H1) and CE subsequently negatively affects FV (H2), establishing the indirect pathway (H4). Green investment (GI) is hypothesized to moderate the positive effect of renewable energy on firm value (H5), such that higher green investment strengthens the relationship between RE and FV. Firm size (SIZE), profitability (ROA), and leverage (DER) are included as control variables.

## RESEARCH METHODS

This study adopts a quantitative research design using secondary panel data to examine the relationships among renewable energy, carbon emission, green investment, and firm value. The research population consists of 91 energy sector companies listed on the Indonesia Stock Exchange. Purposive sampling was applied based on the following criteria: availability of annual and sustainability reports spanning 2022–2024, and adequate disclosure of carbon emission data, renewable and total energy consumption figures, and environmental expenditure information. Application of these criteria yielded a final sample of 38 companies, yielding 114 firm-year observations across the three-year study period.

Data were collected from annual reports and sustainability reports of each sample company, retrieved from the IDX official portal and individual company websites. Firm value (FV) is measured using Tobin's Q, computed by dividing the combined value of market capitalization and total debt by total assets, with PBV employed as an alternative proxy in the robustness analysis. The independent variable, renewable energy (RE), is quantified as the proportion of renewable energy in a firm's overall energy consumption, consistent with prior studies on energy sector firms (Hutahayan et al., 2025; Sitompul et al., 2024). The mediating variable, carbon emission (CE), is captured through carbon emission intensity, derived by dividing aggregate Scope 1 and Scope 2 greenhouse gas emissions by annual revenue in millions of rupiah, following Wang et al. (2022) and Radu & Maram (2021). The moderating variable, green investment (GI), is operationalized as the proportion of environmental expenditure relative to total assets, consistent with Chen & Ma (2021), Huang & Lei (2021), Tullah et al. (2025) and Widarwati et al. (2024). Three control variables are incorporated: firm size (SIZE), measured as the natural log of total assets; profitability (ROA), computed as net income scaled by total assets; and leverage (DER), defined as the ratio of total debt to total equity.

Data analysis was conducted using Stata software. The study employs three fixed-effects panel regression equations to test the hypothesized relationships. The selection of fixed effects over random effects was based on the Hausman test results, which indicated a significant correlation between individual effects and the independent variables across all three models. Equation 1 examines the effect of renewable energy on carbon emission:

$$CE_{it} = \alpha + \beta_1 RE_{it} + \beta_2 SIZE_{it} + \beta_3 ROA_{it} + \beta_4 DER_{it} + \varepsilon_{it} \dots\dots\dots(1)$$

Equation 2 examines the direct effects of renewable energy and carbon emission on firm value:

$$FV_{it} = \alpha + \beta_1 RE_{it} + \beta_2 CE_{it} + \beta_3 SIZE_{it} + \beta_4 ROA_{it} + \beta_5 DER_{it} + \varepsilon_{it} \dots\dots\dots(2)$$

Equation 3 examines the moderating role of green investment through the inclusion of an interaction term between renewable energy and green investment:

$$FV_{it} = \alpha + \beta_1 RE_{it} + \beta_2 GI_{it} + \beta_3 (RE \times GI)_{it} + \beta_4 SIZE_{it} + \beta_5 ROA_{it} + \beta_6 DER_{it} + \varepsilon_{it} \dots\dots\dots(3)$$

Prior to regression estimation, multicollinearity was assessed using the variance inflation factor (VIF). The mediating effect of carbon emission was formally tested using the Sobel-Goodman test, with mediation confirmed if the indirect effect is statistically significant. Robustness of the main findings was assessed by replicating Equations 2 and 3 using PBV as an alternative proxy for firm value.

## RESULTS AND DISCUSSION

Table 1 summarizes the descriptive statistics for all research variables. Tobin's Q records a mean of 1.8018 and standard deviation of 2.5291, reflecting wide dispersion in market valuation across sampled Indonesian energy firms over the observation period. The average RE value of 0.1491 indicates that sampled firms sourced roughly 14.91% of total energy needs from renewable technologies, reflecting the still-limited penetration of clean energy in Indonesia's energy sector. Carbon emission (CE) exhibits a high standard deviation of 13.4149 relative to its mean of 1.9105, indicating substantial heterogeneity in emission intensity across sample companies. Green investment (GI) has a mean of 0.0335, suggesting that environmental expenditure represents a relatively small but present proportion of total assets. Control variables show that the average firm size (SIZE) is 29.8717, profitability (ROA) is 0.1241, and leverage (DER) is 1.0540, all within reasonable ranges for energy sector companies.

Table 1. Descriptive Statistics

| Variable       | N   | Mean    | Std. Dev. | Min     | Max      |
|----------------|-----|---------|-----------|---------|----------|
| FV (Tobin's Q) | 114 | 1.8018  | 2.5291    | 0.55881 | 4.5601   |
| RE             | 114 | 0.1491  | 0.0941    | 0.0100  | 0.7000   |
| CE             | 114 | 1.91051 | 3.4149    | 0.0000  | 139.5854 |
| GI             | 114 | 0.0335  | 0.0239    | 0.0010  | 0.1500   |
| SIZE           | 114 | 29.8717 | 1.51592   | 6.57323 | 2.7557   |
| ROA            | 114 | 0.1241  | 0.1516    | -0.2599 | 0.6163   |
| DER            | 114 | 1.0540  | 1.0881    | 0.0587  | 7.2030   |

Note: FV = Firm Value (Tobin's Q); RE = Renewable Energy; CE = Carbon Emission; GI = Green Investment; SIZE = Firm Size; ROA = Return on Assets; DER = Debt-to-Equity Ratio.

Table 2 presents pairwise correlations among variables alongside variance inflation factor (VIF) diagnostics. The highest pairwise correlation is observed between RE and GI ( $r = 0.747$ ), which reflects a natural tendency for companies with higher renewable energy adoption to also allocate greater environmental expenditure. Despite this relatively high correlation, all VIF values fall comfortably beneath the critical threshold of 10, with a mean VIF of 1.63, indicating that multicollinearity is not a concern in the regression models. Hausman test results confirm the superiority of the fixed-effects specification across all three equations, with the null hypothesis of coefficient equivalence between fixed and random effects estimators rejected at standard significance levels (Eq.1:  $\chi^2 = 14.25$ ,  $p = 0.007$ ; Eq.2:  $\chi^2 = 32.44$ ,  $p = 0.000$ ; Eq.3:  $\chi^2 = 19.76$ ,  $p = 0.003$ ).

Table 2. Correlation Matrix &amp; VIF

| Variable | RE      | CE      | GI      | SIZE   | ROA     | DER    | VIF  |
|----------|---------|---------|---------|--------|---------|--------|------|
| RE       | 1.0000  |         |         |        |         |        | 2.44 |
| CE       | -0.1751 | 1.0000  |         |        |         |        | 1.05 |
| GI       | 0.7466  | -0.1771 | 1.0000  |        |         |        | 2.42 |
| SIZE     | 0.0382  | -0.0815 | 0.0042  | 1.0000 |         |        | 1.20 |
| ROA      | 0.0110  | -0.0868 | 0.1298  | 0.2034 | 1.0000  |        | 1.34 |
| DER      | -0.1210 | -0.0135 | -0.0587 | 0.2304 | -0.3407 | 1.0000 | 1.33 |
| Mean VIF |         |         |         |        |         |        | 1.63 |

Note: All VIF values < 10, indicating no serious multicollinearity.

Table 3 presents the main regression results for all three equations. Equation 1 shows that RE has a significant negative effect on CE ( $\beta = -47.153$ ,  $p = 0.001$ ,  $R^2$  within = 0.1602), supporting **H1**. Equation 2 shows that RE has a significant positive effect on FV ( $\beta = 5.738$ ,  $p = 0.000$ ) and CE has a significant negative effect on FV ( $\beta = -0.009$ ,  $p = 0.000$ ), with the model explaining 97.46% of within-group variance ( $R^2 = 0.9746$ ), supporting **H2** and **H3**. Equation 3 shows that the interaction

term RE×GI is positive and significant ( $\beta = 12.060$ ,  $p = 0.024$ ), while GI is also positive and significant ( $\beta = 13.552$ ,  $p = 0.036$ ), supporting **H5**. The direct effect of RE becomes insignificant in Equation 3 ( $\beta = 1.391$ ,  $p = 0.422$ ).

Table 3. Main Regression Results (Fixed Effect)

| Variable       | Equation.1 (CE)        | Equation.2 (FV)      | Equation.3 (FV)     |
|----------------|------------------------|----------------------|---------------------|
| RE             | -47.153***<br>(13.501) | 5.738***<br>(0.135)  | 1.391<br>(1.722)    |
| CE             |                        | -0.009***<br>(0.001) |                     |
| GI             |                        |                      | 13.552**<br>(6.353) |
| CE×GI          |                        |                      | 12.060**<br>(5.226) |
| SIZE           | 4.752<br>(10.215)      | -0.171*<br>(0.094)   | -0.300**<br>(0.132) |
| ROA            | -0.172<br>(13.842)     | 0.062<br>(0.128)     | 0.109<br>(0.178)    |
| DER            | 1.218<br>(5.076)       | -0.020<br>(0.047)    | 0.023<br>(0.066)    |
| cons           | -134.262<br>(304.000)  | 6.079**<br>(2.809)   | 9.984**<br>(3.941)  |
| R <sup>2</sup> | 0.1602                 | 0.9746               | 0.9539              |
| F-stat         | 3.43**                 | 544.80***            | 241.48***           |
| Obs            | 114                    | 114                  | 114                 |
| Groups         | 38                     | 38                   | 38                  |

Note: \* $p < 0.1$ , \*\* $p < 0.05$ , \*\*\* $p < 0.01$ . Standard errors in parentheses.

Table 4 presents the Sobel-Goodman mediation test results. The Sobel test ( $Z = 3.236$ ,  $p = 0.001$ ), Aroian test ( $Z = 3.218$ ,  $p = 0.001$ ), and Goodman test ( $Z = 3.255$ ,  $p = 0.001$ ) all confirm a significant indirect effect of RE on FV through CE, with an indirect effect of 0.441, supporting **H4**. The coexistence of significant direct and indirect effects indicates partial mediation.

Table 4. Sobel-Goodman Mediation Test (Tobin's Q)

|              | Coefficient | Std. Error          | Z-statistic | p-value |
|--------------|-------------|---------------------|-------------|---------|
| a (RE → CE)  | -47.153     | 13.501              |             |         |
| b (CE → FV)  | -0.009      | 0.001               |             |         |
| Sobel test   |             | 0.136               | 3.236       | 0.001   |
| Aroian test  |             | 0.137               | 3.218       | 0.001   |
| Goodman test |             | 0.136               | 3.255       | 0.001   |
| Conclusion   |             | Mediation supported |             |         |

Note: Indirect effect =  $a \times b = 0.441$ . Significant at  $p < 0.01$ .

Table 5 presents the robustness test results using PBV as an alternative firm value proxy. RE maintains a significant positive effect on FV ( $\beta = 10.564$ ,  $p = 0.000$ ) and CE maintains a significant negative effect ( $\beta = -0.012$ ,  $p = 0.035$ ) in Equation 2. The interaction term RE×GI remains positive and significant in Equation 3 ( $\beta = 54.334$ ,  $p = 0.006$ ). The Sobel mediation test using PBV yields  $Z = 3.447$  ( $p = 0.001$ ), confirming mediation. All main findings remain consistent across both firm value proxies.

Table 5. Robustness Test (PBV)

| Variable | Equation.2           | Equation.3        |
|----------|----------------------|-------------------|
| RE       | 10.564***<br>(0.689) | -5.060<br>(6.321) |

|                |                     |                       |
|----------------|---------------------|-----------------------|
| CE             | -0.012**<br>(0.006) |                       |
| GI             |                     | 37.874<br>(23.325)    |
| CExGI          |                     | 54.334***<br>(19.186) |
| SIZE           | -0.029<br>(0.483)   | -0.349<br>(0.486)     |
| ROA            | 0.784<br>(0.653)    | 1.058<br>(0.652)      |
| DER            | 0.624**<br>(0.240)  | 0.818***<br>(0.243)   |
| cons           | 0.932<br>(14.361)   | 10.943<br>(14.470)    |
| R <sup>2</sup> | 0.8306              | 0.8416                |
| F-stat         | 69.65***            | 61.98***              |
| Obs            | 114                 | 114                   |
| Groups         | 38                  | 38                    |

Note: \*p<0.1, \*\*p<0.05, \*\*\*p<0.01. Standard errors in parentheses.

Mediation test (PBV): Sobel Z = 3.447, p = 0.001, mediation supported.

### ***The Effect of Renewable Energy on Carbon Emission (H1)***

Renewable energy exerts a significant negative effect on carbon emission, confirming H1. This finding demonstrates that energy sector companies in Indonesia that allocate a higher proportion of their total energy consumption to renewable sources achieve measurably lower carbon emission intensity. The magnitude of this coefficient reflects the substantial substitution effect of renewable energy relative to fossil fuel-based energy, which is particularly pronounced in the energy sector where production operations are inherently carbon-intensive. This result is theoretically grounded in stakeholder theory, which argues that firms adopting renewable energy actively fulfill the environmental expectations of a broad range of stakeholders, including regulators, communities, and institutional investors, thereby reducing their exposure to environmental liability (Freeman et al., 2020; Mahajan et al., 2023). Empirically, this finding corroborates consistent evidence across developing economies that renewable energy expansion significantly reduces CO<sub>2</sub> emissions (Akram et al., 2020; Edziah et al., 2022; Saidi & Omri, 2020), and is particularly consistent with Indonesian-specific evidence documenting the dynamic negative impact of renewable energy on CO<sub>2</sub> emissions and ecological footprint (Idroes et al., 2024). The result further aligns with broader cross-country studies confirming that renewable energy combined with green technology accelerates progress toward carbon neutrality targets in emerging economies (Behera et al., 2023; Justice et al., 2024). In the Indonesian context, where fossil fuels still dominate the energy mix and the government has committed to a Net Zero Emission target by 2060, this finding suggests that corporate-level renewable energy transitions contribute meaningfully to national decarbonization objectives, reinforcing the strategic alignment between corporate environmental action and national energy policy.

### ***The Effect of Carbon Emission on Firm Value (H2)***

Carbon emission exerts a significant negative effect on firm value, confirming H2. This result indicates that energy companies with higher carbon emission intensity are systematically valued lower by capital markets, reflecting investor recognition of the financial risks associated with high-carbon operations. From a signaling theory perspective, elevated carbon emission functions as a negative signal to capital markets, communicating heightened exposure to regulatory penalties, carbon pricing mechanisms, reputational damage, and transition risks associated with Indonesia's accelerating energy policy reform (Connelly et al., 2025; Friske et al., 2023). This finding is consistent

with multi-country evidence confirming the negative value relevance of greenhouse gas emissions across diverse institutional contexts (Benkraiem et al., 2022; Choi & Luo, 2021), and aligns with firm-level studies from Taiwan and Korea documenting that lower-emission firms command higher market valuations (Han et al., 2023; Lee & Cho, 2021). The result also corroborates carbon risk literature in corporate finance, which identifies carbon emission reduction as a key mechanism through which environmental strategies translate into financial performance improvements (Busch et al., 2022; Wang et al., 2022). Importantly, this finding challenges the notion that carbon emission has no financial consequence in emerging markets such as Indonesia, suggesting that Indonesian capital markets are increasingly integrating environmental risk into valuation frameworks — a development consistent with the growing adoption of ESG criteria among domestic and foreign institutional investors operating in the Indonesian energy sector.

### ***The Effect of Renewable Energy on Firm Value (H3)***

Renewable energy exerts a significant positive direct effect on firm value, confirming H3. This result indicates that renewable energy adoption enhances firm value among Indonesian energy companies independently of its carbon emission-reducing effect, suggesting that the market rewards renewable energy commitment as a strategic signal beyond its immediate environmental outcomes. Signaling theory provides a robust theoretical explanation for this finding: renewable energy adoption requires substantial capital commitment that opportunistic firms would find difficult to imitate, thereby serving as a credible signal of genuine long-term sustainability orientation that reduces perceived investment risk and attracts sustainability-oriented investors (Connelly et al., 2025; Friske et al., 2023). This finding is consistent with systematic review and empirical evidence from Indonesia confirming that renewable energy positively influences firm performance in the energy sector (Hutahayan et al., 2025; Sitompul et al., 2024), and is corroborated by comparable evidence from European non-financial companies where higher renewable energy usage is associated with superior financial performance (Issa & Hanaysha, 2023). At the policy level, this result supports the proposition that green energy transition strategies contribute to the sustainable development and enhanced financial standing of energy firms (Zhang & Kong, 2022). The strong magnitude of the coefficient ( $\beta = 5.738$ ) relative to other predictors further underscores that renewable energy is not merely an environmental compliance measure but a primary value driver for Indonesian energy companies in the current period of accelerating energy transition, consistent with the growing recognition of renewable energy as a core competitive advantage in capital-intensive industries.

### ***The Mediating Role of Carbon Emission (H4)***

The Sobel-Goodman test confirms a significant indirect effect of renewable energy on firm value through carbon emission (Sobel  $Z = 3.236$ ,  $p = 0.001$ ; indirect effect = 0.441), supporting H4. The coexistence of significant direct (H3) and indirect (H4) effects indicates partial mediation, suggesting that renewable energy enhances firm value through dual pathways: directly as a credible sustainability signal to capital markets, and indirectly by reducing carbon emission intensity, which in turn alleviates environmental risk perceptions and supports higher market valuation. This sequential mediation pathway is theoretically consistent with stakeholder theory, which posits that renewable energy adoption satisfies environmental stakeholder expectations by reducing carbon output, thereby strengthening firm legitimacy and reducing stakeholder-related risks that ultimately manifest in higher market valuations (Freeman et al., 2020; Mahajan et al., 2023). The finding advances the existing literature by providing formal empirical evidence of carbon emission as a transmission mechanism in the renewable energy–firm value relationship, extending prior work that has examined these relationships in isolation (Hutahayan et al., 2025; Sitompul et al., 2024) or without integrating the full causal chain (Benkraiem et al., 2022; Z.-Y. Sun et al., 2022). This result has important theoretical implications: it suggests that the financial benefits of renewable

energy adoption are not solely attributable to market signaling but are partly generated through the real environmental outcomes of emission reduction, which capital markets recognize and reward. This finding thus contributes to a more nuanced understanding of how corporate environmental strategies create financial value — not merely through perception management but through measurable environmental performance improvement.

#### ***The Moderating Role of Green Investment (H5)***

Green investment positively and significantly moderates the effect of renewable energy on firm value ( $\beta = 12.060$ ,  $p = 0.024$ ), confirming H5. This result indicates that the value-enhancing effect of renewable energy is amplified when companies simultaneously allocate greater environmental expenditure, such that firms combining high renewable energy adoption with substantial green investment achieve stronger market valuation outcomes than firms pursuing either strategy in isolation. Signaling theory offers a compelling explanation for this moderating effect: when green investment accompanies renewable energy adoption, the combined signal is stronger and more credible than either action alone, as the simultaneous commitment to clean energy use and environmental capital allocation reduces information asymmetry regarding a firm's genuine sustainability orientation and long-term strategic intent (Connelly et al., 2025; Friske et al., 2023). This finding is consistent with prior evidence that green investment enhances firm performance and value, particularly in capital-intensive industries where environmental expenditure signals operational efficiency and forward-looking risk management (Chen & Ma, 2021; Y. Sun & Yang, 2022; Tang, 2023), and corroborates Indonesian-specific evidence that green investment positively influences firm value (Putrika & Ardianto, 2025; Widarwati et al., 2024). The insignificance of the direct RE effect in Equation 3 ( $\beta = 1.391$ ,  $p = 0.422$ ) further suggests that the market's valuation of renewable energy is contingent on accompanying green investment — companies that adopt renewable energy without committing visible environmental capital expenditure may not fully capture the associated valuation premium. This finding carries important implications for greenwashing risk: firms that claim environmental commitment through renewable energy disclosure without substantive green investment allocation may be perceived by investors as lacking genuine sustainability commitment, thereby forfeiting the valuation benefits documented in this study (Uyar et al., 2020). Collectively, these results suggest that green investment and renewable energy function as complementary strategic assets in creating firm value, and that their combined deployment generates signaling synergies that exceed the sum of their individual effects in the Indonesian energy sector.

#### ***Robustness and Theoretical Contributions***

The robustness tests using PBV confirm that all five hypotheses remain supported under an alternative firm value proxy, strengthening the validity and generalizability of the main findings. The consistent direction and significance of key coefficients across both Tobin's Q and PBV specifications indicate that the documented relationships are not driven by the specific characteristics of any single market-based valuation measure. Theoretically, this study contributes to stakeholder theory by providing empirical evidence that the environmental responsiveness dimension of stakeholder management — specifically through renewable energy adoption — generates measurable financial value through both direct and indirect pathways. The study further advances signaling theory by demonstrating that green investment functions as a boundary condition that enhances the credibility and market impact of renewable energy signals, thereby enriching the theory's application in the environmental finance domain. The moderated mediation framework employed in this study offers a more integrative theoretical model of the renewable energy–firm value relationship than prior single-path studies, suggesting that future research should consider both the mediating mechanisms and boundary conditions through which environmental strategies translate into financial outcomes. In the Indonesian context, the findings

collectively imply that energy companies should treat renewable energy adoption and green investment not as separate sustainability initiatives but as complementary strategic commitments that, when deployed together, generate the strongest and most credible sustainability signals to capital markets in the context of Indonesia's accelerating energy transition agenda.

## CONCLUSION

This study examines the effect of renewable energy on firm value with carbon emission as a mediating variable and green investment as a moderating variable among 38 energy sector companies listed on the Indonesia Stock Exchange during the 2022–2024 period. The findings confirm all five proposed hypotheses: renewable energy negatively affects carbon emission, carbon emission negatively affects firm value, renewable energy positively affects firm value directly, carbon emission partially mediates the renewable energy–firm value relationship, and green investment positively moderates the effect of renewable energy on firm value. These findings are robust to alternative firm value measurement using PBV. For corporate managers, the results suggest that renewable energy adoption and green investment should be treated as complementary strategic commitments, as their combined deployment generates the strongest sustainability signals to capital markets and the highest firm valuation outcomes. For investors, carbon emission intensity is confirmed as a financially material indicator that should be incorporated into equity valuation and investment screening for Indonesian energy sector companies. For regulators and policymakers, the findings support the design of incentive structures that simultaneously encourage renewable energy adoption and environmental capital investment, while strengthening mandatory carbon disclosure requirements in Indonesia's energy sector. This study acknowledges several limitations, including potential selection bias toward more environmentally transparent firms, the restricted three-year study period, reliance on voluntary environmental expenditure disclosure, and the absence of endogeneity correction. Future research is encouraged to extend the sample across multiple sectors, adopt longer time horizons, explore alternative green investment proxies such as green bond issuance or PROPER environmental ratings, apply dynamic panel methods such as Arellano-Bond GMM to address endogeneity, and examine the conditioning role of corporate governance mechanisms such as institutional ownership and board environmental expertise in the renewable energy–firm value relationship.

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