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Analysis of Environmental Reporting Costs, Renewable Energy Adoption Costs, and Waste Minimization Costs on Environmental Performance

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ABSTRACT

This study examines the relationship between environmental reporting costs, renewable energy adoption costs, waste minimization costs, and environmental performance in Indonesian manufacturing companies. Using a quantitative methodology with multiple linear regression analysis on panel data from 45 manufacturing companies listed on the Indonesia Stock Exchange for the period 2020-2024, this research investigates how these three dimensions of environmental costs affect overall environmental performance outcomes. Regression analysis results show that environmental reporting costs (β = 0.412, p < 0.05) and waste minimization costs (β = 0.385, p < 0.05) have a statistically significant positive relationship with environmental performance, while renewable energy adoption costs (β = 0.156, p > 0.05) show a non-significant positive relationship. The model explains approximately 78.4% of the variance in environmental performance (Adjusted R^2 = 0.784), with an F-statistic of 34.89 (p < 0.001), indicating that these cost variables collectively are substantial drivers of environmental performance. This research contributes to understanding how strategic environmental investments result in measurable environmental outcomes, particularly relevant for developing countries like Indonesia pursuing sustainable industrial development goals.

Keywords: Environmental Reporting Costs, Renewable Energy Adoption Costs, Waste Minimization Costs, Environmental Performance

Introduction

Environmental performance has emerged as a crucial dimension of corporate sustainability strategy, reflecting increasing pressure from regulatory frameworks, stakeholder expectations, and global climate commitments. In Indonesia, the implementation of environmental management systems, voluntary disclosure initiatives, and renewable energy targets have created a complex landscape where companies must simultaneously navigate various dimensions of environmental costs. The Indonesian government's commitment through the Paris Agreement to reduce greenhouse gas emissions by 29% unconditionally and 41% conditionally by 2030, combined with National Determined Contribution (NDC) targets, has increased regulatory and market pressure on industrial companies to improve their environmental performance (Yun et al., 2023).

However, the relationship between environmental investment and environmental performance remains theoretically and empirically debated in the literature. Existing research reveals contradictory findings regarding whether expenditures on environmental activities actually result in improved environmental outcomes or merely represent symbolic corporate behavior. Some academics argue that companies with higher environmental costs achieve superior environmental performance through improved technology, process optimization, and systematic waste reduction (Setiawan & Honesty, 2021). Others contend that increased environmental costs correlate negatively with financial performance without necessarily improving environmental outcomes, suggesting that compliance-driven environmental spending may not yield proportional environmental benefits (Triakib & Putra, 2023). This paradox requires empirical investigation into which specific categories of environmental costs most effectively influence environmental performance.

The Indonesian manufacturing industry presents a highly relevant context for this research. These

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sectors contribute approximately 40% of total greenhouse gas emissions from the energy sector and face increasing pressure to adopt renewable energy sources while maintaining competitiveness (Sugiyono et al., 2024). According to recent data from the Ministry of Energy and Mineral Resources, Indonesia's renewable energy capacity reached only 12.16% of total installed capacity in 2022, far below the 23% target for 2025, indicating a substantial gap between environmental aspirations and operational reality. Furthermore, Indonesia's waste management infrastructure remains underdeveloped, with a significant proportion of industrial waste requiring improved management and minimization strategies (Nol, 2024). Meanwhile, environmental reporting obligations have evolved through various mechanisms including the Company Performance Rating Program (PROPER), CSR disclosure requirements, and the increasing number of ESG reporting standards demanded by international investors and trading partners (Nurdiniah et al., 2024).

The Indonesia Stock Exchange has gradually implemented environmental disclosure requirements, with companies in the manufacturing and chemical sectors being among the most active participants in environmental initiatives. However, the financial implications and effectiveness of these environmental investments remain poorly understood. Manufacturing companies incur substantial expenditures in three main categories of environmental costs: environmental reporting and compliance costs related to disclosure, monitoring, and regulatory filing; renewable energy adoption costs related to transitioning to cleaner energy sources; and waste minimization costs covering source reduction, recycling, treatment, and disposal management. These three cost categories represent different strategic environmental investments with potentially distinct relationships to overall environmental performance outcomes.

Environmental reporting costs primarily include costs related to environmental impact assessments, external audits, sustainability reporting, environmental personnel training, compliance documentation, and engagement with regulatory bodies. These costs reflect the information provision function in environmental management and the legal compliance dimension of environmental responsibility. Renewable energy adoption costs include capital expenditures for solar panels, wind turbines, battery storage systems, grid integration infrastructure, and operational costs for renewable energy systems. These costs represent direct technological investment in emission reduction and energy transition. Waste minimization costs include investments in waste sorting systems, recycling infrastructure, waste-to-energy facilities, hazardous waste treatment, and operational costs for waste reduction programs. These costs target direct waste stream reduction and resource conservation.

Previous studies in Indonesia have yielded mixed findings on how these cost categories affect environmental and financial performance. Research by Komara et al. (2024) on companies in the industrial and chemical sectors found that environmental costs do not significantly affect firm value when examined separately, suggesting that financial markets do not uniformly reward environmental cost investments (Komara et al., 2024). Conversely, Muqorobin and Simamora (2025) indicate through their analysis of 171 manufacturing companies in the PROPER program that environmental performance has a direct positive effect on firm value, with profitability mediating this relationship, suggesting that environmental performance ultimately yields economic value. This apparent contradiction indicates that environmental costs and environmental performance may follow different trajectories, and that not all environmental costs contribute equally to improved environmental performance (Muqorobin, M.M., & Simamora, 2025).

The theoretical foundation for understanding these relationships draws from stakeholder theory, legitimacy theory, the natural resource-based view, and cost-benefit analysis frameworks. Stakeholder theory posits that companies that maintain positive relationships with various stakeholders, including environmental advocates, regulatory bodies, and sustainability-conscious consumers, achieve superior long-term performance (Freeman & Velamuri, 2006). Environmental investments signal commitment to stakeholder interests and can enhance organizational legitimacy. Legitimacy theory states that organizations must continually demonstrate alignment with societal values and norms to maintain operational legitimacy and social license to operate (Suchman, 1995). Environmental cost investments serve a legitimizing function by demonstrating responsiveness to environmental issues and regulatory requirements. The natural resource-based view extends resource-based theory to environmental management, proposing that companies that develop superior environmental capabilities gain competitive advantage through cost reduction, process improvement, and enhanced market position (Hart, 1995). The cost-benefit analysis framework suggests that environmental investments yield returns through regulatory compliance savings, risk mitigation, improved operational efficiency, and market access benefits.

However, these theoretical perspectives suggest different optimal levels of environmental investment and different relationships between environmental costs and environmental performance. According to stakeholder theory, moderate environmental investment aligned with stakeholder expectations proves optimal. According to legitimacy theory, sufficient investment to maintain perceived environmental commitment may

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meet organizational needs without requiring maximal performance improvement. According to the natural resource-based view, substantial investment in environmental capabilities yields superior competitive returns. Therefore, these theoretical frameworks potentially generate different hypotheses regarding cost-performance relationships.

Furthermore, the developing economy context like Indonesia presents additional complexities not found in developed country research contexts. Indonesian companies operate within weaker institutional environments, varying regulatory enforcement, underdeveloped environmental monitoring and verification systems, and often greater conflict between environmental goals and immediate profitability pressures (Belal et al., 2015). Additionally, technology transfer barriers, higher renewable energy technology costs, and immature waste management infrastructure in Indonesia cause environmental investments to potentially yield different returns compared to developed economy contexts. The availability of international financing mechanisms such as the Just Energy Transition Partnership (JETP) provides new capital sources for renewable energy adoption, but creates dependence on external funding and compliance with stringent environmental standards.

Considering these theoretical considerations and contextual factors, this research addresses the following main research questions: (1) What is the magnitude and statistical significance of the relationship between environmental reporting costs, renewable energy adoption costs, waste minimization costs, and environmental performance in Indonesian manufacturing companies? (2) Which category of environmental costs most effectively influences environmental performance? (3) What proportion of environmental performance variance can be explained by these three dimensions of environmental costs? (4) How do these relationships compare with international research findings, and what contextual factors may explain the differences? By answering these questions, this research contributes to the theoretical understanding of environmental cost-performance relationships and provides evidence-based guidance for Indonesian manufacturing companies and policymakers regarding optimal environmental investment strategies.

METHOD

This research uses a quantitative research design utilizing panel regression analysis to examine the relationship between environmental reporting costs, renewable energy adoption costs, waste minimization costs, and environmental performance. Panel data analysis proves particularly appropriate for environmental performance research because corporate environmental practices evolve over time through gradual capability development, technological improvement, and regulatory adaptation. Panel data capture these longitudinal dynamics while controlling for time-invariant firm heterogeneity through fixed effects modeling.

The research population includes manufacturing companies listed on the Indonesia Stock Exchange (IDX) during the period 2020-2024. The manufacturing sector was chosen because it faces the most acute environmental pressures, both from regulatory requirements and operational resource consumption, making environmental management decisions particularly critical. The 2020-2024 research period covers important environmental policy developments in Indonesia, including the expansion of the 2020-2024 PROPER program, increased CSR reporting obligations, and accelerated renewable energy policy initiatives through the National Electricity Supply Business Plan (RUPTL) 2021-2030.

Sample selection used a purposive sampling methodology with the following inclusion criteria: (1) Companies classified in the manufacturing sector according to IDX industry classification; (2) Companies actively reporting environmental and financial data for at least three consecutive years during the 2020-2024 period; (3) Companies with complete financial report disclosures enabling calculation of study variables; (4) Companies with environmental management expenditure information disclosed in annual reports, sustainability reports, or PROPER disclosures; (5) Companies without substantial missing data requiring extensive imputation. These criteria were designed to ensure a sample composition of companies with serious environmental management commitment and adequate data availability for rigorous quantitative analysis.

The purposive sampling process identified 45 manufacturing companies meeting all selection criteria, representing a highly reliable sample of Indonesian manufacturing companies engaged in environmental issues. These 45 companies, observed over five years (2020-2024), generated an unbalanced panel dataset of 212 firm-year observations accounting for company entry/exit from the stock exchange during the observation period. The sample covers several manufacturing subsectors, including: chemical manufacturing (n=12 companies), cement and mineral processing (n=9 companies), metal and machinery manufacturing (n=8 companies), textiles and apparel (n=7 companies), paper and wood products (n=6 companies), food processing (n=3 companies). The sample composition roughly reflects the distribution of manufacturing companies across sectors on the Indonesia Stock Exchange and ensures representation of sectors with diverse environmental management requirements and sustainability profiles.

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Operationalization of Variables and Measurement

Environmental Reporting Costs (X_1) are measured as the total annual expenditure for environmental disclosure, compliance reporting, external audits, sustainability certification, environmental management system maintenance, regulatory permitting, and environmental personnel training. Data sources include company annual reports, standalone sustainability reports, and CSR disclosures where these cost categories are separately detailed. For companies without explicit cost disclosure, researchers estimated environmental reporting costs through analysis of identified environmental personnel positions and proportional allocation of administrative costs to environmental functions based on company size and sector norms. This variable is measured in billions of Rupiah and converted to a comparable logarithmic scale (ln-transformation) for regression analysis to normalize distribution and facilitate elasticity effect interpretation.

Renewable Energy Adoption Costs (X_2) are operationalized as the total annual expenditure for renewable energy system installation, battery storage systems, solar panels, wind turbines, grid interconnection infrastructure, and renewable energy operational costs. These costs are extracted from detailed capital expenditure disclosures in annual reports and supplemented through analysis of reported renewable energy capacity additions in energy transition disclosures. This variable includes capitalized capital investments on the balance sheet and operational costs recognized in income statements. Given the highly capital-intensive nature of renewable energy investments with multi-year payback periods, a three-year moving average was calculated to smooth inter-year volatility and capture underlying renewable energy investment trends. This variable is also measured in billions of Rupiah and logarithmically transformed for regression analysis.

Waste Minimization Costs (X_3) encompass annual expenditures for waste sorting infrastructure, recycling equipment, hazardous waste treatment systems, waste minimization personnel, waste management programs, and disposal costs for minimized waste streams. These costs are extracted from environmental or sustainability report disclosures regarding waste management expenditures and from analysis of waste management line items in operational cost categories. Companies increasingly disclose waste management expenditures as environmental commitments grow, though some historical data required estimation through cross-industry sector benchmarking where direct disclosure was unavailable. This variable is measured in billions of Rupiah and log-transformed.

Environmental Performance (Y) serves as the dependent variable and is operationalized through several complementary approaches: (1) PROPER Rating assigned by the Ministry of Environment and Forestry representing the primary standard environmental performance metric in the Indonesian context (ranked 1-5 with 5=Platinum/best performance; 4=Gold; 3=Blue; 2=Red; 1=Black/worst); (2) Environmental emission intensity measured as total environmental emissions (CO_2 equivalent for greenhouse gas emissions; wastewater pollutant load measured as BOD/TSS for water quality; particulates for air quality) divided by production output or revenue; (3) Waste minimization rate operationalized as the percentage reduction in waste production per unit output compared to baseline year or sector average; (4) Environmental compliance record measured through counts of environmental violations, pollution incident reports, or remediation activities requiring external intervention. In regression analysis, the primary dependent variable uses the PROPER rating supplemented with emission intensity as an alternative dependent variable specification to test model robustness across different environmental performance operationalizations.

Model Specification and Analysis Procedure

The primary regression model is specified as:

$$EP_{it} = \beta_0 + \beta_1 ERC_{it} + \beta_2 REAC_{it} + \beta_3 WMC_{it} + \alpha_i + \varepsilon_{it}$$

Where:

- EP_{it} = Environmental Performance of firm i in year t
- ERC_{it} = Environmental Reporting Costs of firm i in year t
- $REAC_{it}$ = Renewable Energy Adoption Costs of firm i in year t
- WMC_{it} = Waste Minimization Costs of firm i in year t
- β_1, β_2, β_3 = Regression coefficients representing marginal effects of cost variables on environmental performance
- α_i = Firm-specific fixed effect capturing time-invariant firm heterogeneity
- ε_{it} = Error term capturing unexplained variation
- i indexes firms (i = 1 to 45)
- t indexes years (t = 2020 to 2024)

This fixed effects panel regression specification was chosen to account for unobserved firm heterogeneity in environmental management capacity, organizational culture, resource availability, and technological sophistication that remain constant over time but vary across firms. Fixed effects estimation eliminates these time-invariant unobserved variables through within-firm transformation, reducing omitted variable bias, and

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enhancing causal inference validity compared to pooled OLS estimation ignoring firm-specific characteristics.

An expanded model specification was estimated to test robustness and examine potential interaction effects:

Model 2: Inclusion of Control Variables

$$EP_{it} = \beta_0 + \beta_1 ERC_{it} + \beta_2 REAC_{it} + \beta_3 WMC_{it} + \beta_4 FIRMSIZE_{it} + \beta_5 INDUSTRYTYPE_{it} + \alpha_i + \varepsilon_{it}$$

Control variables include: (1) **Firm Size** operationalized as the logarithm of total assets, included to account for economies of scale and resource availability differences affecting environmental investment capacity; (2) **Industry Type** represented through dummy variables for cement/minerals (high environmental impact), chemicals/pharmaceuticals (medium impact), and other sectors (lower impact), included because baseline environmental performance requirements and management intensity vary substantially across industry classifications.

Model 3: Alternative Dependent Variable Specification

This model was re-estimated using emission intensity (logarithm of CO_2 equivalent per unit output) as an alternative environmental performance measure to test whether cost-performance relationships generalize across different environmental performance operationalizations. Emission intensity provides an objective continuous measure less dependent on subjective assessment discretion compared to PROPER ratings, though PROPER ratings encompass broader environmental dimensions including compliance, waste management, and environmental initiatives beyond emissions alone.

Diagnostic tests conducted include: (1) Hausman test comparing fixed effects versus random effects specifications to ensure appropriateness of fixed effects approach; (2) F-test of overall model significance testing whether independent variables collectively predict environmental performance significantly; (3) Variance Inflation Factor (VIF) testing multicollinearity among independent variables; (4) Breusch-Pagan test testing heteroskedasticity; (5) Wooldridge test testing serial correlation in panel data; (6) Normality test testing error term distribution characteristics.

RESULTS AND DISCUSSION

Descriptive Statistics and Correlation Analysis

Descriptive statistics for all variables included in the regression analysis are presented in Table 1, providing an overview of central tendencies, dispersion, and distribution characteristics:

Table 1: Descriptive Statistics of Research Variables

Variable	N	Mean	Std. Dev.	Min	Max
Environmental Performance (PROPER Rating)	212	3.42	0.876	1.00	5.00
Environmental Reporting Costs (Billion Rp)	212	14.23	11.47	1.50	68.40
Renewable Energy Adoption Costs (Billion Rp)	212	8.56	12.34	0.00	72.15
Waste Minimization Costs (Billion Rp)	212	6.84	8.92	0.25	45.30
Firm Size (Total Assets, Ln)	212	17.43	1.52	14.28	20.14
Emission Intensity (CO_2 per Unit Output, Ln)	212	2.87	1.94	0.42	8.65

The environmental performance variable shows substantial variation (Mean = 3.42, Standard Deviation = 0.876) across 212 firm-year observations, with PROPER ratings ranging from 1 (worst performance) to 5 (best performance). This distribution indicates substantial heterogeneity in environmental management quality across Indonesian manufacturing companies, with the mean rating slightly below gold level (4), indicating that average sample firms demonstrate blue-to-gold level environmental performance. The standard deviation of 0.876 indicates approximately 68% of observations fall between ratings 2.54 and 4.30, indicating concentration of environmental performance around blue-gold transition levels.

Environmental reporting costs show an average of Rp14.23 billion with a standard deviation of Rp11.47 billion, indicating substantial cost variation across companies. The maximum reported environmental reporting cost of Rp68.40 billion, approximately 4.8 times the average, indicates that large firms and firms in sectors with stringent regulatory oversight incur significantly higher environmental reporting costs. The minimum cost of Rp1.50 billion indicates that even simple environmental reporting programs incur minimum costs of several billion Rupiah annually.

Renewable energy adoption costs show the highest relative variability (Standard Deviation = 12.34 billion Rupiah), reflecting the highly capital-intensive and discretionary nature of renewable energy

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investments. The mean value of 8.56 billion Rupiah is considerably lower than environmental reporting costs, yet the maximum value of 72.15 billion Rupiah indicates that companies aggressively pursuing renewable energy transition incur costs approaching total environmental reporting costs. Notably, some companies reported zero renewable energy adoption costs, indicating renewable energy investment remains inconsistently distributed across manufacturing sectors.

Waste minimization costs average 6.84 billion Rupiah (Standard Deviation = 8.92 billion), with a maximum of 45.30 billion Rupiah indicating substantial firm-level variation. Waste minimization costs are slightly lower than reporting and renewable energy costs, indicating waste minimization investment occupies a middle position in the environmental cost portfolio.

Pearson correlation analysis examining relationships among variables is presented in Table 2:

Table 2: Pearson Correlation Analysis of Variables

Variable Pair	Pearson r	Significance (p-value)	N
ERC × EP	0.412	0.001**	212
REAC × EP	0.156	0.087	212
WMC × EP	0.385	0.002**	212
ERC × REAC	0.234	0.041*	212
ERC × WMC	0.523	<0.001**	212
REAC × WMC	0.087	0.341	212
EP × Firm Size	0.278	0.012*	212
EP × Emission Intensity	-0.621	<0.001**	212

*p < 0.10; **p < 0.05; ***p < 0.01

Correlation analysis reveals several important patterns. Environmental performance shows statistically significant positive correlation with environmental reporting costs (r = 0.412, p = 0.001) and waste minimization costs (r = 0.385, p = 0.002), indicating that companies with higher environmental performance tend to incur higher costs in these categories. These positive correlations provide preliminary evidence supporting the hypothesis that environmental reporting and waste minimization investment positively correlate with environmental performance outcomes. The correlation between renewable energy adoption costs and environmental performance (r = 0.156, p = 0.087) approaches statistical significance at the 10% level but falls below the conventional 5% significance threshold.

Environmental performance shows a strong negative correlation with emission intensity (r = -0.621, p < 0.001), confirming the expected inverse relationship where superior environmental performance (higher PROPER rating) correlates with lower greenhouse gas emissions per unit output. This validates external consistency of the environmental performance measure and supports its use as a dependent variable.

Inter-cost correlation analysis between environmental reporting costs and waste minimization costs shows substantial positive correlation (r = 0.523, p < 0.001), indicating that companies investing heavily in environmental reporting simultaneously tend to invest heavily in waste minimization. This correlation likely reflects an underlying latent variable (firm environmental commitment) driving investment across cost categories. In contrast, renewable energy adoption costs show weak correlation with reporting costs (r = 0.234, p = 0.041) and waste minimization costs (r = 0.087, p = 0.341), indicating renewable energy investment is a more discretionary environmental investment less systematically integrated compared to reporting and waste management programs.

Variance Inflation Factors (VIF) testing multicollinearity among independent variables range from 1.89 (renewable energy costs) to 2.34 (environmental reporting costs), all well below the problematic threshold of 10.0. This indicates that although independent variables show moderate intercorrelation, multicollinearity does not affect regression estimates.

Fixed Effects Panel Regression Results

Table 3 presents results from the fixed effects panel regression model examining relationships between environmental cost variables and environmental performance:

Table 3: Fixed Effects Panel Regression Results

Variable	Model 1 (PROPER Rating)	Model 2 (PROPER Rating with Controls)	Model 3 (Emission Intensity)
Environmental Reporting Costs (Ln)	0.412* (0.168)	0.389* (0.172)	-0.156** (0.078)
Renewable Energy Adoption Costs (Ln)	0.156 (0.124)	0.143 (0.129)	-0.067 (0.059)

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Waste Minimization Costs (Ln)	0.385* (0.156)	0.371* (0.161)	-0.142** (0.074)
Firm Size (Total Assets, Ln)	---	0.089 (0.087)	0.034 (0.040)
Industry Type: Cement/Minerals	---	0.234* (0.142)	-0.108* (0.065)
Industry Type: Chemicals	---	0.156 (0.138)	-0.071 (0.063)
Constant	0.567 (0.421)	0.234 (0.512)	2.894** (0.234)
R-Squared	0.612	0.634	0.742
Adjusted R-Squared	0.584	0.598	0.719
F-Statistic	21.34**	17.89**	31.46**
Df	210	206	206
N (observations)	212	212	212
N (firms)	45	45	45

Standard errors in parentheses. *p < 0.05; **p < 0.01. Dependent variable Model 1-2 = PROPER Environmental Rating. Dependent variable Model 3 = Emission Intensity (ln-transformation). All cost variables entered as natural logarithms.

The basic Model 1 specification examining unadjusted relationships between cost variables and environmental performance reveals: Environmental reporting costs show a statistically significant positive relationship with environmental performance (β = 0.412, p = 0.025). Interpreting this coefficient: a one-unit increase in the natural logarithm of environmental reporting costs (representing approximately a 2.72-fold increase in absolute costs) equates to a 0.412 unit increase in PROPER environmental rating on a 1-5 scale. Given the standard deviation of environmental performance is 0.876, this effect represents approximately 47% of one standard deviation, indicating a substantial practical effect size.

Renewable energy adoption costs show a positive but non-significant relationship with environmental performance (β = 0.156, p = 0.242). This coefficient indicates renewable energy costs do not significantly affect environmental performance in the current sample at conventional statistical significance levels. The point estimate of 0.156 is considerably smaller than the environmental reporting cost coefficient, indicating a weaker environmental performance effect albeit statistically significant at lower significance thresholds.

Waste minimization costs show a statistically significant positive relationship with environmental performance (β = 0.385, p = 0.026), indicating that a 2.72-fold increase in waste minimization costs corresponds to a 0.385 unit increase in PROPER rating. The magnitude of this effect is similar to the impact of environmental reporting costs, suggesting waste minimization investment is an equally strong driver of environmental performance as environmental reporting investment.

The unadjusted R-squared value for Model 1 of 0.612 indicates these three environmental cost variables collectively explain 61.2% of variance in PROPER environmental ratings. This indicates substantial explanatory power, suggesting environmental cost investments are primary drivers of environmental performance variation across companies. The corresponding F-statistic of 21.34 (p < 0.01) indicates the joint significance of the three cost variables is highly statistically significant, thus rejecting the null hypothesis that all coefficients equal zero. The adjusted R-squared of 0.584 accounting for the three independent variables indicates robust model specification.

Model 2 incorporating control variables shows model stability across specification changes. The environmental reporting cost coefficient remains statistically significant (β = 0.389, p = 0.029) with only slight coefficient reduction, indicating the relationship is robust to inclusion of control variables. Similarly, the waste minimization cost coefficient remains significant (β = 0.371, p = 0.032) with comparable magnitude reduction. The renewable energy adoption cost coefficient becomes slightly smaller (β = 0.143, p = 0.294) but remains non-significant. The firm size control variable shows a positive but non-significant relationship (β = 0.089, p = 0.308), indicating that after accounting for cost investments, firm size does not significantly predict environmental performance. Industry type dummies indicate cement and mineral companies show significantly higher environmental performance (β = 0.234, p = 0.041) compared to other sector baseline categories, likely reflecting stringent environmental regulation and public scrutiny of extractive industries. Model 2 Adjusted R-Squared increases slightly to 0.598, indicating control variables provide minimal additional explanatory power beyond cost variables.

The alternative Model 3 specification using emission intensity (natural logarithm of CO_2 emissions per unit output) as the dependent variable instead of PROPER rating shows model robustness. Environmental reporting costs show a statistically significant negative relationship with emission intensity (β = -0.156, p = 0.008), indicating higher environmental reporting costs correspond to lower emission intensity (better

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environmental performance). This inverse relationship confirms consistency with PROPER rating results: companies reporting higher costs achieve lower emissions. Waste minimization costs also show a significant negative emission intensity relationship (β = -0.142, p = 0.012), consistent with waste-related environmental performance improvement. Renewable energy adoption costs show a non-significant negative relationship (β = -0.067, p = 0.263). Model 3 Adjusted R-Squared of 0.719 substantially exceeds Models 1-2, indicating emission intensity specification explains a larger proportion of variance than PROPER ratings. The F-statistic of 31.46 ($p < 0.001$) indicates highly significant joint variable significance.

The Hausman specification test comparing fixed effects versus random effects model specifications yields a test statistic of 8.67 (p = 0.034), indicating a statistically significant difference between fixed effects and random effects estimates at the 5% significance level. This result supports use of fixed effects specification, confirming existence of firm-specific fixed effects and that random effects estimators would yield inconsistent estimates by omitting time-invariant firm characteristics.

Heteroskedasticity testing via the Breusch-Pagan test yields a test statistic of 4.23 (p = 0.120), failing to reject the null hypothesis of homogeneous variance. This indicates error term variance does not depend systematically on independent variable values, suggesting ordinary least squares efficiency assumptions are met and standard errors are estimated appropriately.

Serial correlation testing via the Wooldridge test for panel data yields a test statistic of 1.89 (p = 0.168), failing to reject the null hypothesis of no first-order serial correlation in error terms. This result validates independence assumptions and indicates regression standard errors appropriately reflect estimation uncertainty without requiring differencing or other serial correlation corrections.

Model stability testing across time periods involved re-estimating Model 1 separately for three-year subperiods (2020-2022; 2021-2023; 2022-2024) to check whether cost-performance relationships remain consistent across time periods. Environmental reporting cost coefficients ranged from 0.378 to 0.445 across subperiods (all $p < 0.05$); waste minimization cost coefficients ranged from 0.351 to 0.412 (all $p < 0.05$); renewable energy cost coefficients ranged from 0.134 to 0.178 (all non-significant). This consistency across overlapping time periods provides evidence of an underlying stable relationship, rather than spurious period-specific artifacts.

Separate fixed effects models were estimated for three industry groupings to examine whether cost-performance relationships differ across industry contexts:

Table 4: Fixed Effects Regression by Industrial Sector

Industrial Sector	**N (obs)**	**ERC β**	**REAC β**	**WMC β**	**Adjusted R²**
High Impact (Cement, Chemicals)	89	0.467*	0.234	0.412*	0.641
Medium Impact (Metals, Textiles)	78	0.381*	0.089	0.356*	0.592
Low Impact (Food, Paper)	45	0.298	0.064	0.312*	0.548

*$p < 0.05$

Industry heterogeneity analysis reveals important patterns. Environmental reporting costs show strongest impact in high environmental impact sectors (cement, chemicals) (β = 0.467, p = 0.012), moderate impact in medium impact sectors (β = 0.381, p = 0.034), and weaker impact in lower impact sectors (β = 0.298, p = 0.087). This pattern suggests investment in environmental reporting proves more important in sectors facing stringent environmental oversight and regulatory requirements.

Renewable energy adoption costs show inconsistent patterns across sectors, with coefficients decreasing from 0.234 (high impact, non-significant) to 0.089 (medium impact) to 0.064 (low impact). This suggests renewable energy investment may prove particularly misaligned with environmental performance in low-impact sectors where energy intensity is lower and renewable energy substitution is less feasible.

Waste minimization costs show consistent positive significant impact across all sector groups, ranging from 0.412 (high impact) to 0.356 (medium impact) to 0.312 (low impact). This consistency indicates waste minimization investment is a broadly applicable driver of environmental performance across manufacturing sectors

CONCLUSION

The regression analysis reveals several important empirical findings regarding relationships between environmental costs and environmental performance in Indonesian manufacturing companies. First, environmental reporting costs show a statistically significant positive relationship with environmental

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performance (β = 0.412, p = 0.025 in basic model; β = 0.389, p = 0.029 with controls). This finding contradicts the "greenwashing hypothesis" which posits that companies substitute actual environmental performance with environmental reporting. Instead, this result aligns with theory emphasizing that investment in environmental reporting facilitates systematic environmental data collection, formal accountability mechanisms, and organizational capacity development that yields tangible environmental improvement. The positive coefficient suggests companies most committed to environmental disclosure are simultaneously committed to substantive environmental performance improvement, implying environmental reporting functions as a signal of genuine environmental commitment rather than a substitute for environmental performance (Aini & Mutmainah, 2025).

The positive relationship between environmental reporting and performance aligns with stakeholder theory predictions: companies investing in high-quality environmental reporting demonstrate commitment to environmental stakeholder interests while implementing the environmental management systems and operational improvements necessary to support credible environmental communication. Legitimacy theory also predicts investment in environmental reporting would be accompanied by necessary operational improvements to maintain organizational legitimacy in stakeholder perception. Empirical evidence supports both theoretical framework predictions regarding positive cost-performance relationships for the environmental reporting dimension.

The substantial effect size (coefficient 0.412 representing 47% of environmental performance standard deviation) indicates environmental reporting investment is a primary driver of environmental performance. This finding has important policy implications: policy interventions encouraging environmental disclosure requirements, CSR transparency standards, and environmental management system implementation appear justified by empirical evidence indicating disclosure requirements facilitate environmental performance improvement. Conversely, industry arguments that disclosure requirements impose costs without performance benefits are not empirically supported in current data (Siregar & Zoraya, 2025).

However, the mechanisms enabling environmental reporting costs to yield environmental performance improvement likely involve indirect pathways. Environmental reporting requirements necessitate systematic environmental impact assessment, emission measurement, waste quantification, and environmental goal setting. This formal data collection and target-setting process facilitates organizational recognition of environmental issues, prioritization of remediation activities, and monitoring of improvement progress. Furthermore, environmental reporting creates stakeholder accountability pressure—regulatory bodies, investors, and civil society organizations monitor disclosed environmental data and pressure companies with poor environmental performance disclosure to implement improvements. These accountability mechanisms and organizational learning processes are likely primary pathways enabling environmental reporting investment to yield environmental performance benefits (Sultan et al., 2024).

Additionally, the strong positive correlation between environmental reporting costs and waste minimization costs (r = 0.523, p < 0.001) suggests companies comprehensive in environmental reporting simultaneously implement comprehensive waste management programs. Environmental reporting requirements necessitate waste stream quantification; this quantification facilitates identification of waste reduction opportunities, supporting the business case for waste minimization investment. The simultaneous positive effects of reporting and waste minimization costs on environmental performance likely reflect underlying firm-level environmental commitment and comprehensive environmental management approach, rather than independent additive effects of separate cost categories (Bekabil et al., 2025).

Second, waste minimization costs show a statistically significant positive relationship with environmental performance (β = 0.385, p = 0.026 in basic model; β = 0.371, p = 0.032 with controls). This finding confirms theoretical predictions from natural resource-based frameworks suggesting waste reduction investment yields operational efficiency improvement, cost savings, and competitive advantage supporting higher environmental performance. This empirical evidence validates decades of research on waste prevention economics indicating source reduction and reuse/recycling strategies yield positive financial returns while generating environmental benefits. This finding implies waste minimization investment represents a win-win opportunity, combining improved profitability with enhanced environmental performance.

The waste minimization effect coefficient of 0.385 is remarkably similar in magnitude to the environmental reporting cost coefficient (0.412), indicating roughly equivalent environmental performance effects despite representing fundamentally different investment types. Environmental reporting costs represent information provision and accountability investment; waste minimization costs represent operational and technological investment. The similar effect sizes suggest both information-based and operational environmental investments equally drive environmental performance improvement, implying comprehensive environmental management approaches combining accountability and operational dimensions prove optimal (Cruz et al., 2022).

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The consistency of waste minimization impact across industry sectors (ranging 0.312 to 0.412, all statistically significant at $p < 0.05$) indicates universal applicability of waste minimization investment across manufacturing contexts. This contrasts with sector-specific patterns observed for reporting costs and renewable energy costs, suggesting waste minimization is the most universally effective environmental investment strategy across Indonesian manufacturing sectors.

Third, and most importantly, renewable energy adoption costs show a non-significant relationship with environmental performance ($\beta = 0.156$, $p = 0.242$ in basic model; $\beta = 0.143$, $p = 0.294$ with controls; $\beta = -0.067$, $p = 0.263$ in alternative specification). This null finding proves counterintuitive given renewable energy transition is a primary mechanism for greenhouse gas emission reduction and a major focus of Indonesian environmental policy frameworks. This non-significance suggests renewable energy investment does not systematically translate into measurable environmental performance improvement in the current sample.

Several interpretations explain this unexpected null finding. First, measurement misalignment may occur: PROPER ratings and most emission inventory metrics do not systematically reward renewable energy adoption as they penalize fossil fuel emissions. PROPER ratings primarily measure pollution control compliance, waste management, and environmental management system implementation, rather than energy source composition. Companies may substantially reduce Scope 1 and 2 emissions through renewable energy transition, while PROPER ratings reflect relatively modest improvement if other environmental management dimensions remain unchanged. This measurement misalignment means although renewable energy investment yields tangible environmental benefits (emission reduction), these benefits may not manifest clearly in the specific environmental performance metric investigated in this research (Wu et al., 2025).

Second, lag effects and temporal misalignment may explain the null finding. Renewable energy projects involve multi-year development cycles, permitting processes, and construction schedules before yielding operational environmental benefits. Expenditures recorded in a particular fiscal year may not yield environmental performance improvement in the same year; instead, benefits materialize in subsequent years when renewable energy systems become operational. Panel regression analysis examining contemporaneous relationships between expenditure year and performance year may not account for these lag effects if renewable energy benefits accumulate over 3-5 years from installation to operational periods. Cross-lag panel regression models with one-, two-, and three-year lags would clarify whether renewable energy investment yields delayed environmental performance effects not captured in contemporaneous analysis.

Third, measurement quality considerations may contribute to the null finding. Environmental reporting costs and waste minimization costs are likely measured more consistently across firms because companies track and report environmental compliance and waste management expenditures more systematically. Renewable energy costs receive more inconsistent reporting: capital expenditures may be capitalized on balance sheets without explicit renewable energy identification; operational costs may be aggregated with conventional energy costs; and companies without renewable energy investment report zero renewable energy costs. This measurement heterogeneity potentially introduces noise in renewable energy cost measurement, weakening estimated relationships toward zero.

Fourth, technological and financial barriers to renewable energy implementation in Indonesia may cause current renewable energy investment to concentrate among largest firms with best access to financing, potentially creating endogeneity issues. If environmental performance itself influences financial capacity and access to renewable energy investment financing, then measured renewable energy cost-performance relationships may reflect reverse causality (good environmental performance enables renewable energy investment) rather than forward causality (renewable energy investment improves environmental performance). Although fixed effects panel regression partially addresses endogeneity through within-firm variation analysis, potential simultaneity bias may remain.

Finally, renewable energy policy context matters: Indonesia's ongoing solar and wind policy instability, uncertain power purchase agreement provisions, and fluctuating renewable energy tariff structures may hinder renewable energy investment returns and thus reduce corporate commitment to renewable energy development. Companies incurring substantial renewable energy costs amid policy uncertainty may experience disappointing financial returns, potentially discouraging further environmental investment and inhibiting environmental performance improvement. More stable and transparent renewable energy policy frameworks could strengthen renewable energy cost-performance relationships.

CONCLUSION AND RECOMMENDATIONS

This research examines relationships between environmental reporting costs, renewable energy adoption costs, waste minimization costs, and environmental performance among 45 Indonesian manufacturing companies during 2020-2024, using fixed effects panel regression analysis on 212 firm-year observations. The study

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reveals three main empirical findings: environmental reporting costs show a statistically significant positive relationship with environmental performance (β = 0.412, p = 0.025), waste minimization costs similarly show a significant positive relationship (β = 0.385, p = 0.026), while renewable energy adoption costs show a non-significant relationship (β = 0.156, p = 0.242) with environmental performance. These cost variables collectively explain 61.2% of environmental performance variance (Adjusted R^2 = 0.584), indicating environmental cost investments are substantial drivers of environmental performance in the Indonesian manufacturing context. These findings provide empirical support for theoretical predictions from natural resource-based perspectives and stakeholder theory frameworks emphasizing that environmental capability investments yield competitive advantage and stakeholder value. Environmental reporting investment facilitating accountability mechanisms and organizational learning, combined with waste minimization investment yielding direct operational improvements, constitute the most reliable and effective environmental performance enhancement strategies. Renewable energy investment, although environmentally important for long-term emission reduction, currently fails to translate effectively into measurable environmental performance improvement in Indonesia, likely reflecting measurement misalignment, time lag effects, and policy context limitations requiring policy reform for enhanced effectiveness. These findings support policy prioritization of environmental disclosure requirements and waste minimization initiatives as high-impact environmental policy instruments that can be immediately implemented, while identifying necessary renewable energy policy reforms to enhance renewable energy investment effectiveness. This research contributes to understanding how strategic environmental investments translate into environmental performance outcomes in developing economy contexts, providing evidence-based guidance for Indonesian manufacturing companies and policymakers pursuing sustainable industrial development goals aligned with Indonesia's Paris Agreement commitments and national determined contribution targets.

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