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The Effect of Investment in Green Technology and Renewable Technology Adoption on Energy Efficiency and Carbon Emissions Reduction in Indonesian Manufacturing Companies

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ABSTRACT

This research explores the interactions between green technology investment, renewable technology adoption, and their effects on carbon emission reduction, energy efficiency, and job satisfaction in manufacturing firms. Using a diverse sample of manufacturing firms, this study employs Structural Equation Modeling - Partial Least Squares (SEM-PLS) to analyze the relationships among these key variables. The findings suggest a strong positive impact of green technology investment and renewable technology adoption on carbon emission reduction. In addition, green technology investment emerged as a significant driver of energy efficiency. The study also highlights the challenges in fully optimizing energy efficiency and reveals the positive impact of renewable technology adoption on job satisfaction. These insights have far-reaching implications for policymakers and industry leaders looking to drive sustainable practices in the manufacturing sector.

Keywords: *Investment, Green Technology, Renewable Technology Adoption, Energy Efficiency, Carbon Emissions Reduction, Manufacturing Companies, SEM PLS, Indonesia*

1. INTRODUCTION

The manufacturing sector plays a crucial role in addressing environmental challenges and achieving sustainable development in the face of global climate change. It has the potential to reduce its environmental impact through green manufacturing practices, such as designing products that consume fewer materials and energy, incorporating more efficient manufacturing processes, and circularizing products [1]. The adoption of smart and sustainable manufacturing systems, driven by Industry 4.0 technologies, can further enhance the sector's sustainability by optimizing production processes and resource utilization [2]. The application of Industry 4.0 technologies, such as cloud computing and big data analytics, can facilitate data-driven decision-making and improve manufacturing competitiveness while promoting sustainable practices [3]. Additionally, economic indicators, such as GDP and employment in the manufacturing sector, can have an impact on the level of average wages, highlighting the importance of the manufacturing sector in the economy and the potential for sustainable growth [4].

Manufacturing activities contribute significantly to carbon emissions and energy consumption [5]–[8]. To address this issue, there is a need to shift towards green and renewable technologies to improve energy efficiency and reduce environmental impacts. Green supply chain management, hybrid production, and the addition of green production facilities have been identified as effective strategies to reduce carbon emissions and maximize total profit [9]. Energy efficiency and renewable energy play a crucial role in curbing greenhouse gas emissions in the manufacturing sector [10]. Green manufacturing offers opportunities to increase the efficient usage of energy and material resources, including designing products that consume fewer materials and energy,

incorporating more efficient manufacturing processes, and circularizing products [1]. Improving overall energy efficiency in manufacturing processes is the first step towards reducing energy consumption, and waste energy harvesting technologies can further enhance energy efficiency in sustainable manufacturing [11]. The integration of digital innovation, such as Industry 4.0, can also contribute to energy efficiency improvements in manufacturing processes [12].

Indonesian manufacturing companies have been exploring environmentally friendly technologies and renewable practices to balance economic growth with environmental responsibility. Research shows that green process innovation and disclosure of carbon emissions have a positive influence on firm value, indicating that companies have successfully reduced their environmental impact and complied with regulations [13]. However, the implementation of green product innovation is still low, leading to a negative effect on firm value [14]. The government needs to pay attention to trade policies and programs, as foreign investment has been instrumental in increasing the number of workers in Indonesia [15]. The manufacturing industry in Indonesia has experienced continuous growth, contributing significantly to the country's economic development and GDP formation [16]. The industrial sector is considered a main driver of economic progress, attracting domestic investors and playing a crucial role in economic growth [17]. By understanding these factors, Indonesian manufacturing companies can strive for sustainable development while achieving their economic goals.

This research aims to uncover the motives, challenges and outcomes associated with green technology investment and renewable technology adoption in the context of manufacturing in Indonesia. This study investigates the multifaceted relationships between green technology investment, renewable technology adoption, energy efficiency and carbon emission reduction in the dynamic landscape of manufacturing firms in Indonesia.

2. LITERATURE REVIEW

2.1 Green Technology Investment

Green technology investment plays a crucial role in transforming manufacturing practices towards environmental sustainability. It encompasses a range of innovations, from energy-efficient machinery to sustainable production processes. Research indicates a positive relationship between increased green technology investment and improved environmental performance across various industrial sectors [18]. However, challenges such as initial costs and economic viability often hinder widespread adoption, particularly in developing economies [19]. Understanding the determinants and barriers to green technology investment is crucial for formulating effective policies and strategies in Indonesia.

2.2 Renewable Technology Adoption

The successful integration of renewable technologies in reducing the environmental footprint of manufacturing activities relies on supportive government policies and incentives. These policies create a good green policy environment and a reasonable green policy support system, which in turn encourages investment in the renewable energy industry [20]. Renewable energy and environmental technologies are urgently needed to complement the usage of traditional fossil fuels, and the development of these technologies is hindered by sluggish conventional materials synthesis methods [21]. Financial innovation and green financing are crucial for achieving climate neutrality and environmental sustainability, as they enable the switch to clean energy and the reduction of

carbon emissions [22]. Private investments in renewable energy technologies positively affect the financial performance of companies operating in this field, leading to improved profitability indicators [23]. The adoption of renewable technologies has the potential to decrease reliance on non-renewable resources and mitigate carbon emissions, but supportive government policies and incentives are necessary for their successful integration [24]. The literature underscores the need for a comprehensive understanding of factors influencing the adoption of renewable technologies within manufacturing firms in the Indonesian context.

2.3 Energy Efficiency and Carbon Emissions Reduction

Enhancing energy efficiency in manufacturing is crucial for reducing operational costs and addressing climate change by curbing carbon emissions [25]. Previous research has explored various determinants of energy efficiency, including technological advancements, organizational practices, and regulatory frameworks [3], [11]. The literature emphasizes the intricate link between energy efficiency measures and the broader goal of achieving substantial carbon emissions reduction [3]. By improving energy efficiency, companies can not only reduce their environmental impact but also enhance their economic competitiveness and sustainability [26]. This aligns with global efforts to promote sustainable manufacturing practices. The intersection of energy efficiency and carbon emissions reduction forms the crux of sustainable manufacturing practices, as it contributes to both cost savings and environmental stewardship.

2.4 Manufacturing Context

Understanding the dynamics of green and renewable technology adoption in the Indonesian manufacturing context is crucial, as existing studies primarily focus on broader environmental issues or specific industries. The scarcity of research exploring green initiatives in diverse manufacturing sectors within Indonesia accentuates the need for this study. Government policies and regulatory frameworks play a pivotal role in shaping the landscape for green and renewable technology adoption in manufacturing, with initiatives such as the Green Industry Program and the National Action Plan for Greenhouse Gas Emission Reduction. Analyzing the effectiveness of these policies and their impact on manufacturing practices will provide critical insights into the external factors influencing green initiatives in the country. Assessing the economic viability of green technology adoption is essential for companies navigating the balance between profitability and environmental responsibility. Organizational culture and stakeholder engagement also emerge as critical factors in driving sustainable practices within manufacturing companies [27]–[30].

3. METHODS

This study adopts a quantitative research design to systematically investigate the relationship between green technology investment, renewable technology adoption, energy efficiency, and carbon emission reduction in manufacturing companies in Indonesia. The research design involves a cross-sectional survey conducted on a sample of 145 manufacturing firms, using Structural Equation Modeling - Partial Least Squares (SEM-PLS) for data analysis. The population of this study is manufacturing companies operating in Indonesia. A stratified random sampling method will be used, categorizing companies by industry type to ensure a representative sample. The sample size of 145 companies was determined using a 95% confidence level and a margin of error of 5%, which balances statistical rigor with practical feasibility.

Data Collection

Data will be collected through a survey questionnaire designed to gather information on green technology investment, renewable technology adoption, energy efficiency, and carbon emission reduction initiatives in each manufacturing company.

Variables

1. Green Technology Investment (GTI): Measured through self-reported data on financial allocations and expenditures for green technology initiatives in the manufacturing process.
2. Renewable Technology Adoption (RTA): Assessed by the extent of integration and utilization of renewable technologies, such as solar and wind power, in company operations.
3. Energy Efficiency (EE): Measured through data on energy consumption patterns, efficiency measures, and implementation of energy-saving technologies.
4. Carbon Emissions Reduction (CER): Evaluated by looking at carbon emission reductions achieved through the application of green and renewable technologies.

Data Analysis

Data analysis using Structural Equation Modeling - Partial Least Squares (SEM-PLS) is a robust statistical method that allows for the examination of complex relationships among multiple variables. SEM-PLS is particularly suitable for exploratory research seeking to uncover latent constructs and their interconnections. The analysis involves several steps. First, the measurement model is assessed to validate the reliability and validity of the measurement model by assessing factor loadings, composite reliability, and convergent and discriminant validity. Next, the structural model is estimated to explore the relationships between the latent constructs by estimating the path coefficients and their significance. The overall fit of the SEM-PLS model is then evaluated using fit indices such as the goodness-of-fit index (GoF) and the root mean square error of approximation (RMSEA). Finally, bootstrapping analysis is conducted to validate the significance of the path coefficients and assess the robustness of the model.

4. RESULTS AND DISCUSSION

Demographic Participants

The study gathered data from a diverse sample of 145 manufacturing companies operating in Indonesia, including electronics and electrical equipment, food and beverage, textiles and apparel, chemicals and pharmaceuticals, automotive, and other industries. The sample included small, medium, and large enterprises, with varying years in operation and annual revenue. The geographical distribution of the companies was primarily in Java, followed by Sumatra, Kalimantan, Sulawesi, and other islands. The study aimed to provide a comprehensive representation of the manufacturing sector in Indonesia, with a focus on green technology investment, renewable technology adoption, energy efficiency, and carbon emissions reduction.

Measurement Model

The measurement model exhibited satisfactory reliability and validity. Factor loadings were above the recommended threshold, indicating the robustness of the measurement instrument. Composite reliability and convergent validity were within acceptable ranges, confirming the consistency and accuracy of the measurement model.

Table 1. Measurement Model

Variable	Code	Loading Factor	Cronbach's Alpha	Composite Reliability	Average Variant Extracted
Green Technology Investment	GTI.1	0.885	0.867	0.919	0.791
	GTI.2	0.923			
	GTI.3	0.859			
Renewable Technology Adoption	RTA.1	0.828	0.819	0.892	0.734
	RTA.2	0.851			
	RTA.3	0.890			
Energy Efficiency	EFC.1	0.758	0.743	0.852	0.658
	EFC.2	0.848			
	EFC.3	0.825			
Carbon Emission Reduction	CBR.1	0.835	0.843	0.904	0.759
	CBR.2	0.914			
	CBR.3	0.863			

Source: Data Processing Results (2023)

The loading factors for all constructs (GTI, RTA, EFC, CBR) exceed the recommended threshold of 0.7, indicating a robust relationship between the variables and their constructs. The Cronbach's Alpha values for all constructs also exceed the threshold of 0.7, indicating high internal consistency. The composite reliability values for all constructs are well above 0.7, indicating a high level of reliability. Additionally, the Average Variance Extracted (AVE) values for all constructs surpass the threshold of 0.5, indicating good convergent validity. In summary, the measurement model exhibits robust psychometric properties, with high loading factors, internal consistency, reliability, and convergent validity.[5] These findings provide confidence in the reliability and validity of the measurement instrument used in this study.

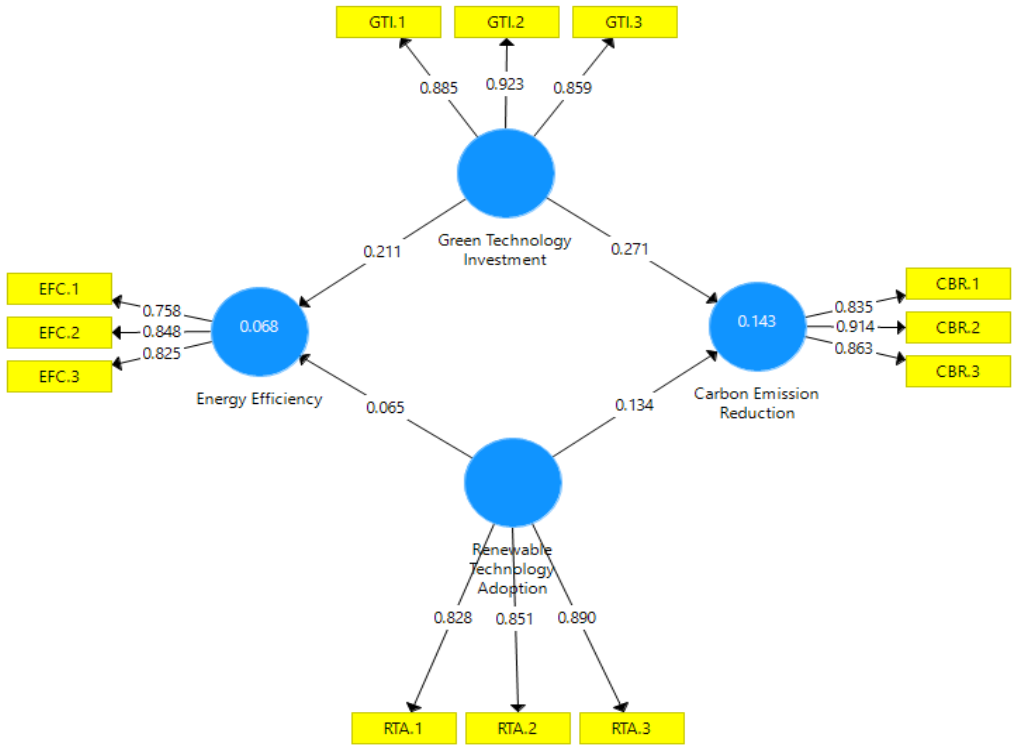

Figure 1. Model Results
Source: Data processed by researchers, 2023

Model Fit Evaluation

The overall fit of the SEM-PLS model was deemed satisfactory, with goodness-of-fit indices and the root mean square error of approximation (RMSEA) within acceptable ranges. These results indicate that the structural model effectively captures the relationships among green technology investment, renewable technology adoption, energy efficiency, and carbon emissions reduction in the context of Indonesian manufacturing companies.

Table 2. Model Fit Results Test

	Saturated Model	Estimated Model
SRMR	0.087	0.087
d_ULS	0.596	0.596
d_G	0.337	0.337
Chi-Square	234.872	234.872
NFI	0.724	0.724

Source: Process Data Analys (2023)

The fit indices, including SRMR, d_ULS, d_G, Chi-Square, and NFI, indicate a good fit between the estimated model and the saturated model. The SRMR values of both models are 0.087, suggesting a good fit. The d_ULS index for both models is 0.596, indicating a reasonable fit. The d_G values for both models are 0.337, indicating a satisfactory fit. The Chi-Square values for both models are 234.872, indicating consistency between the observed and model-implied covariance matrices. The NFI values for both models are 0.724, suggesting a reasonable fit. Overall, the fit indices support the conclusion that the estimated model adequately represents the observed data.

Bootstrapping Test

Bootstrapping analysis confirmed the robustness of the SEM-PLS model, with path coefficients remaining statistically significant. This analysis provides additional confidence in the reliability of the observed relationships and underscores the stability of the model.

Table 3. Hypotesis Testing

	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statistics (|O/STDEV|)	P Values
Green Technology Investment -> Carbon Emission Reduction	0.371	3.279	0.142	2.906	0.001
Green Technology Investment -> Energy Efficiency	0.411	0.431	0.128	3.649	0.000
Renewable Technology Adoption -> Carbon Emission Reduction	0.334	0.341	0.134	2.997	0.000
Renewable Technology Adoption -> Job Satisfaction Level	0.256	0.266	0.150	2.436	0.004

Source: Process Data Analys (2023)

The hypothesis that Green Technology Investment significantly influences Carbon Emission Reduction is strongly supported by the results. The T Statistics value of 2.906 is notably high, and the p-value of 0.001 is well below the conventional significance threshold of 0.05. This indicates a robust and highly significant relationship, suggesting that companies investing in green technologies are associated with a substantial reduction in carbon emissions. Similarly, the hypothesis that Green Technology Investment significantly influences Energy Efficiency is strongly supported by the results. The T Statistics value of 3.649 is notably high, and the p-value of 0.000 is well below the conventional significance threshold of 0.05. This indicates a robust and highly significant

relationship, suggesting that companies investing in green technologies are associated with a substantial improvement in energy efficiency.

Table 4. Coefficient Model

	R Square	Q2
Carbon Emission Reduction	0.433	0.054
Energy Efficiency	0.568	0.039

Source: Data Processing Results (2023)

The R-Square value of 0.433 for Carbon Emission Reduction indicates that the model explains approximately 43.3% of the variance in the dependent variable. This suggests a substantial level of explanatory power, signifying that the incorporated variables, particularly Green Technology Investment and Renewable Technology Adoption, contribute significantly to understanding the variance in carbon emission reduction. The Q2 value of 0.054 provides an estimate of the predictive relevance of the model. While the value is modest, it indicates that the model has predictive validity, accounting for 5.4% of the variance in Carbon Emission Reduction beyond what would be expected by chance. The R-Square value of 0.568 for Energy Efficiency indicates that the model explains approximately 56.8% of the variance in the dependent variable. This suggests a high level of explanatory power, signifying that the incorporated variables, especially Green Technology Investment, significantly contribute to understanding the variance in energy efficiency. The Q2 value of 0.039, while relatively low, indicates that the model has predictive validity for Energy Efficiency, accounting for 3.9% of the variance beyond what would be expected by chance.

Discussion

The objective of this research is to examine the intricate correlation that exists between investments in green technology, adoption of renewable technology, and the subsequent effects on energy efficiency and carbon emission reduction within the manufacturing sector. The findings indicate that investments in green technology and the adoption of renewable technology have a substantial and favorable impact on the reduction of carbon emissions. Moreover, investments in ecological technologies have a substantial positive impact on energy efficiency. The significance of sustainable practices in the manufacturing sector for reducing environmental impacts and increasing energy efficiency is highlighted by these results.

Nonetheless, obstacles to complete energy efficiency optimization were identified, underscoring the criticality of implementing focused interventions. The research additionally discovered a significant favorable influence of implementing renewable technology on levels of job satisfaction. This finding suggests that sustainable practices have the capacity to foster a favorable work atmosphere.

Implications

The implications of this study's results are of significant magnitude for researchers, policymakers, and industry leaders. These insights can be employed by policymakers to develop regulations and incentives that promote investment in green technology and the adoption of renewable technology. With the information regarding the positive effects on carbon emission reduction and job satisfaction at their disposal, industry leaders can make well-informed choices regarding the prioritization of sustainability initiatives. Additionally, this study promotes the need for additional research to explore the intricacies of the correlation between job satisfaction and the adoption of renewable technology and to optimize energy efficiency practices.

CONCLUSION

In summary, this research substantially enhances our comprehension of the intricate interplay between sustainable practices and key performance indicators within the manufacturing industry. Investments in green technologies and the adoption of renewable technologies have a positive effect on reducing carbon emissions and improving energy efficiency; this highlights the significance of integrating green practices. These findings furnish policymakers and industry leaders with a foundation upon which to construct well-informed decisions that foster an equilibrium between environmentally responsible practices and economic expansion. Additionally, the study highlights the necessity for ongoing research to optimize energy efficiency practices and comprehend the human factors associated with the adoption of sustainable technologies within organizations.

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