JPPIPA 10(Special Issue) (2024)

Jurnal Penelitian Pendidikan IPA

Journal of Research in Science Education

http://jppipa.unram.ac.id/index.php/jppipa/index

The Role of Green Manufacturing and Energy Management System in the Implementation of Carbon Emission Disclosure and its Impact on Company Performance in the Power Generation Sector in Serang Regency

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Received: June 01, 2024
Revised: July 17, 2024
Accepted: August 25, 2024
Published: August 31, 2024

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DOI: 10.29303/jppipa.v10iSpecialIssue.7894

Abstract: This study focuses on Steam Power Plant companies (PLTU) in Serang Regency (Suralaya Power Plant, Jawa 7 Power Plant, and Merak Energi Indonesia Power Plant). It investigates the impact of sustainable strategies, specifically energy management and carbon emission disclosure, on company performance. The data was obtained by distributing questionnaires to 270 respondents, which were subsequently analyzed using the Partial Least Square-Structural Equation Modeling (PLS-SEM) approach. The direct analysis shows that green manufacturing not significantly affect company performance, conversely, energy management significantly improves company performance, green manufacturing significantly influences carbon emission disclosure. Energy management also contributes to higher carbon emission disclosure, and carbon emission disclosure positively affects company performance, emphasizing the benefits of transparency for stakeholder trust and operational efficiency. Indirect effects reveal that green manufacturing and energy management positively impact company performance through carbon emission disclosure. This research offers insights for PLTU companies in Serang Regency. Sustainable strategies focusing on energy management and carbon emission disclosure enhance company performance and transparency. Further investigation is needed to understand complex relationships, considering external factors and specific management practices. These findings provide significant insights but are part of the broader puzzle in achieving sustainable business practices and superior performance.

Keywords: Carbon emission; Energy manufacturing; Green manufacturing; Power generation

Introduction

Energy is a fundamental element in economic development and the maintenance of human well-being. The electricity generation sector, particularly Steam Power Plants *(PLTU)* (Tiwari et al., 2021), plays a central role in providing vital electrical energy for economic growth and the quality of life of the population. As of 2020, out of the total national power generation capacity of 72,750.72 MW, approximately 50.40% is generated from PLTU. The ever-increasing demand for electrical energy, addressed by the country through the State Electricity Company (PLN), is met by constructing 35 PLTU units with a total installed capacity of 10,000 MW, with 10 of these PLTU units being built on the island of Java, including 4 in the Serang Regency.

How to Cite:
Hanafiyah, A. A., Rustandi, T., Suadma, U., & Kenedi. (2024). The Role of Green Manufacturing and Energy Management System in the Implementation of Carbon Emission Disclosure and its Impact on Company Performance in the Power Generation Sector in Serang Regency. *Jurnal Penelitian Pendidikan IPA*, *10*(SpecialIssue), 343–351. https://doi.org/10.29303/jppipa.v10iSpecialIssue.7894

The benefits of having these power plants have been felt by the Indonesian people for years through the availability of electricity in their homes. This can be seen in PT PLN (Persero) recording an 8.42 percent year-on-year (YoY) increase in electricity sales to 65.42 Terra Watt hours (TWh) in the first quarter of 2022. The rise in electricity consumption serves as a positive signal for the national economic recovery amid the Covid-19 pandemic. Among all sectors, the textile industry contributed the most, at 2.8 GWh, growing by 14 percent in March 2022. Meanwhile, the iron and steel sector consumed 2.01 GWh, up by 10 percent. The chemical industry also grew by 8 percent, with consumption at 1.6 GWh, and the cement industry grew by 7 percent, with consumption at 1.4 GWh (Imandiar, 2022).

The realized number of customers during the years 2016-2020 experienced an increase from 63.9 million to 78.7 million, adding an average of 3.7 million customers each year. The largest increase in customers still occurred in the household sector, averaging 3.3 million per year, followed by the business sector with an average of 215 thousand customers per year, the public sector with an average of 116 thousand customers per year, and lastly, the industrial sector with an average of 9 thousand customers per year.

However, behind the benefits provided and the increasing number of customers by these power plants, there are also negative impacts that can threaten the sustainability and environmental health in their vicinity. Among the various types of power plants, Steam Power Plants (PLTU) have serious impacts on the surrounding areas. PLTU itself is a power plant that uses fuels such as coal, fuel oil, and Marine Fuel Oil (MFO). Emissions produced by power plants like PLTU contribute to higher levels of air pollution in the region. The air pollutants generated by PLTU contain harmful particles that can affect human health. Some of these particles include arsenic, mercury, nox, lead, pm10, sox, and pm2.5 (Qonitalillah, 2021), furthermore, this sector also significantly contributes to greenhouse gas (GHG) emissions such as carbon dioxide (CO_2), which contributes to global climate change (Pusparisa, 2021).

Climate change is a serious global challenge with impacts that include rising global temperatures, changing patterns of extreme weather, sea-level rise, and ecosystem damage. In the face of this awareness of the dangers, countries worldwide have committed to reducing greenhouse gas (GHG) emissions (Saefullah et al., 2024). In this context, the implementation of sustainable practices in the energy sector becomes crucial. One rapidly evolving sustainable approach is Green Manufacturing, which aims to reduce the environmental impact of manufacturing processes. In the PLTU sector, Green Manufacturing encompasses practices such as fuel efficiency, waste management, and carbon emission reduction. Additionally, the Energy Management System (EMS) serves as a crucial tool for optimizing energy use, reducing operational costs, and lowering carbon emissions.

However, the implementation of Green Manufacturing and EMS in the PLTU sector has not always met expectations. There are unique challenges in adopting sustainable practices in an industrial environment that requires stable and efficient energy production. This involves significant investments in environmentally friendly infrastructure and technology. One essential indicator in measuring the extent to which PLTU companies have adopted sustainable practices is Carbon Emission Disclosure (CED). CED reflects how much information a company discloses about the carbon emissions generated during its operations. The level of disclosure reflects the company's commitment to environmental responsibility and can be a powerful tool in motivating companies to reduce their emissions.

However, the relationship between Green Manufacturing, EMS, CED, and company performance in the PLTU sector is not yet fully understood. Does the direct implementation of Green Manufacturing significantly impact CED, or does the use of EMS have a significant effect on CED? How does CED influence company performance in this sector? These questions form the background of this research.

Several previous studies have explored these aspects, but their findings have often varied. For instance, a study by Abualfaraa et al. (2020) stated that green manufacturing has not fully supported the three pillars of balance: economic, environmental, and social, which are demanded by the current global market. However, Musau et al. (2021) found that green manufacturing positively influences operational performance, significantly reducing production costs due to the implementation of environmentally friendly manufacturing. Regarding EMS, a study by Liu et al. (2021) concluded that the implementation of energy management systems significantly affects company performance, but this contradicts the findings of Halis et al. (2022) who stated otherwise. Similarly, when it comes to CED, there have been differing results. For example, Sibarani et al. (2023) and Zahara (2022) found a positive and significant relationship between CED and company performance. However, Adrati et al. (2022) stated the opposite, finding no significant relationship between CED and company performance.

Furthermore, these studies are often conducted in different contexts and on varying scales, resulting in inconsistent outcomes. Therefore, more detailed, and in-depth research is needed to understand the roles of Green Manufacturing and EMS in CED implementation and their impacts on company performance, especially in the context of PLTU in the Serang Regency. It is also

essential to delve deeper into the practical implications of these research findings. How can PLTU companies in the Serang Regency leverage this knowledge of these relationships to enhance their operations, and to what extent can government policies and stakeholders facilitate positive changes in this sector?

Hence, this research aims to address these questions and provide deeper insights into the relationships between Green Manufacturing, EMS, CED, and company performance in the PLTU sector in the Serang Regency. With a better understanding of these factors, it is hoped that companies and policymakers can take more effective actions to integrate sustainable practices and enhance the performance of this energy sector.

Method

This research employs a quantitative descriptive approach. Quantitative descriptive research aims to depict or explain the phenomena or characteristics of a population or sample using quantitative data. This study focuses on the collection and analysis of numerical data generated from a survey of selected respondents. The findings of this research can offer a better understanding of the characteristics of the observed variables, the relationships among variables, as well as patterns or trends emerging in the data (Johnson & Christensen, 2024).

According to Creswell et al. (2017) based on its level of explanation, this research falls under the category of associative research, which is a type of study aimed at understanding the relationship or correlation between two or more variables. This study focuses on identifying whether there is an association between these variables and to what extent this association is strong or weak. The primary objective of associative research is to explore relationships among variables without attempting to determine causality (Kenedi, 2022). In associative research, data are collected from a sample of the population or a group representing the phenomenon under investigation by distributing questionnaires to respondents with assessments using a Likert scale.

The population in this study comprises all employees in the three power plants located in Serang Regency (Suralaya Power Plant, Jawa 7 Power Plant, and Merak Energi Indonesia Power Plant), with a total of 7,238 individuals. The sample size used in this research was determined based on the analysis method employed, which is Partial Least Squares - Structural Equation Model (PLS-SEM). The minimum sample size was calculated using the inverse square root method, assuming a significance level of 5% and a minimum path coefficient of 0.2, resulting in a minimum sample size of 155 (Hair et al., 2021). For this study, a sample size of 270 respondents was designated. The sampling technique employed was simple random sampling, where population members were randomly and independently selected (Sekaran & Bougie, 2016).

The operationalization of the Green Manufacturing variable is measured based on indicators from Rachmawati (2021), subsequently, the Energy Management System is assessed using indicators from, Carbon Emission Disclosure is evaluated based on indicators from Damas et al. (2021) and Company Performance is gauged using indicators from Nur Irawan (2019).

Results and Discussion

Result

Evaluation of Reflective Measurement Model

The initial stage in assessing a reflective measurement model involves evaluating the proportion of an indicator's variability accounted for by its underlying construct. This assessment informs us about the reliability of the indicator. To calculate the explained variance of an indicator, we square its loading, which represents the correlation between the indicator and the construct. Indicator loadings exceeding 0.7 are advised because they signify that the construct accounts for over 50 percent of the indicator's variability, demonstrating satisfactory indicator reliability (Hair et al., 2021).

This research applied a criterion of a loading factor above 0.7, resulting in the removal of constructs with values below 0.7. As illustrated in Figure 2, constructs with loading factors above 0.7 were retained. Loading factors above 0.7 indicate that a construct can account for more than 70 percent of the indicator's variance. This signifies strong indicator reliability, confirming their suitability for measuring the intended constructs in the study. A higher loading factor signifies a stronger relationship between the indicator and its corresponding construct, implying that the indicator is dependable for measuring the intended variables.

The next phase in evaluating a reflective measurement model involves assessing internal consistency reliability. This reliability measure evaluates how closely related indicators that measure the same construct are to each other. The reliability level is assessed using Cronbach's Alpha and Composite Reliability, with the threshold set at > 0.7 (Hair et al., 2021).

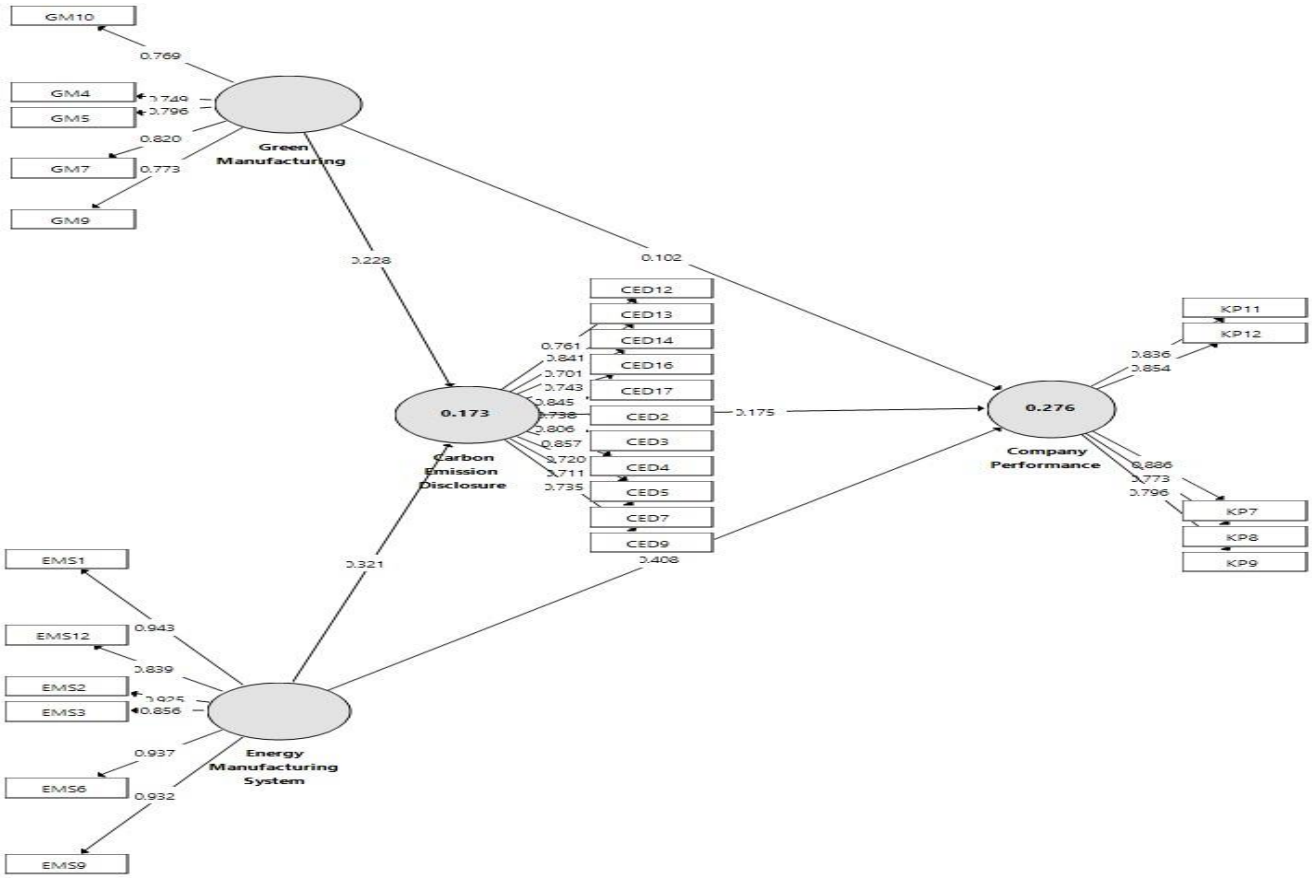

Figure 1. Outer loading

Table 1. Cronbach's Alpha and Composite Reliability

Parameters	Cronbach's Alpha	Composite Reliability
Carbon Emission Disclosure	0.931	0.941
Company Performance	0.887	0.917
Energy Manufacturing System	0.956	0.965
Green Manufacturing	0.842	0.887

The test results indicate that all variables have values above 0.7. This demonstrates a high level of reliability for the set of indicators within a construct or measurement scale, which is also an indication that the measurement tool or instrument used possesses an adequate level of internal consistency and reliability.

The third phase involves evaluating the convergent validity of each construct. Convergent validity assesses how well a construct comes together to account for the variance observed in its indicators. The measure used to assess the convergent validity of a construct is the average variance extracted (AVE) from all the indicators within that construct. Hence, the AVE is essentially the same as the communality of a construct. An AVE of at least 0.50 is considered the minimum acceptable threshold – an AVE of 0.50 or greater signifies that the construct accounts for 50 percent or more of the variance among the indicators that constitute the construct (Hair et al., 2021).

Table 2. Average Variance Extracted

Parameters	Average Variance Extracted
Carbon Emission Disclosure	0.594
Company Performance	0.689
Energy Manufacturing System	0.821
Green Manufacturing	0.611

Based on Table 2, it is observed that the AVE values for all constructs are above 0.5. This signifies that these constructs possess a satisfactory level of convergent validity, reinforcing the understanding that they are reliable and consistently represent the intended variables.

The fourth phase involves evaluating discriminant validity. This measurement assesses how much a construct differs empirically from other constructs within the structural model. In this study, we employ the Heterotrait-Monotrait Ratio (HTMT) of correlations to evaluate discriminant validity. HTMT is calculated as the average correlation among indicators across different constructs relative to the geometric mean of the average correlations among indicators measuring the same construct. The threshold value for the HTMT used in this study is < 0.85 (Hair et al., 2021).

Table 3. Heterotrait-Monotrait Ratio (HTMT)

Parameters	Carbon Emission Disclosure	Company Performance	Energy Manufacturing System	Green Manufacturing
Carbon Emission Disclosure				
Company Performance	0.373			
Energy Manufacturing System	0.363	0.513		
Green Manufacturing	0.291	0.226	0.128	

The test results reveal that the HTMT values for all constructs are < 0.85. This indicates that these constructs can be empirically distinguished from one another within the structural model, demonstrating that they are not excessively correlated and effectively represent distinct concepts or variables in this study.

Evaluation of Structural Model

Coefficient of Determination (R^2)

The R^2, which stands for the variance explained in each of the endogenous constructs, serves as an indicator of the model's ability to explain variation within the dataset, often referred to as in-sample predictive power. The R^2 scale spans from 0 to 1, with higher values signifying a stronger explanatory capability. In general terms, R^2 values of 0.75, 0.50, and 0.25 can be categorized as substantial, moderate, and weak, respectively (Hair et al., 2021).

Table 4. R-Square

Parameters	R Square
Carbon Emission Disclosure	0.173
Company Performance	0.276

These R^2 values represent the proportion of variance explained by the independent variables in the model for each respective endogenous construct. For "Carbon Emission Disclosure," the R^2 of 0.173 indicates that the independent variables in the model collectively explain 17.3% of the variance in carbon emission disclosure. For "Company Performance," the R^2 of 0.276 suggests that the independent variables in the model jointly account for 27.6% of the variance in company performance. In both cases, the R^2 values are moderate, indicating that there are other factors or variables not included in the model that also influence these constructs.

Table 5. Direct Effect Testing

Relationship Between Variables	Original Sample	T Statistics	P Values	Result
Green Manufacturing -> Company Performance	0.102	1.782	0.075	Not Significant
Energy Manufacturing System -> Company Performance	0.408	6.955	0.000	Significant
Green Manufacturing -> Carbon Emission Disclosure	0.228	3.844	0.000	Significant
Energy Manufacturing System -> Carbon Emission Disclosure	0.321	5.184	0.000	Significant
Carbon Emission Disclosure -> Company Performance	0.175	3.142	0.002	Significant

Table 6. Indirect Effect Testing

Relationship Between Variables	Original Sample	T Statistics	P Values	Result
Green Manufacturing -> Carbon Emission Disclosure -> Company Performance	0.040	2.337	0.020	Significant
Energy Manufacturing System -> Carbon Emission Disclosure -> Company Performance	0.056	2.661	0.008	Significant

Hypothesis Testing

Hypothesis testing is conducted based on the results of the Inner Model (structural model) testing, which includes parameter coefficients and t-statistics. To determine whether a hypothesis is accepted or rejected, factors such as the significance values between constructs, t-statistics, and p-values are considered. Hypothesis testing in this research was performed using SmartPLS 4.0 software. These values can be observed from the bootstrapping results. The rules of thumb applied in this study are t-statistics >1.96 with a significance level of p-value of 0.05 (5%) and positive beta coefficients. Hypothesis testing comprises both direct and indirect effects among the variables within the inner model.

Discussion

The Impact of Green Manufacturing on Company Performance

The test results indicate that the path coefficient between Green Manufacturing and Company Performance is 0.102, with a t-statistic value of 1.782 < 1.96 and a p-value of 0.075 > 0.05. Therefore, it can be concluded that Green Manufacturing has a positive yet statistically insignificant relationship with Company Performance, leading to the rejection of Hypothesis 1. This finding contradicts previous studies (Afum et al.,

2020; Musau & Rucha, 2021) which concluded that the implementation of green manufacturing in companies enhances both operational and economic performance. The lack of a significant impact of green manufacturing on the performance of a steam power plant company may be attributed to factors such as the plant's initial efficiency, external influences like government regulations and energy price fluctuations, the substantial implementation costs.

In the context of a Steam Power Plant (PLTU), green manufacturing focuses on generating electricity while emphasizing the efficient management of production waste to minimize environmental impact, prevent pollution, and ensure that production residues do not disrupt the surrounding community or cause pollution.

The Impact of Energy Manufacturing System on Company Performance

Based on the path coefficient results obtained, the relationship between the energy manufacturing system and company performance is 0.408, with a t-statistic value of 6.663 > 1.96 and a p-value of 0.000 < 0.05. Hence, it can be concluded that there is a significant influence of the energy manufacturing system on company performance. A positive coefficient parameter signifies that as the utilization of the energy manufacturing system increases, the performance of the PLTU Company also improves, thus confirming the acceptance of Hypothesis 2. This finding aligns with the study conducted by Liu et al. (2021), which stated that the implementation of energy management systems significantly affects the performance of state-owned enterprises (BUMN). The adoption of EMS enables BUMNs to reduce pollution payments and energy costs, thereby driving a significant improvement in BUMN performance.

Energy management system is a process encompassing activities, practices, and energy management processes. The implementation of an energy management system (EMS) can reduce carbon emissions, save costs, and enhance productivity, ultimately achieving effective energy management that, in turn, enhances company performance.

The Impact of Green Manufacturing on Carbon Emission Disclosure

The test results reveal that the path coefficient between the green manufacturing system and carbon emission disclosure is 0.228, with a t-statistic value of 3.844 > 1.96 and a p-value of 0.000 < 0.05. Hence, it can be inferred that green manufacturing has a positive and significant influence on carbon emission disclosure. A positive coefficient parameter implies that the better the implementation of green manufacturing, the more transparent the carbon emission disclosure produced by the PLTU company, thus confirming the acceptance of Hypothesis 3.

These findings align with the research conducted by Damas et al. (2021) and Sari et al. (2021), which emphasize that green strategies or green innovations have a positive impact on carbon emission disclosure. This implies that companies implementing green strategies tend to be more motivated to disclose information about their carbon emissions. Green strategies encompass strategic processes, implementation, environmental performance, and financial competitive performance. These criteria reflect a focus on environmental responsibility, including carbon emissions management within a company. Green manufacturing plays a supportive role in disclosing information about carbon emissions. Present-day society is more interested in companies that prioritize environmental preservation and sustainability. Consequently, companies today are competing to implement green strategies, which encompass products, services, and processes aimed at reducing waste generation.

The Impact of Energy Manufacturing System on Carbon Emission Disclosure

The research findings indicate that the path coefficient between the energy management system and carbon emission disclosure is 0.321, with a t-statistic of 5.184 > 1.96 and a p-value of 0.000 < 0.05. Therefore, it can be concluded that the energy management system has a positive and significant impact on carbon emission disclosure. A positive coefficient parameter implies that the better the implementation of the energy management system, the more transparent the carbon emission disclosure reported by the PLTU company, thus confirming the acceptance of Hypothesis 4.

These results align with research conducted by Cao et al. (2022) emphasizing that environmental management systems significantly affect carbon emission disclosure. Environmental management systems impact carbon-intensive industries, which actively contribute significantly to carbon emissions. EMS assists companies in identifying, measuring, and managing the carbon emissions generated by their operations. EMS provides a structured framework for tracking and monitoring energy consumption and carbon emissions associated with production processes. With this system in place, companies can more effectively identify sources of carbon emissions, implement strategies to reduce emissions, and transparently disclose related information to stakeholders.

Furthermore, EMS encourages companies to adopt sustainable practices that contribute to carbon emission reduction. The implementation of EMS often involves

close monitoring of energy consumption, operational efficiency, and more efficient resource utilization. This makes companies more aware of the environmental impact of their activities and encourages them to commit to reducing carbon emissions. As a result, companies tend to be more open in disclosing information about their carbon emissions as part of sustainable practices and corporate social responsibility.

Thus, EMS not only helps companies manage their carbon emissions more effectively but also encourages them to be more transparent in communicating information about their carbon emissions to stakeholders such as investors, consumers, and regulators.

The Impact of Carbon Emission Disclosure on Company Performance

The test results reveal that the path coefficient between carbon emission disclosure and company performance is 0.175, with a t-statistic of 3.142 > 1.96 and a p-value of 0.002 < 0.05. Therefore, it can be concluded that carbon emission disclosure has a positive and significant influence on company performance. A positive coefficient parameter implies that the more transparent the reporting of carbon emission disclosure, the better the performance of the PLTU company, thus confirming the acceptance of Hypothesis 5.

These findings support previous research conducted (Nisa, 2023; Zahara, 2022) which concluded that carbon emission disclosure has a significant positive impact on a company's value and performance. By disclosing data that reflects the company's efforts to reduce its environmental impact, the company can enhance the trust of stakeholders such as investors, consumers, and regulators. Moreover, carbon emission disclosure can motivate companies to adopt sustainable strategies and green practices, which, in turn, can improve operational efficiency, reduce energy costs, and enhance the company's reputation. Therefore, strong company performance in carbon emission disclosure can bring long-term benefits, including business sustainability, access to capital, and a competitive advantage in an environmentally-conscious economy.

The Impact of Carbon Emission Disclosure as mediator variable between Green Manufacturing and Company Performance

From the testing of the indirect effect, it is evident that green manufacturing has a positive and significant influence on company performance through carbon emission disclosure, with a path coefficient of 0.040, where the t-statistic value of 2.337 > 1.96 and a p-value of 0.020 < 0.05. Conversely, the direct impact of green manufacturing on company performance is found to be not significant. Therefore, it can be concluded that this mediation is a full mediation (Hair et al., 2021), indicating that the independent variable cannot significantly affect the dependent variable without going through the mediator variable. Thus, Hypothesis 6 is accepted.

This occurrence can be explained by the fact that Green Manufacturing encourages companies to adopt sustainable practices, which in turn enhance Carbon Emission Disclosure. In other words, companies implementing Green Manufacturing tend to focus more on carbon emission reduction efforts, naturally reflected in improved Carbon Emission Disclosure reporting. This, in turn, contributes to enhanced Company Performance.

As a result, the direct effect of Green Manufacturing on Company Performance may not be significant because the primary influence of Green Manufacturing on Company Performance is channeled through Carbon Emission Disclosure, a critical indicator in assessing environmental responsibility and sustainable corporate practices. Consequently, full mediation is a reasonable phenomenon in the context of this research.

The Impact of Carbon Emission Disclosure as Mediator Variable between Energy Manufacturing System and Company Performance

From the indirect effect testing, it was found that the energy manufacturing system has a positive and significant impact on company performance through carbon emission disclosure, with a t-statistic of 2.661 > 1.96 and p-value of 0.008 < 0.05. Additionally, the direct influence of the energy manufacturing system on company performance was also found to be significant. Therefore, it can be concluded that this mediation is only partial and falls into the category of complementary (Hair et al., 2021), thus supporting Hypothesis 7.

In this context, partial mediation with complementary characteristics suggests that there are two complementary paths of effect. One path represents the direct influence of the energy manufacturing system on company performance, while the other path represents the influence through carbon emission disclosure. Both paths work together to enhance company performance. Consequently, this mediation is considered complementary, indicating that carbon emission disclosure does not diminish the impact of the energy manufacturing system but rather supports it in improving company performance.

This finding aligns with the concept that an energy manufacturing system focused on energy efficiency and carbon emission reduction can directly enhance company performance. Simultaneously, carbon emission disclosure reinforces this effect by increasing transparency and corporate accountability regarding

environmental issues. Both elements work collaboratively to achieve better company performance.

Conclusion

This research provides valuable insights for PLTU companies in Serang Regency. Particularly, sustainable strategies focusing on energy management and carbon emission disclosure can positively impact company performance while enhancing environmental transparency. Although the implementation of green manufacturing does not directly affect company performance, its vital role in improving carbon emission disclosure suggests that sustainable aspects should be considered as part of a holistic business strategy. However, its essential to note that this study requires further investigation to better understand the complex relationships between these variables. Other variables that may influence outcomes, such as external factors or more specific management practices, also need consideration. While these findings offer significant insights, they are just a part of the larger puzzle in achieving sustainable business practices and superior performance

Acknowledgments
The writing team would like to express its deepest thanks to all parties who have been involved and helped with this research.

Author Contributions
This article was prepared by four authors, namely A.D.H, T.R, U.S, and K. All members of the writing team carried out each stage together.

Funding
This research received no external funding.

Conflicts of Interest
The authors declare no conflict of interest.

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