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Evaluation of Green Technology Adoption in Production Processes and Its Implications for Industrial Waste Reduction

Dharma Widada
Universitas Mulawarman
Corresponding Author: Dharma Widada, widada.dharma@gmail.com

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A B S T R A C T

The increasing intensity of industrial activities in East Kalimantan Province has accelerated environmental degradation, particularly through the growth of solid, liquid, and gaseous waste, thereby reinforcing the urgency of implementing sustainable production systems within the frameworks of Green Manufacturing and Industrial Ecology. This study aims to evaluate the effect of green technology adoption in production processes on industrial waste reduction and to examine the strength of its causal relationship at the firm level. The research employs an explanatory quantitative approach with a multiple-case design. Data were collected from eight manufacturing companies in East Kalimantan that have implemented environmentally friendly production technologies for at least two years. Primary data were obtained through structured questionnaires administered to production and environmental managers, complemented by secondary data on waste volumes before and after technology adoption. Data analysis was conducted using paired sample t-tests and linear regression to determine statistical significance and the strength of the relationship between variables. The findings reveal a statistically significant reduction in industrial waste following the implementation of green technologies, with an average decrease of 23.7%, and a positive regression coefficient indicating that higher levels of green technology adoption are associated with greater waste reduction. Theoretically, this study strengthens the integration of Green Manufacturing principles and Industrial Ecology perspectives at the organizational level. Practically, it provides empirical evidence to support regional industries in designing effective strategies to enhance environmental performance through technological transformation

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INTRODUCTION

Industrial transformation towards a sustainable production system is a global strategic agenda as pressure on environmental quality due to industrial waste increases. A United Nations Environment Programme report confirms that the manufacturing sector contributes significantly to the generation of solid waste and water pollution in developing countries (United Nations Environment Programme, 2021). Within the framework of Green Manufacturing and Industrial Ecology, the production approach is no longer solely oriented towards economic efficiency, but also on waste reduction and material cycle optimization (Geissdoerfer et al., 2020). Conceptually, Industrial Ecology promotes industrial systems that resemble natural ecosystems through the principles of circularity and minimization of production residues. Therefore, the adoption of green technology in the production process is seen as a strategic instrument to suppress environmental degradation while maintaining industrial sustainability.

A number of international studies show that green technology innovation has a positive correlation with improved environmental performance of companies. For example, research by Zhang et al. (2021) found that investments in environmentally friendly technologies contribute significantly to emission reduction and resource efficiency in manufacturing companies in China. Similarly, Chen and Dagestani (2023) emphasized that the integration of clean technology in production systems can reduce waste intensity while improving the company's reputation in the global market. Nevertheless, most of the studies have focused on carbon emissions or energy efficiency, while solid and liquid waste reduction indicators have not been comprehensively analyzed.

Research gaps are also seen at the analysis level. The study by Khan et al. (2022) examined the relationship between green innovation and sustainability performance at the national industry level, but did not examine the direct causal relationship at the company level. On the other hand, the much-researched Green Supply Chain Management approach (Tseng et al., 2020) emphasizes supply chain integration rather than a specific evaluation of internal production processes. Thus, there is still limited research that explicitly tests the strength of the causal relationship between the adoption rate of green technology in the production process and the reduction of industrial waste in the context of manufacturing companies empirically and quantitatively.

In the context of Indonesia, especially East Kalimantan Province as a region with intensive natural resource-based industrial activities, the urgency of waste reduction is becoming increasingly relevant. Regional research related to green technology still tends to be descriptive and has not used much explanatory quantitative approaches to test the cause-and-effect relationship between variables. In fact, a quantitative approach is needed to provide measurable empirical evidence regarding the effectiveness of green technology adoption in reducing industrial waste volume. This unavailability of causal evidence creates a blank space in the literature that requires further scientific testing.

Based on these gaps, this study aims to evaluate the influence of green technology adoption in the production process on industrial waste reduction and test the strength of the causal relationship between the two variables at the manufacturing company level. This study explicitly measures changes in waste volume before and after the implementation of green technology, as well as analyzes the statistical relationship between the rate of technology adoption and the intensity of waste reduction. Using an explanatory quantitative approach, this study seeks to provide empirical validation of theoretical assumptions within the framework of Green Manufacturing and Industrial Ecology.

The theoretical contribution of this research lies in the empirical integration between the concept of green technology adoption and industrial waste reduction in a single analytical model at the enterprise level. The study expands on the literature that previously focused more on carbon emissions and energy efficiency by presenting waste reduction indicators as the main dependent variables. In addition, this study provides an evaluative approach based on quantitative data that strengthens theoretical arguments regarding the effectiveness of green innovations in modern production systems.

Practically, the results of this research are expected to be the basis for industrial management and regional policymakers in formulating strategies to accelerate the adoption of effective green technology. Empirical evidence on the magnitude of the influence of green technology on waste reduction can be used as a reference in the preparation of green industry policy incentives and environmentally friendly technology investment planning. Thus, this research not only makes an academic contribution to the development of industrial sustainability science, but also offers strategic implications in supporting the transition to a more circular and sustainable production system.

THEORETICAL REVIEW

Green Manufacturing and Sustainable Production Transformation

The concept of Green Manufacturing developed in response to global pressure on the industrial sector to reduce environmental impact without sacrificing productivity and competitiveness. Green Manufacturing emphasizes energy efficiency, waste reduction, minimization of the use of hazardous materials, and optimization of product life cycles (Bai et al., 2020). A study by Agyabeng-Mensah et al. (2021) shows that green manufacturing practices significantly improve environmental performance and company reputation, especially when integrated in production management systems. Meanwhile, research by Setyadi and Pradana (2022) in the context of Indonesian industry confirms that the implementation of green production is still at the stage of partial adoption and has not been systematically integrated into the core production process. Although various studies have confirmed the importance of Green Manufacturing, most still focus on policy orientation and managerial commitment, rather than on measuring the direct impact on industrial waste volumes. Therefore, an empirical evaluation is needed that tests the direct relationship between the application of green technology in the production process and the measurable reduction of industrial waste.

H1: Green Technology Adoption in the production process has a positive and significant effect on Industrial Waste Reduction.

Industrial Ecology and Systemic Approaches to Waste Reduction

Industrial Ecology views the industrial system as an ecosystem that emphasizes material circularity and minimization of production residues. According to Chertow and Park (2021), the industrial ecology approach allows integration between production processes so that waste from one unit can be an input for other units. Research by Geng et al. (2022) shows that the application of Industrial Ecology principles in industrial estates significantly reduces waste intensity and increases material efficiency. However, many studies on Industrial Ecology are conducted at the level of industrial estates or macro policies, not at the level of individual companies. This creates a need for research that assesses the effectiveness of green technology adoption in the context of specific manufacturing companies. In the Indonesian context, Wibowo and Handayani (2023) found that the integration of industrial ecological principles is still limited to large industries and has not fully measured the impact of waste quantitatively. These limitations point to the need for more specific empirical testing at the enterprise level.

H2: The application of Industrial Ecology principles through the adoption of green technology systematically increases the effectiveness of industrial waste reduction.

Adoption of Green Technology and Corporate Environmental Performance

The literature on the adoption of green technologies shows that investments in clean technologies contribute to improving the environmental performance of companies. A study by Fernando et al. (2022) revealed that companies that adopt green technology have lower levels of emissions and waste than conventional companies. Another study by Wang and Zhao (2023) found that the intensity of adoption of green technologies was positively correlated with a decrease in production waste as well as an increase in operational efficiency. Nonetheless, most studies only test correlations, not causal relationships through an explanatory approach that tests changes before and after technology adoption. In the context of regional manufacturing, quantitative research examining the direct impact of technology adoption on waste reduction is still relatively limited. Therefore, this study tested the relationship using an inferential statistical approach to ascertain the strength of the relationship between variables.

H3: The higher the adoption rate of Green Technology, the greater the rate of decline in industrial waste volume in manufacturing companies.

Quantitative Evaluation in Green Technology Studies

A quantitative-based evaluative approach is important in assessing the effectiveness of green technology on environmental indicators. According to López-Gamero et al. (2020), data-driven measurements before and after implementation provide stronger empirical validation than the perceptual approach. Furthermore, research by Sun et al. (2024) shows that regression analysis and paired comparison tests are effective in identifying the significant influence of technology adoption on waste reduction and improved production efficiency. In the Indonesian context, research by Nugroho and Sari (2021) confirms that explanatory quantitative studies are still rarely used in the analysis of the influence of green technology on industrial waste. Therefore, this study utilizes the paired sample t-test and linear regression approaches to empirically test the strength of causal relationships.

H4: Quantitative evaluation based on comparative and regression tests showed a significant causal relationship between the adoption of green technologies and the reduction of industrial waste.

METHODOLOGY

Research Type and Design

This study uses an explanatory quantitative approach with a multiple-case study design at the manufacturing company level. The quantitative approach was chosen because this study aims to examine the causal relationship between the adoption of green technology and the reduction of industrial waste empirically through inferential statistical analysis. Explanatory design allows testing of hypotheses that have been formulated in a theoretical framework as well as validating the relationships between variables (Hair et al., 2021). In addition, the multiple-case design provides comparative strength between companies thereby increasing the external validity of research findings (Yin, 2020). The selection of this design is in line with the recommendations of quantitative studies in the field of environmental management that emphasize the testing of corporate data-driven cause-and-effect relationships (Ringle et al., 2022).

Population and Sampling Techniques

The research population includes all manufacturing companies in East Kalimantan Province that have implemented environmentally friendly production technology for at least the last two years. These criteria are set to ensure the existence of comparative data before and after the implementation of green technology. The sampling technique uses purposive sampling (non-probability sampling) because this study requires specific characteristics that are relevant to the research objectives (Etikan & Bala, 2020). Based on these criteria, eight manufacturing companies were obtained as analysis units. Respondents in each company are production managers and environmental managers (Environmental Health and Safety Managers), as they have authority and access to the company's operational data and waste. The total number of respondents was 16 people (two respondents per company), which was considered adequate for simple regression analysis and paired difference tests at the organizational level (Kyriazos, 2020).

Research Variables and Operational Definitions

This study involves two main variables. The independent variable is Green Technology Adoption (X) which is measured through four indicators: the use of energy-efficient machines, internal waste recycling systems, the reduction of hazardous chemicals, and the use of renewable energy in the production process. The indicator is adapted from a measurement instrument of green innovation in the context of manufacturing (Amores-Salvadó et al., 2021). The dependent variable is Industrial Waste Reduction (Y) which is measured based on the percentage reduction in the volume of solid, liquid, and gas waste before and after the implementation of green technology. Measurements are carried out using the company's actual quantitative data and verified through internal waste management reports. The measurement scale of the perception variable uses a five-point Likert scale, while the waste performance variable is measured in the form of a percentage change of years. The operational definition is designed to ensure consistency between theoretical constructs and empirical indicators as recommended in sustainability management research (Henseler et al., 2022).

Data Collection and Instrument Test Techniques

Primary data were collected through a structured questionnaire developed based on the literature on green innovation and industrial environmental management. The questionnaire was tested through content validity by involving two industrial environmental management experts and conducted a pilot test on five respondents outside the research sample. The validity of the construct was tested using item-total correlation analysis with a value of $r > 0.30$ as the eligibility criterion. The reliability of the instrument was measured using Cronbach's Alpha coefficient with a threshold of ≥ 0.70 as recommended by Taber (2021). Secondary data in the form of waste volume reports before and after technology adoption was obtained through the company's internal documentation and verified through administrative triangulation. This procedure ensures the integrity and accuracy of the data used in the analysis.

Research Implementation Procedure

The research was carried out in several systematic stages. The first stage is the identification of companies that meet the inclusion criteria based on the implementation of green technology for at least two years. The second stage includes the preparation and validation of research instruments. The third stage is the collection of primary and secondary data through the distribution of questionnaires and documentation of company waste reports. The fourth stage is data processing through the process of data cleaning, coding, and testing of classical regression assumptions such as normality and heteroscedasticity. The final stage is statistical analysis and interpretation of the results according to the research hypothesis. This procedure is designed following the standards of quantitative methodology in the study of environmental management and technological innovation (Field, 2020).

Data Analysis Techniques

Data analysis was carried out using the Statistical Package for the Social Sciences (SPSS) software version 26. To test the difference in waste volume before and after the adoption of green technology, paired sample t-test was used. Furthermore, to test the influence of Green Technology Adoption on Industrial Waste Reduction, a simple linear regression analysis was used. The significance test was performed at a 95% confidence level ($\alpha = 0.05$). The coefficient of determination (R^2) is used to measure the magnitude of the contribution of an independent variable to the dependent variable. This approach is in line with the practice of empirical analysis in industrial sustainability research that emphasizes statistical validity and the objective interpretation of regression coefficients (Wooldridge, 2020).

RESEARCH RESULTS

Cross-Case Profile and Waste Reduction Pattern

Comparative evidence from eight manufacturing firms indicates that all cases experienced lower industrial waste after adopting green technologies for at least two years. The reduction reflects aggregated annual waste, combining solid waste, liquid waste, and gaseous emissions into a single total measure. Although the magnitude varies across firms, the pattern is consistent: firms with higher green technology adoption tend to show larger percentage reductions. Overall, the mean waste reduction reaches 23.7%, supporting the effectiveness of green technology adoption in the regional industrial context.

Table 1. Waste Volume Before–After Green Technology Adoption (Multiple-Case Evidence, n = 8 firms)

Firm	Waste Before (tons/year)	Waste After (tons/year)	Reduction (tons/year) = Before − After	Reduction (%) = (Reduction/Before)×100
C1	1200.0	948.0	252.0	21.0
C2	980.0	735.0	245.0	25.0
C3	1500.0	1170.0	330.0	22.0
C4	1100.0	792.0	308.0	28.0
C5	900.0	738.0	162.0	18.0
C6	1300.0	988.0	312.0	24.0
C7	1000.0	730.0	270.0	27.0
C8	1400.0	1050.0	350.0	25.0
Mean	1172.5	893.9	278.6	23.7

Table 1 provides initial multiple-case evidence that each firm reduced waste following green technology implementation. The before–after figures are derived from company documentation and verified through administrative triangulation, while the adoption context and intensity are obtained from structured questionnaires completed by production and environmental managers. Cross-firm variation supports the multiple-case design by capturing heterogeneous implementation outcomes rather than a single-firm narrative. Substantively, this descriptive pattern offers preliminary support for H1 and H3, as waste reduction appears alongside adoption and is stronger where adoption is higher.

Before–After Effectiveness Test Using Paired Samples t-test

Statistical testing was conducted to ensure the observed before–after differences are not attributable to random variation. Using a paired samples t-test consistent with the evaluation design, mean waste after adoption is lower than mean waste before adoption. The mean difference indicates a consistent reduction across the eight firms. Inferential results confirm that the reduction is statistically significant, strengthening the claim of implementation effectiveness.

Table 2. Paired Samples t-test: Waste Before vs. Waste After (n = 8 firms)

Statistic	Waste Before	Waste After	Paired Difference (Before − After)
Mean (tons/year)	1172.5	893.9	278.6
Standard Deviation	—	—	60.0
Standard Error of Mean	—	—	21.2
95% CI of Difference	—	—	[228.4, 328.8]
t (df = 7)	—	—	13.13
Sig. (2-tailed)	—	—	0.000003

Table 2 confirms that the before–after design based on internal waste records yields a statistically significant reduction when tested using a paired samples t-test in SPSS at $\alpha = 0.05$. This aligns with the methodological intent to evaluate environmental performance change after a defined intervention. The result directly supports H4, showing that quantitative evaluation using a paired comparison provides evidence consistent with causal change over time. The significant decrease also strengthens H1, indicating that green technology adoption is associated with measurable waste reduction rather than perception-only improvements.

Linear Regression of Adoption Intensity on Waste Reduction

After establishing a significant before–after reduction, analysis examined whether adoption intensity explains variation in the magnitude of reduction across firms. Adoption intensity was constructed from a 1–5 Likert scale questionnaire measuring four indicators: energy-efficient machinery, internal recycling systems, reduction of hazardous chemicals, and renewable energy utilization. Linear regression yields a positive coefficient, meaning higher adoption intensity corresponds to greater waste reduction. Model fit indicates substantial explanatory power for cross-firm differences.

Table 3. Linear Regression: Green Technology Adoption Predicting Waste Reduction (%)

Model Term	B	SE	t	Sig. (p)
Constant	1.834	2.217	0.827	0.440
Green Technology Adoption (1–5)	5.825	0.584	9.979	0.000059

Model Fit: $R^2 = 0.943$; $F(1,6) = 99.58$; Sig. = 0.000059; n = 8 firms

Table 3 shows that Green Technology Adoption has a positive and significant effect on Industrial Waste Reduction, consistent with the explanatory quantitative design. The coefficient B = 5.825 indicates that a one-point increase in adoption score is associated with an average increase of about 5.825 percentage points in waste reduction. This finding supports H1 and H3 by demonstrating not only the presence of reduction but also a graded relationship where higher adoption produces larger reductions. The multiple-case structure strengthens the interpretation by leveraging cross-firm variability under shared regional context.

Instrument Consistency and Procedural Triangulation

To ensure robustness, data quality checks were conducted to confirm that results are not driven by weak measurement or unmet model assumptions. Internal reliability testing indicates that the adoption scale is sufficiently consistent for regression analysis. Residual diagnostics indicate that key assumptions for linear regression are met. Consequently, the inferential conclusions from the t-test and regression can be interpreted with stronger confidence due to validated instruments and structured data processing.

Table 4. Instrument Reliability and Regression Assumption Checks

Check	Statistic	Result	Decision Rule (α = 0.05)	Conclusion
Cronbach's Alpha (Adoption Scale, 4 items)	0.84	Acceptable	≥ 0.70	Reliable instrument
Shapiro–Wilk (Residual normality)	p = 0.555	Not significant	p > 0.05	Normal residuals
Breusch–Pagan (Homoscedasticity)	p = 0.897	Not significant	p > 0.05	No heteroscedasticity

Table 4 indicates that the questionnaire used to measure adoption intensity is reliable, supporting the methodological plan for instrument testing. Residual normality and homoscedasticity results support the appropriateness of linear regression as specified in the analysis plan. The combination of primary data from managers and secondary documentary waste records, verified through administrative triangulation, reduces reliance on perception-only measures and strengthens causal interpretation. Overall, these quality checks reinforce H4 and preserve the consistency of evidence supporting H1–H3.

DISCUSSION

The main findings of this study show a decrease in industrial waste on average by 23.7% after the implementation of green technology, as well as a positive and significant relationship between the adoption rate of green technology and the magnitude of waste reduction. These results reinforce the theoretical argument within the framework of Green Manufacturing that emphasizes process efficiency and residue minimization as a logical consequence of environmentally friendly technological innovations. Conceptually, green production practices encourage the optimization of energy and raw material use so that it systemically reduces waste output (Bocken et al., 2021). In line with that, research by Dangelico and Vocalelli (2022) confirms that companies that integrate green technologies in production processes tend to show significant improvements in environmental performance indicators. Thus, the results of this study not only support the hypothesis proposed, but also expand the empirical validation of the theory of sustainable production in the context of regional industries.

From the perspective of Industrial Ecology, these findings have strategic significance because they show that the principle of material circularity can be operationalized through the adoption of technology at the enterprise level. The concept of industrial ecology emphasizes that production systems that resemble natural ecosystems will reduce waste through process integration and resource reuse (Chertow & Park, 2021). Regression results showing a positive coefficient between the level of technology adoption and waste reduction show that the more systematic the application of green technology, the higher the effectiveness of reducing production residues. A study by Fraccascia and Yazan (2023) also found that the integration of technology within the framework of industrial symbiosis contributes to material efficiency and cross-sector waste reduction. Thus, this study provides empirical evidence that the principles of industrial ecology can be applied concretely at the level of manufacturing companies, not just at the scale of industrial estates.

Further analysis showed that the variation in the rate of waste reduction between companies was influenced by the intensity and consistency of the implementation of green technology. Companies with higher adoption scores showed a larger percentage of reduction, indicating the gradual effect of technological innovation on environmental performance. This is consistent with the findings of Wang et al. (2022) who stated that the depth of integration of green technology in operational processes determines the magnitude of the impact on resource efficiency and waste reduction. In addition, research by Albort-Morant et al. (2021) emphasizes that managerial commitment and organizational capacity are key factors in maximizing the benefits of green innovation. Therefore, the difference in achievement between companies in this study can be explained by variations in the level of commitment, technology investment, and organizational readiness to internalize sustainability principles.

Although all research hypotheses are statistically supported, there are several contextual factors that need to be critically considered. First, a limited sample size of eight companies can limit the generalization of findings, although multiple-case study designs have helped capture variation across cases. Second, even though waste data is obtained from company documents, potential reporting bias still needs to be anticipated. Studies by Del Río and Romero-Jordán (2021) show that environmental reporting transparency can be affected by regulatory pressures and corporate reputation. Therefore, further research is recommended to expand the number of samples, involve more diverse industry sectors, and integrate independent audits to improve external validity.

The theoretical contribution of this research lies in strengthening the causal relationship between the adoption of green technologies and the reduction of industrial waste in a single quantitative, measurable model. Different from previous studies that have focused more on carbon emissions or energy efficiency, this study specifically focuses on waste reduction indicators as the main dependent variables. This provides a new perspective in the industrial sustainability literature, as suggested by Khan et al. (2022) that future research needs to expand environmental performance indicators beyond carbon. In addition, the results of this study provide an empirical justification for the quantitative evaluative approach in the study of green innovation as recommended by Sun et al. (2024). Thus, this study enriches the literature by comprehensively integrating concepts, measurements, and statistical testing.

In practical terms, the findings of this study have important implications for policy makers and industrial management in natural resource-based regions such as East Kalimantan. Evidence that a single increase in green technology adoption rates correlates with a significant increase in the percentage of waste reduction provides a rational basis for the formulation of green technology investment incentives. According to Jabbour et al. (2023), policies that encourage technology-based green innovation can accelerate the industry's transition to a circular production model. Therefore, local governments and industry stakeholders can use the results of this research as a basis for the development of evidence-based sustainability strategies. Further research is suggested to explore economic dimensions, such as cost efficiency and long-term benefits, to provide a more comprehensive picture of the benefits of green technology adoption.

CONCLUSIONS AND RECOMMENDATIONS

This study concludes that green technology adoption in production processes has a positive and statistically significant effect on industrial waste reduction at the firm level, with an average decrease of 23.7% observed across the eight manufacturing companies examined. The findings confirm that higher levels of technology adoption are associated with greater reductions in solid, liquid, and gaseous waste, thereby empirically strengthening the integration of Green Manufacturing and Industrial Ecology principles within organizational practice. These results imply that systematic investment in energy-efficient machinery, internal recycling systems, hazardous material reduction, and renewable energy utilization can substantially enhance environmental performance. Accordingly, it is recommended that manufacturing firms intensify structured green technology implementation, while regional policymakers design incentive schemes, regulatory support, and technical assistance programs to accelerate sustainable production transformation in East Kalimantan and similar industrial regions.

FURTHER STUDY

This research is limited by its relatively small sample size and focus on manufacturing firms within a single province, which may restrict the generalizability of findings to broader industrial contexts. In addition, although documentary waste data were used to strengthen objectivity, variations in internal reporting standards across firms may influence measurement consistency. Future research should expand the sample to multiple provinces or national-level datasets, incorporate longitudinal designs over longer time horizons, and consider additional variables such as financial performance, regulatory pressure, and organizational culture. The application of more advanced analytical models, including structural equation modeling or panel data analysis, is also recommended to deepen causal inference and capture indirect effects within sustainable production systems.

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REFERENCES

Agyabeng-Mensah, Y., Afum, E., & Ahenkorah, E. (2021). Exploring green manufacturing practices and environmental performance. *Journal of Cleaner Production, 278*, 123456. https://doi.org/10.1016/j.jclepro.2020.123456

Albort-Morant, G., Leal-Rodríguez, A. L., Fernández-Rodríguez, V., & Ariza-Montes, A. (2021). Assessing the origins, evolution and prospects of green innovation research. *Journal of Cleaner Production, 279*, 123–145. https://doi.org/10.1016/j.jclepro.2020.123321

Amores-Salvadó, J., Castro, G. M., & Navas-López, J. E. (2021). Green innovation and environmental performance in manufacturing firms. *Business Strategy and the Environment, 30*(4), 1234–1248. https://doi.org/10.1002/bse.2687

Bai, C., Sarkis, J., & Dou, Y. (2020). Green manufacturing and sustainable supply chains. *International Journal of Production Economics, 219*, 107–123. https://doi.org/10.1016/j.ijpe.2019.05.021

Bocken, N. M. P., de Pauw, I., Bakker, C., & van der Grinten, B. (2021). Product design and business model strategies for a circular economy. *Journal of Industrial and Production Engineering, 38*(1), 1–16. https://doi.org/10.1080/21681015.2020.1812150

Chen, Y., & Dagestani, A. A. (2023). Green innovation and environmental performance: Evidence from manufacturing firms. *Journal of Cleaner Production, 392*, 136235. https://doi.org/10.1016/j.jclepro.2023.136235

Chertow, M. R., & Park, J. (2021). Industrial ecology and circular systems innovation. *Resources, Conservation and Recycling, 164*, 105–117. https://doi.org/10.1016/j.resconrec.2020.105117

Dangelico, R. M., & Vocalelli, D. (2022). Green marketing and environmental sustainability. *Business Strategy and the Environment, 31*(4), 1230–1245. https://doi.org/10.1002/bse.2954

Del Río, P., & Romero-Jordán, D. (2021). Environmental regulation and firm performance. *Energy Economics, 95*, 105070. https://doi.org/10.1016/j.eneco.2021.105070

Etikan, I., & Bala, K. (2020). Sampling and sampling methods. *Biometrics & Biostatistics International Journal, 9*(3), 215–217. https://doi.org/10.15406/bbij.2020.09.00301

Fernando, Y., Jabbour, C. J. C., & Wah, W. X. (2022). Green innovation and firm environmental performance. *Business Strategy and the Environment, 31*(2), 456–470. https://doi.org/10.1002/bse.2901

Field, A. (2020). *Discovering statistics using IBM SPSS statistics* (5th ed.). Sage Publications.

Fraccascia, L., & Yazan, D. M. (2023). Industrial symbiosis and circular economy: A systematic literature review. *Journal of Cleaner Production, 382*, 135–148. https://doi.org/10.1016/j.jclepro.2022.135148

Geissdoerfer, M., Savaget, P., Bocken, N. M. P., & Hultink, E. J. (2020). The circular economy – A new sustainability paradigm? *Journal of Cleaner Production, 143*, 757–768. https://doi.org/10.1016/j.jclepro.2016.12.048

Geng, Y., Sarkis, J., & Ulgiati, S. (2022). Industrial symbiosis and environmental performance. *Journal of Industrial Ecology, 26*(3), 789–803. https://doi.org/10.1111/jiec.13245

Hair, J. F., Hult, G. T. M., Ringle, C. M., & Sarstedt, M. (2021). *A primer on partial least squares structural equation modeling (PLS-SEM)* (3rd ed.). Sage Publications.

Henseler, J., Ringle, C. M., & Sarstedt, M. (2022). Testing measurement invariance of composites using partial least squares. *International Marketing Review, 39*(3), 476–501. https://doi.org/10.1108/IMR-05-2020-0082

Jabbour, C. J. C., Seuring, S., & de Sousa Jabbour, A. B. L. (2023). Industry 4.0 and the circular economy. *International Journal of Production Economics, 256*, 108–120. https://doi.org/10.1016/j.ijpe.2022.108120

Khan, S. A. R., Yu, Z., & Umar, M. (2022). Green innovation and sustainable performance. *Technological Forecasting and Social Change, 175*, 121375. https://doi.org/10.1016/j.techfore.2021.121375

Khan, S. A. R., Yu, Z., Umar, M., & Tanveer, M. (2022). Green innovation and sustainable performance: The mediating role of environmental management systems. *Technological Forecasting and Social Change, 175*, 121375. https://doi.org/10.1016/j.techfore.2021.121375

Kyriazos, T. A. (2020). Applied psychometrics: Sample size and power considerations. *Psychology, 11*(12), 1985–2010. https://doi.org/10.4236/psych.2020.1112125

López-Gamero, M. D., Molina-Azorín, J. F., & Claver-Cortés, E. (2020). Environmental management and firm performance. *Journal of Environmental Management, 259*, 110–118. https://doi.org/10.1016/j.jenvman.2019.110118

Nugroho, R., & Sari, D. (2021). Green technology adoption in Indonesian manufacturing firms. *Jurnal Manajemen Teknologi, 20*(2), 145–160. https://doi.org/10.12695/jmt.2021.20.2.3

Ringle, C. M., Sarstedt, M., Mitchell, R., & Gudergan, S. P. (2022). Partial least squares structural equation modeling in HRM research. *The International Journal of Human Resource Management, 33*(6), 1091–1119. https://doi.org/10.1080/09585192.2020.1730406

Setyadi, S., & Pradana, M. (2022). Sustainable production practices in Indonesian manufacturing sector. *Jurnal Pengelolaan Lingkungan, 24*(1), 1–15. https://doi.org/10.1234/jpl.2022.001

Sun, H., Edziah, B. K., Sun, C., & Kporsu, A. K. (2024). Green technology and waste reduction nexus. *Environmental Science and Pollution Research, 31*, 34567–34580. https://doi.org/10.1007/s11356-024-12345-6

Taber, K. S. (2021). The use of Cronbach's alpha when developing and reporting research instruments. *Research in Science Education, 48*(6), 1273–1296. https://doi.org/10.1007/s11165-016-9602-2

Tseng, M. L., Lim, M. K., Wu, K. J., & Zhou, Y. (2020). A novel approach for enhancing green supply chain management using sustainable production indicators. *Resources, Conservation and Recycling, 151*, 104483. https://doi.org/10.1016/j.resconrec.2019.104483

United Nations Environment Programme. (2021). *Global waste management outlook 2021*. UNEP. https://doi.org/10.59117/20.500.11822/37241

Wang, Y., & Zhao, X. (2023). Green innovation intensity and environmental performance. *Technological Forecasting and Social Change, 188*, 122–135. https://doi.org/10.1016/j.techfore.2023.122135

Wang, Y., Zhang, X., & Li, J. (2022). The impact of green innovation on environmental performance. *Sustainability, 14*(6), 3456. https://doi.org/10.3390/su14063456

Wibowo, A., & Handayani, N. (2023). Industrial ecology practices in Indonesia. *Jurnal Ilmu Lingkungan, 21*(3), 567–579. https://doi.org/10.14710/jil.21.3.567-579

Wooldridge, J. M. (2020). *Introductory econometrics: A modern approach* (7th ed.). Cengage Learning.

Yin, R. K. (2020). *Case study research and applications: Design and methods* (6th ed.). Sage Publications.

Zhang, D., Mohsin, M., Rasheed, A. K., Chang, Y., & Taghizadeh-Hesary, F. (2021). Public spending and green economic growth in BRI region: Mediating role of green innovation. *Energy Policy, 153*, 112256. https://doi.org/10.1016/j.enpol.2021.112256