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Article

Integration of Waste Management and Environmental Impact Assessment for Sustainable Manufacturing in Sukolego Tofu Production

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Abstract

The tofu production process, particularly in small- to medium-scale industries like Sukolego Tofu Production, generates various types of waste that pose environmental challenges. This study aims to integrate waste management practices and environmental impact analysis within a sustainable manufacturing framework. This study uses a quantitative method with a causal associative approach to measure Waste Management (X1), Environmental Impact Assessment (X2), and Sustainable Manufacturing (Y). Data was collected through questionnaires distributed to 50 people living around the Sukolego Tofu Factory. Data that meets the validity, reliability, and classical assumption tests is processed to produce a linear regression equation. The analysis results indicate that the Environmental Impact Assessment (EIA) variable has a positive and significant effect on Sustainable Manufacturing, both partially and simultaneously. However, the Waste Management variable does not exhibit a significant effect. This is supported by the significance (Sig.) values, where the EIA variable yields a value of 0.004 ($p < 0.05$), indicating statistical significance, whereas the Waste Management variable yields a value of 0.702, which is not statistically significant.

Keywords: Waste Management, Environmental Impact Assessment, Sustainable Manufacturing, Tofu Production.

1. Introduction

The growing demand for environmentally responsible production has urged industries of all scales, including traditional food manufacturers, to adopt sustainable practices [1]. One such industry is tofu production, which is known for generating considerable amounts of solid and liquid waste [2];[3]. When not properly managed, this waste contributes to environmental degradation, such as water and soil pollution, and can negatively affect the health and well-being of surrounding communities [4];[5]. Sukolego Tofu Production, a small-to-medium-sized enterprise located in Indonesia, represents a typical tofu manufacturing unit facing the challenge of balancing productivity and environmental responsibility. The PLS-SEM based empirical model shows that Green Supply Chain Management (GSCM) practices enhance Zero Waste Management and green innovation (eco-innovation), which significantly reduces environmental impact and improves corporate environmental performance [6].

Although tofu is considered a sustainable food product due to its plant-based origin, the production process often lacks proper waste management systems and ecological assessment practices. While tofu contributes to a lower environmental footprint than animal-based protein sources, the sustainability of the final product is significantly influenced by how it is manufactured [7]. In many small- to medium-scale tofu industries, especially in developing regions, waste such as soybean residue (okara), wastewater, and by-products are frequently disposed of without adequate treatment [8]. This can result in environmental issues, including water pollution, foul odors, and increased organic load in surrounding ecosystems [9]. Furthermore, the absence of structured environmental impact assessments means these negative externalities often go unmonitored and unmitigated. Without proper intervention, the tofu production process can contradict the principles of sustainability that the product represents. Therefore, it is essential to integrate waste management improvements and environmental monitoring into the production framework to align the value chain with the Sustainable Development Goals [10]. This gap underscores the need for a structured approach that integrates waste handling and environmental impact analysis within a broader sustainable manufacturing framework.

Sustainable manufacturing creates products through economically sound processes that minimize negative environmental impacts while conserving energy and natural resources [10], [11]; [12]. This approach maximizes production efficiency and profitability, emphasizing long-term ecological stewardship and social responsibility. By integrating environmental considerations into each stage of the manufacturing lifecycle—from raw material selection, production, distribution, to waste disposal—sustainable manufacturing seeks to reduce carbon emissions, prevent pollution, and limit the depletion of finite resources [13]; [14]. Moreover, it encourages the use of renewable energy sources, cleaner technologies, and closed-loop systems to enhance sustainability. In doing so, sustainable manufacturing contributes to achieving broader goals such as climate change mitigation, sustainable economic growth, and compliance with environmental regulations [15]. For industries such as tofu production, where traditional processes may lack environmental safeguards, adopting sustainable manufacturing practices is crucial to reducing their ecological footprint while maintaining productivity and competitiveness [16]. Applying this concept to tofu production involves enhancing operational efficiency and minimizing environmental impact through improved waste management and process optimization.

This study examines the integration of waste management practices and environmental impact analysis in supporting sustainable manufacturing at the Sukolego Tofu Production facility. To achieve this, the research applies a multiple linear regression method, with Waste Management and Environmental Impact Analysis as exogenous variables and Sustainable Manufacturing as the endogenous variable. The aim is to quantitatively assess the influence of these two factors on the implementation of sustainable manufacturing practices. The results will provide practical insights and strategic recommendations for enhancing environmental performance in small-scale tofu production industries.

2. Materials and Methods

This research was conducted at the Sukolego Tofu Production Factory in Sidoarjo, East Java, Indonesia. This site was selected because it was relevant to the study's focus on small-scale tofu manufacturing and its associated environmental management challenges. The data collection process employed both interview methods and the distribution of structured questionnaires to gather comprehensive information related to waste management practices, perceived environmental impacts, and sustainability awareness.

The questionnaires were designed using a Likert scale, allowing respondents to express the degree of their agreement or disagreement with various statements related to the research variables. A total of 50 respondents were selected from the residential community surrounding the Sukolego Tofu Factory. The sample was determined based on purposive sampling, targeting individuals who were directly or indirectly affected by the factory's operations and thus had relevant insight into the area's environmental conditions. Purposive sampling was employed to ensure that respondents had relevant, experiential knowledge of the environmental effects of the Sukolego Tofu Factory. This method enabled the study to gather targeted, context-rich insights that might not have been captured through a purely random sample.

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Data was processed using the SPSS (Statistical Package for the Social Sciences) software. After confirming that the data met the necessary assumptions, the study applied multiple linear regression analysis to examine the relationship between the independent variables, Waste Management (X1) and Environmental Impact Analysis (X2), and the dependent variable, Sustainable Manufacturing (Y). Lastly, hypothesis testing was conducted using the t-test (to assess the significance of individual predictors), the F-test (to evaluate the overall model significance), and the coefficient of determination (R^2) to measure the proportion of variance [17].

Table 2. Waste Management Indicators

Item	Score
WM 1	Community awareness of waste separation practices
WM 2	Perceived cleanliness of surrounding areas
WM 3	Observed waste disposal methods
WM 4	Reported environmental issues related to waste
WM 5	Community perception of waste reduction efforts
WM 6	Access to information on waste handling
EIA 1	Public awareness of EIA documents (e.g., AMDAL, UKL-UPL)
EIA 2	Perception of environmental degradation (air, water, land)
EIA 3	Community involvement in environmental consultations
EIA 4	Visibility of mitigation infrastructure (e.g., filtration, treatment)
EIA 5	Responsiveness to community complaints
EIA 6	Perceived commitment to sustainability and environmental improvement
SM 1	Perceived reduction in environmental pollution
SM 2	Awareness of eco-friendly production practices
SM 3	Community perception of resource efficiency (e.g., water, energy)
SM 4	Perceived social responsibility of the factory
SM 5	Community satisfaction with factory communication and transparency
SM 6	Community participation opportunities in environmental programs

3. Results and Discussion

The output of the normality test was obtained using the Kolmogorov-Smirnov method, a statistical technique commonly employed to assess whether a dataset follows a normal distribution.

Table 1. Normality Test.

Item	Score
Kolmogorov-Smirnov	0.836
Asymp. Sig (2-tailed)	0.486

The normality test using the Kolmogorov-Smirnov (K-S) method is conducted to determine whether the residuals (or data) follow a normal distribution, which is one of the key assumptions in linear regression analysis [18]. In the test output, the Asymp. Sig. (2-tailed) The value is 0.486. This p-value is then compared to the commonly used significance level of 0.05. Since the value of 0.486 is greater than 0.05, we fail to reject the null hypothesis, which states that the data follow a normal distribution. In other words, no statistically significant deviation from normality is detected in the data.

The output of the heteroscedasticity test using the Glejser method provides insight into whether the variance of the residuals (errors) in a regression model is constant, a key assumption of the classical linear regression model [19]. Heteroscedasticity violates this assumption, potentially leading to inefficient estimates and misleading statistical inferences.

Table 3. Heteroscedasticity Test.

Variables	Score
Waste Management	0.225
Environmental Impact	0.383

From the output, the significance values for the Environmental Impact variable and the Waste Management variable are 0.383 and 0.225, respectively. Since the values are greater than 0.05, there are no indications of heteroscedasticity. The output of the multicollinearity test indicates that

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the Tolerance value for the Environmental Impact variable and the Waste Management variable is 1.000, which is greater than 0.10, indicating no multicollinearity in the regression model.

Table 4. Multicollinearity Test.

Variables	Score
Waste Management	1.000
Environmental Impact	1.000

Meanwhile, the VIF (Variance Inflation Factor) values for the Environmental Impact variable and the Waste Management variable are 1.000; this value is less than 10.00, indicating no multicollinearity in the regression model. A Variance Inflation Factor (VIF) value of 1.000 is theoretically ideal and suggests no linear correlation between the predictor variables. However, in real-world datasets, such a perfectly uncorrelated relationship is extremely rare, as even slight overlaps in predictor variables typically result in VIF values greater than 1.0. In this study, the VIF values of 1.000 for both Waste Management and Environmental Impact variables are still statistically plausible, but likely influenced by the small number of predictor variables (only two), reducing the chance for inter-variable correlation.

The Adjusted R-Square is a modified version of R-Square (R^2) that adjusts for the number of explanatory variables in a regression model [20]. It reflects how well the independent variables explain the variation in the dependent variable while penalizing the addition of irrelevant predictors. Unlike R^2, the Adjusted R^2 can decrease if a new variable doesn't significantly improve the model [21].

Table 5. Coefficient of Determination Test.

Item	Score
Waste Management Environmental Impact	0.126

While the model demonstrates a statistically significant relationship, its explanatory power is modest (Adjusted R^2 = 0.126), indicating that additional factors beyond waste management and environmental impact likely contribute to sustainable manufacturing at the Sukolego Tofu Factory.

Table 6. Coefficient of Determination Test.

Item	Score
Waste Management Environmental Impact	0.016

Based on the F-test results, the significance value is 0.016, which is less than the threshold value of 0.05. This indicates that the regression model is statistically fit, and it can be concluded that the variables Environmental Impact and Waste Management have a significant simultaneous effect on the Sustainable Manufacturing Approach.

The partial significance test results show that the Environmental Impact variable has a p-value of 0.004 (<0.05), indicating a statistically significant influence on the Sustainable Manufacturing Approach. In contrast, the Waste Management variable has a p-value of 0.702 (> 0.05), suggesting that it does not have a significant individual effect.

Table 7. Coefficient of Determination Test.

Item	t	Sig
Constant	2.337	0.024
Waste Management	-0.385	0.702
Environmental Impact	2.985	0.004

However, based on the F-test, the simultaneous significance value is 0.024 (< 0.05), confirming that the regression model is significant. Thus, it can be concluded that the Environmental Impact variable plays an important role, while Waste Management does not, although their combination still provides a meaningful explanation of the dependent variable.

The regression coefficient for Waste Management (X_1) is -0.702, which means that for each one-unit increase in Waste Management, the value of the Sustainable Manufacturing Approach is predicted to decrease by 0.702 units, assuming the Environmental Impact variable remains constant. This negative relationship suggests that, in the context of this model, higher waste

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management is associated with a reduction in the sustainable manufacturing index, possibly due to other underlying trade-offs or operational challenges [22].

On the other hand, the coefficient for Environmental Impact (X_2) is 0.004, indicating that for every additional unit increase in the Environmental Impact score, the Sustainable Manufacturing Approach is predicted to increase by 0.004 units, holding Waste Management constant. Although this coefficient is relatively small, its positive value suggests a direct relationship between environmental considerations and sustainable manufacturing. In summary, the regression equation shows contrasting influences of the two independent variables: while Environmental Impact contributes positively (albeit slightly) to sustainable manufacturing practices, Waste Management appears to have a negative association within the scope of this model.

Based on the findings, local tofu producers are encouraged to go beyond technical compliance in waste management by actively engaging with community perceptions and improving the visibility of sustainability efforts. While environmental impact assessments were positively associated with sustainable manufacturing, waste management did not significantly contribute — a potential result of misperceptions or inadequate implementation. To address this, producers should enhance transparency, improve operational practices, and collaborate with stakeholders in participatory waste initiatives. Additionally, adopting simple EIA tools, promoting cleaner production, and aligning sustainability actions with local concerns can lead to more meaningful and perceived improvements in environmental responsibility.

4. Conclusions

Environmental Impact has a statistically significant effect on the Sustainable Manufacturing Approach. This implies that improvements or changes in ecological impact considerations will likely influence the implementation of sustainable manufacturing practices. The statistically significant effect of the Environmental Impact variable on the Sustainable Manufacturing approach suggests that concerns related to ecological consequences, such as emissions, pollution, resource depletion, and waste generation, play a critical role in shaping sustainable manufacturing practices [23]. This significance implies that organizations are more likely to adopt strategies and technologies aligned with sustainability principles when they emphasize minimizing their environmental footprint [24]. On the other hand, waste management does not show a significant effect, suggesting that its influence on sustainable manufacturing is not strong enough to be statistically confirmed in this model or dataset. One possible explanation for why Waste Management does not demonstrate a statistically significant effect on the Sustainable Manufacturing Approach is that its influence may be indirectly mediated through other variables not captured in the current model, such as technological capabilities, regulatory compliance, organizational culture, and employee awareness. [25].

However, when both variables are tested using the F-test, the overall regression model is significant, indicating that at least one of the variables (in this case, Environmental Impact) explains a portion of the variance in the Sustainable Manufacturing approach [26]. In contrast, the insignificant effect of Waste Management highlights a potential disconnect between existing waste-handling practices and their perceived impact on sustainability. This could be due to several reasons: the waste practices may not yet meet community expectations; their benefits may not be clearly communicated; or their influence may be mediated through unobserved variables such as technology adoption, operational scale, or management commitment. This calls for more integrated waste strategies that are not only technically effective but also socially visible and inclusive.

References

[1] S. Prasanna, P. Verma, and S. Bodh, "The role of food industries in sustainability transition: A review," *Environ Dev Sustain*, pp. 1–21, 2024.

[2] T. Li, C. Zhan, G. Guo, Z. Liu, N. Hao, and P. Ouyang, "Tofu processing wastewater as a low-cost substrate for high activity nattokinase production using

Bacillus subtilis," *BMC Biotechnol*, vol. 21, pp. 1–12, 2021.

[3] R. Novasani, Y. C. Winursito, M. C. P. A. Islami, and A. Pervaya, "Analisis Alternatif Penerapan Produksi Bersih Pada Salah Satu Industri Tahu Kediri Melalui Model Interaktif," in *Prosiding Seminar Nasional Waluyo Jatmiko*, 2023, pp. 571–580.

[4] M. Islami, A. Suryadi, J. F. Zahirah, and G. A. K. Sa'idan, "Penyuluhan Pembuatan Puding Kulit Pisang Sebagai Solusi Zero-Waste Di Desa Pasi, Kabupaten Lamongan, Jawa Timur," *INCOME: Indonesian Journal of Community Service and Engagement*, vol. 2, no. 3, pp. 214–220, 2023.

[5] M. Colimoro, M. Ripa, R. Santagata, and S. Ulgiati, "Environmental impacts and benefits of tofu production from organic and conventional soybean cropping: improvement potential from renewable energy use and circular economy patterns," *Environments*, vol. 10, no. 5, p. 73, 2023.

[6] "scholar".

[7] M. Cellura, M. A. Cusenza, S. Longo, L. Q. Luu, and T. Skurk, "Life cycle environmental impacts and health effects of protein-rich food as meat alternatives: a review," *Sustainability*, vol. 14, no. 2, p. 979, 2022.

[8] K. Dhamodharan, T. Konduru, M. Kannan, and S. K. Malyan, "Techno-economic feasibility and hurdles on agricultural waste management," in *Emerging trends to approaching zero waste*, Elsevier, 2022, pp. 243–264.

[9] G. Singh, A. Singh, P. Singh, R. Shukla, S. Tripathi, and V. K. Mishra, "The fate of organic pollutants and their microbial degradation in water bodies," *Pollutants and water management: resources, strategies and scarcity*, pp. 210–240, 2021.

[10] K. Aravindaraj and P. R. Chinna, "A systematic literature review of integration of industry 4.0 and warehouse management to achieve Sustainable Development Goals (SDGs)," *Cleaner logistics and supply chain*, vol. 5, p. 100072, 2022.

[11] I. Khan, F. Hou, H. P. Le, and S. A. Ali, "Do natural resources, urbanization, and value-adding manufacturing affect environmental quality? Evidence from the top ten manufacturing countries," *Resources Policy*, vol. 72, p. 102109, 2021.

[12] A. Suryadi and M. C. P. A. Islami, "Analysis of data mining at supermarket x in Surabaya using market basket analysis to determine consumer buying patterns," *Nusantara Science and Technology Proceedings*, pp. 28–32, 2022.

[13] A. E. Torkayesh *et al.*, "Integrating life cycle assessment and multi criteria decision making for sustainable waste management: key issues and recommendations for future studies," *Renewable and Sustainable Energy Reviews*, vol. 168, p. 112819, 2022.

[14] M. C. P. A. Islami, R. N. Sari, M. Waluyo, and Q. Z. M. Arifin, "Analysis of green product implementation strategy in the batik industry to develop eco-friendly," in *IOP Conference Series: Earth and Environmental Science*, IOP Publishing, 2025, p. 012029.

[15] N. O. Ndubisi, X. A. Zhai, and K. Lai, "Small and medium manufacturing enterprises and Asia's sustainable economic development," *Int J Prod Econ*, vol. 233, p. 107971, 2021.

[16] M. Islami, A. Suryadi, J. F. Zahirah, and G. A. K. Sa'idan, "Penyuluhan Pembuatan Puding Kulit Pisang Sebagai Solusi Zero-Waste Di Desa Pasi, Kabupaten Lamongan, Jawa Timur," *INCOME: Indonesian Journal of Community Service and Engagement*, vol. 2, no. 3, pp. 214–220, 2023.

[17] X. Xu, H. Du, and Z. Lian, "Discussion on regression analysis with small determination coefficient in human-environment researches," *Indoor Air*, vol. 32, no. 10, p. e13117, 2022.

[18] X. J. Bilon, "Normality and significance testing in simple linear regression model for large sample sizes: a simulation study," *Communications in Statistics-Simulation and Computation*, vol. 52, no. 6, pp. 2781–2797, 2023.

[19] I. Đalić and S. Terzić, "Violation of the assumption of homoscedasticity and detection of heteroscedasticity," *Decision*

DOI:10.4186

Making: Applications in Management and Engineering, vol. 4, no. 1, pp. 1–18, 2021.

[20] S. Deilami, K. Abbasi, A. Houshyar, H. Izadneshan, and H. M. Beni, "Study the effect of temperature variation and intrinsic layer thickness on the linear response of a PIN photodetector: A finite element method approach," *Results in Engineering*, vol. 17, p. 100810, 2023.

[21] G. James, D. Witten, T. Hastie, R. Tibshirani, and J. Taylor, "Linear model selection and regularization," in *An Introduction to Statistical Learning: with Applications in Python*, Springer, 2023, pp. 229–288.

[22] K. Rüdele, M. Wolf, and C. Ramsauer, "Synergies and trade-offs between ecological and productivity-enhancing measures in industrial production–a systematic review," *Management of Environmental Quality: An International Journal*, vol. 35, no. 6, pp. 1315–1353, 2024.

[23] H. Ali, T. Chen, and Y. Hao, "Sustainable manufacturing practices, competitive capabilities, and sustainable performance: moderating role of environmental regulations," *Sustainability*, vol. 13, no. 18, p. 10051, 2021.

[24] S. Sahoo, A. Kumar, and A. Upadhyay, "How do green knowledge management and green technology innovation impact corporate environmental performance? Understanding the role of green knowledge acquisition," *Bus Strategy Environ*, vol. 32, no. 1, pp. 551–569, 2023.

[25] I. H. V Gue, N. S. A. Lopez, A. S. F. Chiu, A. T. Ubando, and R. R. Tan, "Predicting waste management system performance from city and country attributes," *J Clean Prod*, vol. 366, p. 132951, 2022.

[26] H. Wang, "Role of environmental degradation and energy use for agricultural economic growth: Sustainable implications based on ARDL estimation," *Environ Technol Innov*, vol. 25, p. 102028, 2022.

DOI:10.4186