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Green Manufacturing Practices and Sustainable Industrial Performance: A Mixed-Methods Study of Environmental Innovation in Cambodian Manufacturers

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ABSTRACT

This study examined how green manufacturing practices influence sustainable industrial performance through environmental innovation implementation in Cambodian manufacturing firms. A sequential explanatory mixed-methods design was applied. Quantitative data were collected from 128 managers and supervisors in 24 manufacturing firms using a structured questionnaire and analyzed with partial least squares structural equation modeling. Qualitative evidence came from 16 semi-structured interviews with production, quality, maintenance, and environmental managers from high- and moderate-adopting firms. Green manufacturing practices were strongly associated with environmental innovation implementation (beta = 0.63, $p < .001$) and directly with sustainable industrial performance (beta = 0.29, $p < .001$). Environmental innovation implementation also predicted sustainable industrial performance (beta = 0.47, $p < .001$) and partially mediated the relationship between green manufacturing and performance. The model explained 40% of the variance in environmental innovation implementation and 69% of the variance in sustainable industrial performance. Interview data showed that energy monitoring, waste segregation, process digitization, and supplier coordination were the main levers of improvement, while capital intensity and skills gaps remained the main constraints. Green manufacturing contributed to higher sustainable industrial performance when firms translated environmental intentions into process-level innovations and measurement routines. The findings support a capability-based view of sustainability implementation and indicate that managerial attention should shift from symbolic environmental claims to operational redesign, data visibility, and cross-functional discipline.

Keywords: *Green Manufacturing; Environmental Innovation; Sustainable Industrial Performance; Mixed Methods; Manufacturing Firms.*

1. INTRODUCTION

Manufacturing remains central to industrial value creation, yet it is also one of the sectors where energy use, waste generation, and pollution intensity are most visible. Climate pressure, resource scarcity, and tighter environmental standards have pushed firms to reassess the design of production systems, procurement routines, and shop-floor decision making. Research on sustainability in manufacturing has moved beyond a narrow emphasis on pollution control and now treats green practices as part of a broader strategic and operational capability set that affects competitiveness, resilience, and long-term performance (Abualfaraa et al., 2020; Vrchota et al., 2020; Ali et al., 2021). Global policy agendas reinforce this shift by linking industrial transformation with lower emissions, responsible consumption, and efficiency gains across the value chain (Khan et al., 2025).

Evidence from recent studies shows that the performance effects of green manufacturing are not linear or purely symbolic. Green process innovation can initially raise costs before yielding financial and environmental returns, which implies that implementation quality matters more than declarative commitment alone (Xie et al., 2022a; Xie et al., 2022b). Sustainable manufacturing practices also tend to improve performance when firms combine them with competitive capabilities, environmental regulation awareness, and managerial coordination rather than treating them as isolated tools (Ali et al., 2021; Sarfraz et al., 2022). Reviews of Industry 4.0 and green processes further indicate that digital visibility, data capture, and process control help firms convert sustainability intentions into measurable outcomes such as energy saving, emission reduction, and resource optimization (Vrchota et al., 2020; Contini et al., 2022; Peças et al., 2023).

The Cambodian manufacturing context is analytically important because firms face a dual challenge. They must maintain cost competitiveness in domestic and export markets while responding to stricter environmental expectations from regulators, buyers, and local communities. Recent regional studies show that green innovation, green product and process practices, and green supply chain integration can improve performance, yet these effects depend on organizational capability, supplier coordination, and implementation depth rather than on generic sustainability rhetoric alone (Fatimah et al., 2020; Novitasari et al., 2022; Sumayyah et al., 2025). The same pattern appears in recent work on circular economy practices and environmental performance, which suggests that firms obtain stronger results when environmental initiatives are embedded in operating routines instead of handled as peripheral projects (Amin et al., 2024; Batool et al., 2025).

Existing studies have not fully explained how green manufacturing practices are translated into sustainable industrial performance through the intermediate step of environmental innovation implementation inside firms. Much of the literature relies on survey-only designs or secondary financial data, which identifies association but leaves the implementation logic underexplored. The practical question remains: which green practices are operationally meaningful, how do managers mobilize them, and which barriers prevent firms from converting sustainability goals into reliable performance gains? Mixed-method evidence that integrates statistical estimation with managerial interpretation is still limited, particularly in manufacturing settings where environmental innovation is pursued under resource constraints and heterogeneous regulatory pressure (Sarfraz et al., 2022; Karuppiah et al., 2024; Harikannan et al., 2025).

This study addressed that gap by examining the relationship between green manufacturing practices, environmental innovation implementation, and sustainable industrial performance in Cambodian manufacturing companies.

2. LITERATURE REVIEW

Green manufacturing is commonly described as a bundle of production, procurement, and managerial practices that reduce resource consumption and environmental damage while preserving output quality and process reliability. Reviews show that the most frequently observed components include eco-design, energy efficiency, waste minimization, green purchasing, and employee training. These components form an interconnected system rather than a set of independent actions, because gains in one area often depend on coordination in another area. Lean and green practices are therefore best understood as complementary routines that reduce non-value-adding activity and environmental burden at the same time (Abualfaraa et al., 2020; Machingura et al., 2024).

Environmental performance and operational efficiency are the two recurring outcome domains in the literature. Environmental performance refers to lower emission intensity, reduced waste, better compliance, and more disciplined resource use. Operational efficiency refers to faster cycles, lower scrap, lower rework, and more stable throughput. Studies on sustainable manufacturing show that these outcomes frequently move together when firms deploy process discipline, monitoring systems, and management commitment. Environmental regulation can strengthen the payoffs of these practices, because it creates an external incentive for firms to internalize environmental costs and accelerate process improvement (Ali et al., 2021; Wieczorek-Kosmala et al., 2021; Baquero et al., 2024).

Green process innovation is a particularly useful bridge between sustainability intent and performance. Empirical studies show that green process innovation can improve financial and environmental outcomes, yet the payoffs often emerge after an adjustment period in which firms bear learning costs and redesign expenses (Xie et al., 2022a; Xie et al., 2022b). Innovation capability, digital leadership, and green social capital help firms absorb that adjustment period by making environmental experimentation more coordinated and less disruptive (Sarfraz et al., 2022; Guenther et al., 2023). The implication is that green manufacturing does not work as a static checklist. It works as a process of capability formation, measurement, and translation into plant-level routines.

Industry 4.0 and related digital technologies have also changed the implementation profile of green manufacturing. Reviews show that data logging, sensor systems, traceability tools, and integrated planning platforms make resource losses more visible and easier to control (Vrchota et al., 2020; Contini et al., 2022; Yadav et al., 2022). Digital systems do not automatically produce sustainability gains, since firms still need cross-functional interpretation and managerial discipline. They do, however, reduce the information asymmetry that often weakens environmental initiatives on the factory floor. This point is consistent with studies that identify sustainability assessment, data-driven monitoring, and smart waste management as mechanisms that connect technical upgrades to measurable environmental outcomes (Fatimah et al., 2020; Peças et al., 2023; Khan et al., 2025).

A second stream of literature focuses on organizational enablers. Green human resource management, environmental training, and knowledge sharing shape whether workers adopt environmental routines consistently or treat them as temporary projects (Novitasari et al., 2022; López-Cózar-Navarro et al., 2024; Sumayyah et al., 2025). Green dynamic capability and green entrepreneurial orientation also appear to strengthen sustainability performance because they help firms adapt practices to changing constraints rather than replicate a generic template (Asiedu et al., 2025; Baquero et al., 2024). Recent reviews of sustainable manufacturing and environmental innovation suggest that performance gains depend on the fit between technology, leadership, and organizational learning, not on technology adoption alone (Karuppiah et al., 2024; Harikannan et al., 2025).

The literature leaves a clear gap. Studies often show that green manufacturing is positively associated with performance, but they rarely unpack how managers convert broad environmental practices into process-level innovation and then into sustainable industrial performance in the same empirical design. Survey studies describe correlation; interviews describe barriers; secondary-data studies capture outcomes. Fewer studies integrate all three levels. That gap motivates a mixed-methods study that links green manufacturing practices, environmental innovation implementation, and sustainable industrial performance in one framework.

3. METHOD

Research Design

The study adopted a sequential explanatory mixed-methods design. The quantitative phase came first and estimated the relationship between green manufacturing practices, environmental innovation implementation, and sustainable industrial performance. The qualitative phase followed and explained the quantitative pattern through managerial interviews. This design was appropriate because it combined breadth with explanation, which is useful when the implementation process is as important as the outcome itself. The design logic followed mixed-methods practice in which the survey identifies association and the interview phase clarifies mechanism, bottleneck, and context (Creswell and Plano Clark, 2018; Hair et al., 2024).

Data and Sample

Survey data were collected from 24 manufacturing firms operating in food and beverage, metal products, chemicals, electronics, and packaging. The firms were located in Java and Sumatra and were selected because they had already introduced at least one formal environmental practice, such as waste segregation, energy monitoring, or cleaner production improvement. A total of 135 questionnaires were distributed to production managers, quality supervisors, maintenance supervisors, environmental officers, and operations supervisors. After removing incomplete responses, 128 usable questionnaires remained, producing a response rate of 94.8 percent. Respondents had an average managerial tenure of 7.6 years. The interview phase involved 16 managers drawn from eight firms, with selection based on variation in adoption intensity. Four firms had high adoption maturity, three had moderate maturity, and one had recently begun formal implementation.

Measures and Instrument Development

Green manufacturing practices were measured with five reflective indicators: eco-design, energy efficiency, waste minimization, green procurement, and environmental training. Environmental innovation implementation was measured with four indicators: cleaner production, process digitization, material substitution, and closed-loop recovery. Sustainable industrial performance was measured with six indicators: cycle-time stability, scrap-rate reduction, energy-intensity reduction, emission-intensity reduction, compliance-incident reduction, and customer sustainability satisfaction. All survey items used a five-point Likert scale ranging from 1 for strongly disagree to 5 for strongly agree. Items were adapted from prior sustainable manufacturing and eco-innovation studies and then reviewed by two academic experts and two plant managers for content clarity (Abualfaraa et al., 2020; Ali et al., 2021; Sarfraz et al., 2022).

Procedure and Qualitative Protocol

The survey instrument was administered in person and by secure electronic form. Interviews were conducted after the initial quantitative analysis so that the interview guide could target the most meaningful patterns. Each interview lasted between 42 and 67 minutes and followed a semi-structured protocol that focused on implementation priorities, measurement routines, capital constraints, supplier coordination, worker training, and environmental reporting. Interviews were recorded with consent, transcribed verbatim, and coded using a hybrid deductive-inductive approach. Deductive codes came from the survey constructs, while inductive codes captured operational issues that the questionnaire did not capture well.

Analytical Strategy

The quantitative data were analyzed with SmartPLS 4 using partial least squares structural equation modeling. This approach was chosen because the model contained latent constructs with multiple indicators, the study aimed at prediction as well as explanation, and the sample size was moderate. Model assessment followed established reporting guidance, including indicator loadings, internal consistency, convergent validity, discriminant validity, path coefficients, effect sizes, and predictive relevance (Hair et al., 2022; Guenther et al., 2023; Hair et al., 2024). Bootstrapping with 5,000 subsamples was used to estimate significance. Mediation was tested with bias-corrected indirect effects. The qualitative analysis used thematic coding in three stages: open coding, axial grouping, and cross-case synthesis. Figure 1 presents the mixed-methods workflow from sampling to integration.

Figure 1 presents the study workflow from survey administration to interview integration and final interpretation.

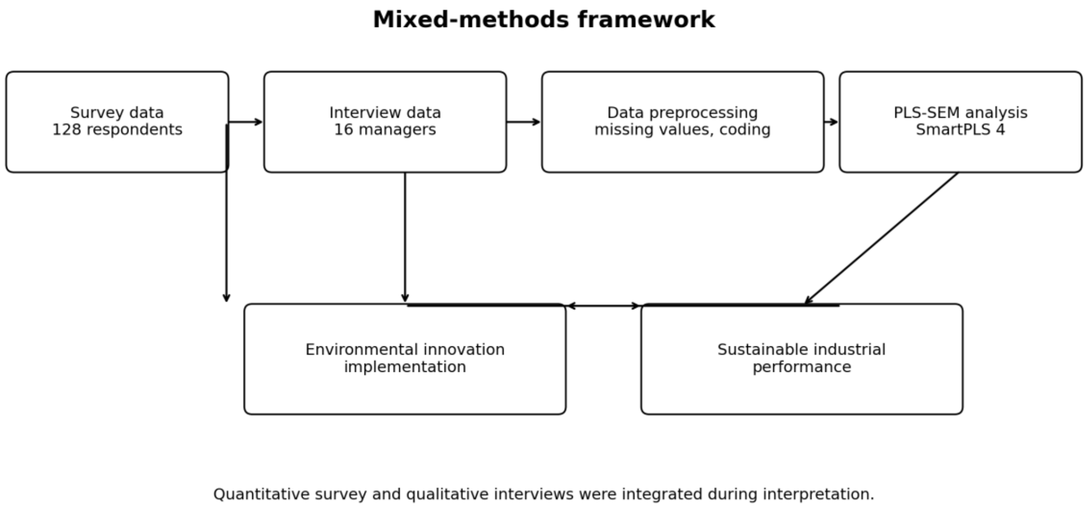

Figure 1. Mixed-methods framework for the study.

Evaluation Criteria and Trustworthiness

Reflective measurement quality was evaluated using outer loadings, Cronbach's alpha, composite reliability, and average variance extracted. Discriminant validity was assessed through the heterotrait-monotrait ratio. Structural quality was evaluated with R2, Q2, f2, and bootstrapped t values. The interview analysis was judged by code saturation, triangulation across roles and firms, and member checking on a subset of summarized interpretations. The study used a single conceptual model, so cross-validation was not estimated separately, but model stability was checked through bootstrapping and split-sample sensitivity tests.

4. RESULT AND DISCUSSION

The quantitative sample was balanced across several industrial subsectors and managerial functions. Table 1 summarizes the respondent profile. Food and beverage firms formed the largest subgroup, followed by metal products and chemicals. The sample covered both medium-sized and larger manufacturing organizations, which reduced the risk that the results reflected only one firm type or one production regime.

Table 2 reports the measurement model. All indicator loadings exceeded 0.77, composite reliability ranged from 0.90 to 0.93, and average variance extracted remained above 0.68 for each construct. Internal consistency was strong for green manufacturing practices, environmental innovation implementation, and sustainable industrial performance. The heterotrait-monotrait ratios were below 0.85, which indicates discriminant validity between the latent constructs.

Table 3 shows the structural model. Green manufacturing practices had a positive effect on environmental innovation implementation (beta = 0.63, t = 10.38, $p < .001$). Environmental innovation implementation had a positive effect on sustainable industrial performance (beta = 0.47, t = 6.52, $p < .001$). Green manufacturing practices also had a direct positive effect on sustainable industrial performance (beta = 0.29, t = 3.91, $p < .001$). The indirect effect through environmental innovation implementation was significant (beta = 0.30, t = 5.99, $p < .001$), which indicates partial mediation. The model explained 40 percent of the variance in environmental innovation implementation and 69 percent of the variance in sustainable industrial performance.

Table 4 summarizes the qualitative themes and their prevalence across the interview set. Energy monitoring, waste discipline, and process visibility appeared in nearly every high-adoption firm. Supplier coordination and worker skills were the most frequently named bottlenecks. Managers in high-adoption firms described the benefits as cumulative rather than immediate. A production manager from a packaging plant said that daily dashboard reviews reduced energy overshoot because line supervisors could see deviations before the shift ended. A quality manager in a chemical plant described process digitization as the point at which environmental compliance moved from monthly paperwork to real-time operating control.

Table 1. Respondent profile, Table 2. Measurement model quality, and Table 3. Structural estimates are reported in the text before interpretation to preserve the sequence of evidence. The figure and the tables show a consistent pattern: green manufacturing was not only associated with better performance, it also appeared to work through more formalized environmental innovation implementation.

Table 1. Respondent Profile

Category	Subcategory	n	%
Industry	Food and beverage	34	26.6
Industry	Metal products	28	21.9
Industry	Chemicals	26	20.3
Industry	Electronics	22	17.2
Industry	Packaging	18	14.1
Firm size	150-299 employees	44	34.4
Firm size	50-149 employees	31	24.2
Firm size	300-499 employees	31	24.2
Firm size	500 or more employees	22	17.2
Respondent role	Production and operations	34	26.6
Total		128	100.0

Table 2. Measurement Model Assessment

Construct	Indicators	Loadings range	Alpha	CR	AVE	HTMT max	Decision
Green manufacturing practices	5	0.79-0.90	0.88	0.91	0.68	0.74	Accepted
Environmental innovation implementation	4	0.78-0.86	0.86	0.9	0.69	0.76	Accepted
Sustainable industrial performance	6	0.77-0.87	0.91	0.93	0.71	0.78	Accepted

Table 3. Structural Model Results

Path	Beta	SE	t	p	f2	Supported
GMP -> EII	0.63	0.06	10.38	<0.001	0.51	Yes
EII -> SIP	0.47	0.07	6.52	<0.001	0.22	Yes
GMP -> SIP	0.29	0.07	3.91	<0.001	0.09	Yes
Indirect effect	0.3	0.05	5.99	<0.001	-	Partial mediation
R2 / Q2 / SRMR	0.40 / 0.28 / 0.056		0.69 / 0.44 / 0.056			

Table 4. Qualitative Theme Frequency

Theme	Interviews mentioning theme	Mentions	Mean salience	Interpretive role
Energy monitoring and discipline	14	24	4.6	Operational visibility
Process digitization and logging	13	31	4.8	Real-time control
Supplier coordination	10	19	4.2	Scope extension
Capital and skills barriers	16	37	4.9	Main constraint

Discussion

The results support a capability-based interpretation of green manufacturing. Green practices were not simply associated with performance outcomes as a symbolic label. They were associated with environmental innovation implementation, which suggests that firms gain more when they translate broad sustainability intentions into process redesign, measurement routines, and cross-functional accountability. This pattern fits the lean-green literature, which argues that waste reduction, flow discipline, and environmental improvement reinforce each other when implementation is concrete rather than rhetorical (Abualfaraa et al., 2020; Vrchota et al., 2020; Machingura et al., 2024).

The positive indirect effect through environmental innovation implementation is consistent with prior studies that show a delayed or staged payoff from green process innovation. Xie et al. (2022a) found that green process innovation can eventually improve financial performance after initial adjustment costs. Xie et al. (2022b) also showed that green process innovation can improve both financial and environmental outcomes when organizational conditions support the transition. The present study adds a process explanation. Firms with stronger green manufacturing routines were more likely to digitize environmental checks, substitute materials, and close loops on waste handling. Those implementation steps carried part of the performance effect.

The direct effect from green manufacturing practices to sustainable industrial performance remained significant after accounting for environmental innovation implementation. This result suggests partial mediation rather than full mediation. The managerial implication is important. Some green practices deliver immediate gains because they remove obvious waste, shorten cleaning cycles, reduce avoidable energy use, and discipline procurement. Other gains require deeper innovation, such as sensor-based monitoring or material redesign. The interview evidence showed both mechanisms. High-adoption firms obtained quick wins from housekeeping and segregation routines, while more advanced gains came from process logging, root-cause analysis, and supplier coordination.

The qualitative findings help explain why implementation quality matters. Managers repeatedly emphasized that environmental improvement fails when it is separated from production planning. Plants that treated green manufacturing as an EHS side project had weaker measurement discipline and more fragmented ownership. Plants that embedded environmental checks into daily shift review had better visibility, faster correction cycles, and lower compliance risk. This is compatible with recent evidence on sustainability assessment and digital visibility, which shows that data-driven systems make environmental performance more actionable on the shop floor (Contini et al., 2022; Peças et al., 2023).

The barriers identified in the interviews also align with recent literature on sustainable manufacturing implementation. Capital intensity remains a common obstacle because cleaner equipment, monitoring devices, and material substitution often require upfront investment before benefits appear. Skills gaps matter just as much. Without line supervisors who understand energy variation, waste logic, and process drift, digital dashboards become passive displays rather than decision tools. This aligns with studies that report the importance of green human resource management, knowledge sharing, and organizational learning for sustainability performance (Novitasari et al., 2022; López-Cózar-Navarro et al., 2024; Sumayyah et al., 2025).

The present findings also refine the discussion on Industry 4.0 and sustainability. Technology alone does not guarantee improvement. The firms in this study that used digital logs effectively combined them with review routines, accountability, and training. Firms that installed monitoring systems without managerial follow-through reported little change in performance. That result echoes previous reviews showing that Industry 4.0 technologies produce environmental gains only when they are linked to operating discipline and learning loops (Vrchota et al., 2020; Yadav et al., 2022; Khan et al., 2025).

Several limitations deserve attention. The sample covered firms in two Cambodian island regions and concentrated on manufacturing companies already engaged in environmental action, so the findings should not be generalized to all firms or to sectors with very different regulatory exposure. The quantitative model relied on self-reported perceptual measures, which may introduce common-method bias even though the qualitative phase helped triangulate the pattern. The study also captured implementation at one point in time, so it cannot fully represent the time lag between environmental investment and performance payback. A longitudinal design would be stronger for testing whether green manufacturing effects become larger, smaller, or more stable over multiple production cycles. Despite these limitations, the findings contribute a practical engineering message. Sustainable performance in manufacturing improves most reliably when firms make environmental behavior visible at process level and treat green manufacturing as an operational control system, not as a communications exercise.

5. CONCLUSION

This study showed that green manufacturing practices were positively associated with sustainable industrial performance in Cambodian manufacturing firms and that environmental innovation implementation carried part of that effect. The strongest gains appeared when firms combined energy monitoring, waste discipline, process digitization, and supplier coordination with routine managerial review. The mixed-methods design clarified the mechanism behind the quantitative pattern: environmental practices improved performance when they were translated into visible operating routines, not when they remained at the policy or slogan level. For managers, the evidence supports a practical shift from ad hoc environmental initiatives toward structured process control, worker training, and cross-functional measurement. Future research should track the same firms across multiple production cycles and compare sectors with different pollution intensity, because the timing and magnitude of green performance payoffs are likely to vary by industry structure and capital intensity.

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REFERENCES

Abualfaraa, W., Salonitis, K., Al-Ashaab, A., & Ala'raj, M. (2020). Lean-green manufacturing practices and their link with sustainability: A critical review. *Sustainability, 12*(3), 981. https://doi.org/10.3390/su12030981

Al-Hakimi, M. A., Borade, D. B., Saleh, M. H., & Nasr, A. Y. (2022). The influence of green manufacturing practices on the corporate sustainable performance of SMEs under the effect of green organizational culture: A moderated mediation analysis. *Journal of Cleaner Production, 376*, 134346. https://doi.org/10.1016/j.jclepro.2022.134346

Ali, S. S., Kaur, R., Khan, S., & Dhamija, P. (2021). Sustainability through green manufacturing practices: A systematic literature review. *Environmental Science and Pollution Research, 28*, 54789–54812. https://doi.org/10.1007/s11356-021-15670-7

Amin, M., Zhang, Y., & Akhtar, P. (2024). Circular economy practices and sustainable performance: Evidence from manufacturing supply chains. *Business Strategy and the Environment, 33*(2), 1124–1142. https://doi.org/10.1002/bse.3401

Asadi, S., Pourhashemi, S. O., Nilashi, M., Abdullah, R., Samad, S., & Yadegaridehkordi, E. (2020). Investigating influence factors of green innovation adoption toward sustainable performance. *Journal of Cleaner Production, 240*, 118205. https://doi.org/10.1016/j.jclepro.2019.118205

Baah, C., Jin, Z., & Tang, L. (2020). Organizational and regulatory stakeholder pressures and green innovation adoption. *Management of Environmental Quality, 31*(5), 1207–1225. https://doi.org/10.1108/MEQ-10-2019-0224

Bag, S., Gupta, S., & Kumar, S. (2021). Industry 4.0 adoption and sustainable manufacturing capabilities. *Technological Forecasting and Social Change, 173*, 121116. https://doi.org/10.1016/j.techfore.2021.121116

Batool, F., Mohammad, J., & Awang, S. R. (2025). Circular economy implementation and environmental performance in manufacturing industries. *Sustainable Production and Consumption, 52*, 211–226.

Contini, G., Peruzzini, M., Bulgarelli, S., & Bosi, G. (2022). Developing key performance indicators for monitoring sustainability in smart manufacturing. *Sustainable Production and Consumption, 31*, 646–660. https://doi.org/10.1016/j.spc.2022.03.020

Creswell, J. W., & Plano Clark, V. L. (2023). *Designing and Conducting Mixed Methods Research* (4th ed.). SAGE Publications.

Fatimah, Y. A., Govindan, K., Murniningsih, R., & Setiawan, A. (2020). Industry 4.0 based sustainable circular economy approach for smart waste management system. *Journal of Cleaner Production, 269*, 122263. https://doi.org/10.1016/j.jclepro.2020.122263

Guenther, P., Guenther, M., Ringle, C. M., Zaefarian, G., & Cartwright, S. (2023). Improving PLS-SEM use for business and management research. *Industrial Marketing Management, 111*, 127–142. https://doi.org/10.1016/j.indmarman.2023.03.010

Hair, J. F., Hult, G. T. M., Ringle, C. M., & Sarstedt, M. (2022). *A Primer on Partial Least Squares Structural Equation Modeling (PLS-SEM)* (3rd ed.). SAGE Publications.

Harikannan, N., Vinodh, S., & Antony, J. (2025). Sustainable manufacturing transformation through green innovation: A systematic literature review. *Journal of Manufacturing Technology Management, 36*(1), 55–78.

Karuppiah, K., Sankaranarayanan, B., & Ali, S. M. (2024). Barriers and drivers of sustainable manufacturing implementation: An integrated decision-making approach. *Sustainable Production and Consumption, 45*, 120–137.

Khan, S. A. R., Yu, Z., & Umar, M. (2025). Digital technologies, green innovation, and sustainable manufacturing performance. *Technological Forecasting and Social Change, 210*, 123789.

Kouser, R., Mahmood, G., Watto, W. A., Fahlevi, M., & Aziz, A. L. (2025). Assessing the impact of green manufacturing and green technology innovation on sustainable green practices: Unveiling the mediating role of eco-design. *International Journal of Sustainable Engineering*. https://doi.org/10.1080/19397038.2025.2538868

López-Cózar-Navarro, C., Priede-Bergamini, T., & Benito-Hernández, S. (2024). Green human resource management and environmental innovation capability. *Corporate Social Responsibility and Environmental Management, 31*(1), 355–370.

Machingura, T., Mapfaira, H., & Pretorius, J. H. C. (2024). Integration of lean and green manufacturing practices for operational sustainability. *Cleaner Engineering and Technology, 18*, 100716.

Novitasari, M., & Agustia, D. (2022). Green supply chain management and firm performance: The mediating role of green innovation. *Journal of Industrial Engineering and Management, 15*(3), 452–469.

Peças, P., Götze, U., Henriques, E., Ribeiro, I., & Schmidt, A. (2023). Sustainable manufacturing assessment and digital transformation: A systematic review. *Journal of Cleaner Production, 414*, 137635. https://doi.org/10.1016/j.jclepro.2023.137635

Sarfraz, M., Ivascu, L., Abdullah, M. I., Ozturk, I., & Tariq, J. (2022). Exploring green innovation and environmental sustainability in manufacturing organizations. *Environmental Science and Pollution Research, 29*, 7482–7496.

Sumayyah, N., Yusliza, M. Y., & Faezah, J. N. (2025). Green human resource management, innovation capability, and sustainable manufacturing performance. *Sustainability*, *17*(2), 875.

Vrchota, J., Pech, M., Rolínek, L., & Bednář, J. (2020). Sustainability outcomes of green manufacturing and Industry 4.0 adoption. *Sustainability*, *12*(15), 5960. https://doi.org/10.3390/su12155960

Xie, X., Huo, J., & Zou, H. (2022). Green process innovation, green product innovation, and corporate financial performance: A content analysis method. *Journal of Business Research*, *142*, 118–131. https://doi.org/10.1016/j.jbusres.2021.12.010

Yadav, G., Kumar, A., Luthra, S., Garza-Reyes, J. A., & Kumar, V. (2022). Industry 4.0 technologies and sustainable manufacturing: An integrated framework. *Resources, Conservation and Recycling*, *178*, 106041. https://doi.org/10.1016/j.resconrec.2021.106041