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Hybrid Green Technology Adoption in Indonesian MSMEs: A Conceptual Readiness Model

Albert William Wibisono
Universitas Atma Jaya Yogyakarta, Sleman, Indonesia

ABSTRACT

As Indonesia advances its commitments to digital transformation and environmental sustainability, Micro, Small, and Medium Enterprises (MSMEs) face structural constraints that limit the adoption of high-cost green and digital technologies. Existing frameworks often treat digitalization and sustainability as separate and resource-intensive processes, creating barriers for MSMEs operating with limited capital and capabilities. This study develops a conceptual Hybrid Green Technology Readiness Model that integrates the Twin Transition framework with principles of frugal innovation. Using a structured synthesis of recent literature on MSME digital maturity, sustainability readiness, and low-cost technology adoption, this study proposes a readiness matrix based on two dimensions: digital maturity and ecological awareness. The model demonstrates that basic digital tools, such as cloud-based services, digital payments, route optimization, and simple inventory systems, can simultaneously enhance operational efficiency and reduce environmental impact. By reframing sustainability as an efficiency-driven and value-creating process rather than a compliance burden, the proposed framework offers a practical pathway for MSMEs in developing economies. This study contributes to sustainability and entrepreneurship literature by providing a context-sensitive and accessible model to support inclusive green and digital transformation in Indonesian MSMEs.

Keywords: Twin Transition; Indonesian MSMEs; Digital Frugality; Green Technology; Conceptual Framework

INTRODUCTION

Macroeconomic Landscape and the Urgency of Transformation

The Indonesian economy exhibits distinctive structural characteristics, in which its stability and resilience are highly dependent on the Micro, Small, and Medium Enterprises (MSME) sector. Based on the latest aggregated data for 2023 and projections for 2024, the number of MSMEs in Indonesia has reached approximately 66 million business units (DPP Gapembi, 2024). This quantitative dominance is aligned with their substantial economic contribution, accounting for around 61 percent of the national Gross Domestic Product, equivalent to approximately IDR 9,580 trillion (DPP Gapembi, 2024). Furthermore, MSMEs function as a critical social safety net by absorbing approximately 97 percent of the national workforce, thereby sustaining the livelihoods of more than 117 million people (DPP Gapembi, 2024). These conditions indicate that the sustainability and competitiveness of MSMEs have direct implications for national economic stability and societal welfare.

Nevertheless, the magnitude of MSMEs' economic role is accompanied by significant structural vulnerabilities. Indonesian MSMEs currently operate in an environment characterized by uncertainty, complexity, and rapid change, which is further intensified by two major disruptions: the acceleration of digital transformation and the escalating global

CONTACT Albert William Wibisono. Universitas Atma Jaya Yogyakarta. Jl. Babarsari No. 44 Yogyakarta, Sleman, Daerah Istimewa Yogyakarta, Indonesia, 55281. albertwilliam158@gmail.com.

ecological crisis. The Indonesian government has set an ambitious target to digitalize up to 30 million MSMEs; however, in practice, the digitalization agenda often proceeds independently from national sustainability and decarbonization initiatives (Biro Humas Kementerian Kominfo, 2024). Contemporary academic literature suggests that future economic competitiveness is increasingly shaped by the integration of digital transformation and environmental sustainability, commonly referred to as the Twin Transition concept (Abilakimova et al., 2025).

The primary challenge in implementing the Twin Transition in developing countries such as Indonesia lies in both the perception and reality of cost constraints. Most MSMEs operate with narrow profit margins and limited capital, causing the adoption of high-cost green technologies or complex enterprise-level digital systems to be perceived as impractical (Galib et al., 2024). In addition, disparities in digital infrastructure across regions and the low level of digital literacy among micro-entrepreneurs further exacerbate adoption barriers. If these conditions remain unaddressed, Indonesian MSMEs risk falling behind in global value chains that increasingly demand compliance with environmental, social, and governance standards.

Research Problem Formulation and Novelty

Based on the aforementioned conditions, the central problem addressed in this study concerns how to formulate an approach capable of bridging global demands for digitalization and sustainability with the resource constraints faced by Indonesian MSMEs. Conventional approaches often fail because they attempt to transplant large-scale corporate solutions into micro and small enterprise contexts without sufficient structural adaptation.

This study introduces novelty by integrating the perspective of Frugal Innovation into the Twin Transition framework. Frugal Innovation emphasizes the principle of achieving more with limited resources, thereby reframing digitalization not as an investment in expensive hardware, but as the strategic utilization of readily available digital technologies such as smartphones, cloud-based applications, and everyday digital platforms. This approach enables operational efficiency gains that inherently contribute to the reduction of waste and energy consumption. An additional element of novelty lies in the cross-disciplinary synthesis that integrates literature from information technology, environmental sustainability, and Indonesian MSME behavior to formulate a conceptual model that is both applicable and contextually grounded.

Research Objectives and Contributions

This study aims to conceptually elucidate the mechanisms linking digital transformation and environmental sustainability within the context of Indonesian MSMEs, as well as to explain how a frugal approach can serve as a key enabler in the implementation of the Twin Transition. Furthermore, this research seeks to develop an integrated readiness model that combines dimensions of digital maturity and sustainability preparedness into a simple and accessible evaluation framework for MSME practitioners. The findings of this study are expected to contribute academically to the advancement of literature on green technology and sustainable entrepreneurship in developing economies. From a practical perspective, the results are intended to serve as a reference for MSME actors, policymakers, and other stakeholders in designing digitalization and sustainability strategies that are realistic, inclusive, and aligned with the structural characteristics of Indonesian MSMEs.

The Evolution of the Twin Transition Concept and Its Relevance for SMEs

The concept of the Twin Transition evolved as a response to the global necessity of aligning economic growth with the limitations of the environment's carrying capacity. Initially, digital transformation and environmental sustainability agendas developed separately and were often positioned as conflicting interests. Digital transformation was viewed as a driver of economic efficiency and productivity, while the environmental agenda was frequently associated with limiting economic activity. However, recent literature indicates a paradigm shift towards the integration of these two agendas, where digital technology is understood as a key enabler in achieving environmental sustainability.

The Twin Transition is defined as a simultaneous process combining digital transformation and green transformation, operating on the assumption that the utilization of digital technology can accelerate decarbonization and resource efficiency (Tabares et al., 2025). This synergy occurs through several primary mechanisms. First, dematerialization of business processes, where physical and paper-based activities are replaced by digital solutions, thereby reducing material consumption and transportation emissions. Second, data-driven optimization, which is the use of digital data to improve energy and resource efficiency in production and distribution (Abilakimova et al., 2025). Third, supply chain transparency, enabled by digital technologies that allow for more accurate and accountable tracking of production and distribution processes (Youssef, 2025).

Nevertheless, the literature also highlights a digital paradox: the reality that digital technology itself possesses an environmental footprint through data center energy consumption and increased electronic waste. Therefore, the success of the Twin Transition, particularly at the SME scale, relies heavily on a sustainable approach to digitalization (Abilakimova et al., 2025). This approach emphasizes the selection of technology that is appropriate, efficient, and aligned with business capacity, ensuring that the resulting environmental benefits outweigh the ecological costs of using said technology. In the context of Indonesian SMEs, this implies avoiding excessive or non-strategic digitalization.

Frugal Innovation as the Foundation for Hybrid Green Technology

From the perspective of Resource-Based View (RBV) theory, competitive advantage is generally linked to the ownership of valuable and hard-to-imitate resources. However, for SMEs, resource constraints are a primary characteristic. Frugal Innovation emerges as an alternative approach that emphasizes resourcefulness and creativity in utilizing limited resources to create economic and social value (Sharuddin & Roddin, 2025). Frugal Innovation is characterized by significant cost reduction efforts through the simplification of designs and processes, a focus on core functions truly needed by users, and a tendency to produce lower ecological impacts due to more efficient material and energy usage (Achmad & Wiratmadja, 2024). In the digital context, Frugal Innovation is realized through the utilization of widely available digital platforms—such as instant messaging apps, social media, and cloud-based services—to support complex business activities without requiring expensive technological investments (Claudia & Wijaya, 2023). This approach is highly relevant for Indonesian SMEs as it enables the simultaneous integration of digitalization and sustainability. By utilizing simple digital technologies, SMEs can enhance operational efficiency while reducing waste and energy consumption, thereby forming the foundation for hybrid green technology that is both contextual and affordable (Djaelani & Darmawan, 2021).

Digital Maturity Models for Indonesian SMEs

To understand the readiness of SMEs to adopt digital technology, various digital maturity models have been developed in the literature. These models generally encompass dimensions of people, process, strategy, technology, and integration (Rafiah et al., 2022). Empirical studies in West Java and other regions in Indonesia (Rafiah et al., 2022) indicate that the majority of SMEs remain at the early stages of maturity where they are classified as Digital Observers or Digital Indifferent. A key finding from this literature is that the "People" dimension is often more ready compared to "Strategy" or "Technology Integration." This means that SME practitioners possess basic skills in using devices/gadgets but lack the strategic vision to integrate these technologies into a coherent business model. This creates an opportunity for policy interventions that focus on enhancing strategic capabilities rather than merely providing technical assistance.

Sustainability Readiness and Model Integration Gaps

As global market demands for sustainable business practices increase, SMEs are faced with the need to demonstrate their environmental performance. However, global sustainability reporting standards are generally too complex and disproportionate for the scale of SMEs. The OECD Platform on Financing SMEs for Sustainability (OECD, 2025) and the ACCA Sustainability Reporting for SMEs (Association of Chartered Certified Accountants, 2024) guide have introduced the concept of tiered reporting. This framework emphasizes a transition from basic awareness of environmental impact, moving toward the implementation of simple efficiency measures, and finally to the stage of more structured information disclosure to stakeholders. However, the integration between sustainability readiness and digital maturity remains relatively underexplored, particularly in the context of Indonesian SMEs. This gap serves as the foundation for the development of the conceptual model of hybrid green technology in this study, where digital maturity is positioned as the primary enabler for increasing SME sustainability readiness in a gradual and realistic manner.

METHOD

This study adopts a descriptive qualitative approach with a conceptual research design. The primary method employed is an extended conceptual synthesis based on a systematic literature search, aimed at integrating and synthesizing scholarly findings from multiple disciplines, particularly strategic management, information systems, and environmental sustainability. This approach is selected because the objective of the study is not to test empirical hypotheses, but to develop a conceptual model that explains the interrelationship between digital adoption and sustainability readiness among Indonesian MSMEs within a hybrid green technology framework.

The data collection process was conducted through a systematic search of scientific literature across accredited national and international academic journal databases. The selected literature was limited to recent publications within the 2023-2025 period to ensure alignment with the latest developments in digital transformation and sustainability dynamics. The search focused on articles addressing MSME digital transformation, green economy initiatives, MSME resilience, frugal innovation, and the environmental impacts of digital technologies. In addition to journal articles, this study also utilized secondary sources such as industry reports, government policy documents, and reports from international organizations that provide statistical data and illustrative cases of digital and green technology implementation.

The literature search employed combinations of keywords representing the core themes of the study, including Twin Transition in MSMEs, low-cost digital technology adoption, green technologies, and the environmental impacts of digital infrastructure usage. All retrieved sources were subsequently screened based on topic relevance, publisher credibility, and contextual suitability for MSMEs in developing economies, particularly Indonesia. The collected data were analyzed using content analysis and narrative synthesis techniques. Content analysis was conducted by identifying recurring patterns, key concepts, and principal findings in the literature, especially those related to digital infrastructure efficiency, logistics process optimization, digital-based waste management, and structural barriers to technology adoption among MSMEs. Narrative synthesis was then applied to integrate these findings into a coherent conceptual framework.

To enhance analytical robustness, this study employed source triangulation by comparing theoretical insights from academic literature with secondary empirical data reported in policy documents and technical reports from international institutions. This approach enables the conceptual linkage between specific forms of digital technology adoption and their potential environmental impacts, such as energy efficiency improvements and emissions reduction. The final outcome of this analytical process is the formulation of a Hybrid Green Technology Conceptual Model that with integrity maps the levels of digital maturity and sustainability readiness of Indonesian MSMEs.

RESULT

Infrastructure Efficiency: Cloud Computing as a Green Solution for MSMEs

Based on technical data compiled from industrial literature and sustainability reports from global cloud providers, a quantitative comparison reveals significant efficiency disparities between on premise infrastructures and cloud services for the SME scale.

Table 1. Environmental Efficiency Comparison: On-Premise vs. Cloud Computing for MSMEs

Performance Parameter	On-Premise Infrastructure (Standalone Physical Server)	Cloud Infrastructure (Shared Services/SaaS)	Impact Analysis on SMEs
Device Utilization	Low (5-10%). Servers often run 24/7 to serve intermittent workloads, resulting in "zombie" energy waste.	High (40-70%). Cloud providers use virtualization and multi-tenancy to dynamically share physical resources among thousands of users.	Radical asset efficiency; one physical server serves hundreds of SMEs, reducing the need for new hardware production (embodied carbon reduction).
Power Usage Effectiveness (PUE)	High (~1.97). Nearly half of the energy is used for inefficient cooling (standard AC).	Low (1.1 - 1.2). Hyperscale data centers use advanced cooling (outside air, evaporation) and AI-	Aggregate reduction in electricity consumption. For SMEs, this means no

		based power management.	electricity bill spikes due to IT devices.
Carbon Footprint Reduction	Baseline (Standard Emissions).	>90% Emission Reduction. specifically for small business scales (<100 users), cloud efficiency provides the highest emission reduction impact.	SMEs can claim greener business operations without additional investment.

Operational Metrics in Logistics and Supply Chain

Empirical findings from various global case studies demonstrate that the implementation of digital algorithms in logistics operations leads to measurable performance improvements. In terms of fuel efficiency and travel distance, route optimization software has been shown to reduce total mileage and fuel consumption by approximately 10-30%. Furthermore, improvements in fleet utilization are achieved through smarter shipment consolidation strategies, which can reduce the total number of routes and the required fleet size by 29-42% (Finmile, 2025). These operational enhancements subsequently translate into significant financial benefits, with total logistics cost savings typically reported within the range of 15-30%. Beyond logistics, similar positive outcomes are observed in digital commerce practices. For example, case studies involving market traders who adopted WhatsApp Business for digital marketing indicate that optimizing digital catalog features can increase revenue by 20-50% (Mustofa et al., 2025).

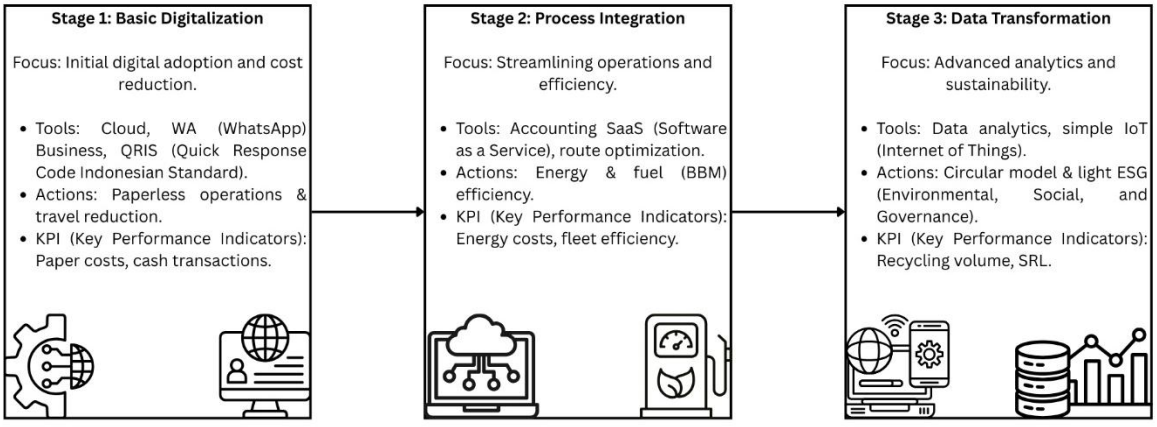
Digital Waste Management Outcomes

Data obtained from the pilot implementation of the AKSI application across Bogor, Depok, and Jakarta illustrates the effectiveness of digital systems in monitoring and managing waste streams. Within a relatively short period of operation, the application enabled the collection and documentation of 327 tons of plastic waste and 800 tons of organic waste, demonstrating its practical capacity to support data-driven waste management initiatives (WWF, 2025).

The Hybrid GreenTech Readiness Model

Based on the synthesis of the findings above regarding transformation, green economy, and frugal innovation, this study produced a Conceptual Model for Hybrid GreenTech Readiness.

Figure 1. Conceptual Model for Hybrid GreenTech Readiness



The operational framework of this model is detailed in the matrix below.

Table 2. Twin Transition Integration Matrix for Indonesian SMEs

Performance Parameter	Frugal Technology Focus	Green Action Focus	Key Performance Indicators (KPI)
Stage 1: Basic Digitalization (Efficiency)	a) Cloud Migration (Email, Drive, Basic POS) b) WhatsApp Business for CRM c) Digital Payments (QRIS)	a) Paperless Office (Reduction of office supplies) b) Reduction of physical travel for administrative/banking transactions	a) % Decrease in paper & printing costs b) % Non-cash transactions
Stage 2: Process Integration (Optimization)	a) Integrated Accounting/Inventory Apps (SaaS) b) Logistic Route Optimization (Maps/Aggregators) c) Organic Digital Marketing	a) Operational energy efficiency (Electricity/Fuel) b) Minimization of dead stock (waste prevention) c) Market education on green products	a) Decrease in energy cost per output unit b) Fleet usage efficiency
Stage 3: Data Transformation (Innovation)	a) Customer Data Analytics b) Simple IoT (Temp/Humidity sensors) c) Digital Supply Chain Collaboration	a) Circular Business Models (Refill, Repair, Recycle) b) Food waste reduction c) Simple ESG Reporting	a) Volume of recycled waste b) Sustainability Readiness Level (SRL) Score

DISCUSSION

Interpreting Infrastructure Efficiency and the "Zombie Energy" Phenomenon

The data in Table 1 highlights a structural inefficiency in traditional SME operations. The contrast between on premise utilization (5-10%) and cloud utilization (40-70%) confirms the prevalence of "zombie energy" consumption, electricity consumed without commensurate productive output. In the context of Indonesia, where industrial electricity tariffs are adjusted periodically, the transition to the cloud offers more than just environmental benefits; it provides cost predictability. By shifting from Capital Expenditure (CapEx) to Operational Expenditure (OpEx), SMEs align their technology spending with fluctuating cash flows.

Furthermore, the adoption of SaaS tools enables the dematerialization of business processes, removing paper from receipts and invoices, which directly contributes to waste reduction and natural resource conservation (Adobe Acrobat Sustainability Report, 2023).

Frugal Innovation in Logistics and Market Access

The results in Operational Metrix subsection suggest that environmental contributions by SMEs need not rely on radical innovation but rather on frugal implementation. The reduction in fuel consumption (10-30%) is achieved not through expensive satellite systems, but through accessible tools like Google Maps or low-cost aggregators. This confirms that operational efficiency is the most realistic entry point for SMEs to engage in sustainability. The use of aggregators lowers the entry barrier, allowing SMEs to access advanced algorithms via a "technology-as-a-service" model. Similarly, the revenue increase seen in WhatsApp Business usage (Operational Metrix sub section) illustrates how simple digital tools function as "Mini-ERPs," reducing physical footprints (catalogs/brochures) while democratizing access to markets for sustainable products (e.g., Kreskros or SukkhaCitta).

Frugal Implementation in SME Practice

The implementation of frugal innovation principles within SME practices emphasizes the utilization of solutions that are simple, affordable, and easily adopted without sacrificing functional effectiveness. In the context of logistics route optimization, SMEs are not required to independently develop satellite-based systems, big data analytics, or complex optimization algorithms. Conversely, the frugal approach enables SMEs to leverage widely available technologies through devices and platforms that are already familiar in their daily operational activities.

One of the most tangible forms of frugal implementation is the use of free or low-cost navigation applications that provide features such as multi-stop routing, travel time estimation, and real-time traffic information. By utilizing these features, SMEs can structure delivery sequences more efficiently, avoid congestion, and minimize travel distance without requiring additional investment in hardware or complex technical training. In practice, operational decisions based on these simple applications are capable of generating significant efficiency impacts, particularly for SMEs with local and regional distribution scales (Priyono et al., 2020).

Furthermore, logistics aggregator platforms play a crucial role as enablers in the application of frugal-based route optimization. Many digital logistics service providers have integrated route optimization algorithms, shipment consolidation, and efficient fleet selection into their systems. Through the "technology as a service" model, SMEs can access advanced technological capabilities without having to own or manage the digital infrastructure directly. This model significantly lowers the entry barrier to the adoption of green and digital technologies, which has historically been a major constraint for SMEs.

This frugal approach also has strategic implications for enhancing the adaptive capacity of SMEs. By adopting user-friendly and flexible technologies, SMEs can engage in incremental learning regarding more efficient logistics management. This process allows digital transformation and sustainability to proceed simultaneously yet non-disruptively, aligning with the characteristics of SMEs that tend to avoid high operational risks. Furthermore, frugal implementation in route optimization demonstrates that SME contributions to carbon

emission reduction do not always require radical innovation. Operational efficiency based on simple technology serves as the most realistic entry point to encourage sustained sustainability practices. Thus, frugal innovation functions as a bridge between SME resource limitations and global demands for digital and environmental transformation, while strengthening the relevance of the Twin Transition concept in the context of developing economies.

Implications of the Twin Transition Matrix

The implications of the Twin Transition Matrix highlight a critical shift in how sustainability and digital transformation are perceived. The Hybrid GreenTech Readiness Model presented in Table 2 refutes the traditional assumption that meaningful sustainability can only be achieved through advanced or high-cost technological investments. At the first stage, labelled Efficiency, the model establishes that even basic forms of digitalization, such as the adoption of QRIS and cloud-based systems, already contribute to environmentally friendly practices by minimizing the use of physical materials. The second stage, Optimization, demonstrates that the integration of digital systems enables organizations to achieve quantifiable reductions in both energy consumption and waste generation. Finally, the third stage, Innovation, emphasizes that data serves as the foundational driver for the development of circular business models and long-term sustainable ecosystems. Overall, the model suggests that the Twin Transition process is not strictly linear, as sustainability benefits can emerge even at the earliest stages of digital adoption, reinforcing the concept of sustained sustainability.

Structural Challenges and Limitations

Although the results demonstrate substantial benefits of the proposed model, a closer examination of the supporting literature reveals several structural challenges that limit its broader applicability. First, there is a significant gap in sustainability literacy. While the adoption and usage of digital tools among SMEs are relatively high, their understanding of how these technologies relate to environmental sustainability remains limited. (Galib et al., 2024) emphasize that the primary bottleneck is cognitive rather than technical, indicating that access to digital tools does not automatically translate into awareness of their ecological implications. Second, financing constraints continue to hinder GreenTech adoption. (Harto et al., 2024) note that many financial institutions classify green micro-investments as high-risk ventures due to the absence of traditional physical collateral. Nevertheless, the emergence of digital transaction records and SaaS-based operational data presents an alternative mechanism for assessing credit risk, thereby offering a pathway to unlock sustainable financing opportunities. Finally, infrastructure inequality remains a critical issue. The effectiveness of cloud-based solutions depends heavily on stable and continuous internet access. (Hapiz et al., 2025) highlight that uneven internet infrastructure across Indonesia creates barriers for SMEs located outside major urban areas. Consequently, for the Hybrid GreenTech Readiness Model to achieve inclusivity, system developers should consider implementing offline-first or hybrid digital architectures that can accommodate varying levels of connectivity.

CONCLUSION & RECOMMENDATION

This research concludes that the integration of digitalization and environmental sustainability through a hybrid green technology approach constitutes a realistic and highly relevant strategy for Indonesian MSMEs. Through the development of the Hybrid Green Technology

Conceptual Model represented in the Twin Transition Integration Matrix, this study demonstrates that digital technology adoption functions not merely as a tool for business efficiency, but as a practical mechanism for incrementally reducing the environmental footprint of MSMEs. Distinct from conventional sustainability approaches that emphasize regulatory compliance and high-technology investment, the proposed model positions frugal innovation as its central logic. The synthesis of literature and empirical data indicates that the utilization of basic digital technologies, such as cloud computing, logistics route optimization, and data-driven applications, can generate significant environmental impacts when adopted in aggregate by the ecosystem of over 66 million business units in Indonesia. Consequently, the Twin Transition in the context of Indonesian MSMEs is not exclusive; rather, it can be operationalized through technologies that are already available and affordable.

Based on these findings, the study offers managerial recommendations emphasizing a gradual and efficiency-based transformation strategy. MSME practitioners are advised to initiate transformation by adopting digital technologies that resolve core operational issues, such as financial recording and customer communication, which simultaneously yield environmental benefits through the reduction of paper usage and physical travel. Furthermore, rather than developing costly independent systems, MSMEs should integrate into existing digital ecosystems, including marketplaces, logistics aggregators, and SaaS applications, to obtain operational efficiency and sustainability as a natural by-product. These sustainability practices resulting from digital efficiency can subsequently be monetized as a value differentiator in digital marketing strategies, particularly to effectively reach an increasingly environmentally conscious consumer base.

From a policy perspective, the research suggests that government bodies and policymakers must eliminate the conceptual separation between digitalization and sustainability agendas within MSME training programs by emphasizing the direct correlation between digital efficiency and environmental impact. To further accelerate this transition, governments should design fiscal incentives, market access programs, or public procurement schemes based on sustainability performance indicators derived from MSME digital data, such as non-cash transaction volumes or logistics efficiency records. Additionally, the development of simplified and contextual sustainability reporting standards is essential to facilitate MSME access to green financing and integration into global supply chains. Ultimately, this study affirms that Indonesian MSMEs possess the potential to become key actors in the transition toward an inclusive green economy, provided that digital transformation is directed through a conceptual framework aligned with their limitations and operational realities.

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