# Strategic Technology Adoption for Sustainablity Performance in SME: A Comprehensive Review

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## ABSTRACT

This systematic literature review investigates the strategic adoption of technology for sustainability and resilience in small and medium-sized enterprises (SMEs). Despite growing recognition of technology's role in enhancing sustainability, SMEs face challenges in integrating technological innovations that foster long-term environmental and economic resilience. Using the PRISMA framework, we systematically reviewed 33 primary studies published in 2024 from leading academic databases, including Scopus and Web of Science. The findings are organized into three key themes:(1)Digital Transformation & Technological Innovation,(2)Sustainability, Resilience & Green Practices , and (3) Organizational Strategy , Competitive Advantage & Business Model Innovation. Our analysis reveals that while digital transformation is integral to advancing sustainable practices in SMEs, organizational and strategic barriers often hinder the full potential of technological adoption. The results highlight the importance of aligning technological innovations with business models that emphasize resilience and competitive advantage. This review provides critical insights into the current state of knowledge on the intersection of technology, sustainability, and resilience, offering actionable recommendations for SMEs aiming to leverage technology for long-term success. The study underscores the need for continued research into the barriers and enablers of technology adoption in the context of SME sustainability and resilience, particularly in a rapidly evolving global marketplace.

**Keywords:** Technology adoption, sustainability, sustainable, SMEs

## INTRODUCTION

Small and medium-sized enterprises (SMEs) face significant challenges in maintaining competitiveness and achieving sustainable growth in dynamic markets. Digital transformation is critical for enhancing operational efficiency, fostering innovation, and building resilience, enabling SMEs to adapt to market changes (Martínez-Peláez et al., 2023; Mick, Kovaleski, & Chiroli, 2024; Mick, Kovaleski, Mick, et al., 2024) Integrating digital transformation with sustainability practices further equips SMEs to meet the rising demand for environmentally responsible business models, ensuring competitiveness in an eco-conscious market (Hajishirzi et al., 2022; Melo et al., 2023). This synergy supports improved efficiency while aligning with

environmental and social goals essential for long-term success. However, SMEs often face resource limitations, skill shortages, and a lack of structured strategies, which impede the full benefits of this integration. Strategic roadmaps that align digital initiatives with sustainability goals, emphasizing digital maturity, organizational culture, and stakeholder engagement, are crucial to overcoming these barriers (Martínez-Peláez et al., 2024). Opportunities such as artificial intelligence and circular economy principles offer pathways to strengthen resilience, competitiveness, and environmental stewardship (Dinis-Carvalho et al., 2023; Kumar et al., 2024).

Industry 4.0 technologies, including IoT, big data, and smart factories, enable SMEs to innovate, optimize resources, and achieve sustainability objectives while navigating complex environments (Yaqub & Alsabban, 2023; Zhuo et al., 2024). These tools enhance decision-making and operational efficiency but require addressing challenges like financial constraints, lack of skilled labor, and inadequate infrastructure (Amoah et al., 2021; Rahnama et al., 2022). Aligning digital transformation with economic, environmental, and social dimensions of sustainability is essential for achieving meaningful results (Costa Melo et al., 2023; Garcia-Perez et al., 2023; S. S. Kim, 2021) . Leadership and organizational culture also play key roles, influencing the integration of sustainability into strategies and overcoming resistance to change (Amoah et al., 2023; Holl & Rama, 2024; Philbin et al., 2022).A supportive culture and effective leadership are critical for driving innovation and embedding sustainable practices through digital technologies. Addressing these challenges requires a comprehensive approach, combining technology adoption with long-term sustainability commitments. Support from governments, including infrastructure development, financial incentives, and training programs, is vital for enabling SMEs to adopt technologies and integrate sustainability effectively (Hundal et al., 2023; Kumar et al., 2023). By improving digital and sustainability capabilities through targeted programs, SMEs can successfully implement and scale their transformation efforts.

**Research Question**

Defining the Research Questions (RQs) is a crucial task during the planning phase and is considered the most important part of any systematic literature review (SLR), as it shapes the entire review methodology (Kitchenham, 2007). We applied the PICo framework, a mnemonic commonly used in qualitative research To formulate the research questions (Lockwood et al., 2015). PICo stands for Population, Interest, and Context. The following research questions were developed for this study:

RQ1: How does the adoption of digital technologies and technological innovations impact the sustainability performance of SMEs?

RQ2: In what ways do technology adoption and green practices enhance the sustainability and resilience of SMEs in the service sector?

RQ3: How do SMEs leverage technology adoption to innovate their business models and gain competitive advantage while enhancing sustainability?

## LITERATURE REVIEW

The adoption of technology plays a crucial role in enhancing sustainability in SMEs, especially in the service sector, despite various challenges. For example, Indonesia Kurniasari et al. (2023) emphasizes that financial literacy and technological readiness are critical for SMEs' digital transformation, especially for traditional businesses competing with more modern ones. Similarly, Ghana Amoah et al. (2023) highlights the importance of social media for SMEs to reach customers, noting that customer pressure, employee competence, and resources are key drivers, although barriers like industry pressures may limit adoption. To overcome these challenges, strong leadership and financial support are necessary. In the context of emerging technologies, Alqahtani et al. (2023) highlight the importance of data security, service costs, and organizational readiness for adopting cloud computing (CC) in SMEs, particularly in developing economies. Furthermore, Arora et al.

(2024) argues that Industry 5.0 technologies, including AI and cloud computing, improve communication, transparency, and productivity, advancing sustainability and growth.

Additionally, Santos et al. (2024) points out that digital solutions tailored to SMEs in Brazil can enhance both efficiency and sustainability. Dinis-Carvalho et al. (2023) reveal that combining digital transformation with lean practices in the Portuguese cutlery sector resulted in improved productivity and reduced throughput time, demonstrating the potential for resource optimization. Despite the potential of digital tools, SMEs face several barriers to adoption. Alqahtani et al. (2023) emphasize the importance of cultural awareness and trust in facilitating successful digital transformations. Moreover, Hernandez et al. (2023) discuss how information systems can help green supply chains in developing countries, where adoption is often more difficult. In the service sector, Islam Bhuiyan et al. (2024) note that digital transformation enables SMEs to reduce costs and improve efficiency, while Alam et al. (2024) stress that cleaner production technologies, driven by regulatory and customer pressures, are vital for SME sustainability .

Resource constraints continue to be a significant challenge for SMEs, particularly in terms of infrastructure and financial limitations. Alam et al. (2024) show that cleaner production technologies in Malaysian SMEs are heavily influenced by factors such as management commitment and financial capacity. Abd Rashid et al. (2021) suggest that Islamic crowdfunding could provide an alternative means to address financial barriers. The impact of technology on sustainability differs by region, with factors like government support and management commitment playing key roles. In the service sector, digital technology adoption is essential for improving sustainability. Odegbesan et al. (2023) find that ICT adoption helps Nigerian SMEs overcome resource constraints and improve productivity. Vrontis et al. (2022) show that in India, digital tools improve both economic sustainability and social value in SMEs. The TOE framework is commonly used to examine factors influencing technology adoption. Odegbesan et al. (2023) note that organizational readiness is the primary factor for successful ICT adoption, followed by technological and environmental considerations. Vrontis et al. (2022) argue that aligning digital adoption with entrepreneurial orientation enhances its effectiveness, highlighting both internal and external factors that impact digital transformation and sustainability outcomes. Quantitative studies confirm these findings. Odegbesan et al. (2023) use structural equation modeling (SEM) and artificial neural networks (ANN) to demonstrate that ICT adoption drives sustainability in Nigerian SMEs, with organizational readiness being the most significant factor. Vrontis et al. (2022) apply partial least squares structural equation modeling (PLS-SEM) to show that digital adoption, combined with entrepreneurial orientation, leads to enhanced value creation and improved sustainability in SMEs.

**Emerging Opportunities**

Recent studies emphasize the transformative role of Artificial Intelligence (AI) in driving innovation and sustainability in SMEs. AI's integration with automation, data analytics, and decision-making enhances operational efficiency, reduces costs, and boosts competitiveness. For example, Kumar et al. (2024) highlight AI's integration with cloud computing to optimize logistics, while Mokonyama et al. (2022) discuss AI-powered autonomous vehicles (AVs) improving safety and profitability. Dinis-Carvalho et al. (2023) show how AI combined with Industry 4.0 and Lean practices aligns with Sustainable Development Goals (SDGs), reducing production times and increasing output. AI also supports sustainability in SMEs by optimizing energy usage, reducing waste, and promoting cleaner production. Alam et al. (2024) argue that AI can help reduce environmental footprints, while Sassanelli et al. (2023) highlight AI and Industry 4.0 technologies, like predictive maintenance, improving sustainability through better resource usage.

AI's integration into decision-making processes further transforms SMEs. Studies by Santos et al. (2024) emphasize how AI, alongside Big Data and IoT, enables smarter operations and supports adoption. Soomro et al. (2024) note that AI's predictive analytics and market forecasting offer opportunities for SME growth by enhancing decision-making. AI also boosts competitiveness by enabling agile, data-driven responses to market changes. Islam Bhuiyan et al. (2024) suggest that AI fosters digital transformation and enhances customer engagement. Soomro et al. (2024) highlight AI's potential in predictive analytics, enabling SMEs to anticipate market trends and make proactive decisions, particularly in volatile environments.


Figure 1 AI in SME

Circular Economic (CE) principles, emphasizing resource efficiency, waste reduction, and recycling, are reshaping sustainability practices for SMEs. Recent studies highlight how CE adoption enhances both environmental and economic outcomes. R. Kumar et al. (2023) identify key factors for successful CE implementation in Indian SMEs, such as government incentives and consumer awareness, leading to improved material reuse and waste reduction. Amoah et al. (2023) show how social media fosters transparency in supply chains, supporting resource-efficient operations. Technology adoption is essential for effective CE integration. Arsawan et al. (2024) and Santos et al. (2024) demonstrate that technologies, including Industry 4.0 tools, enable SMEs to implement circular practices. Studies by Dinis-Carvalho et al. (2023) explore how automation and AI reduce waste and improve production efficiency.

Challenges such as limited resources and unfavorable economic conditions persist, but Alam et al. (2024) emphasize the role of government support and customer pressure in overcoming these barriers. Alam et al. (2022) and Abd Rashid et al. (2021) discuss how sustainable technologies and financing options, such as Islamic crowdfunding, can support CE adoption. These studies illustrate that adopting CE principles provides SMEs with opportunities for innovation, waste reduction, and competitive advantage.

## METHODOLOGY

The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework is widely used in systematic literature reviews to ensure transparency, completeness, and consistency (Page et al., 2021).

### Identification

This study utilized key steps in the systematic review process to gather a considerable amount of relevant literature. The process began with selecting keywords and identifying related terms through resources like dictionaries, thesauri, encyclopaedias, and prior studies. These terms were then used to create search strings for the Web of Science and Scopus databases. As a result, 1,686 publications were initially retrieved from both databases that were relevant to the study topic.

### Screening

In the screening phase, potentially relevant studies are reviewed to ensure they align with the research questions. This step often includes selecting studies on Malaysian e-learning, with duplicate records removed at this stage. After initially discarding 1,394 publications, 292 papers remained for further analysis based on specific inclusion and exclusion criteria (see Table 1). Literature was prioritized as the main source of valuable insights, encompassing book series, book reviews, meta-syntheses, meta-analyses, conference proceedings,

and book chapters not included in the most recent research. Only English-language publications from 2024 were considered, resulting in the exclusion of 53 duplicate studies.

Table 1 The selection criterion of searching

| Criterion | Inclusion | Exclusion |
|---|---|---|
| Language | English | Non- English |
| Timeline | 2024 | <2024 |
| Literature Type | Journal (Article) | Conference, Book, Review |
| Publication Stage | Final | In Press |

**Eligibility**

In the third phase, called the eligibility stage, 239 articles were selected for further review. During this step, each article's title and main content were closely assessed to ensure they met the inclusion criteria and were relevant to the study's research objectives. As a result, 206 articles were excluded for reasons such as being outside the field, having an unrelated title, an abstract not aligned with the study's aims, lack of full-text access, or not being grounded in empirical evidence. This left a total of 33 articles for the final review.

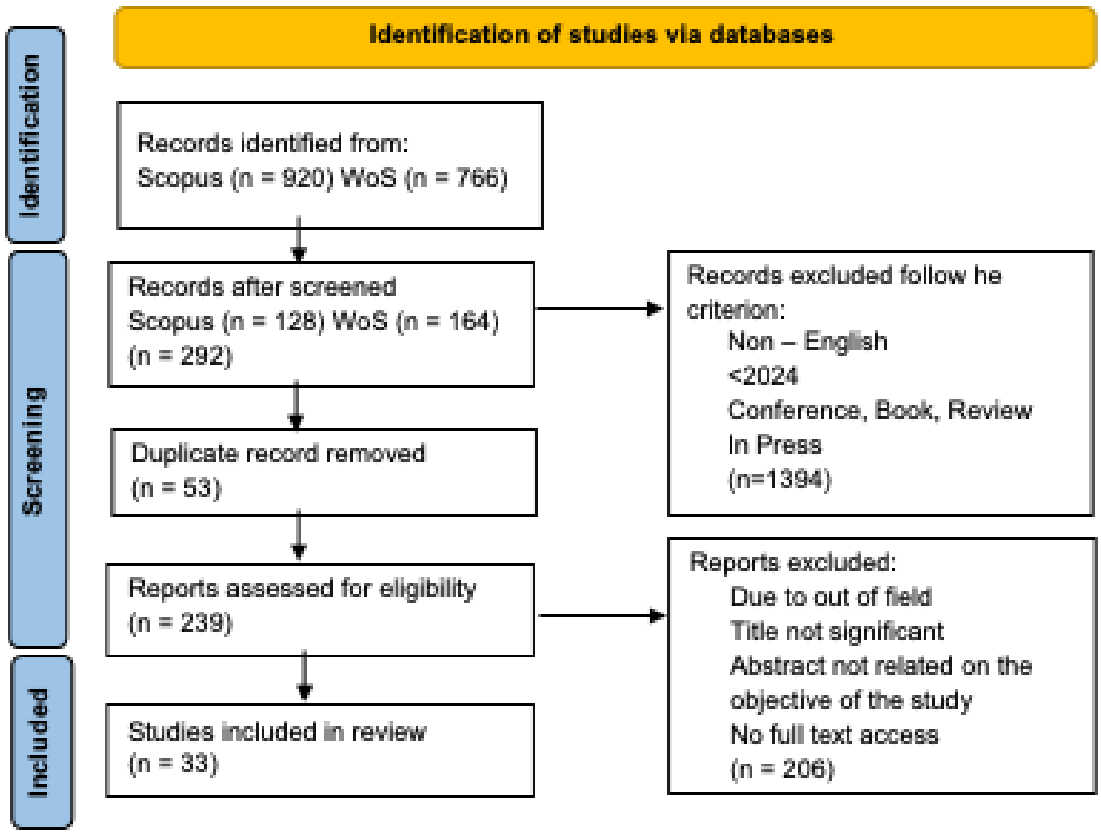


Figure 2 Flow diagram of suggested study

**Data Abstraction and Analysis**

In this study, an integrative analysis was employed as an assessment method to examine and synthesize a variety of research designs, particularly quantitative methods. Figure 2 illustrates how the authors thoroughly reviewed a set of 33 publications to find statements or content relevant to the study's focus. The authors then examined major studies on sustainability in Malaysia, analyzing the methodologies and research findings of each. Collaboration among co-authors helped shape themes based on the study's evidence. Finally, the authors cross-checked the outcomes to ensure consistency in theme development, and any disagreements between concepts were discussed collaboratively.

### Quality of Appraisal

Based on Kitchenham (2007) methodology, once the primary studies were identified, the next steps involved evaluating their quality and conducting a quantitative analysis. This study applied the quality assessment framework outlined by Abouzahra et al. (2020), which includes six distinct criteria specifically designed for systematic literature reviews.

Table 2 provides the evaluation outcomes for the selected primary studies. It illustrates a quality assessment approach in which reviewers independently assess each study based on predefined criteria. Each criterion is rated as 'Yes' (Y), 'Partly' (P), or 'No' (N). The scoring system uses a three-point scale: a full score of 1 is given for 'Yes' (Y) if the criterion is completely satisfied, 0.5 for 'Partly' (P) when partially met with limitations, and 0 for 'No' (N) when the criterion is not fulfilled.

• QA1. Is the purpose of the study clearly stated?

• QA2. Is the interest and the usefulness of the work clearly presented?

•QA3. Is the study methodology clearly established?

• QA4. Are the concepts of the approach clearly defined?

•QA5. Is the work compared and measured with other similar work?

•QA6. Are the limitations of the work clearly mentioned?

After the quality assessment was completed, the results indicate that the majority of the 33 primary studies demonstrated high quality, with most scoring above 5.5 (91.67%) and several, such as PS5, PS7, PS8, PS10, PS28, and PS30, achieving a perfect score of 6 (100%). These studies excelled in meeting the predefined criteria, particularly in clearly stating their purpose, usefulness, and methodology. A few studies, including PS13 and PS16, scored below 4.0, highlighting significant gaps. The weakest area overall was QA6, where many studies failed to adequately address limitations. Despite these variations, the assessment confirmed that most studies met the quality threshold, ensuring their inclusion in further analysis.

## FINDINGS

### Theme Formulations

The themes were revised for consistency through a careful selection process that evaluated their relevance and validity. Feedback from experts led to further refinements, ensuring the themes' coherence and suitability.

### Theme 1: Digital Transformation and Technological Innovation

The adoption of digital technologies is crucial for improving sustainability in small and medium enterprises (SMEs), especially in their operations, environmental impact, and long-term performance. Technologies like artificial intelligence (AI), cloud computing (CC), and cybersecurity systems are key to enhancing sustainability outcomes. For example,) Saqib & Qin (2024) found that digital innovations in logistics boosted environmental, social, and economic sustainability while A. Kumar, Pujari, et al. (2024) showed that AI and CC adoption led to reduced resource consumption, benefiting environmental sustainability. Additionally, Al-Somali et al. (2024) highlighted cybersecurity's role in maintaining business sustainability, especially in Saudi Arabia's service and manufacturing sectors. Despite these benefits, SMEs, particularly in emerging markets, face significant challenges in adopting digital technologies. Tripathi & Singh (2024) emphasized that digital readiness, supported by government policies and skills development, is essential for a successful transformation in Saudi Arabia's Ha'il region. Vergallo et al. (2024) also stressed the need for comprehensive frameworks to assess the carbon impact of digitalization and ensure sustainability. Without adequate preparation, SMEs may struggle to fully realize the benefits of digital transformation.

The Digital Green framework, discussed by Vergallo et al. (2024), helps SMEs assess the environmental impact of digital processes, mitigating the ecological costs of digitalization. Saqib & Qin (2024) further confirmed that digitalization in logistics supports environmental sustainability and strengthens social and economic dimensions, promoting a balanced approach to sustainability. Moreover, digital transformation is recognized as a key driver of SME growth. Studies show that technologies such as cloud computing, AI, and big data analytics enhance operational efficiency, reduce costs, and improve product quality. Al-Somali et al. (2024) demonstrated that digital adoption strengthens resilience and sustainability while Soomro et al. (2024) emphasized the economic and social benefits of digital tools like social media and big data analytics in Pakistan. Trueba-Castañeda et al. (2024) also noted that digitalization improves environmental responsibility and enhances SME reputation, making it crucial for sustainable development.

Digital transformation helps small and medium-sized enterprises (SMEs) align with sustainability goals, including carbon neutrality, through advanced technologies. Zheng et al. (2024) describe three phases: the 'enabler' phase, which fosters innovation; the 'disruptor' phase, altering value creation; and the 'expertise' phase, refining business models. This process supports SMEs in reducing carbon emissions while enhancing efficiency. However, SMEs in developing countries face challenges such as limited funding and technical skills. Telukdarie et al. (2024) recommend a dual global and local analysis to address these issues, highlighting the need for digital literacy and advocacy to help Thai SMEs access capital markets. A supportive ecosystem with training and financial aid is crucial. Additionally, SMEs are pressured to adopt advanced technologies like Industry 4.0 and 5.0. Madhavan et al. (2024) observe that while many seafood SMEs still use older technologies, there is a shift towards Industry 5.0, which prioritizes human-centred and sustainable practices, aligning with the United Nations Sustainable Development Goals (SDGs).

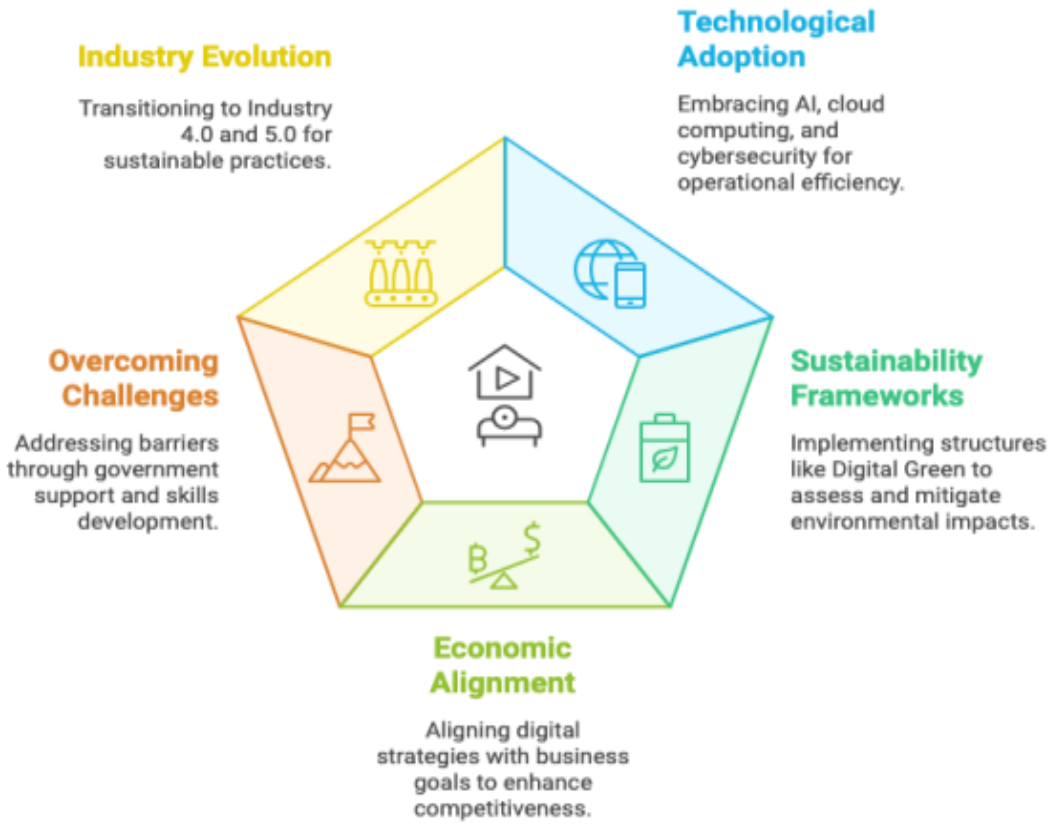


Figure 3 Digital transformation in SMEs

**Theme 2: Sustainability, Resilience, and Green Practices**

Adopting green practices, digital technologies, and sustainability certifications is critical for improving the sustainability performance of small and medium enterprises (SMEs). Combining green supply chain

management (GSCM) with Industry 4.0 technologies has been shown to enhance financial and social outcomes, driving measurable sustainability improvements. Total quality management (TQM) further strengthens the relationship between technology adoption and sustainability, as demonstrated by Pakistani SMEs, which reported increased operational efficiency and resilience through integrating traditional methods with modern technologies (Huang et al., 2024). In Saudi Arabia, digital tools like big data analytics have reduced waste and improved operational performance, underscoring their role in fostering environmental responsibility and competitiveness (Asiri et al., 2024).

Despite these benefits, challenges remain. For example, Australian SMEs adopting circular economy (CE) practices often overlook energy and resource management, limiting broader sustainability integration. Clear policies and strategies are required to support CE adoption (Chakraborty et al., 2024). Innovations like digital twins, which provide real-time lifecycle data to optimize resource efficiency, offer potential solutions but face barriers due to gaps in digitalization (Mügge et al., 2024). In regions such as The Gambia, small-scale fisheries encounter difficulties in achieving sustainability certifications due to limited regulatory support and frequent evaluations, highlighting the need for inclusive and accessible certification systems (Nyiawung & Foley, 2024). Research highlights the synergy between digital tools and sustainable practices in SMEs. Advanced technologies such as digital twins, big data, AI, and blockchain enhance environmental performance and decision-making (Hernández et al., 2024) . Emphasizing environmental, social, and governance (ESG) principles, (Kumar et al., 2024)demonstrate how technological innovation drives environmental improvements. In Malaysia and Indonesia, government incentives, regulatory pressures, and perceived benefits have encouraged SMEs to adopt cleaner production technologies, though successful implementation depends on aligning external support with internal capabilities (Alam et al., 2024; Prihantini et al., 2024). del Socorro Encinas-Grijalva et al. (2024) underscore the importance of organizational culture and technical capacity in achieving digital and sustainable transformations, while Roostika et al. (2024) highlight the role of digital technologies in advancing sustainable development goals (SDGs). In conclusion, integrating GSCM, CE practices, and advanced technologies can enhance SME performance, sustainability, and resilience. However, addressing barriers such as technological limitations, unstructured processes, and unequal access to certifications remains essential for maximizing these benefits.

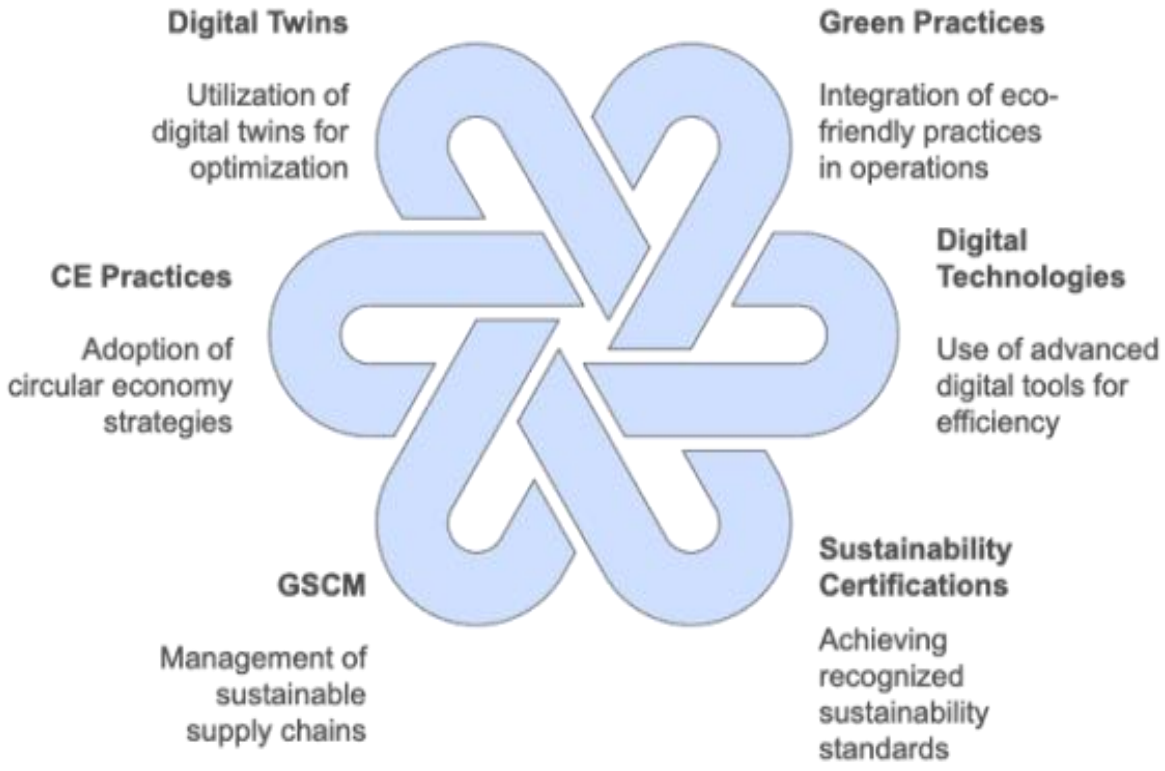


Figure 4 Enhancing sustainability

**Theme 3: Organizational Strategy, Competitive Advantage, and Business Model Innovation**

The adoption of digital technologies and innovative strategies is pivotal for enhancing the sustainability and resilience of small and medium-sized enterprises (SMEs). Studies highlight that digital marketing, innovation, and entrepreneurship are essential drivers of competitive advantage, sustainability, and adaptability in dynamic markets. Aligning these strategies with corporate social responsibility (CSR) further improves SME performance and long-term viability (Awad & Martín-Rojas, 2024; Muis et al., 2024). Digital marketing enables SMEs to expand their customer base, engage more effectively, and respond to market trends, enhancing competitive positioning and business outcomes. However, Muis et al. (2024) note that innovation alone does not significantly improve marketing performance unless integrated within a broader competitive strategy. Entrepreneurship and CSR are also central to resilience strategies for SMEs. Combining digital tools with entrepreneurial initiatives and CSR efforts strengthens adaptability and addresses economic, social, and environmental challenges (Al-Housani et al., 2024; Awad & Martín-Rojas, 2024). For example, during crises like the COVID-19 pandemic, SMEs that embraced CSR and digital technologies adapted more effectively, fostering resilient business models. Programs such as Qatar's Ryadah initiative highlight the importance of entrepreneurial ecosystems in resource-dependent economies, enhancing access to resources and supporting diversification (Al-Housani et al., 2024) . Digital technologies also contribute to operational efficiency and sustainability, as in the textile industry, where they optimize resource use and reduce environmental impacts. Khan et al. (2024) emphasize that green employee behaviors and responsible digital practices are crucial for sustainable outcomes, alongside policies aligning tax incentives and CSR with technological advancements.

Further, studies by Budiarto et al. (2024) and Aini et al. (2024) underscore how digitalization and creative strategies support competitiveness and sustainability. Digital tools enable SMEs to improve operations, develop innovative products, and respond quickly to challenges, ensuring long-term success. Policy-driven initiatives, such as China's cross-border e-commerce strategies, boost entrepreneurship and lower operational barriers, fostering SME growth in smaller cities (Yuan et al., 2024). Similarly, Zhu et al. (2024) explore fintech's role in resource management for sustainable development, demonstrating how green finance reduces adoption barriers and promotes environmentally friendly practices, particularly in E7 countries. Innovation policies also play a critical role in sustainability transitions. Luo et al. (2024) highlight how R&D funding and business support in Hong Kong drive energy technology innovation, enabling SMEs to adopt cleaner technologies. Balanced policies combining demand-side measures and research-driven initiatives are vital for small economies to achieve sustainable innovation. Overall, integrating digital technologies, innovation, and strategic policies equips SMEs to navigate market challenges, optimize operations, and maintain long-term competitiveness and sustainability.

**Trends**

**Across Industries**

Studies reveal distinct patterns in technological adoption and sustainability between manufacturing and service sectors. Al-Somali et al. (2024) found that cybersecurity systems enhance resilience and sustainability in both Saudi Arabian manufacturing and service industries, though resilience and culture had no significant mediating effects. Huang et al. (2024) showed that green supply chain management (GSCM) practices improve performance in Pakistani manufacturing SMEs, with Industry 4.0 technologies acting as mediators. In logistics, Saqib & Qin (2024) found that digital innovation improves sustainability across environmental, social, and economic aspects in Chinese SMEs. Manufacturing sectors, as seen with digital twins (Mügge et al., 2024), focus on lifecycle management and circular economy strategies, while service sectors, like higher education, integrate eco-friendly reengineering (Vergallo et al., 2024).

Manufacturing SMEs prioritize digital technologies, CSR, and employee eco-behavior to boost sustainability (Khan et al., 2024), whereas service SMEs focus on big data analytics and sustainable technology integration for improved business outcomes (Asiri et al., 2024). Technologies such as geomembranes in salt farming (Prihantini et al., 2024) highlight manufacturing's focus on technical efficiency, while service SMEs, like those in food and beverage, emphasize digital marketing for competitiveness (Muis et al., 2024). Green finance and fintech in manufacturing support sustainability (Zhu et al., 2024), while service sectors benefit from cross-

border e-commerce (Yuan et al., 2024). Challenges persist in manufacturing, where industries like seafood processing are slow to adopt Industry 4.0 (Madhavan et al., 2024), while service industries focus more on digital tools for growth (Aini et al., 2024).Overall, the manufacturing sector emphasizes operational efficiency, while service industries prioritize customer engagement and data-driven strategies.

**Regional Difference**

In comparing developed and developing regions, key differences in technology adoption and sustainability efforts emerge. In Saudi Arabia, Al-Somali et al. (2024) and Tripathi & Singh (2024) emphasize the role of government support and digital readiness in boosting SME performance under Vision 2030. Pakistan focus on TQM and Industry 4.0 technologies for sustainability, as highlighted by Huang et al. (2024). Similarly, Kumar et al., (2024) discuss the adoption of AI and cloud computing in India, aimed at overcoming infrastructure and financial barriers to environmental sustainability.

In Australia, Chakraborty et al. (2024) note that circular economy practices in SMEs prioritize water conservation and emissions reduction, although resource management is less prioritized than expected. In West Africa, Nyiawung & Foley (2024) point to challenges in achieving sustainability certification due to institutional and resource constraints. Saudi Arabia sees higher adoption rates of advanced technologies like Big Data Analytics (Asiri et al., 2024), while developing regions like Indonesia use digital platforms, such as live streaming, to build market trust (Roostika et al., 2024). In Europe, AI and blockchain adoption lead to stronger sustainability outcomes for SMEs (Hernández et al., 2024). However, SMEs in developing regions like Indonesia and South Africa face financial and skill constraints, limiting digital adoption (Telukdarie et al., 2024) . Tailored solutions like ICT4D show promise in bridging these gaps. In Thailand and Peru, SMEs leverage digital transformation for capital access and HR management, with digital literacy playing a key role in Thailand (Tanapaisankit et al., 2024) and digital competencies fostering sustainability in Peru (Espina-Romero et al., 2024). In Pakistan and E7 countries, SMEs focus on economic and social value creation through digital tools like IoT and big data (Soomro et al., 2024; Zhu et al., 2024). Policy frameworks also vary by region. In Hong Kong, Luo et al. (2024) note demand-side policies promoting energy technology adoption, though funding for clean energy R&D is lacking. In Malaysia, regulatory pressures and government interventions are key drivers of cleaner production technologies (Alam et al., 2024), reflecting a more compliance-driven approach compared to Hong Kong's broader policy guidance.

**Analysis of Framework and Case Studies**

The Organizational Cybersecurity Framework discussed by Al-Somali et al. (2024) highlights that cybersecurity systems enhance resilience and performance without mediation from culture. This is evident in Intel's pilot project, which used a risk heat map to identify vulnerabilities and prioritize investments, significantly reducing data breaches through strict access controls. In terms of technology adoption, Saqib & Qin (2024) emphasize the positive impact of technology integration on sustainability via the Diffusion of Innovation (DOI) framework. Companies adopting AI and cloud computing have reported improved operational efficiency, particularly in manufacturing, where AI-driven insights lead to reduced waste. Green Supply Chain Management (GSCM), explored by Huang et al. (2024) , improves social and financial performance through the mediating effects of Industry 4.0 technologies and Total Quality Management (TQM). Companies implementing GSCM principles optimize their supply chains with real-time data analytics and IoT technologies, enhancing resource management. Chakraborty et al. (2024) link the Circular Economy (CE) to water conservation and emissions reduction while identifying barriers like undefined processes. Companies that redesign products for reuse or recycling minimize waste and enhance brand reputation. Vergallo et al. (2024) discuss how carbon-aware digitalization can guide eco-friendly transformations through the Digital Green Framework. Organizations using digital tools for sustainability reporting improve transparency; for example, firms employing blockchain technology for supply chain transparency enhance stakeholder trust while reducing emissions. In conclusion, the reviewed frameworks and case studies illustrate the practical application of theoretical findings in enhancing organizational resilience, sustainability, and performance through technology adoption.

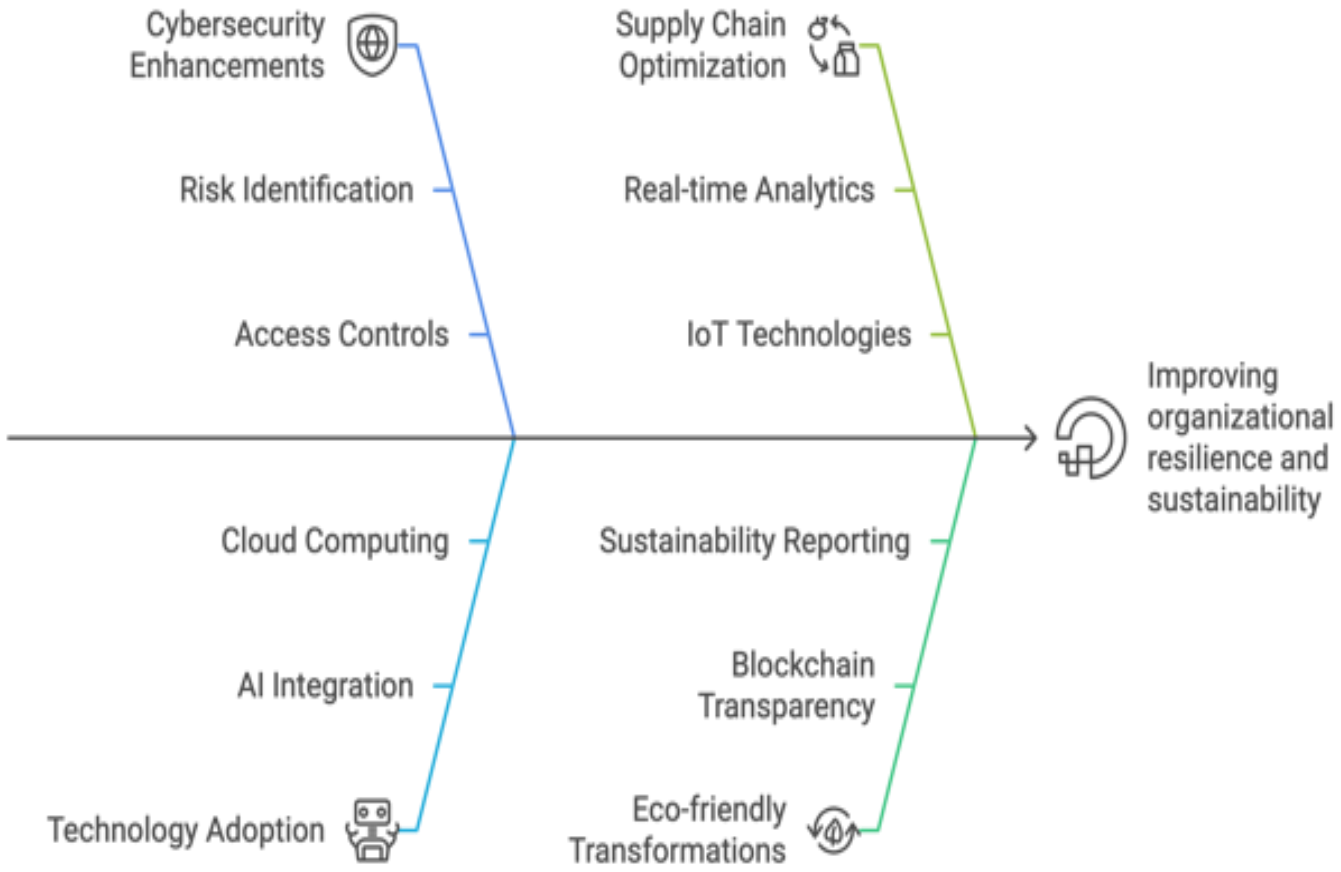


Figure 5 Enhancing organization resilience and sustainability

## DISCUSSION AND CONCLUSION

### Discussion

### Theme Discussion

Digital technologies are key to improving sustainability in SMEs by enhancing their environmental, social, and economic performance. AI, cloud computing, and cybersecurity help optimize operations and reduce resource consumption. However, SMEs, particularly in developing regions, face challenges such as limited finances and technical skills. Government support, training programs, and access to digital tools are crucial for overcoming these barriers. Frameworks like the Digital Green model ensure that digital advancements align with sustainability goals, enabling SMEs to adopt more sustainable business models.

Incorporating green practices, digital technologies, and sustainability certifications is vital for enhancing the sustainability performance of SMEs. Combining green supply chain management (GSCM) with technologies like Industry 4.0 can improve financial, environmental, and social results, boosting efficiency and resilience. Digital tools such as big data analytics, digital twins, and blockchain help optimize resource use and decision-making, improving both environmental impact and competitive edge. Cleaner production technologies (CPTs) reduce environmental harm, with government support encouraging their adoption in certain regions. However, SMEs face challenges like limited resources, lack of digital skills, and difficulties accessing sustainability certifications, especially in developing areas. The adoption of circular economy practices and digital solutions like digital twins is also hindered by unclear strategies and policy gaps.

The integration of digital technologies, innovation, and strategic policies is vital for enhancing SME sustainability and resilience. Digital marketing, entrepreneurship, and CSR drive competitive advantages,

sustainable practices, and market adaptability. Innovation ecosystems, supportive policies, and digital tools boost efficiency, sustainability, and competitiveness. Clean energy innovation and policy initiatives, like cross-border e-commerce and fintech support, enhance resource access and economic growth. This synergy helps SMEs optimize resources, adopt eco-friendly practices, and achieve long-term viability in dynamic markets.

**Forward Looking Perspectives**

The integration of Artificial Intelligence (AI) with Circular Economy (CE) principles positions SMEs to seize future opportunities by driving sustainability, innovation, and adaptability. AI technologies, such as predictive analytics and automation, enable SMEs to optimize resource usage, minimize waste, and improve decision-making, laying a foundation for long-term competitiveness. Looking ahead, advancements in AI will further streamline supply chains, enhance recycling processes, and enable more efficient resource flows, empowering SMEs to meet the demands of a circular economy. As Industry 5.0 evolves, its human-centric and interconnected approach will open new avenues for SMEs to improve resilience and productivity. AI's capabilities will play a pivotal role in optimizing entire product lifecycles, from sustainable production to efficient disposal, ensuring alignment with future market and regulatory expectations. While challenges like organizational readiness and resource constraints remain, SMEs that prioritize strategic adoption of AI and CE practices are better positioned to tap into emerging markets and future-proof their operations. This convergence will offer unparalleled opportunities for sustainable growth, enabling SMEs to thrive in an increasingly sustainability-focused global economy.

**Key Findings Across Industries and Regions**

The findings highlight significant differences in how SMEs adopt technology and sustainability strategies across industries and regions. SMEs must tailor their approaches to industry-specific needs—such as using geomembranes in agriculture or AI for data analysis—and regional factors like infrastructure and economic development. Developing regions should prioritize government funding and capacity-building, while synergies between CSR and digital transformation can enhance resilience and crisis management. SMEs in developing regions can learn from Thailand and Peru's practices, which improve funding access and HR systems, while those in developed regions can adopt fintech and cost-effective innovations from emerging markets. Innovation ecosystems in advanced economies, like Hong Kong, address funding gaps and boost R&D, while developing economies, such as Malaysia and East Java, depend more on government support and regulatory alignment for sustainable practices.

Industry characteristics also shape implementation strategies. Manufacturing sectors benefit from frameworks like digital twins, emphasizing CSR and eco-behavior, while service industries focus on operational reengineering, big data analytics, and sustainable technologies. SMEs in advanced economies face prioritization challenges, whereas those in developing regions grapple with structural and governance issues. Overall, the study underscores the need for tailored strategies based on industry and regional contexts to foster sustainability, resilience, and competitiveness in SMEs.

**Practical Implications**

Adopting technology in SMEs brings tangible benefits such as cost savings, improved efficiency, revenue growth, and environmental sustainability. Technologies like carbon-aware digitalization and geomembrane technology reduce costs by enhancing operational efficiency and minimizing environmental impact. AI, cloud computing, and Industry 4.0 further boost efficiency, leading to increased productivity and profitability. Digital technologies strengthen competitive advantages, improving market access and driving revenue growth. Strategies incorporating digital channels and green technologies also enhance product marketability and business sustainability. In terms of environmental sustainability, AI, cloud computing, and circular economy practices support emissions reduction, water conservation, and eco-friendly transformations. Overall, technology adoption enhances business performance, reduces costs, fosters revenue growth, and supports environmental goals, making it crucial for long-term success and sustainability in SMEs.

# RECOMMENDATIONS

The integration of Artificial Intelligence (AI) with Circular Economy (CE) principles offers Small and Medium Enterprises (SMEs) significant opportunities to enhance sustainability and competitiveness. To leverage this convergence, SMEs should adopt AI-driven resource optimization strategies, such as predictive analytics for better demand forecasting and inventory management, which can minimize waste throughout the product lifecycle. Additionally, employing AI in recycling processes can improve efficiency and increase material recovery rates. SMEs should explore circular business models, like product-as-a-service, using AI to tailor offerings that align with sustainability goals. Focusing on sustainable product design through AI can also facilitate the creation of products that are easier to reuse or recycle. Investing in digital transformation is crucial; integrating digital tools and blockchain technology can enhance supply chain transparency and compliance with sustainability standards. Building organizational readiness through training on AI and CE principles is essential, as is fostering a culture of innovation that encourages collaboration. SMEs should seek government support and funding opportunities to promote sustainable practices and consider partnerships with other organizations focused on sustainability to amplify their impact.

Finally, implementing clear metrics to monitor progress will help SMEs assess the effectiveness of their initiatives and adapt strategies as needed. Staying informed about evolving regulations will enable them to remain compliant while identifying new market opportunities. By adopting these strategies, SMEs can position themselves as leaders in sustainability while enhancing operational efficiency in a competitive landscape.

### Conclusion

In conclusion, the adoption of digital technologies presents significant opportunities for SMEs to enhance sustainability and competitiveness, but achieving these benefits requires overcoming challenges. A successful transition to sustainable practices will depend on integrating advanced technologies with policy support, targeted skills development, and resource allocation. By embracing digital tools and innovative strategies, SMEs can improve business operations, foster growth, and strengthen resilience, contributing to both competitive advantage and global sustainability goals. However, effective implementation will require addressing operational and structural obstacles to ensure long-term success in a dynamic market environment.

### Conflict of Interest

The authors state they have no conflicts of interest to disclose concerning this research.

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# APPENDIX

Appendix A

Table 2 Assessment Performance

| Data | QA1 | QA2 | QA3 | QA4 | QA5 | QA6 | Total Mark | Percentage (%) |
|---|---|---|---|---|---|---|---|---|
| PS1 | Y | Y | Y | Y | P | Y | 5.5 | 91.67 |
| PS2 | Y | Y | Y | Y | Y | P | 5.5 | 91.67 |
| PS3 | Y | Y | Y | Y | N | Y | 5 | 83.33 |
| PS4 | Y | Y | P | Y | N | Y | 4.5 | 75 |
| PS5 | Y | Y | Y | Y | Y | Y | 6 | 100 |
| PS6 | Y | Y | Y | Y | P | Y | 5.5 | 91.67 |
| PS7 | Y | Y | Y | Y | Y | Y | 6 | 100 |
| PS8 | Y | Y | Y | Y | Y | Y | 6 | 100 |
| PS9 | Y | Y | Y | Y | P | Y | 5.5 | 91.7 |
| PS10 | Y | Y | Y | Y | Y | Y | 6 | 100 |
| PS11 | Y | Y | Y | Y | P | Y | 5.5 | 91.7 |
| PS12 | Y | Y | Y | Y | P | P | 5 | 83.3 |
| PS13 | Y | Y | Y | P | P | N | 3.5 | 58.33 |
| PS14 | Y | Y | Y | P | P | Y | 4.5 | 75 |
| PS15 | Y | Y | Y | Y | P | N | 4 | 66.67 |
| PS16 | Y | Y | Y | P | P | N | 3.5 | 58.33 |
| PS17 | Y | Y | Y | P | Y | Y | 5 | 83.33 |
| PS18 | Y | Y | Y | Y | P | N | 4.5 | 75% |
| PS19 | Y | Y | Y | Y | Y | N | 5 | 83.33% |
| PS20 | Y | Y | Y | Y | P | N | 4.5 | 75% |
| PS21 | Y | Y | Y | Y | P | Y | 5.5 | 91.67% |
| PS22 | Y | Y | Y | Y | P | N | 4.5 | 75% |
| PS23 | Y | Y | Y | Y | P | Y | 5.5 | 91.67% |
| PS24 | Y | Y | Y | Y | Y | P | 5.5 | 91.67% |
| PS25 | Y | Y | Y | Y | P | Y | 5.5 | 91.67% |
| PS26 | Y | Y | Y | Y | Y | P | 5.5 | 91.67% |
| PS27 | Y | Y | Y | Y | P | P | 5 | 83.33% |
| PS28 | Y | Y | Y | Y | Y | Y | 6 | 100% |
| PS29 | Y | Y | Y | Y | P | P | 5 | 83.33% |
| PS30 | Y | Y | Y | Y | Y | Y | 6 | 100% |
| PS31 | Y | Y | Y | Y | P | Y | 5.5 | 91.67% |
| PS32 | Y | Y | Y | Y | P | P | 5 | 83.33% |
| PS33 | Y | Y | Y | P | P | P | 4.5 | 75% |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | |

Appendix B

Table 3 Comparative Findings

| No | Authors | Scopus | WoS | Theme | Industry | Region | Finding | Theory / Framework |
|---|---|---|---|---|---|---|---|---|
| 1 | (Al-Somali et al., 2024) | / | / | 1 | Manufacturing, Services | Developed | Cybersecurity systems enhance resilience and performance; resilience and culture do not mediate or moderate. | Organizational Cybersecurity Framework |
| 2 | (Saqib & Qin, 2024) | / | / | 1 | Logistics | Developed | Technology adoption and integration positively impact environmental, social, and economic sustainability. | Diffusion of Innovation (DOI) |
| 3 | (Tripathi & Singh, 2024) | / | | 1 | Services | Developed | Awareness and preparation positively influence business performance via intention to use, skills, and government support. | Technology Adoption Model |
| 4 | (A. Kumar, Pujari, et al., 2024) | / | | 1 | Manufacturing | Developing (India) | AI and cloud computing improve environmental sustainability by enhancing operational efficiency and accessibility. | Adoption and Diffusion Framework |
| 5 | (Huang et al., 2024) | / | | 2 | Manufacturing | Developing (Pakistan) | GSCM improves performance in social and financial terms; Industry 4.0 technologies and TQM play mediating and moderating roles. | Green Supply Chain Management (GSCM) |
| 6 | (Chakraborty et al., 2024) | / | | 2 | Manufacturing | Developed | Circular economy adoption linked to water conservation, emissions reduction, and barriers like undefined processes. | Circular Economy (CE) |
| 7 | (Vergallo et al., 2024) | / | / | 1 | Services | Developed | Carbon-aware digitalization reduces environmental costs and guides eco-friendly transformations. | Digital Green Framework |
| 8 | (Trueba-Castañeda et al., 2024) | / | / | 1 | Multi-sectorial | Developed | Digitalization enhances environmental responsibility, efficiency, and profitability. | Reflexive Structural Equation Model |
| 9 | (Mügge et al., 2024) | / | / | 2 | Manufacturing | Developed | Digital twins enhance lifecycle management and support circular economy decision-making. | Digital Twin Concept |
| 10 | (Nyiawung & Foley, 2024) | / | | 2 | Fisheries | Developing | Certification systems hindered by inequitable governance and resource access in West Africa. | Social Science Governance Approach |
| 11 | (Al-Housani et al., 2024) | / | / | 3 | Multi-sectorial | Developing | Entrepreneurship drives diversification in resource-based economies like Qatar. | Innovation Ecosystem Framework |
| 12 | (Binnui & Iamsaard, 2024) | / | | 3 | Agriculture-based | Developing | A comprehensive 8P's strategy improves product marketability, leveraging digital channels and community collaboration for sustainable growth. | Marketing Mix |
| 13 | (Asiri et al., 2024) | / | | 2 | Services, Manufacturing | Developed | BDA adoption driven by perceived ease of use and management support significantly impacts business performance in Saudi SMEs. | Structural Equation Modeling (SEM) |
| 14 | (A. Kumar, Yadav, et al., 2024) | / | | 2 | Handicraft Industry | Developing | Technological innovation and ESG principles significantly enhance environmental performance and foster eco-friendly practices. | PLS-SEM |
| 15 | (Zheng et al., 2024) | / | / | 1 | High Technology SMEs | Developed | Digital technology evolves from enabler to disruptor to expertise, transforming business models and enabling carbon neutrality. | Evolutionary Process Model |
| 16 | (Roostika et al., 2024) | / | | 2 | Digital Economy | Developing | Live streaming fosters trust and market accessibility but has limited influence on impulse buying without customer awareness. | Social Cognitive Theory (SCT) |
| 17 | (Khan et al., | / | | 3 | Textile | Developing | Digital technologies, CSR, and green | SEM Framework |

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| | 2024) | | | | Manufacturing | | employee behavior improve sustainable performance; TA is unaffected by CSR activities. | |
| 18 | (Muis et al., 2024) | / | | 3 | Food and Beverage | Developing (Indonesia) | Digital marketing improves competitive advantage and marketing performance; innovation impacts only indirectly through competitive advantage. | Resource-Based View (RBV) |
| 19 | (Telukdarie et al., 2024) | / | / | 1 | Cross-Industry | Developing Countries | Two-tier approach (global analysis and country-specific needs) aids sustainable digital transformation and mitigates digital challenges. | ICT4D Framework |
| 20 | (Hernández et al., 2024) | / | / | 2 | Cross-Industry | Developed (Europe) | Data gathering/analysis technologies improve sustainability actions; larger SMEs benefit more significantly than smaller ones. | Not specified |
| 21 | (Prihantini et al., 2024) | / | | 2 | Salt Farming | Developing (Indonesia) | Geomembrane technology improves technical efficiency; adoption is influenced by socioeconomic factors such as age, gender, and land ownership. | Logistic Regression, DEA, PSM |
| 22 | (Awad & Martín-Rojas, 2024) | / | | 3 | Cross-Industry | Developed (Spain) | CSR, digital technologies, and entrepreneurship synergistically boost organizational resilience and sustainability practices. | Dynamic Capabilities Theory |
| 23 | (Zhu et al., 2024) | / | / | 3 | Manufacturing | Developing (E7) | Green finance and fintech reduce CO2 emissions, enhance green growth, and improve ecological footprints. | EKC Hypothesis |
| 24 | (Yuan et al., 2024) | / | | 3 | Services | Developing (China) | Policies in pilot zones enhance entrepreneurial vitality by 13.3%, especially in services and small cities. | Quasi-Natural Experiment |
| 25 | (Soomro et al., 2024) | / | / | 1 | Mixed (General SMEs) | Developing (Pakistan) | IoT, social media, and blockchain create economic and social value; AI has minimal impact. | SEM-ANN Hybrid |
| 26 | (Espina-Romero et al., 2024) | / | / | 1 | Mixed (General SMEs) | Developing (Peru) | Digital competencies improve HR management and foster sustainable practices and organizational culture. | Structural Equation Modeling (SEM) |
| 27 | (Budiarto et al., 2024) | / | | 3 | Mixed (General SMEs) | Developing (Indonesia) | Digitalization and creativity enhance competitive advantage, leading to sustained SME performance. | None specified |
| 28 | (Tanapaisankit et al., 2024) | / | | 1 | Mixed (General SMEs) | Developing (Thailand) | Digital literacy and advocacy are crucial for accessing new capital markets and enhancing credibility. | Mixed-Methods Approach (CFA, SEM) |
| 29 | (Aini et al., 2024) | / | / | 3 | Services | Developing (East Java) | Management orientation positively impacts digital business and growth. Digital platforms effectively enhance SME operations and growth. | None mentioned |
| 30 | (Luo et al., 2024) | / | / | 3 | Mixed | Developed (Hong Kong) | Heavy reliance on overarching policy strategies and demand-side policies; insufficient R&D support for clean energy technologies, compared to peer jurisdictions. | Correspondence Analysis |
| 31 | (Alam et al., 2024) | / | | 2 | Manufacturing | Developing (Malaysia) | Adoption influenced by regulatory pressure, government support, and environmental uncertainty. Perceived cost is not a significant predictor. | Technology-Organization-Environment (TOE) |
| 32 | (del Socorro Encinas-Grijalva et al., 2024) | / | / | 2 | Mixed | Developing (Mexico) | Dual transformation readiness depends on strategy, culture, and organizational and technical capabilities. | None mentioned |
| 33 | (Madhavan et al., 2024) | / | | 1 | Manufacturing (Seafood) | Developing (Thailand) | Minimal Industry 4.0 adoption; higher readiness for Industry 5.0 practices in business processes and communication. | Seven-Factor Framework |