International Journal of Education, Management Sciences and Professional Studies (IJEMPS)
Vol. 1 Issue 2 (AS) PRINT *ISSN:3115-5065* || E-ISSN:3115-5545
URL: https://journals.iempsglobal.org/index.php/IJEMPS

THE ROLE OF TECHNOLOGY IN DRIVING SUSTAINABILITY PRACTICES AND GREEN BUSINESS ADOPTION AMONG SMALL AND MEDIUM ENTERPRISES IN DEVELOPED NATIONS

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Abstract

Small and medium-sized enterprises (SMEs) play a crucial role in developed economies but also contribute significantly to environmental degradation. Shifting SMEs towards sustainable practices is vital for achieving global climate goals. Digital technology offers strong potential to support this transition, yet uptake remains limited. This study explores how technology adoption and access to technology education influence sustainability and green business models in SMEs, while also examining economic, technical, and organisational barriers. A systematic review of 84 peer-reviewed articles (2010–2025) reveals that both technology use and education are positively linked to improved sustainability and innovation. However, challenges such as high costs, skills gaps, and policy uncertainty hinder progress. The findings highlight the need for supportive ecosystems, comprising effective policies, education, and financial incentives to enable SMEs to adopt greener practices. Strategic recommendations are offered for policymakers, SME leaders, and educators.

Keywords: Technology, Green Businesses, SMEs, Sustainability, Developed Nations

Introduction

Small and Medium Enterprises (SMEs) are vital to global economic systems, comprising the majority of businesses and contributing significantly to employment across both developed and developing nations (Adams, I. A., Gyamfi, S., & Amuzuvi, C. K., 2021; World Bank, 2023). Their presence in resource-intensive sectors such as manufacturing and logistics makes them key stakeholders in achieving sustainability targets, including the UN SDGs and the Paris Agreement (Gennitsaris, S., Oliveira, M. C., Vris, G., & Kontaridis, S, 2023; Ketenci & Wolf, 2024). Even incremental improvements in SME sustainability practices can yield substantial environmental and economic benefits at scale. Over the past two decades, sustainability has

shifted from a peripheral CSR concern to a strategic business imperative. Firms increasingly integrate sustainability into core operations, recognising its role in enhancing performance, resilience, and competitive advantage (Kurucz, E. C., Colbert, B. A., & Wheeler, D. 2009; Liboni, L. B., Cezarino, L. O., Alves, M. F. R., & Stacchezzini, R. P., 2022). A growing body of evidence indicates that companies exhibiting robust and genuine sustainability practices frequently demonstrate superior operational performance, which translates into enhanced financial outcomes and improved resilience to market volatilities (Clark *et al*., 2014). This demonstrates a tangible and measurable link between the adoption of sustainable practices and overall business success, moving beyond mere ethical considerations into the realm of strategic financial management.

Digital technologies such as IoT, AI, blockchain, and data analytics are emerging as powerful enablers of sustainable transformation. These tools help SMEs optimise resource use, reduce waste, and improve environmental performance (Tripathi, S., Bachmann, N., Brunner, M., Rizk, Z., & Jodlbauer, H., 2024). Moreover, access to digital skills and sustainability education is essential for fostering innovation and building capacity for green transition, as reflected in frameworks like the European Sustainability Competence Framework (Hamburg, 2020; Kioupi & Voulvoulis, 2022). Despite growing recognition of sustainability's strategic value and the transformative potential of digital technologies, SMEs in developed economies continue to face a persistent "implementation gap", a disconnect between sustainability awareness and the adoption of technology-enabled green practices (Martins *et al*., 2022). This gap is compounded by a "digital divide," where SMEs struggle to integrate advanced technologies relative to larger firms, reinforcing competitive and economic disparities (OECD, 2021).

A key challenge lies in the limited understanding of how the adoption of digital technology and education translates into measurable sustainability outcomes within SMEs. Existing research often treats technology drivers, educational factors, and implementation barriers in isolation, overlooking their complex interdependencies. Economic, technical, and organisational constraints frequently dilute or obstruct the impact of digital solutions, hindering sustainable transformation. Therefore, a holistic and integrated analysis is needed to uncover how these elements interact and influence SMEs' capacity to adopt green business models effectively.

To investigate how digital technology adoption facilitates sustainability practices and supports the development of green business models among SMEs in developed economies.

1. To examine the evolution and scope of sustainability practices among SMEs from 2010 to 2025.
2. To assess the role of technology education and training in enhancing SMEs' capacity for green innovation.
3. To identify and evaluate economic, technical, and organisational barriers that moderate the relationship between technology adoption and sustainability outcomes.

These objectives are directly translated into the study's central research questions, which operationalise the inquiry:

- What is the relationship between digital technology adoption and sustainability practice implementation in SMEs?
- How does access to technology education influence SMEs' capacity for green innovation and sustainability?
- To what extent do economic, technical, and organisational barriers moderate the impact of technology adoption and education on green business model adoption?

Finally, to empirically test the propositions inherent in the aim and questions, the study puts forward three formal hypotheses:

- **H_1**: Digital technology adoption positively influences the implementation of sustainability practices in SMEs.
- **H_2**: Access to technology education enhances SMEs' green innovation capacity and broadens sustainability practices.
- **H_3**: Economic, technical, and organisational barriers negatively moderate the relationship between technology adoption, education, and green business model implementation.

This study offers valuable contributions to academia, industry, and policy. For scholars, it presents an integrated framework linking technology adoption, education, and barriers, thereby advancing theoretical understanding of SME sustainability. It addresses gaps in longitudinal and cross-national analyses. For SME owners and managers, the research provides practical insights into leveraging digital technologies and workforce development for improved efficiency, competitiveness, and compliance. For policymakers, it identifies key intervention areas and supports the design of targeted policies and incentives to overcome adoption barriers. Overall, the study aims to inform strategies that close the implementation gap and promote inclusive, sustainable economic transformation. The research focuses on SMEs within developed economies, particularly OECD member states, over the period 2010–2025. This scope enables analysis of both historical trends and emerging developments in sustainability and technology adoption. Developed nations offer robust regulatory environments, richer data availability, and greater access to digital infrastructure and support schemes, making them ideal for this investigation. Moreover, their practices often serve as benchmarks for global policy and industry standards. The study spans multiple sectors, acknowledging that adoption patterns may vary across industries.

Literature Review

Conceptual Dialectics

This study is grounded in three interrelated concepts: sustainability, technology adoption, and green business models. In the context of SMEs, sustainability now encompasses the integration of environmental, economic, and social objectives into core business strategy, moving beyond traditional CSR. Although SMEs often face resource constraints, their collective environmental impact and strategic role in achieving global targets such as the UN SDGs make their engagement in sustainability essential (Klewitz & Hansen, 2014). In developed economies, sustainability is increasingly viewed as a strategic imperative for competitiveness and legitimacy (Porter & Kramer, 2019). Technology acts both as an enabler and a barrier. Digital tools, such as AI, IoT, and cloud-based systems, support SMEs in improving efficiency, transparency, and environmental performance (Ghobakhloo, 2020). Innovations like renewable energy systems and circular economy platforms facilitate deeper transitions. However, adoption is often hindered by financial costs, limited expertise, and integration challenges, creating tension between potential and practical implementation (Horbach, 2019).

Green business models represent a comprehensive shift in organizational strategy, embedding sustainability into products, services, and value propositions (Bocken *et al*., 2014). For SMEs, these models offer opportunities for innovation, differentiation, and alignment with ESG standards increasingly demanded by global supply chains and conscious consumers (Deng *et al*., 2024). Their successful adoption depends on internal readiness, external support, and institutional context. Together, sustainability serves as the strategic goal, technology as the enabler, and green business models as the operational framework. Yet, gaps persist between intent and execution, particularly in SMEs' use of technology education and organizational learning. This study investigates how digital adoption and education enhance sustainability and green innovation capacity in SMEs across developed nations.

Figure 1 below illustrates the conceptual framework, showing technology adoption driving sustainability practices and green business adoption, with technology education as an enabler and barriers as moderators.

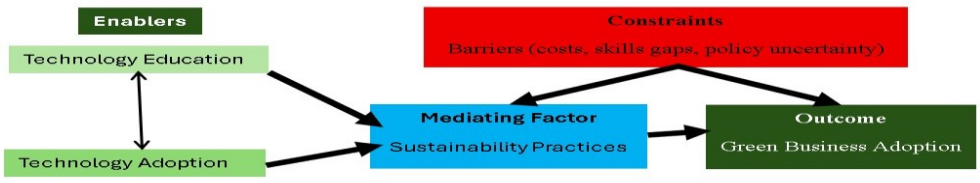


Figure 1: Conceptual Framework

Theoretical Perspectives

The adoption of technology-driven sustainability practices in SMEs can be understood through several interrelated theoretical frameworks.

Diffusion of Innovation Theory (Rogers, 2003) explains how new technologies are adopted at different rates, influenced by factors such as perceived benefits, complexity, and observability. SMEs often fall into the "late majority" or "laggard" categories due to limited resources and risk aversion (Ghobakhloo, 2020).

The **Resource-Based View (RBV)** (Barney, 1991) posits that competitive advantage stems from unique internal capabilities, including technological assets and eco-innovation knowledge. However, without investment in technology education, SMEs may struggle to fully exploit these resources (Bai *et al*., 2017).

The **Triple Bottom Line (TBL)** framework (Elkington, 1997) urges firms to balance economic, social, and environmental goals. For SMEs, technology is a key enabler of this balance, supporting long-term resilience (Stubbs & Cocklin, 2008). In recent years, advanced technologies have become more available to SMEs for enhancing their goals.

Institutional Theory (DiMaggio & Powell, 1983) highlights external pressures—such as regulations, industry norms, and ESG expectations—that drive SMEs to adopt sustainable practices, particularly when integrated into global supply chains (Del Río *et al*., 2016).

Together, these perspectives offer a comprehensive lens for examining how technology influences sustainability in SMEs.

Empirical Review

Over the past 15 years, research has shown both progress and persistent challenges in SME sustainability. Early studies (2010–2025) found that SMEs primarily adopted reactive, cost-driven eco-efficiency measures (Klewitz & Hansen, 2014). More recent work highlights a shift towards proactive eco-innovation and strategic integration of sustainability (Albort-Morant *et al*., 2017; Daddi *et al*., 2018). Digital technologies have played a central role in this transition. Tools associated with Industry 4.0 have improved efficiency and enabled sustainable product development (Ghobakhloo, 2020). However, adoption remains uneven, with many SMEs lacking the capacity to implement these technologies effectively (Horbach, 2019). Education and training are critical enablers. Structured programmes have been shown to enhance eco-innovation capacity and competitiveness (Santolaria et al., 2011; Sarkis *et al*., 2019; Cantele & Zardini, 2018). Nonetheless, barriers such as financial constraints, skills shortages, and regulatory complexity persist (Horbach *et al*., 2012; Albort-Morant *et al*., 2017). While subsidies can support adoption, long-term change depends on sustained investment in organisational learning (Bai *et al*., 2017).

Gap in the Literature

Despite growing interest in SME sustainability, several gaps remain. First, most studies are cross-sectional, lacking longitudinal insight into how practices evolve, an issue this study addresses by covering the 2010–2025 period. Second, while technology education is often acknowledged, few studies systematically assess its direct and indirect effects on green innovation. Third, much of the literature is country-specific, limiting broader cross-national

comparisons. Finally, the influence of rising global ESG pressures on SME technology adoption remains underexplored, despite its growing relevance to market access and competitiveness. This study responds to these gaps by examining temporal trends, evaluating the role of technology education, and analysing how barriers moderate green business model adoption across diverse developed economies.

Methodology

This study employs a qualitative design, structured as an explanatory systematic literature review. It aims to explore how technology facilitates or hinders sustainability and green business model adoption among SMEs in developed economies. Thematic analysis was employed to identify and interpret patterns across secondary data sourced from institutional reports, policy documents, and peer-reviewed publications spanning the period from 2010 to July 2025.

The study defines its population conceptually as SMEs operating within OECD member countries that engage in sustainability-related activities. This inclusive approach captures a broad spectrum of practices and adoption pathways without limiting the analysis to specific sectors or regions. A purposive sampling strategy was adopted, focusing on OECD countries with robust environmental reporting and high data availability. This cross-national approach enables comparative analysis across diverse contexts. The final sample comprised 84 studies and reports that met strict inclusion criteria, ensuring relevance and data richness. Data were drawn exclusively from secondary sources. Quantitative data came from OECD, Eurostat, the U.S. Small Business Administration (SBA), and Japan's METI. Peer-reviewed articles from Scopus and Web of Science provided qualitative insights and contextual depth, supporting a comprehensive understanding of adoption trends and influencing factors. Validity was ensured through data triangulation, comparing findings across multiple sources. OECD statistics were cross-referenced with national datasets and supported by qualitative case studies. Reliability was enhanced by selecting only authoritative and peer-reviewed sources with transparent methodologies.

Following the PRISMA protocol, an initial search yielded 642 records. After removing duplicates and screening titles and abstracts, 315 unique records remained. Of these, 231 were excluded for not meeting the inclusion criteria. The final synthesis included 84 full-text articles and reports, all relevant to SMEs, technology adoption, and sustainability in OECD economies. This process is summarised in the PRISMA flow diagram presented in Figure 2.

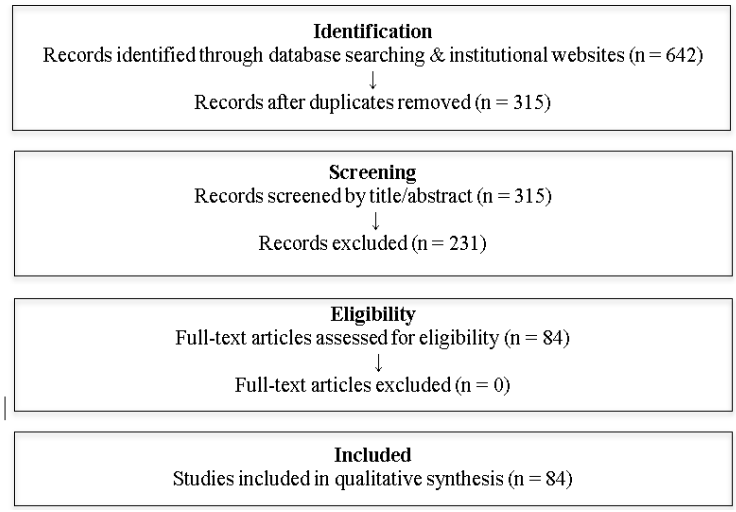


Figure 2: PRISMA Flow Diagram of the Study Selection Process

Operationalisation of Variables

Key constructs were defined to support consistent coding and analysis:

9. **Sustainability practices**: Adoption of eco-efficiency measures (e.g., waste reduction, energy saving), use of renewable energy (e.g., solar, wind), and circular economy strategies (e.g., recycling, reuse).
10. **Technology adoption**: Uptake of digital platforms (e.g., cloud computing), renewable energy technologies, and Industry 4.0 tools (e.g., IoT, AI, automation).
11. **Access to technology education**: Participation in formal training, government initiatives, or industry-led programmes aimed at enhancing sustainability-related digital skills.
12. **Barriers**: Constraints categorised as economic (e.g., high costs), technical (e.g., lack of expertise), and organisational/institutional (e.g., policy uncertainty).
13. **Green business adoption**: Strategic shift in operations or offerings towards sustainability, evidenced by certifications (e.g., ISO 14001), sustainable supply chains, or green product lines.

These definitions guided the thematic coding and analytical synthesis.

Apriori Expectations

Before analysis, the following themes were anticipated:

- **Technology** as a key enabler of SME sustainability, with digital tools and renewable energy driving efficiency and innovation.
- **Technology education** as a facilitator of green innovation, with higher adoption rates linked to accessible, high-quality training.

- **Barriers** as persistent constraints, including financial limitations, skills shortages, and institutional uncertainty.

Cross-country variation within the OECD was also expected, with stronger institutional support observed in countries like Germany and the Nordics compared to others such as the United States.

Analytical Techniques

Thematic analysis was conducted using Braun and Clarke's (2006) six-phase framework:

- Familiarisation with data through repeated reading.
- Generation of initial codes.
- Identification of potential themes.
- Review and refinement of themes.
- Definition and naming of themes.
- Production of the final report, integrating narrative and illustrative examples.

Themes were derived from institutional datasets, policy documents, and academic literature, and presented via summary tables, narrative synthesis, and visual figures.

Software

Microsoft Excel was used for data organisation and visualisation. NVivo supported the coding and management of qualitative data. However, emphasis remained on the interpretive rigour of thematic analysis rather than software automation

Results and Findings

Hypothesis Testing and Thematic Evidence

The comprehensive analysis of the 84 selected studies provided robust support for all three hypotheses advanced in this research. The strength of evidence, however, varied noticeably across different national contexts, reflecting the influence of distinct institutional frameworks, policy environments, and cultural attitudes towards sustainability and innovation. The key findings for each hypothesis are summarised in Table 1 and further elaborated thematically in Table 2.

Table 1: Summary of Hypothesis Testing

Hypothesis	Indicators	Strength of Support	Key Evidence
H_1	Tech Adoption → Sustainability Practices	Strong	German manufacturing SMEs adopting IoT-based digital monitoring systems achieved a 15% reduction in energy use (Horbach, 2019). Dutch SMEs in the textile sector used digital tools for circular economy strategies, cutting waste output by 30% (Daddi et al., 2021).
H_2	Tech Education → Innovation Capacity	Moderate to Strong	SMEs participating in EU-funded eco-innovation workshops in the Netherlands showed a marked increase in waste valorisation and renewable integration projects (Cantele & Zardini, 2018).
H_3	Barriers moderate H_1 & H_2	Strong	41% of U.S. SMEs cited uncertainty about Return on Investment as the primary obstacle to investing in sustainability technology (SBA, 2022). Japanese SMEs reported high upfront costs and a shortage of skilled green-tech workers as critical constraints (METI, 2021).

Table 2: Thematic Evidence Matrix by Country

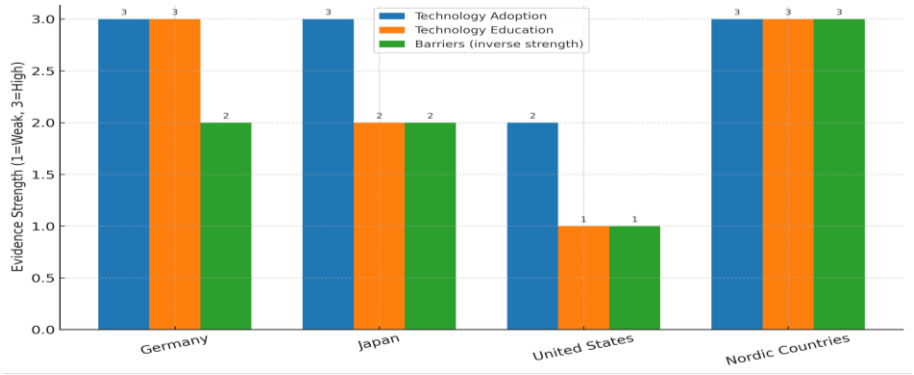
Theme	Germany	Japan	United States	Nordic Countries
Technology Adoption	High, particularly in automotive and manufacturing SMEs, driven by	High in specific areas like precision manufacturing and robotics,	Uneven; highly concentrated within clean-tech clusters	High and widespread across sectors; strongly driven by national policy

Theme	Germany	Japan	United States	Nordic Countries
	Industry 4.0 policies.	slower adoption of renewables.	and venture-backed firms; slower in traditional sectors.	mandates and carbon targets.
Technology Education	Strong, supported by a well-established dual apprenticeship system that integrates eco-innovation skills.	Moderate; a noticeable gap exists in digital and green skills training for SMEs compared to large firms.	Weak and fragmented; significant disparities between urban tech hubs and rural areas; lack of a cohesive national program.	Strong; features comprehensive, government-subsidised training and lifelong learning initiatives accessible to SMEs.
Key Barrier	Persistent skills gaps, particularly among smaller firms, the cost of the renewable energy transition for very small SMEs.	High initial investment costs, policy uncertainty for smaller firms, and limited availability of a skilled green workforce.	High perceived financial risk and ROI uncertainty; fragmented policy support at the federal level; regulatory complexity.	Minimal compared to other regions due to extensive policy support, high public trust, and generous subsidy schemes.

Visualisation of Evidence Strength

The comparative evidence strength of the core constructs across the different national contexts is presented in Figure 2. This visualisation highlights the stark contrast between the Nordic nations and Germany, which demonstrate strong institutional support for both technology drivers, and the United States, where evidence of barriers is more prominent.

Figure 3: Evidence Strength of Technology Drivers and Barriers Across Countries



Discussion of Findings

The findings affirm the central role of technology in advancing sustainability within SMEs across developed economies. The positive link between technology adoption and improved environmental performance (H_1) supports the Resource-Based View, demonstrating that digital and green technologies act as strategic assets, which is evident in energy efficiency gains among German SMEs (Horbach, 2019).

The second hypothesis (H_2) is also validated, highlighting the importance of technology education in building green innovation capacity. EU-funded training initiatives in the Netherlands (Cantele & Zardini, 2018) illustrate how targeted upskilling enhances SMEs' ability to absorb and apply new knowledge.

The third hypothesis (H_3) confirms that barriers (economic, technical, and institutional) moderate the effectiveness of technology adoption. Success in Nordic countries and Germany is linked to coherent policy frameworks and financial support, while fragmented policies in the United States (SBA, 2022) and sector-specific challenges in Japan demonstrate how barriers can inhibit progress, even in technologically advanced contexts.

These findings underscore the interplay between internal capabilities and external institutional support. For technology to drive sustainability effectively, SMEs require an enabling ecosystem that reduces adoption risks and supports long-term transformation.

Conclusion

This study explored how technology and education influence sustainability and green business adoption among SMEs in developed nations, based on secondary data from 2010 to 2025. Key conclusions include:

- Technology adoption significantly enhances sustainability practices, improving efficiency and reducing waste (H_1).

- Technology education is vital for fostering innovation and expanding sustainability efforts (H_2).
- Barriers like financial, technical, and institutional can undermine these benefits, with impacts varying across national contexts (H_3).
- By integrating the Resource-Based View and Institutional Theory, the study offers a nuanced understanding of SME sustainability, moving beyond simplistic narratives of technology as a universal solution.

Recommendations

Policymakers

- Develop integrated policy frameworks combining financial incentives with regulatory clarity.
- Fund targeted education programmes to build digital and green skills within SMEs.

Industry Associations and Educational Institutions

xlviii. Expand collaborative training initiatives aligned with green economy needs.

xlix. Create digital platforms for resource sharing and peer learning.

SME Owners and Managers

27. Engage in partnerships to access shared resources and funding.

28. Invest strategically in employee upskilling to strengthen innovation capacity.

Researchers

- Conduct longitudinal studies to track sustainability progress over time.
- Investigate sector-specific dynamics to understand how barriers and drivers vary across industries.

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