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REVIEW ARTICLE

An Analytical Review on the Effects of Industry 4.0

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Abstract

Small and medium-scale enterprises (SMEs) are the backbone of the global economy, yet they risk falling behind in the digital age. This analytical and bibliometric review examines the effects of Industry 4.0 on SMEs worldwide from 2013 to 2023. Using analytical methodology, the review identifies and analyses relevant empirical studies conducted across various regions and industries, shedding light on the challenges and opportunities that 4IR adoption presents for SMEs. Key themes emerge, including the role of digitalisation in boosting SMEs' productivity, competitiveness, and sustainability. However, a concerning disparity exists between developed and developing countries regarding adoption rates. This highlights the need for a targeted support programme to help SMEs leverage 4IR technologies. The review also emphasises future research's importance in addressing knowledge gaps and informing policy strategies that promote inclusive economic growth. By understanding the complex dynamics of SMEs engagement with 4IR, this research provides useful insights for policymakers, practitioners, and researchers seeking to navigate the digital transformation journey.

Keywords SMEs, fourth industrial revolution, industry 4.0, analytical review

1. Introduction

Since the beginning of civilisation, continuous technological improvement has been a major factor in human development. The phases of this technological progress can be traced to when mankind used simple tools to enhance the output of goods and services, from the discoveries of steam engines that used coal to the innovations of engines, innovative computer programming and machinery powered by electricity. The fourth industrial revolution (4IR) was made possible with internet facilities, which led to the digitalisation, artificial intelligence, and automation of the production process using Information and Communications Technologies (ICT). Considering that the World Trade Organization defines “electronic commerce” as “the production, distribution, marketing, sale or delivery of goods and services by electronic means” (Borchert et al., 2020; WTO, 1996). In consonant with this definition, 4IR can be classified as digital trade embedded with cross-border data using technologies (Borchert et al., 2020). This Industry 4.0 revolution has shifted the paradigm of goods and services from increased production to improved and enhanced productivity through automation, digitalisation and improved cyber-technology (Sima et al., 2020). From an international trade perspective, e-commerce, digitalisation, technological innovation and other elements of Industry 4.0 enhance industrial development, investments, and global trade volume (Borchert et al., 2020). According to the World Bank (2020), except for Africa, trade increased by 3% from 2020 to 2021 due to e-commerce, digitalisation, and technology. Africa’s total export contribution to GDP is 1%, and global trade is less than 2% (Niringiye & Tuyiragize, 2010). The 4IR can improve cost, product quality, competitive advantages, revenue, export, and sustainable supply chains (Islam et al., 2022; Tandrayen-Ragoobur, 2022). Considering the enormous positive change Industry 4.0 has on international trade and industrial development, developing countries need to adopt innovation. Disparate from the previous industrial revolutions, as shown in Figure 1, the idea of I4.0, as coined (Schwab, 2015), is to create a scenario where virtual and physical manufacturing systems flexibly operate globally.

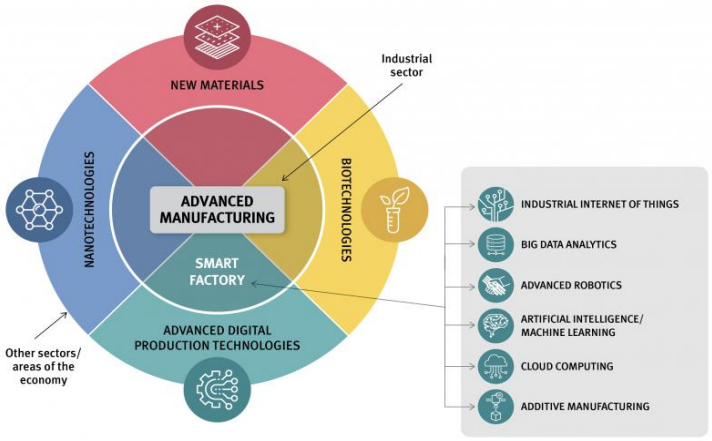

Figure 1. Pictorial representation of Industry 4.0.

Source: D'ensemble (2022); Delera et al. (2022) and UNIDO (2020)

The scope of Industry 4.0 is wider, and it entails connected smart machines, systems, 3D and 4D printing, renewable energies, gene sequencing, nanotechnology, and quantum computing. The integration of these technologies and their interplay across the realms of the digital, physical, and biological is what makes Industry 4.0 distinctive from the existing ones (Delera et al., 2022; Iberdrola, 2022). It is believed that the 4IR will lead to greater output of goods and services with less usage of the workforce because of the sophisticated technologies in use, more global income, better standard of living for the countries adopting it, efficient transport and communication systems, a cleaner environment that will enhance economic growth. The theoretical justification of a firm's technological innovation decision is based on Schumpeter (1950) revolutionary work (Jayashree, Reza, Malarvizhi, et al., 2021). Recent studies by Yuan et al. (2021); Ganne and Lundquist (2019); Johnson (2019) and Park and Choi (2019) focus on the digitalisation of the economy and issues relating to finance. While Balog and Demidova (2021); Sima et al. (2020) acknowledged human capital (knowledge and skill acquisition), business strategy, trade, decision-making, industrial sector, institutional structure, small and medium-scale enterprises (SMEs) inclusion in the global value chain, structure of information process, country environment, R&D investment, and access to financial resources are the reasons behind technological innovation within firms.

Specifically, Industry 4.0 is leaving behind SMEs in most developing countries despite their enormous contribution to the global economy (Begnini et al., 2023). While there are several studies on SMEs across various regions, it is worth mentioning that technology adoption related to Industry 4.0 has more pronounced effects on SMEs in developing nations than in other regions (Ascúa, 2021). In contrast, European SMEs are experiencing notable benefits from ongoing digitalisation processes, with surveys indicating that over 70% of them are leveraging digital tools effectively (Abel-Koch, 2016; Ganne & Lundquist, 2019). This digital integration enables SMEs to seamlessly incorporate international customers and suppliers into their value chains, enhancing global trade participation. Moreover, research indicates that internet usage reduces the cost of exports for SMEs, prompting increased engagement in technologically driven trade practices (Cusolito et al., 2016). Furthermore, with most SMEs knowledge of low production, adaptability and implementation, empirical studies on the effect of automation, digitalisation, and advanced technology with financial availability in improving manufacturing and services output are relatively scarce. Not only that, but many of the few existing studies also focus on the determinants and impacts on large firms and at the macro level using cross-country and panel data instead of country-specific and firm-level data that will reveal what the fact says—resulting in policy formulation that is not directly relevant to SMEs. Therefore, there is a need to inculcate the not-too-large manufacturing industries with automation, digitalisation, and hyper-technology to enable more competitive advantage with global counterparts and to benefit from the manufacturing sector's global value chain for increased trade and productivity. To achieve this feat, the changes the 4IR has brought to the manufacturing and services sector require thorough analyses from manufacturers' and researchers' points of view. Against the backdrop of I4.0's transformative influence, this study endeavours to undertake a comprehensive yet-to-be-studied analytical and bibliometric review to analyse the impacts of the 4IR on SMEs within empirical research. The primary objectives include scrutinising the barriers impeding the internationalisation endeavours of SMEs in the manufacturing and service sectors, particularly on fostering sustainable development. Moreover, the study seeks to analyse the ramifications of digitalisation and automation on SMEs while delving into the nuances of financial constraints encountered by SMEs operating in goods production versus those entrenched in service-oriented domains. In addition, it aims to explore existing research about SMEs' readiness, performance, strategic business orientation, implications, implementation, and integration into the global value chain and propose potential avenues for future research initiatives. Ultimately, the aim is to furnish policymakers with actionable insights to facilitate the enhanced participation of SMEs in

international trade and empower developing countries' SMEs to embrace I4.0 technologies before being left behind by the frontrunner economies.

2. Methodology

2.1 Data collection

The analytical review adheres to the PRISMA standards, ensuring a thorough exploration of major issues within the cited articles, including description, comparison, and evaluation (Gold et al., 2015). As part of this study, a bibliometric analysis was conducted to discern research trends concerning the impact of 4IR on SMEs. The analytical review was conducted from January 2024 to March 2024. The study period covers ten years, from 2013 to 2023. The choice of the study period is underscored by when Industry 4.0 first appeared in a peer-reviewed journal in 2011 (Sima et al., 2020). The academic database employed for this review is Web of Science (WoS). This database contained quality and reliable journals (Hussein et al., 2019) relating to Industry 4.0 and SMEs. To get the appropriate articles, modify search such as Boolean/Phrase 'AND' for agreement and 'OR' for comparison studies was used to choose relevant journals using the following search topic and keywords: *"4.0 SMEs" OR "SMEs Fourth Industrial Revolution" OR "Industry 4.0 SMEs" OR "Small "And" Medium-sized Enterprises 4IR" OR "4IR SMEs Manufacturing Sustainability"*. After refining the search criteria, 556 relevant articles were identified. To organise and delete duplicate articles and citations, all identified articles and citations were exported/saved into the EndNote X21 software, where the duplicates were found and deleted. Review, book review, editorial material, retraction, retracted items, meeting abstract, and letter were excluded. Other excluded from this study were articles not written in English language. To avoid bias selection, the initial 556 and the final 30 selected articles retrieved from the WoS database articles were categorised based on the issues raised, data used, estimation method, main findings of the authors, period of study, and gaps. They were stored in an EndNote library categorised under a newly created group set named "SMEs all" and "SMEs empirical" for convenient access. A separate Excel file was downloaded from the WoS, containing these articles' detailed and full scientific attributes. These attributes include authorship (single or collaborative), thematic focus, keywords, research type, publisher records, affiliations, and citations. This Excel file serves as a comprehensive repository of information on empirical studies on SMEs within the context of the 4IR. The final 30 journals selected were based on a collective agreement between two independent researchers using the Oxford Quality Scale approach (Nyagadza et al., 2022). Hence, Figure 2 shows the process used to select relevant review journals.

2.2 Method used to assess and select relevant articles

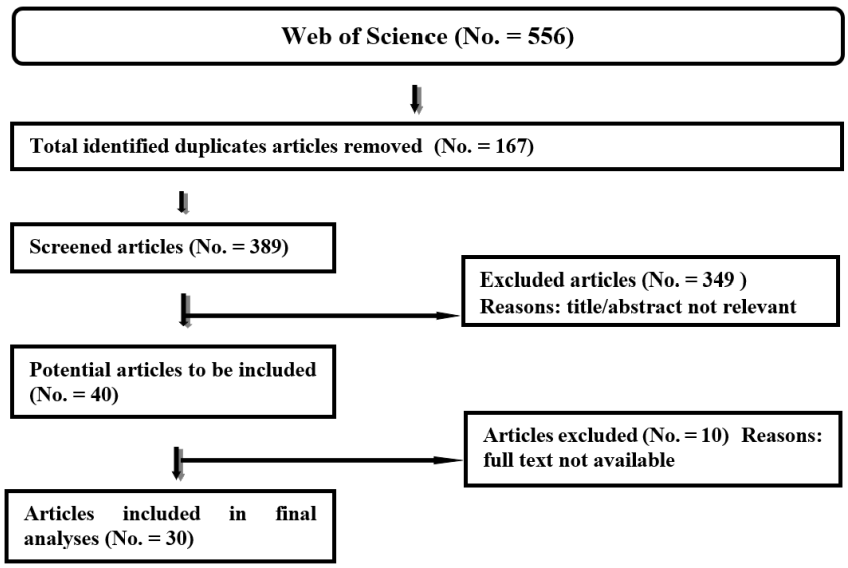

Figure 2. Flowchart of articles selected for study.

Source: Author's

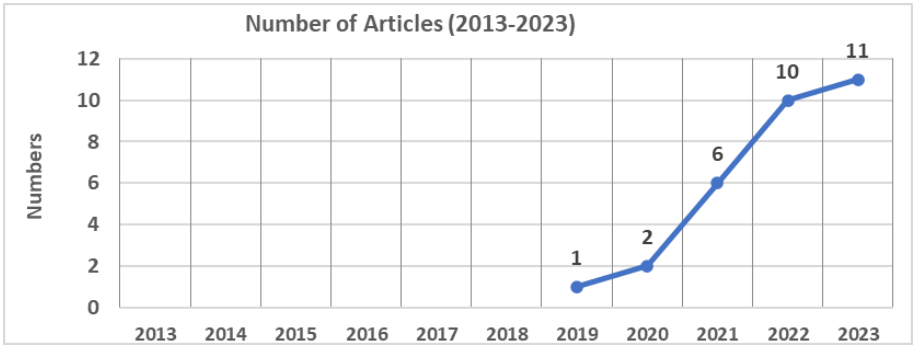

Figure 3. Trend of the articles.

Source: Author's computation

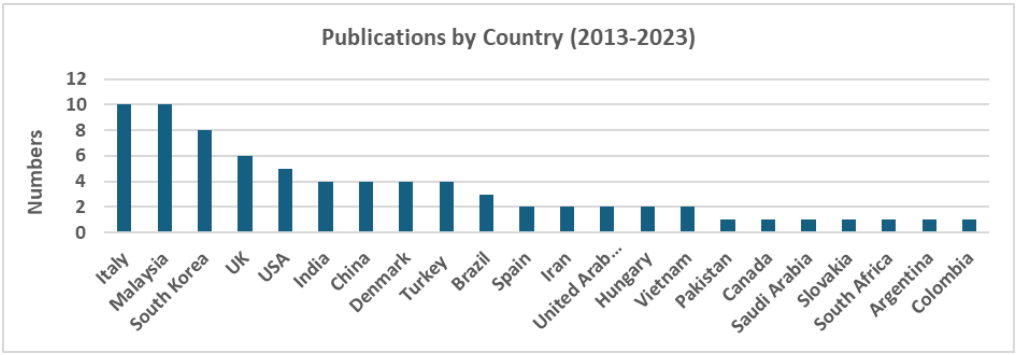

Figure 4. Author's affiliation by country.

Source: Author's computation

3. Results and Discussion

Despite the rapidly expanding research on 4IR impact on SMEs globally, there needs to be more analytical and bibliometric reviews of empirical studies. Much of the existing research tends to lean towards theoretical and conceptual exploration (Antony et al., 2023), often citing insufficient data as a barrier to conducting empirical investigations (Stentoft et al., 2021). This research represents a pioneering analytical and bibliometric review of the intersection between 4IR and SMEs. Also, a prevalence of 4IR SME research is noted among developed regions and Asian researchers; this is attributed to the novelty of the topic and the advanced technological innovations required, which are often lacking in many developing countries, necessitating more time to measure the impacts. The results and discussion are structured into three classifications based on the aforementioned. Firstly, the analysis focuses on examining the attributes of the articles, including publication timelines, author affiliations, and geographical distribution. The second phase involves categorising the articles based on their methodologies. The predominant themes identified in the articles are explored, focusing on understanding key findings and emerging trends in conceptualisation. In the third stage, attention is given to analysing and identifying areas requiring further investigation within the SMEs and 4IR landscape.

3.1 Attributes of the Articles

The data extracted from the WoS database, as illustrated in Figure 3, reveal that the empirical journal with the topic 4IR impact on SMEs did not appear in the literature until 2019. Subsequently, it exhibited a steady increase in momentum over the following years, indicating a burgeoning research area.

In the distribution of articles published on related concepts and impacts of the I4.0 on SMEs by countries of authors, as depicted in Figure 4, it is evident that Italy (10), Malaysia (10), South Korea (8), UK (6), USA (5), India (4), and China (4) emerge as the top contributors. The substantial publication output may stem from robust research and development (R&D) investments and targeted policies to improve industry 4.0 technological adoptions. Conversely, only one African country, South Africa, had one article focusing on 4IR/SMEs. Africa's relatively low research output can be attributed to several factors, including the scarcity of resources such as capital needed for the implementation and highly skilled labour required for the technical know-how. Also, the absence of supportive policies to foster the adoption of technological innovations and drive development in the region contributes to this phenomenon.

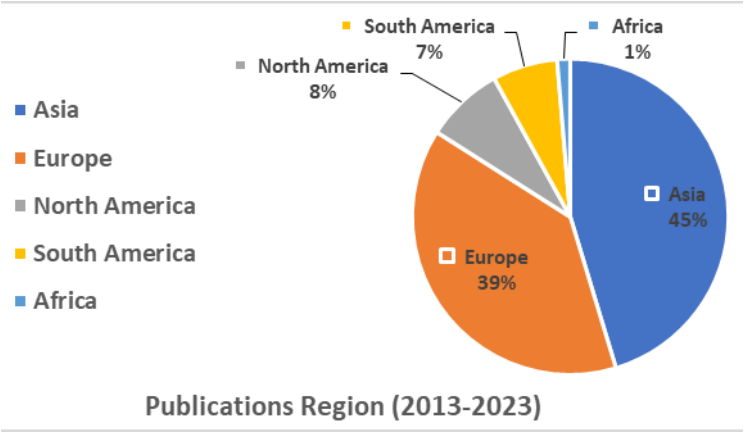

Figure 5. Percentage of articles by region (2013-2023).

Source: Author's computation

In Figure 5, the geographical distribution of articles by region reveals that Asia leads with 45%, followed by Europe with 39%, North America with 8%, and South America with 7% in terms of embracing the 4IR in manufacturing production and adopting new technologies to streamline tasks in SMEs. However, the African region lagged significantly, with only 1.% of the articles published focusing on 4IR and SMEs.

In terms of discussing article publication sources and percentage of articles by research disciples, Table 1 highlights that four journals (bolded for easy identification) out of the entire selection of 30 journals published more than one article related to 4IR/SMEs in a particular journal outlet, while 26 journals published single articles on the subject. Notably, the analysis of this Table shows that approximately 73.3% of the publications focus on management, business, economics, and social sciences disciplines. In contrast, around 26.7% of the articles concentrate on other disciplines, such as science and engineering technology. Hence, the success of 4IR/SMEs requires a multidisciplinary approach to achieve the desired results.

3.2 Themes

The analysis of the articles was structured and organised into sub-themes. However, upon closer examination, it became apparent that many existing studies on SMEs primarily focused on the definition of 4IR, assessing the firms' readiness to adopt Industry 4.0 and examining firm management and entrepreneurial perspectives. These studies often utilised models to infer operational patterns, business performance, product development, and the effectiveness of government policies in fostering innovation development. Despite initially accessing 556 publications from WoS, only 30 studies employed empirical estimation techniques that addressed the research objectives. This highlights a significant gap between the intended focus of the research and the actual empirical evidence provided in the literature. The limited number of articles identified in the study can be justified by the extant literature on the theoretical and conceptual aspects of 4IR effects on SMEs. This imbalance is primarily attributed to the scarcity of empirical methodologies and readily available open data in this field (Hwang & Kim, 2021). As such, while theoretical and conceptual discussions abound, empirical studies are relatively sparse, leading to a gap in the literature this research intends to address. Hence, in Tables 2, 3, 4, and 5, the articles were categorised based on the aims, data, methods of estimation, and main findings, as well as recommendations. This categorisation maintains a clear distinction between the themes while emphasising different aspects of Industry 4.0 empirical study based on the objectives and perspectives of the analysis.

In Table 2, the eight articles explore various aspects related to SMEs' readiness and strategic orientation for implementing I4.0 technologies. They explore factors influencing I4.0 technology adoption, such as open innovation practices, lean 4.0 integration, competence centres' roles, and digitalisation barriers. The studies employ diverse research methodologies, including surveys, interviews, and qualitative analysis, to examine the adoption experiences of SMEs in Italy, Vietnam, Brazil, Argentina, and India. The findings highlight the importance of technological competencies, environmental characteristics, CEO perceptions, and cultural aspects in driving SMEs' adoption of I4.0 technologies. Importantly, the articles underscore the challenges SMEs face, such as knowledge gaps, infrastructure deficiencies, human resource shortages, and resistance to change, while emphasising the advantages of adopting I4.0, including improved efficiency, product development, cost minimisation, market expansion, and increased competitiveness.

Table 1. Articles by publication source.

Source: Author's computation

S/N.	Journal Source	#Papers
1	Annals of Operations Research	1
2	**Applied Sciences-Basel**	**2**
3	Business Strategy and The Environment	1
4	Competitiveness Review	1
5	European Business Review	1
6	European Planning Studies	1
7	Heliyon	1
8	Humanities & Social Sciences Communications	1
9	IEEE Transactions on Engineering Management	1
10	**Journal of Cleaner Production**	**2**
11	Journal of Family Business Management	1
12	Journal Of Industrial Information Integration	1
13	Journal of the International Council for Small Business	1
14	Journal Of Transport and Supply Chain Management	1
15	Management & Marketing-Challenges for the Knowledge Society	1
16	Organizacija	1
17	Production Planning & Control	1
18	R & D Management	1
19	Regional Studies	1
20	Small Business Economics	1
21	**Sustainability**	**4**
22	Technology Analysis & Strategic Management	1
23	**Technological Forecasting and Social Change**	**2**
24	Technology in Society	1
	Total	***30***

The articles in Table 3 explore the adoption and implementation of Industry 4.0 technologies among SMEs in diverse countries, including Korea, Denmark, Slovenia, Iran, Malaysia, Zimbabwe, and China. The research methodologies employed include surveys, questionnaires, and regression analysis. These studies investigate the factors influencing the adoption of core I4.0 technologies, such as big data, artificial intelligence, 3D printing, Internet of Things (IoT), robotics, cloud computing, and blockchain. The findings highlight several positive outcomes associated with I4.0 adoption for SMEs. These include increased productivity, competitiveness, innovation, export activities, and supply chain resilience. Also, the studies identify various drivers and barriers affecting SMEs' readiness for I4.0 adoption. Drivers include positive managerial perceptions, perceived advantages, compatibility with existing systems, organisational preparedness, strong top management support, and favourable technical and environmental factors. By and large, these articles contribute significantly to the understanding of the opportunities and challenges surrounding I4.0 adoption and implementation for SMEs in different industrial contexts.

3.2.1 Theme: Organizational Readiness and Strategic Orientation for Industry 4.0

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3.2.2 Theme: Adoption and Implementation of Industry 4.0 Technologies

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3.2.3 Theme: Impact of Industry 4.0 on Organizational Performance

The seven articles in Table 4 explore the effect of Industry 4.0 innovations on organisational performance, mainly focusing on sustainability objectives, such as circular economy (CE), applications, Triple Bottom Line (TBL) sustainability, and credit risk management among SMEs. Factors such as innovation characteristics, top management commitment, IT infrastructure, paradoxical leadership, strategic flexibility, competent human capital, and organisational ambidexterity concerning I4.0 adoption and its impact on sustainable performance were examined. The empirical methodologies utilised are surveys, SEM, ordinary least squares, and linear model analysis, using data from SMEs in Malaysia, Palestine, China, and various European states. The findings highlight the significance of three key factors for SMEs: strategic orientations, organisational readiness for Industry 4.0 (I4.0), and effective utilisation of I4.0 technologies. These factors contribute to improvements in both sustainable performance and credit risk management efficacy.

3.2.4 Theme: Strategic Implications and Business Context of Industry 4.0

The analysis of six articles in Table 5 unveils the multifaceted nature of I4.0 adoption for SMEs in diverse business settings. These studies move beyond the technology itself, delving into the strategic implications for smaller enterprises. A critical theme is the need for practical risk assessment alongside seamless technology integration. While I4.0 promises efficiency gains, understanding and mitigating potential risks is crucial. Using diverse methodologies, including online surveys, analysis of firms' data, questionnaires, interviews, and secondary data analysis. The investigation covers different geographical contexts, such as India, Korea, Hungary, Italy, and Spain. The research emphasises the importance of equipping workforces with the necessary skills to navigate I4.0 through knowledge-sharing and development initiatives. Furthermore, the studies explore I4.0's potential to support sustainable manufacturing practices through resource efficiency, aligning with circular economy principles. External support systems like research and transfer institutes (RTIs) are highlighted as valuable resources for SMEs, bridging knowledge gaps and providing necessary tools. The interplay between knowledge-intensive business services (KIBS) and regional manufacturing productivity is also explored, suggesting I4.0 can catalyse regional economic development. In conclusion, these studies offer a comprehensive perspective on I4.0 complexities for SMEs. Policymakers, practitioners, and researchers can develop informed approaches to navigate successful I4.0 adoption and integration for a broader range of SMEs and regional contexts by considering the strategic implications, challenges, and opportunities. This deeper understanding will unlock the full potential of I4.0, ensuring its benefits reach all corners of the industrial landscape.

Table 2. Articles by methodologies employed.

Source: Author's computation

Author	Aims/Objectives	Sample/data; Method/estimation technique	Main findings
Petruzzelli et al. (2022)	To examine the function of Open Innovation (OI) in facilitating I4.0 technology adoption by SMEs in Campania, Italy.	107 questionnaires (November 2018 - February 2019) for SMEs' CEOs; Binomial regression and standard robust error models.	SMEs leveraging I4.0 technologies gain from OI practices through extensive collaborations and deep partnerships. Also, SMEs with STEM-educated employees exhibit higher rates of I4.0 technology adoption, showing the importance of OI and skilled human resources as drivers of SMEs' digital transformation.
Qureshi et al. (2023)	To examine the relationship between Lean 4.0 (L4.0) integrates lean practices into I4.0 readiness for SMEs aiming to enhance manufacturing supply chain sustainability.	220 questionnaires to Indian SMEs in manufacturing firms; SEM.	Leadership at the forefront, customer-centric approaches, and employee development notably impact the uptake of advanced L4.0 practices such as total productive maintenance, cutting-edge manufacturing technologies and statistical process control. The L4.0 positively impacts the operational and technological readiness of SMEs for I4.0 implementation, contributing to a sustainable manufacturing supply chain.
Ietto et al. (2022)	To analyse the function of competence centres (CCs) in supporting Italian SMEs to achieve human-centred implementation and adoption of the I4.0 paradigm.	Key informants: SME managers interviews based on six case studies on different CCs; Multiple case study method.	In Italy, the function of CCs in aiding SMEs implementation of I4.0 technologies showed an understanding of a human-centred perspective in I4.0 conducting awareness-raising initiatives and practical interventions to assist SMEs.
Le et al. (2023)	To identify the correlation and significance of key drivers influencing firms' I4.0 technology adoption in Vietnam.	Questionnaire for 396 SMEs; SEM-neural network approach.	Vietnamese enterprises demonstrate a positive and significant adoption of I4.0 technology, driven by technological competencies, environmental characteristics, perceived CEO, and subjective norms.
Denicolai et al. (2021)	To examine the readiness of SMEs to the adoption of I4.0 core technologies (Al, digitisation, and	Questionnaire for 438 SMEs; The Harman's single factor test; Tobit model.	There exists a positive impact of Al readiness on SMEs' international performance but null on export intensity. While there exists a

	internationalisation), export intensity and sustainability readiness in Lombardy, Italy.		positive correlation between digitalisation and sustainability, they become competing growth trajectories once Italian SMEs are foreignised.
Fiorini et al. (2023)	To investigate the absorption and dissemination challenges four Tuscan (Florentine leather, Santa Croce tanning, Prato textile and Arezzo jewellery) industrial districts (IDs) SMEs in Italy faced due to I4.0 technologies adoption.	Face-to-face interviews /questionnaire for 101 four Tuscan IDs firms (Florentine Leather - 42, Santa Croce Tanning -16, Prato Textile - 16, Arezzo Jewellery -27); Perspectives and real-world experiences.	Absorption and dissemination of I4.0 practices vary among firms within different districts. The small firms in some districts demonstrate flexibility and serve as bridges in filling the gaps related to I4.0 technologies, contrary to the expectation that SMEs might encounter I4R difficulties. This underscores the significance of competencies 4.0, culture 4.0, and collaboration (regarding dissemination and absorption) for IDs I4.0 technology usage.
Begnini et al. (2023)	To analyse the importance of digital technologies and the barriers associated with digitalisation by SMEs in Brazil.	Questionnaire for 210 small family business managers; SEM	Digital strategy implementation (knowledge, workers' qualifications, and management abilities) positively correlated with technology usage. The barriers hindering digitalisation are telecom infrastructure, business culture and digital security.
Ascúa (2021)	To compare Argentina and Brazil SMEs I4.0 digital technologies adoption experiences. Such as benefits, motivations and challenges associated with digital technology.	30 interviews conducted with 15 SMEs firms in Brazil and Argentina: Qualitative analysis and exploratory design.	SMEs' gradual benefits of I4.0 technologies adoption are for efficiency, product and new business model development, cost minimisation, serving customers and suppliers, market expansion, and increased competitiveness. While lack of knowledge about I4.0 technologies, infrastructure deficiency, qualified human resources shortage, change resistance, and difficulties in accessing financing are the obstacles.

Table 3. Articles by methodologies employed.

Source: Author's computation

Author	Aims/Objectives	Sample/data; Method/estimation technique	Main findings
Chung et al. (2022)	To identify the degree to which Korea's SMEs manufacturing firms are aware of the technological characteristics of 4IR key technologies.	Questionnaires for 207 Korean SMEs; Structural equation modelling (SEM).	The 4IR technology adoption impacted supply chain structures, enhanced competitiveness, and drive innovation performance positively.
Hwang and Kim (2021)	To study the impact of utilising 4IR leading technologies (AI, 3D printing, Big Data, IoT, Robotics, Cloud Computing, 5G mobile network, Virtual/Augmented Reality and blockchain) on the productivity of Korean SMEs.	Firm-level cross-sectional SMEs data; Stochastic production frontier (SPF), Broyden-Fletcher-Goldfarb-Shanno (BFGS), the conditional means and the maximum likelihood estimator (MLE).	The Korean manufacturing SMEs adopting 4IR technologies since 2014, when the government adopted 4IR have their output increased by over 26 percent on average compared to non-adopters of the 4IR main technologies. The study recommends that to close the technology gap, elevate technical efficiency, and increase productivity, SMEs should embrace 4IR technologies and create strategic partnerships with foreign SMEs. The government must formulate policies to enable all SMEs to use 4IR technologies.
Stentoft et al. (2021)	To explore the drivers and barriers influencing I4.0 readiness and practice among SMEs in Denmark.	Questionnaires for 190 manufacturers and qualitative interviews; Factor analysis.	The lack of managers' perception regarding I4.0 drivers, rather than their perceptions of barriers, impedes the expansion of I4.0 readiness and the adoption of connected technologies among SMEs.
Naglic et al. (2020)	To investigate I4.0 influences on firms' export markets and performances in Slovenia.	Questionnaire for 81 top management Slovenian firms; Multiple regression and factor analysis methods.	The high investment in 4IR technologies (digitalisation), positively impacts firms' exportation, improves export market orientation, enhances firms' foreign market competitiveness, and enables effective data management and competition.
Ghobakhloo and Ching (2019)	To explore the factors influencing the adoption of digital technologies in Iranian and Malaysian manufacturing SMEs.	Questionnaire for 60 SMEs managers (30 Iranians and 30 Malaysians); Pearson correlations, multiple and logistic regressions, t-tests.	Businesses using advanced technologies highlight the potential benefits and report improvements. Also, the key factors identified for SMEs adopting new Industry 4.0 technologies are strategic planning, perceived value, cost, and compatibility when making these decisions.

Shahzad et al. (2023)	The effect of I4.0 adoption and paradoxical leadership influences on Malaysia's SMEs sustainable performance.	Questionnaire for 123 SMEs in Malaysia; Partial Least Squares - SEM.	Top management support, relative advantage, competitive pressure, and compatibility influence Malaysian SMEs IR4.0 technologies adoption.
Ko et al. (2020)	To analyse the status and challenges SMEs in Korea faced in implementing I4.0 factories.	Questionnaire for 113 SMEs with smart factories; ANOVA and Correlation analysis.	Implementation of 4.0 technologies creates challenges of unemployment, defect rate, data management, and low utilisation of integration systems for SMEs in Korea.
Munongo and Pooe (2022)	The adoption and integration of Industry 4.0 technologies and supply chain (SC) resilience linkage on Zimbabwean SMEs during COVID-19.	Questionnaire for 318 SMEs managers. Logit regression model.	4IR and SC have a positive link because of education, personal innovation, ICT literacy and security. However, SMEs managers hesitate to adopt 4IR technologies due to ignorance and the high cost required.
Liu and Cao (2022)	To examine the determining factors influencing the collaborative robot innovation adoption among small and medium businesses in Guangdong Province, China.	Questionnaire for 373 SMEs; Using Diffusion of Innovations Theory (DOI) and Technology-Organization-Environment Framework (TOE); SEM.	Technical factors such as compatibility, relative advantage, trialability and observability positively correlate with the adoption of collaborative robots among SMEs. Also, organisational factors (organisational readiness and top management support) and environmental factors (agent support) demonstrated significant positive correlations with adoption.

Table 4. Articles by methodologies employed.

Source: Author's computation

Author	Aims/Objectives	Sample/data; Method/estimation technique	Main findings
Jayashree, Reza, Malarvizhi, et al. (2021)	To explore the correlation between Industry 4.0 adoption and sustainability objectives within SMEs. It delves into the role of relative advantage, innovation characteristics, complexity, compatibility, observability, and trialability enabling successful I4.0 integration for SMEs sustainability.	Questionnaires-based survey from 396 SMEs in Malaysia; SEM.	Technology innovation characteristics significantly and positively influence I4.0 implementation and sustainability goals by 58 percent. Thus, SMEs must prioritise developing and effectively implementing I4.0, emphasising key innovation traits like relative advantage, compatibility, complexity, observability, and trialability to enhance performance and sustainability objectives.
Jayashree, Reza, Malarvizhi and Mohiuddin (2021)	To explore how factors such as supply chain integration, top management commitment, and IT infrastructure affect I4.0 implementation in Malaysian SMEs and their subsequent impact on Triple Bottom Line (TBL) sustainability.	Questionnaires for 199 Malaysian SMEs employees; SEM.	The IT infrastructure and top management commitment significantly affect I4.0 implementation and SMEs sustainability. However, supply chain integration is insignificant. Also, the relationship between TBL sustainability and I4.0 determines implementing I4.0 effectively.
Hossain et al. (2023)	To assess how the combined effect of I4.0 adoption and paradoxical leadership styles impacts the sustainability of Malaysian SMEs.	Questionnaire for 395 SMEs in Malaysia; SEM.	Adopting I4.0 technologies significantly affects corporate sustainable performance and mediates with organisational ambidexterity within manufacturing SMEs. Paradoxical leadership demonstrates a significant impact on organisational ambidexterity but insignificantly affects corporate sustainable performance.
Findik et al. (2023)	To examine the correlation between 4.0 and circular economy (CE) and its effects on SMEs in 27 Europe member states and 12 non-E Europe countries.	SMEs firm-level survey data (Flash Eurobarometer 486); ordinary least square and instrumental variables (IV) methods.	The adoption of I4.0 core technologies positively correlated with an increase in SMEs' CE applications thereby promoting sustainability and resource efficiency such as saving water, energy conservation, and integrating sustainability into product development.

Dwikat et al. (2023)	To examine how strategic flexibility (SF), turbulent environment (TE), competent human capital (CHC), and influence the sustainable performance (SP) of Palestine SMEs.	Questionnaire for 245 SMEs in Palestine; Partial Least Squares - SEM.	Supportive governmental policies, effective managerial tools, investment in SF and CHC and thorough evaluation of the turbulent environment collectively contribute positively to the sustainable performance of SMEs.
Lu et al. (2022)	To develop a method for selecting credit risk features for Chinese SMEs adopting I4.0 technologies to mitigate financing challenges and enhance creditworthiness.	3 banks credit datasets for SMEs; 1. 2,044 (1,816 non-default and 228 default customers), 2. 2,157 (60 credit indicators; 9% defaulters), 3. 3,111 (80 credit indicators; 2% defaulters). Linear model analysis.	The Particle Swarm Optimization (PSO) and Biogeography-Based Optimization (BWO) algorithms used in predicting credit risk through credit scoring methods are important in the banking sector, and SMEs within the I4.0 landscape. It shows the importance of harnessing big data technology and artificial intelligence algorithms to enhance credit risk management efficacy.
Ed-Dafali et al. (2023)	To explore how sustained competitive advantage (SCA), strategic orientations (entrepreneurial and market orientation), and organisational ambidexterity are linked with I4.0 readiness.	Questionnaire for 144 SMEs in emerging markets; Partial least squares–SEM.	I4.0 readiness mediates the relationship between a firm's strategic orientations (entrepreneurial and market) and its supply chain agility (SCA). Interestingly, entrepreneurial orientation has a more significant influence on SCA than market orientation.

Table 5. Articles by methodologies employed.

Source: Author's computation

Author	Aims/Objectives	Sample/data; Method/estimation technique	Main findings
Tamvada et al. (2022)	To identify and prioritise the risks connected with Indian SMEs implementing Industry 4.0.	Online survey for 17 years of experienced SMEs experts (March 2021 to August 2021); Fuzzy Analytical Hierarchy Process (AHP) technique.	The factors that contribute to the risks hindering 4.0 adoption among Indian SMEs are ins financing, technological limitations, ope challenges such as inadequate employee qualif ambiguity regarding economic benefits in l aspects, supply chain issues, societal and enviro concerns, and cybersecurity vulnerabilities.
Chung and Kim (2022)	To develop strategies for integrating 4IR technology into the service sector in Korea.	Korea's Survey of Business Activities (2018) firms' data; Heckman, two-stage, and multinomial probit.	Business family networks, external collaboration rights, labour efficiency and internal R&D sign influence the adoption or development of 4IR tec in service firms.
Csizmadia et al. (2023)	To investigate the impact of I4.0 technologies on human workforces, knowledge storage and sharing in Hungary.	122 questionnaires to leaders in SMEs; Cramer's V.	Implementing Industry 4.0 technologies fa knowledge sharing and collaboration among resources by leveraging collaborative technolog emerging social media as practical to communicating and connecting within SMEs.
Neri et al. (2023)	To analyse the role of I4.0 in supporting SMEs in Italy in practising CE dynamics.	15 top-management interviews with 10 Italian SMEs; Descriptive.	Adopting 14.0 (digital and core technologies) e the performance of SMEs in CE, as the production improves.
Hervas-Oliver (2022)	To investigate how research and transfer institutes (RTIs) affect I4.0 technologies integration in the case of SMEs in Vinalopó Footwear, District, Spain.	Face-to-face interviews for 45 SMEs in Vinalopó Footwear, case study, Spain; qualitative analysis.	Despite limited SMEs involvement with RTIs, RT as important intermediaries that help SMEs withi to drive innovation, and technologies, engage embrace digitisation initiatives, build networ facilitate knowledge dissemination.
Vaillant et al. (2021)	To examine the relationship between knowledge-intensive business services (KIBS) and their impact on regional manufacturing productivity in local economies in Europe.	Secondary data (2012-2014) from Eurostat databases and Regional Entrepreneurship and Development Index for 121 EU regions; Spatial autoregressive (SAR), ordinary least squares (OLS), and spatial models.	A higher proportion of technology-oriented kno intensive business services (T-KIBS) in a region co with increased manufacturing productivity, reflec rise in gross value added (GVA) per worker. Facto supportive entrepreneurial environment, manufacturing firms, agglomeration economies GDP per capita, and a favourable regional locat positively influenced productivity.

3.3 Future Research Directions for SMEs

The future research directions offer a comprehensive framework for advancing the understanding of organisational readiness and strategic orientation for I4.0 adoption, as outlined in Table 2. These directions encompass various dimensions, including geographical considerations, demographic influences, technological evolution, and policy effectiveness. Expanding research beyond regional boundaries, as suggested by Petruzzelli et al. (2022) and Denicolai et al. (2021), holds promise for gaining insights into how contextual factors shape I4.0 adoption dynamics. In addition, investigating the impact of demographic characteristics, as emphasised by Le et al. (2023), can provide nuanced perspectives on adoption patterns across diverse organisational settings. The evolution of Competence Centres (CCs) into European Digital Innovation Hubs, longitudinal studies on CC-SMEs interactions, and exploring external actors' roles, as proposed by Ietto et al. (2022), offer avenues for understanding the ecosystem surrounding I4.0 implementation. Fiorini et al. (2023) underscore the significance of exploring variations in firm behaviours within Industrial Districts (IDs) and evaluating the effectiveness of policy interventions in promoting collective I4.0 implementation. Employing longitudinal methodologies and comparative analyses, as advocated by Begnini et al. (2023), can illuminate the temporal and contextual dynamics influencing I4.0 adoption. Ascúa (2021) highlights the importance of studying the implications of new digital technologies on organisational practices and market dynamics, suggesting a holistic approach to understanding the transformative impact of I4.0. Furthermore, empirical studies on readiness in different manufacturing SMEs and service industries, as emphasised by Qureshi et al. (2023), are essential for capturing sector-specific challenges and opportunities in I4.0 adoption. These future research directions offer a roadmap for advancing scholarly inquiry into organisational readiness and strategic orientation for I4.0 adoption, contributing to informed decision-making and policy formulation in the rapidly evolving digital landscape.

The future research direction collectively highlights several critical areas for further investigation on theme (Table 3) Industry 4.0 (I4.0) adoption and implementation. Firstly, there is a pressing need for broader and more inclusive studies that transcend single respondents and narrow geographic focus, as emphasised by Naglic et al. (2020). This would enhance the generalizability of findings and enable international comparisons, thereby enriching the understanding of technology adoption dynamics across diverse contexts. Building on this foundation, Hwang and Kim (2021) stress the importance of considering contextual factors such as organisational culture, human capital, and policy effectiveness in assessing the long-term impacts of technology adoption on SMEs' productivity. Such comprehensive analyses are essential for identifying the nuanced drivers and barriers to adoption and informing targeted policy interventions. Moreover, Stentoft et al. (2021) advocate for comparative research to explore differences in technology adoption practices across firms and nations. Such research can provide valuable insights for policymakers and industry stakeholders seeking to promote the adoption of I4.0 technologies. In parallel, Ko et al. (2020) highlight the need for tailored policies and strategies to address the unique challenges SMEs face in implementing smart factory technologies. This includes overcoming barriers to adoption and creating a supportive environment conducive to technological innovation and growth. The insights from Chung et al. (2022) highlight the importance of future research on enhancing support for SMEs in adopting smart technologies. This suggests a need for studies investigating specific strategies and policies facilitating technology adoption, especially within the evolving global supply chain landscape. Additionally, exploring emerging technology utilisation across diverse sectors and extending research beyond Korea can offer broader insights and identify productivity enhancement opportunities. Furthermore, Munongo and Pooe (2022) underscore the importance of collaborative efforts involving various stakeholders to facilitate technology adoption among SMEs. In addition, Shahzad et al. (2023) advocate for research to inform policy frameworks and support business ecosystems, particularly in emerging economies like Malaysia. Such initiatives are crucial for creating an enabling environment that fosters innovation and technology adoption across industries. Future research should focus on developing a maturity model for assessing SMEs' readiness for smart manufacturing, utilising strategic planning techniques and longitudinal case studies. Expanding the research model beyond Iranian and Malaysian SMEs to include diverse business contexts is essential. Conducting in-depth case studies and analytical modelling techniques can further enrich the understanding of manufacturing digitalisation and inform strategies for enhancing SMIDT adoption among SMEs globally (Ghobakhloo & Ching, 2019). Lastly, Liu and Cao (2022) propose investigating the mechanisms underlying collaborative robot adoption's effects on SMEs performance and competitiveness. Addressing these directions collectively can advance I4.0 adoption knowledge and inform strategies across industries and contexts. Therefore, addressing these research directions collectively can contribute to advancing knowledge and informing strategies for successfully adopting and implementing Industry 4.0 technologies across various contexts and industries.

In Table 4, theme: the impact of Industry 4.0 on organisational performance, Jayashree, Reza, Malarvizhi, et al. (2021) study needs to address potential challenges or barriers for SMEs in implementing Industry 4.0

technologies. Similarly, Jayashree, Reza, Malarvizhi and Mohiuddin (2021) focus on Malaysian manufacturing SMEs, neglecting broader industry or regional perspectives. They also advocate for exploring alternative data collection methods beyond questionnaire-based surveys. To address these limitations, Findik et al. (2023) propose utilising longitudinal data or multiple surveys to observe dynamic interactions between Industry 4.0 technologies and Corporate Environmental (CE) practices over time. They suggest employing comprehensive methodologies, using alternative data collection methods beyond traditional questionnaire-based surveys and conducting comparative analyses across different regions and industries to identify variations in technology adoption and its impact on CE practices among SMEs. Furthermore, Hossain et al. (2023) and Ed-Dafali et al. (2023) studies highlight the importance of investigating moderating factors influencing the relationship between technology adoption, organisational capabilities and sustainability outcomes in SMEs. Future research should explore how factors such as strategic flexibility and orientations impact the effectiveness of Industry 4.0 initiatives in SMEs. Dwikat et al. (2023) emphasise the need to explore additional factors affecting the sustainable performance of SMEs, particularly in Palestine. Lastly Lu et al. (2022) suggest delving deeper into understanding how Industry 4.0 technologies influence credit risk assessment and management for SMEs. This could involve studies that evaluate the assessment and optimisation algorithms within credit risk prediction frameworks, identifying best practices for leveraging Industry 4.0 technologies in financial management processes. Future research on this theme should delve deeper into these considerations to unlock the full potential of Industry 4.0 for SMEs.

In the strategic implications and business context of I4.0, Tamvada et al. (2022) highlight the limitation of sample size in understanding the hindrances to I4.0 implementation in India. They suggest further investigation to examine the evolving impact on SMEs as they progress in adopting I4.0 technologies. Csizmadia et al. (2023) emphasise the need to identify specific I4.0 technologies that facilitate knowledge sharing in SMEs and explore their implications for the human workforce. Future research should investigate the dynamics between technology adoption and workforce management within the I4.0 framework. Furthermore, Chung and Kim (2022) advocate for further exploration of the diversity among sectors and firms within the service industry. They suggest employing panel data analysis to understand better how individual technological choices contribute to understanding the 4IR at the firm level. Neri et al. (2023) also stress the importance of expanding sample sizes and conducting empirical analyses in different contexts to study the relationships between digital technologies and circular economy practices. This includes examining variations within and outside Italy to understand the broader implications of digitalisation on sustainability. Also, Vaillant et al. (2021) suggest further research to explore additional dimensions of KIBS heterogeneity and their implications for regional development. Understanding KIBS's diverse roles and impacts on regional economies can help validate and extend existing findings. Hervas-Oliver (2022) suggests exploring digitisation efforts in diverse contexts and technologies to enhance ID functionality and digitisation approaches within and outside Italy. This broader perspective can provide valuable insights into the factors influencing successful digitisation initiatives. By addressing these research directions collectively, future studies can advance knowledge and inform strategies for leveraging Industry 4.0 technologies in diverse business contexts.

4. Conclusion

This study carried out an analytical and bibliometric review that sheds light on the evolving research landscape concerning the effect of Industry 4.0 core technologies on SMEs. Akin to any research, this review aimed to be comprehensive. Studies not written in English or based on conceptual and theoretical perspectives were excluded to maintain focus. The analysis focused on 30 selected empirical studies published in journals indexed in the WoS database from 2013 to 2023. The findings indicate I4.0 potential to transform productivity, competitiveness, and sustainability, especially in global trade and industrialisation. While SMEs and family businesses in Europe, Asia and the Americas are leading the adoption of core 4IR technologies. However, as seen from the study, challenges hinder SMEs' full adoption and utilisation in developing countries, particularly Africa and the Middle East. Their concern is that Industry 4.0 will lead to unemployment, particularly among low-skill/ low-pay workers in situations where 4IR is fully adopted. As well it will create the issue of income inequality as the gap between high-skill labour wages and low-skill wages will be too wide (Beier et al., 2022). Other challenges include high consumer expectations, reluctance among conservative SMEs to adopt new technologies due to the high financial cost, and cybersecurity threats affecting national and international security. (Delera et al., 2022; Schwab, 2015; Zervoudi, 2020). To avert the challenges, this study recommends that the government encourage human capital development, higher education, R&D investment, and relevant skill acquisition aligned with Industry 4.0. In addition, financial institutions should be strengthened to support SMEs and enable the affordability of new technologies. Further, the government can use taxation to curtail income inequality by taxing the high-skill income

earners more and the low-skills-low-wage workers less. The study emphasises the urgency for SMEs to embrace Industry 4.0 technologies to remain competitive in the global market and boost their output. Importantly, these findings offer valuable insights for further research exploring the intersection of SMEs and Industry 4.0..

Declarations

Data availability Data will be made available upon reasonable request.

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