IMPACT OF INDUSTRY 4.0 ON THE INTEGRATION OF SMES INTO GVCS: A SYSTEMATIC LITERATURE REVIEW

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Abstract
The study aims to investigate the integration of Small and Medium-sized Enterprises (SMEs) into global value chains (GVCs) with Industry 4.0 enablement. This integration is essential, yet research on the comprehensive application of Industry 4.0 digital technologies for this purpose is limited. This study addresses the established gap through a systematic literature review (SLR) using the PRISMA methodology to analyze the impact of Industry 4.0 technologies on SME integration into global value chains. Utilizing VOSviewer for bibliometric analysis, the research identifies key themes such as innovation, digital transformation, and smart manufacturing, alongside critical technologies like the Internet of Things, big data analytics, and artificial intelligence. The SLR analyzed 955 relevant articles published between 2015 and 2023. The findings reveal a significant lack of comprehensive literature on the integration of SMEs into global value chains, particularly regarding the exploration of technologies such as blockchain, robotics, and cybersecurity, in both academic and industrial settings. There is therefore a need for industry players, academia, and policymakers to establish more targeted strategies for SMEs and global value chain integration in the context of Industry 4.0.
Keywords: Industry 4.0, SMEs, Global value chains, SLR, Bibliometric analysis.
DOI: https://doi.org/10.24818/beman/2026.16.1-02

Business Excellence and Management
Volume 16 Issue 1 / March 2026

1. INTRODUCTION

The emergence of Industry 4.0 has significantly reshaped the dynamics of global value chains (GVCs), offering both opportunities and challenges for small and medium-sized enterprises (SMEs). SMEs are considered to be the main drivers of value creation and employment; they also contribute to the diversification and resilience of economies (Serumuga-Zake & Van der Poll, 2021). Despite the critical role SMEs play in global economies, a large percentage of these enterprises fail within the first few years of their establishment (Anaifoghe & Ramsuraj, 2023). According to Adelowotan (2021), this high failure rate is primarily due to constraints they are faced with, i.e., lack of finance, barriers to market entry, knowledge management, lack of access to infrastructure, lack of innovation, lack of market information, poor communication channels, lack of requisite skills and knowledge, poor regulatory framework, crime, and corruption. For SMEs to overcome these constraints and enhance their growth and development, one key strategy to consider is their integration into regional and global value chains, through backward and forward linkages (Nyagadza, et al, 2022). A significant body of literature exists examining the context of Industry 4.0 and its intersection with SMEs and GVC integration, producing a highly heterogeneous body of work. However, there is a lack of comprehensive synthesis focusing on how these technologies collectively facilitate SME participation in GVCs. Therefore, this study aims to bridge this gap by employing a systematic literature review of the key concepts of this research. This study answers the following questions:

1. How do Industry 4.0 digital technologies impact the integration of SMEs into global value chains?
2. What Industry 4.0 technologies are most commonly adopted by SMEs for global integration?
3. What gaps exist in the literature regarding the role of under-researched Industry 4.0 technologies in SME integration into GVCs?

This is aimed at establishing the impact of Industry 4.0 digital technologies on the integration of SMEs into global value chains.

1.1 The role of SMEs and global value chains in the evolving landscape of industry 4.0

SMEs are the most abundant business enterprises; they account for 99% of businesses and contribute towards 60% of employment in OECD countries (Alakbarov & Hasanov, 2024). The definition of SMEs in literature includes a combination of a number of factors i.e., number of employees, market capitalization, revenues, size of the economy in which they operate, and the rate of economic development in the specific countries they operate (Enaifoghe & Vezi-Magigaba, 2023). The most commonly used variable seems to be the number of employees: 200 to 250 in OECD countries, 300 to 500 in Japan, and the USA (Abe, 2015), and less than 250 employees in South Africa (Enaifoghe & Vezi-Magigaba, 2023). SMEs also

operate in varied environments, i.e., rural, urban, provincial, national, and international. They are flexible to technological evolutions and are adaptable to market fluctuations and customer requirements, and their structures allow for more rapid decision-making (Anaifoghe & Ramsuraj, 2023). SME growth and development is supported by integration into global value chains (Nyagadza, et al, 2022).

Global value chains are described as "a full range of cross-border, value-added business activities that are required to bring a product or service from the conceptual design, sourcing of raw materials, intermediate input stages, to production, marketing, distribution, and supplying to the final consumer" (Abe, 2015). Involvement in global value chains includes vertical and horizontal firm linkages. Vertical integration is typically evident in the electronics and automotive sectors, whilst horizontal firm linkages are mostly in export-oriented agribusinesses, food processing, and handicrafts (Chen, 2019). Efficient management of all processes in global value chains is supported by Industry 4.0 digital technologies (Baio Junior & Carrer, 2022).

Industry 4.0 entails the implementation of integrated industrial automation systems (Baio Junior & Carrer, 2022).These connected systems, together with integrated sensors, collect and monitor large sets of data used by organizational software, enabling factories to be smart and, in turn, allowing analysis that might enhance decision-making, waste reduction, improvement of quality, speed of processes, and cost reduction (Baio Junior & Carrer, 2022). Industry 4.0 encompasses a large array of emerging digital technologies that have the capacity to influence organizations, regional and international economies, societies, and governments. These technologies include big data analytics, cyber-physical systems, cloud computing, internet of things, robotics, augmented reality, and additive manufacturing (Ferrigno et al, 2023). Brief explanations are provided below:

- Big data analytics: This entails the utilization of digital technologies to conduct analysis, four dimensions are considered, i.e., volume, variety, value, and velocity (Fanoro, Božanic', & Sinha, 2021).
- Cyber-physical systems: This element integrates sensors, internet data, and algorithms with machinery, helping to improve efficiencies by enabling continuous monitoring, feedback, and production control, often independent of human intervention (Naudé, 2021).
- Internet of Things: This is a structure through which physical elements communicate with computers through the implementation of intelligent and self-optimising devices and sensors, this ensures that operational data is easily accessible (Fanoro, Božanic', & Sinha, 2021).
- Cloud computing: This technology provides on-demand services for storage, processing, and connectivity capacity with usage-based payments. Large amounts of data are stored in server

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networks, allowing for data access from any location, from different devices and platforms, at any time (Baio Junior & Carrer, 2022).

- Additive manufacturing: Also called rapid prototyping, this technology typically utilizes layer-by-layer based printing, converting loose-based charges to a 3D object based on available data and numerical models (Fanoro, Božanic', & Sinha, 2021).
- Autonomous robots: Robots are able to perform manual and cognitive tasks, boosting work activities that are replaceable and can compensate for labour force shortages. They can also adopt their movements and provide data aiding decision-making in real-time (Baio Junior & Carrer, 2022).
- Augmented reality: This technology allows the linking or overlapping of physical and virtual elements in real-time. Components of augmented reality can include augmented reality goggles, cameras, projectors, earphones, tablets, etc., which are used to overlap the virtual world with reality (Baio Junior & Carrer, 2022).

Industry 4.0 is already altering competition between organizations and how added customer value is created (Mahdiraji et al, 2023). With Industry 4.0 increasing industrial productivity and organizational performance, organizations will have to re-think how these new technologies will impact their bargaining power within their industries and how they will re-organize their strategic capabilities (Mahdiraji et al, 2023). The subsequent section provides a survey of the research landscape with regard to the three key concepts discussed above.

1.2 Exploring the research gaps

Numerous studies have been undertaken, particularly those related to SMEs and global value chains. Research conducted by Dutta et al (2021) examines the priorities for the digitization of quality procedures in SMEs regarding the use of Industry 4.0 technology. The report highlighted that although there is a substantial body of literature on quality practices and their importance in continuous improvement, research on the digitalization of quality practices in a digitally enabled context is scarce. Other studies examined the application of lean principles in SMEs, emphasizing digitization as a facilitator, particularly for Lean-Green practices (Queiros et al, 2022). The study demonstrated that digitalization facilitates information dissemination, impacting performance measurement systems, value chain integration, and organizational enhancements. Conversely, a study by Dilyard, Zhao, & You (2021) observed a paucity of research interest in the digitization and lean-green implementation inside SMEs. The research examines the possible function of digital technology in enhancing the resilience of global value chains to mitigate disruptions resulting from global economic shocks. The authors advocate for the use of sophisticated

Industry 4.0 technologies in SMEs, multinational corporations, and global value chains to enhance resilience and adaptability. Chen's (2019) study examines the use of technology by SMEs to engage in global value chains and integrate industrial supply networks. The research examines certain Industry 4.0 technologies, including the Internet of Things (IoT) and cyber-physical systems (CPS), within the Taiwanese textile sector. The author of this study posits that certain technical factors must be evaluated when examining the adoption of new Industry 4.0 digital technologies.

Additionally, there are studies examining other subjects associated with Industry 4.0, such as the impacts of COVID-19, circular economy, and business models. One research used a systematic literature review using the PRISMA 2020 framework to examine the characteristics of SMEs before and during the pandemic. This paper presents a model for assessing the adoption of Industry 4.0 and the digital transformation of SMEs, the digital integration of global value chains, and the involvement of SMEs in global value chains for sustainable growth and trade expansion (Madhavan et al, 2022). A separate study performed a systematic literature review of Industry 4.0 and the circular economy via the lens of global value chains (Awan et al, 2022). This study determined that the literature connecting Industry 4.0 and the circular economy is still nascent, and advancements in global value chains have received little scholarly attention. The concluding piece examined the significant effects of Industry 4.0 on SME business models via a thorough literature review (Soondka & Smuts, 2021). The research indicated that by evaluating the effects of business models, SMEs may use Industry 4.0 technology platforms for value creation, and for these technologies to generate value, they must be congruent with business models.

The analyzed articles highlight a deficiency in the literature regarding the integration of sophisticated technologies and various technical elements in the implementation of Industry 4.0. There is a need to establish a cohesive Industry 4.0 framework and more targeted industry-specific strategies for SMEs and global value chain integration in the context of Industry 4.0. The examined literature revealed a deficiency of studies addressing the intersection of digitization and Lean-green practices in small and medium-sized enterprises (SMEs) concerning sustainability. Research on Industry 4.0 and the circular economy is scarce, particularly concerning advancements in global value chains.

2. METHOD

The study employs a systematic literature review to establish the impact of Industry 4.0 digital technologies on the integration of SMEs into global value chains. The study adopts an SLR approach using the PRISMA guidelines to pursue its objectives. The PRISMA approach is currently considered to be the most preferred among the standard systematic review approaches (Mwanza, Telukdarie, & Igusa, 2023). This

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approach is found to be appropriate as the process involved is structured, transparent, and replicable. It also provides an objective foundation for eliminating studies that are not aligned with the research topic and avoids the bias trap provided by traditional reviews (Abdullah & Khan, 2021).This paper employs a combination of SLR and bibliometric analysis. SLR is conducted by entering the required keywords in the Scopus database, and then a sample of research papers is extracted by employing the inclusion and exclusion criteria. Scopus is one of the largest databases of peer-reviewed literature and consists of articles from leading publications (Abdullah & Khan, 2021). The search strings inputted in Scopus (Title, Abstract, keyword) are used to produce the most relevant studies of this research area. In the second stage, text mining using VOSviewer is performed to understand the emerging themes from literature. The identified research themes are classified using descriptive statistics. Detailed discussions are provided in the sections below.

2.1 Exploring the research gaps

The study aims to include relevant quantitative and qualitative research publications between 2015 and 2023. The research focuses on the key concepts of integrating SMEs into global value chains using Industry 4.0 digital technologies. The authors chose this period because the dawn of Industry 4.0 can be traced back to 2011, and relevant literature regarding the study's topic is found from 2015. The source types considered are only journals published in the English language. Conference papers, reviews, book chapters, and notes are excluded.

2.2 Information sources

Scopus is an online database used for the identification and selection of all eligible and relevant published literature to answer the research questions. This database is used to improve the quality of peer-reviewed articles from leading publishers.

2.3 Search strategy

This research paper aims to explore the integration of SMEs into global value chains using industry 4.0 digital technologies. To establish an overview of the research landscape, the first search incorporated the key concepts ''SME'', '' global value chain'' and ''Industry 4.0''. The search string ''sme AND global AND value AND chains AND industry 4.0'' was inputted in Scopus and yielded 9 documents. All the documents were in English and consisted of 4 articles, 2 reviews, 1 book chapter, 1 conference paper, and 1 note. Seven documents were reviewed, i.e., 4 articles, 2 reviews, and 1 conference paper; these were studied to gain an appreciation of the emerging themes in this field of study. The search output produced limited

research studies, which were thus deemed to be insufficient to address the research objectives. The studies are presented in Table 1.

TABLE 1. PAPERS FROM THE 1ST-TIER QUERY (OVERVIEW OF THE RESEARCH LANDSCAPE)

Author(s)	Title	Author Keywords
(Suchek, Ferreira, & Fernandes, 2024)	''Industry 4.0 and global value chains: what implications for circular economy in SME?''	Circular economy; Resource-based view; Global value chain; SME; Industry 4.0
(Chen, 2019)	''Value Creation by SMEs Participating in Global Value Chains under Industry 4.0 Trend: Case Study of Textile Industry in Taiwan''	cyber-physical system; global value chain; Industry 4.0; innovation; internet of things; SMEs
(Madhavan, Wangtueai, Sharafuddin, & Chaichana, 2022)	''The Precipitative Effects of Pandemic on Open Innovation of SMEs: A Scientometrics and Systematic Review of Industry 4.0 and Industry 5.0''	COVID-19; PRISMA; industry 4.0; systematic review; industry 5.0; pre-pandemic; SMEs
(Prause, 2015)	''Sustainable business models and structures for industry 4.0''	Business models; E-Residency; Industry 4.0; Organisational structures
(Queiros, Nocera, Junior, & Melo, 2022)	''Digitalization as an Enabler to SMEs Implementing Lean-Green? A Systematic Review through the Topic Modelling Approach''	artificial intelligence; latent dirichlet allocation (LDA); digital transformation; industry 4.0; digitalization; lean; lean-green; machine learning; small and medium enterprise (SME); systematic literature review; topic modelling
(Singh, Kumar, & Bhardwaj, 2023)	''Sustainable Manufacturing: Road to Carbon Zero Footprints''	Carbon footprints; Carbon neutral; Carbon zero; Carbon zero manufacturing; Net zero emission; Industry 4.0; SDGs; Sustainable manufacturing
(Dutta, Kumar, Sindhwani, & Singh, 2021)	''Digitalization priorities of quality control processes for SMEs: a conceptual study in perspective of Industry 4.0 adoption''	Digitalization; Industry 4.0; SME; Integration; PDCA; Quality;

Source: Authors' research

TABLE 2. SECOND-TIER SEARCH STRINGS

Source	Search string	Results
Scopus	sme AND Industry 4.0 AND Business AND Model global AND value AND chain AND digital AND integration global AND value AND chain AND Industry 4.0 sme AND global AND value AND chain AND Innovation Horizontal AND Vertical AND integration AND industry 4.0 sme AND digital AND transformation sme AND collaboration AND Industry 4.0 Industry 4.0 AND value AND creation sme AND digitalization digitalization AND customer requirements sme AND industry 4.0 innovation AND sme AND digital AND technologies Industry 4.0 AND sustainability AND global AND value AND chain Industry 4.0 AND circular AND economy AND global AND value AND chain	3245
	After applying filters: years -2015 to 2023; document type- Article (reviews, books, conference paper, notes, were excluded); language-English; source type-journal	1304

Source: Authors' research

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The articles were studied comprehensively, establishing research contexts, themes, and keywords. Second-tier search strings were then developed from this review. Keywords are selected in a manner that provides broad coverage to ensure that no studies are omitted. Fourteen search strings outlined in Table 2 were developed to explore a broader scope of the topic. The search yielded 3245 articles after combining documents from the 14 search strings. The study includes all relevant peer-reviewed journals between the years 2015 and 2023, which focus on the key concepts of integrating SMEs into global value chains using Industry 4.0 technologies. The source types considered were only journals published in the English.

The initial number of documents before applying filters is 3245. Filters were applied, 1941 documents were automatically filtered out and 1304 documents remained. The 1304 documents were screened for duplicates. Manual screening was performed by using conditional formatting in excel. A total of 320 documents were removed as duplicates. Once all the duplicates had been removed, a total of 984 documents remained. Following the removal of duplicates, screening was conducted based on titles to determine the relevance of the articles. Only the results which were applicable to the research topic were considered i.e. aligned to the research objectives. From screening of the titles, a total of 22 documents were excluded. The remaining 962 records were screened by abstract, 7 documents were excluded. The documents excluded based on titles and abstracts were not relevant to the research topic. 955 documents remained. The articles excluded based on titles and abstract consisted of irrelevant studies i.e. predictive maintenance in SMEs, energy conservation, banking etc. Although SMEs are mentioned in most of the excluded studies, they did not incorporate industry 4.0 technologies or global value chains.

3. RESULTS

This section offers a descriptive analysis of search output patterns and themes with respect to how research in the field of SME integration into global value chains using industry 4.0 digital technologies evolved over time. The search results yield publication trends over time, as well as the distribution of research papers by publisher and research themes. The research trend indicating the evolution of emerging research themes over time, keyword analysis, and co-authorship analysis are also discussed.

3.1 Publications per year

Figure 1 provides the trend of publications from 2015 to 2023. It is observed that very few studies were published at the inception of the search period, this can be attributed to Industry 4.0 being a novel research field which started as the German government's project in 2011, intended to promote the digitalization of manufacturing systems and processes (Bigliardi, et al., 2023). Less than 10 articles are

published in 2015 and 2016. The rate of publication indicates an exponential increase from 2016 to 2023. There was, however, a marginal increase between 2020 and 2021. The most numerous publications was recorded in 2023, with 244 articles. The number of publications is anticipated to increase higher than the current figures if the current trajectory is maintained.

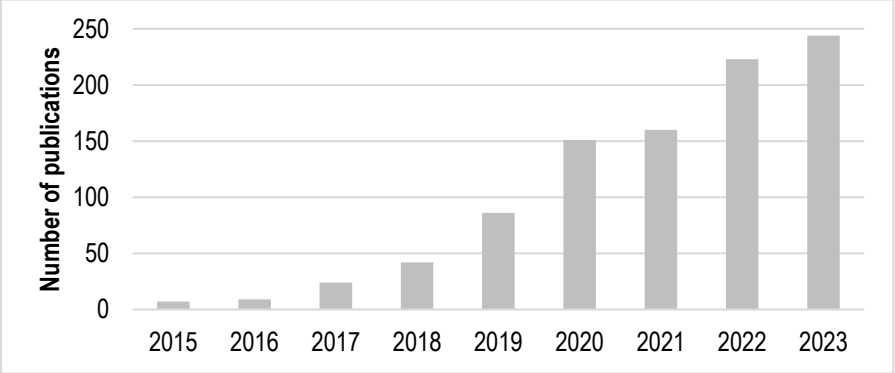

FIGURE 1. PUBLICATIONS PER YEAR (2015 TO 2023)
Source: Authors' research

3.2 Publications per source

This subsection analyses the distribution of publications per journal title in order to identify leading sources of the published articles.

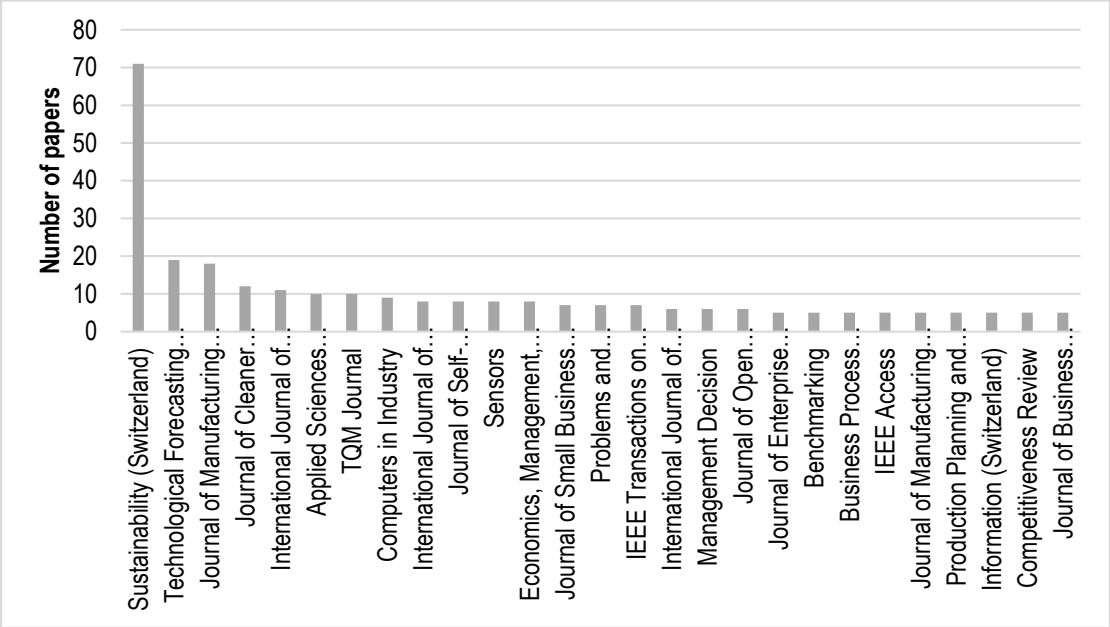

FIGURE 2. LEADING PUBLISHED STUDIES PER PUBLICATION SOURCE
Source: Authors' research

The leading journals published in the field of SMEs, global value chains, and Industry 4.0 are indicated in Figure 2. The highest publications are from Sustainability (Switzerland) with 71 articles, followed by

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Technological Forecasting and Social Change (19), Journal of Manufacturing Technology Management (18), Journal of Cleaner Production (12), International Journal of Production Research (11) and, Applied Sciences (Switzerland) and TQM journal at 10 articles each.

The leading journal, Sustainability (Switzerland), is a cross-disciplinary open-access journal focusing on the economic, environmental, cultural, and social sustainability of people. The journal scope is aligned with the research topic as it impacts socio-economic, cultural, and sustainability aspects. The journals with the most publications after Sustainability (Switzerland), i.e., Journal of Manufacturing Technology Management and Technological Forecasting and Social Change, incorporate methodologies of manufacturing-related research and the future of methodology and practice of technology. It is therefore expected that more research in this field will be published due to their technology and future orientation.

3.3 Research categories

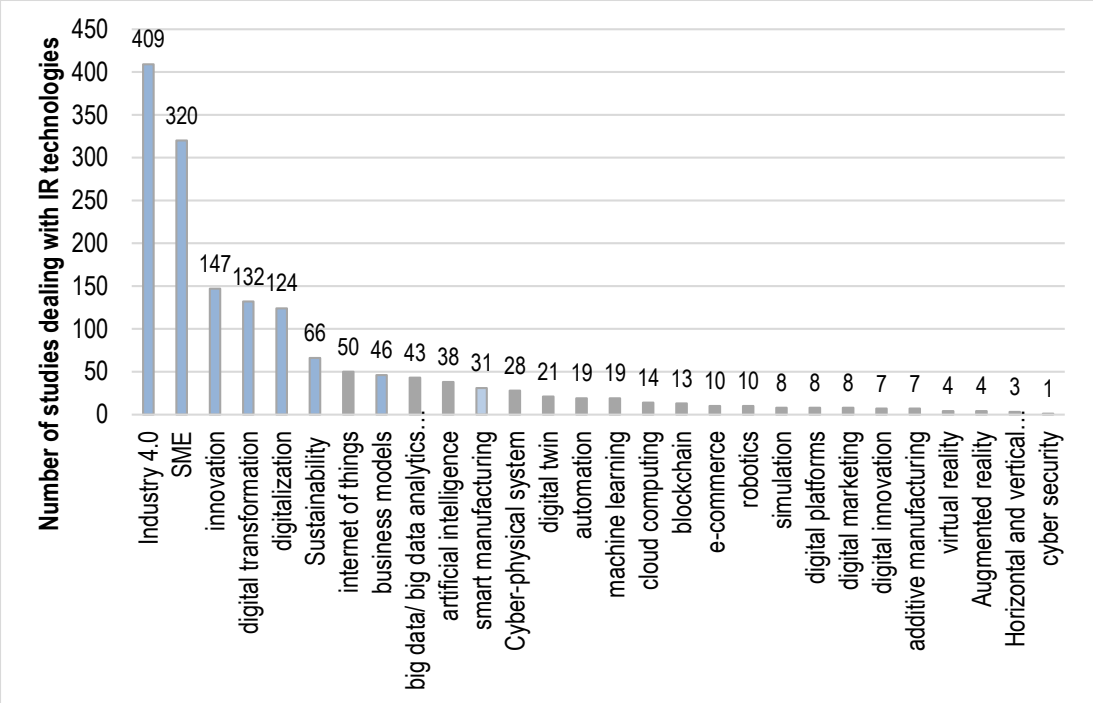

FIGURE 3. RESEARCH THEMES AND 4IR DIGITAL TECHNOLOGY IMPACT
Source: Authors' research

3.4 Co-authorship analysis

VOSviewer is utilized to get an overview of research themes with regards to the integration of SMEs into global value chains when utilizing industry 4.0 digital technologies as an enabler. The paper visualizes the linkage between these themes as well. Collaboration between researchers is observed through co-

authorship analysis. In co-authorship networks, the nodes represent countries or authors that are connected when they have the same authorship of a paper.

Co-authorship analysis - Country

The minimum number of documents per country was set at 5, and the minimum number of citations per author at 1, yielding 50 countries that met the threshold out of 98. The dominant countries are mostly from Europe, Asia, and the United States. Brazil and South Africa are participants, representing South America and Africa, respectively. The dominant countries researching SME integration into global value chains are India, China, the United Kingdom, Italy, Germany, the United States, Spain, Indonesia, and France.

Co-authorship analysis – Author

The minimum number of documents per author and the minimum number of citations per author was set at 1, yielding 799 authors who met the threshold out of 942. The total number of links is 0, indicating no co-authorship. The number of authors selected was 100. The overlay visualization in VOSviewer yielded 100 items with zero links. This is an indication of low collaboration among authors in this field.

3.5 Keyword analysis

Key industry 4.0 technologies studied, as indicated in figure 4, include artificial intelligence, the Internet of Things, cyber-physical systems, big data, digital twins, robotics, and additive manufacturing. The main themes that were researched include Industry 4.0, digital transformation, digitalization, SME, global value chains, innovation, sustainability, circular economy, business model, smart manufacturing, and sustainability. The VOSviewer network map indicates that the themes are grouped into 10 clusters, indicated by different colours. The clusters and their related themes are outlined below.

- Cluster 1: Additive manufacturing, artificial intelligence, automation, big data analytics, cyber-physical systems, digital thread, digital, industrial internet of things (IIoT) and industrial IoT, internationalization, machine learning, robotics, and social media.
- Cluster 2: Business models, circular economy, digital economy, digital supply chain, digital technologies, ecosystem, industry 5.0, integration, interoperability, manufacturing, risk management, supply chain, sustainable development, sustainable manufacturing, transformation, value chain.
- Cluster 3: Business model innovation, business strategy, change management, collaboration, competitive advantage, competitiveness, digital maturity, digital transformation and maturity, digitalization, dynamic capabilities, leadership, performance, technological innovation, and value co-creation.

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- Cluster 4: Cyber-physical system, deep learning, 4IR, IIoT, industry 4.0, knowledge management, quality 4.0, smart factory, structural equation modeling, sustainability, SLR, triple bottom line, value creation.
- Cluster 5: Automotive industry, business model, digitalization, global value chain, globalization, industrial policy, innovation, resilience, upgrading.
- Cluster 6: Digital marketing, digital technology, digitalization, energy efficiency, entrepreneurship, information technology, logistics, SME performance, and supply chain management.
- Cluster 7: Digital entrepreneurship, digital platforms, e-commerce, international business, management, SME, and technologies.
- Cluster 8: Decision making, digital innovation, financial performance, manufacturing industry, resource-based view, sustainable development goals, Servitization.
- Cluster 9: Barriers, maturity model, readiness, readiness assessment, smart manufacturing.
- Cluster 10: Innovativeness, technology adoption.

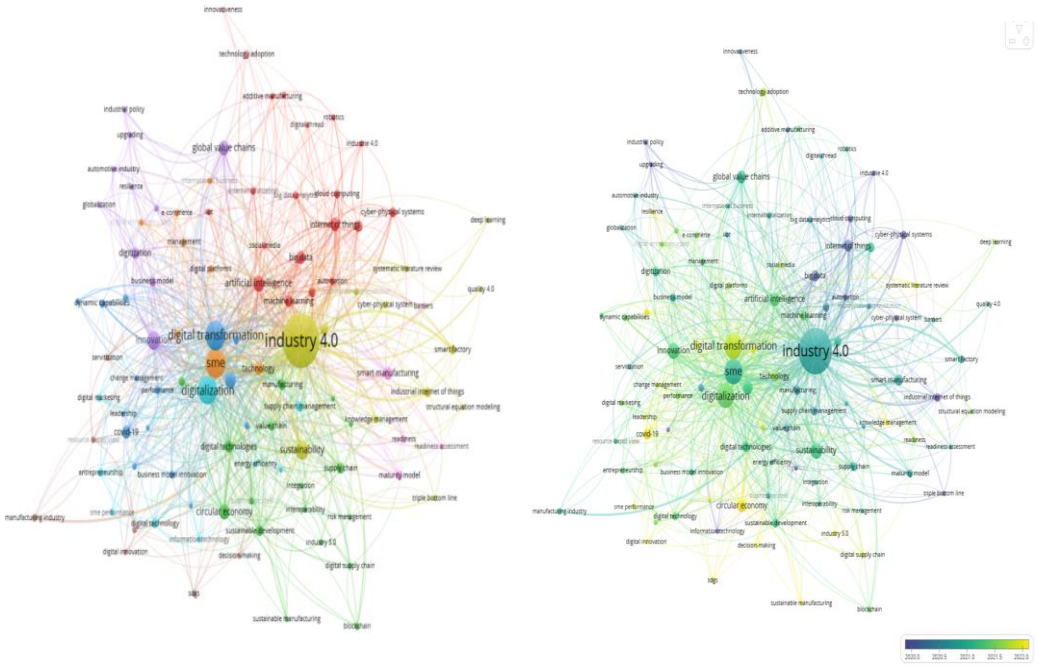

FIGURE 4. KEYWORD ANALYSIS (LEFT) AND RESEARCH TOPIC EVOLUTION OVER TIME (RIGHT)
Source: Authors' research using VOSviewer

3.6 Research trend

The VOS viewer overlay visualization in Figure 4 (right) indicates the evolution of the research topic over time. The research was conducted from 2015 to 2023. However, the concentration of themes researched,

as highlighted by the map, is from 2019 to 2023. The map indicates that concepts such as the industrial Internet of Things, Industry 4.0, cyber-physical systems, and logistics, gained traction in 2019. The research then evolved to Industry 4.0, SME, business model, cloud computing, big data, smart factory, smart manufacturing, and maturity model in 2020. In 2021, towards 2022, the research focus shifted to innovation, digitalization, digital transformation, digital platforms, digital marketing, digital supply chain, machine learning, artificial intelligence, resource-based view, global value chains, sustainability, and sustainable development. This entails a move from an organizational perspective to a global systems perspective. From 2022 to 2023, the researched themes concentrated more on concepts such as circular economy, sustainable development goals and sustainable manufacturing, collaboration, digital innovation, technology innovation, knowledge management, industry 5.0, and SLR.

4. DISCUSSION

4.1 Current state of research

There has been an increasing research interest regarding the integration of SMEs into GVCs with industry 4.0 technologies as an enabler. Although the research topic is fairly new, dating back to 2011, the exponential increase in research publications in this field highlights this interest, and it is anticipated that the number of publications will keep increasing, given the technology and future orientation of the topic. The highest publications are from Sustainability (Switzerland), followed by Technological Forecasting and Social Change, Journal of Manufacturing Technology Management, Journal of Cleaner Production, and International Journal of Production Research. The dominant countries researching SME integration into global value chains are India, China, the United Kingdom, Italy, Germany, the United States, Spain, Indonesia, and France. There is, however, limited collaboration between authors, as indicated by the co-authorship analysis discussed in the results section. The paper highlights a shift in the research trend from an organizational perspective to a global systems perspective, and the latest research output indicates a concentration of concepts such as circular economy, sustainability, collaboration, digital innovation, technology innovation, knowledge management, and industry 5.0.

Considering the period between 2015 and 2023, the most researched industry 4.0 digital technologies include the IoT, AI, big data analytics, CPSs, and digital twins. Moeuf et al. (2018) highlighted IoT and AI as the most accessible tools for SMEs seeking operational improvements in an Industry 4.0 context. In contrast, this study reveals that technologies such as blockchain, robotics, and cybersecurity, receive comparatively limited scholarly attention, despite their potential to address critical challenges like transparency, supply chain security, and labour shortages. This divergence extends prior study by Chen

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(2019), where the author found that while there was strong adoption of cyber-physical systems in specific sectors like Taiwan's textile industry, the author noted the absence of robust frameworks for broader technological integration. The research also established that the most researched areas are industry 4.0, SME, innovation, digital transformation, digitalization, sustainability, and business models. The study established a gap in the literature with regards to the investigation and adoption of the less-researched Industry 4.0 technologies, providing an opportunity for future research.

Industry 4.0 technologies facilitate real-time data acquisition, processing, sharing, and analysis, thus providing an opportunity for the optimization of value chains. These technologies allow for the integration of information and operational systems, affecting decisions and overall process efficiencies (Baio Junior & Carrer, 2022). They provide interconnection of global value chains, enabling real time automated coordination between value chain participants and greater transparency (Mavilia & Pisani, 2021). A brief discussion of some of the most researched industry 4.0 technologies is provided below.

- The potential benefits of big data analytics include flexibility of production lines, improvement of quality of goods or services, optimization of production resources, capability to comprehend market demands, and the ability to customize goods and services in real-time (Baio Junior & Carrer, 2022).
- Cyber-Physical Systems offer the benefit of integrating sensors, data, and algorithms with equipment, helping to enhance efficiencies in manufacturing processes by facilitating continuous monitoring, feedback, and process control, often independent of human intervention (Naudé, 2021).
- Internet of Things (IoT) is a structure through which physical elements communicate with computerized systems via intelligent devices, sensors, ensuring easy accessibility of industrial data (Fanoro, Božanic', & Sinha, 2021). IoT improves waste reduction and efficiency gains through faster response and adaptation by production systems (Baio Junior & Carrer, 2022).
- Artificial intelligence aims to supplement and extend the efficiency of human labour in specific tasks with the final goal of co-existence between man and machine (Liu, et al., 2018).
- Digital twins is an emerging technology that provides the ability to have insights into the interaction of different parts of a system, the inner working of the system, and the future behaviour of their physical counterpart in an actionable manner for stakeholders and users (Botín-Sanabria, et al., 2022).

The study also highlights the main research themes emanating from text mining, which was enabled by VOS viewer. 10 keyword clusters were produced, and the dominant themes are Industry 4.0, SME, global value chains, digitalization, digital transformation, innovation, sustainability, business model innovation,

and circular economy. Industry 4.0 digital technologies are critical for the digitalization of organizations and value chains. Digitalization provides an opportunity for SMEs to transform for agility, flexibility, and improved responsiveness (Dutta et al, 2021). The literature cites that, as much as digitalization has been critical as a driver of change throughout global value chains, many organizations acknowledge the need to adopt it; however, few are prepared, especially SMEs (Chen, 2019). It is thus important for existing and emerging ventures to develop radical business process models to exploit the industry 4.0 digital technologies in order to disrupt global markets (Hannibal, 2020). A business model basically describes a rationale of how organizations create, deliver, and capture value (Turienzo, Cabanelas, & Lampón, 2023). Literature suggests that new business models are geared toward service design, network approaches, and open innovation than traditional industrial enterprises (Prause, 2015).

An important research theme that is gaining interest with regard to the system integration of SMEs into GVCs using industry4.0 digital technologies is the concept of sustainability and circular economy. Several studies explore the relevance of industry 4.0 digital technologies as drivers of sustainability, and evidence suggests that these technologies already present important resources for circular economy adoption, which is key for sustainable development (Singh, Kumar, & Bhardwaj, 2023). Literature offers examples of how digital platforms are enabling cross-sectional circular economy transition in SMEs. A specific example is an operational service (DOS), which forms a key part of an innovative digital platform called DigiPrime. There is a fundamental part played by the presented DOS for SMEs; it highlights the financial benefits of energy and resource efficiency, access to innovative manufacturing processes, and the potential for improving competitiveness across disciplines(Pedone et al, 2021).

4.2 Opportunities and challenges

The study established that some of the Industry 4.0 digital technologies are not fully exploited. These technologies include automation, cloud computing, machine learning, blockchain, e-commerce, additive manufacturing, robotics, simulation, virtual reality, augmented reality, and cybersecurity. This represents an opportunity to improve the system integration of SMEs into global value chains. Some of the benefits of these technologies are discussed below.

- Blockchain technology could provide opportunities to value chain participants by enhancing access to real-time data linked to products, i.e., timing, location, labour, environment, verification of standards, and ethical practices, and addressing the lack of interoperability as it enables end-to-end data transparency (Nair & Landani, 2020).

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- Cyber security is another example of digital technologies that could limit cyber-crimes and the potential for corruption by reducing direct contact between stakeholders i.e., government and business (Adegbite & Govender, 2021).
- Additive manufacturing can enhance market entry possibilities for manufacturing SMEs as the technology enables the production of stronger and lighter parts, enhancing efficiencies, reducing waste, and increasing speed to market (Fanoro, Božanic', & Sinha, 2021).
- Cloud computing can assist with synchronizing value chain production records, which can be accessed from different locations (Nair & Landani, 2020).
- The characteristics of global value chains can also be scrutinized through simulation tools to allow optimization of decisions and resource efficiency in complex systems (Baio Junior & Carrer, 2022).
- Robotics can also be used for compensation of labour shortages in global value chains (Baio Junior & Carrer, 2022).

The investigation of industry 4.0 technologies could expansively provide solutions to the constraints faced by SMEs and global value chains. Some of the constraints include lack of finance, barriers to market entry, knowledge management, lack of access to infrastructure, lack of innovation, lack of market information and poor communication channels, lack of requisite skills and knowledge, poor regulatory framework, crime, and corruption. Future research should comprehensively research the role that industry 4.0 digital technologies could play in reducing the effect of the above-mentioned constraints on SMEs and global value chains.

5. CONCLUSIONS

It is argued that Industry 4.0 is facing major adoption issues by both SMEs and global value chains. Literature suggests that this is due to the complex nature of the concept, which is misunderstood by organizations, coupled with the lack of a comprehensive roadmap, the need for strategic direction, clear implementation guidelines, investments required to realize horizontal and vertical integration, outcome uncertainty, and the capability and maturity of organizations (Gerrikagoitia et.al, 2019). This study investigated the impact of industry 4.0 digital technologies on the system integration of SMEs and GVCs. The main themes researched are Industry 4.0, SME, GVCs, digitalization, digital transformation, innovation, sustainability, circular economy, and business model innovation. The most researched industry 4.0 digital technologies were found to be the IoT, AI, big data analytics, CPSs, and digital twins. The study established a gap in literature with regard to researching some technologies that are deemed critical in the

system integration of value chains. It was also established that an important research theme that is gaining interest is the concept of sustainability and circular economy, although the literature is still sparse in covering this concept. It should also be noted that more collaboration between researchers in this field is required to grow the body of knowledge, and research interest in this field should be encouraged in other parts of the world, considering that most research is carried out in Asia, Europe, and North America.

The study established the current state of research regarding the application of Industry 4.0 digital technologies in the system integration of SMEs into global value chains. The study also discussed how these technologies contribute to the said integration. The major challenges faced by SMEs and global value chains, which can be tackled by the application of specific industry 4.0 technologies, were also discussed; this study thus provided steps to answering the research questions. The literature review established gaps in the literature with regard to incorporating advanced technologies and a number of technological aspects when implementing Industry 4.0. This finding suggests that there could be a lack of interoperability within value chains. Literature also established a need for the development of an integrated industry 4.0 digital framework and more precise industry-specific approaches to SMEs and global value chain integration. In terms of sustainability, the reviewed papers established scarcity in the literature regarding digitalization and lean-green implementation in SMEs. There is also a gap in research on Industry 4.0 and circular economy, especially regarding circular economy developments in global value chains. The study was limited by only considering the Scopus online database; other databases were not included in the review. It is suggested that future research considers other databases to expand the number of articles for review. The study confirmed the literature review by establishing that as much as industry 4.0 digital technologies are covered with regard to the research's topic, few studies explore comprehensive system integration of SMEs into global value chains. Future research should also consider a comprehensive system integration using all relevant industry 4.0 technologies. It is also important to conduct industry-specific research to examine the depth and breadth of industry 4.0 digital technologies from different perspectives.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

The authors declare that they have not used any Generative AI and/or AI-Assisted technologies during the preparation of this work.

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